Using Ontological Engineering to Organize Learning/Instructional Theories and Build a Theory-Aware Authoring System

Yusuke Hayashi, *Department of Knowledge Systems, Institute of Scientific and Industrial Research (I.S.I.R), Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka, 567-0047 Japan*
hayashi@ei.sanken.osaka-u.ac.jp

Jacqueline Bourdeau, *LICEF Research Center, TÉLUQ-UQAM, 100, Sherbrooke St. West, Montreal (Quebec) Canada H2X 3P2*
jacqueline.bourdeau@licef.teluq.uqam.ca

Riichiro Mizoguchi, *Department of Knowledge Systems, Institute of Scientific and Industrial Research (I.S.I.R), Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka, 567-0047 Japan*
miz@ei.sanken.osaka-u.ac.jp

Abstract. This paper describes the achievements of an innovative eight-year research program first introduced in Mizoguchi and Bourdeau (2000), which was aimed at building a theory-aware authoring system by using ontological engineering. To date, we have proposed OMNIBUS, an ontology that comprehensively covers different learning/instructional theories and paradigms, and SMARTIES, a theory-aware and standards-compliant authoring system to create learning/instructional scenarios based on OMNIBUS. This approach was intended to bridge the gap between theory and practice in scientific and technological development, including learning/instruction support. The goals of this study included the following: that computers would (a) *understand* a variety of learning/instructional theories based on their organization, (b) *utilize* such understanding to help authors build learning/instructional scenarios, and (c) *make* such theoretically sound scenarios interoperable

within the framework of technology standards. This paper suggests an ontological engineering solution to achieve these three goals and describes the implementation and feasibility demonstrations of the basic functions of SMARTIES, a solution that supports the design of learning/instructional scenarios based on multiple theories. Although the evaluation is far from complete in terms of practical use, we believe that the results of this study speak to high-level technical challenges of ITS authoring systems and the other areas of AIED, and therefore constitute a substantial contribution.

Keywords: ontology, instructional design, learning theories, instructional theories, standard technologies

INTRODUCTION

Standardized technologies in the field of Technology-Enhanced Learning (TEL) are currently undergoing remarkable development. Learning Objects (LOs), Learning Object Metadata (LOM, IEEE LTSC, 2002) and IMS Learning Design (IMS LD, IMS, 2003) are the core technologies that are currently in active use in TEL. In this field, research has focused on sharing and reusing LOs to build learning scenarios. Information technology standards for learning and training (hereafter called standard technologies) (IEEE LTSC, 2002; Devedzic, 2006; Paquette, Rosca, Mihaila & Masmoudi, 2006; Dicheva, 2008) are used to search for LOs and combine them together. From this research, a significant problem has emerged: learning/instructional theories are rarely referred to in scenario creation and LOs are commonly combined without any theoretical basis, resulting in the production of low-quality learning content.

"Connexions" depicts a typical example of this problem. This open service provided by Rice University[1] is a Web-based system that helps users to freely develop LOs and learning scenarios and make them publicly available. As of this writing, 389 learning scenarios and 6,953 LOs (respectively called "collections" and "modules" in Connexions) have been registered and their numbers continue to increase. However, as no pedagogic guidelines or restrictions are provided to create learning scenarios (i.e., combining LOs), users are granted total freedom to combine elements. The educational appropriateness of the resulting learning scenarios cannot thus be guaranteed. In addition, the IMS LD standard is intended to be independent from learning/instructional theories, which may result in the creation of inappropriate learning scenarios.

These challenges reveal a disjunction between learning/instructional theories and standard technologies. Theory-neutrality can be advantageous since it favours freedom in learning/instructional design, but it also has a drawback due to the lack of guidelines for combining LOs to realize a theory-based learning/instructional scenario. This disjunction creates difficulties when theories are used with technology standards. In order to address this issue, there has been a growing call to develop an authoring system that allows users of technology standards to easily access learning/instructional theories and also support them in creating scenarios that reflect such theories.

In order to build such a system, the following significant issues must be addressed:

---

[1] http://cnx.org/

i) how to make computers "understand" a variety of learning/instructional theories;
ii) how to "utilize" such theories to help instructional designers develop learning scenarios;
iii) how to make it possible to "share" scenarios prepared in formats which comply with standard technologies.

We have used an ontology engineering approach to investigate these issues. Regarding the first issue, "to 'understand' a variety of theories," it is necessary to first clarify the similarities and differences of various theories. If the underlying conceptual structure that clearly identifies such similarities and differences can be extracted and organized, it will then be possible to systematize and compare a variety of theories. In this study, the learning-support-related theory ontology "OMNIBUS" was built as a conceptual base, in an attempt to structure a variety of theories in a declarative manner (Mizoguchi & Bourdeau 2000; Mizoguchi, Hayashi & Bourdeau, 2007).

The second issue, "to utilize" the theories, is also a highly significant one. Although the similarities and differences of various theories can be clarified by way of declarative definitions (Bourdeau & Mizoguchi, 2004), the "use" of such theories requires certain procedural interpretations. Even the authoring systems that are currently considered to be the best in the TEL field incorporate a single learning/instructional theory in a procedural way, making implicit the relationship between the system behaviour and the theory on which the background knowledge of the system is built. As the background knowledge is not available for explicit modification, the system cannot easily be updated to incorporate new knowledge and/or theory evolution. This serious challenge not only affects the TEL authoring systems, but it also impacts knowledge-based systems in a variety of fields, making it an issue to be addressed by ontology engineering. This study suggests a mechanism that consistently enables the declarative definition of theories and their procedural usage on the basis of OMNIBUS (Hayashi, Bourdeau & Mizoguchi, 2006a; 2006b).

Based on both "understanding" and "utilization," theory-aware authoring systems (Mizoguchi & Bourdeau, 2000) can help authors understand and use theories in order to create individual or collective learning scenarios. Such an authoring system was developed: it is called SMARTIES (Hayashi, Bourdeau & Mizoguchi, 2006a; Mizoguchi, Hayashi & Bourdeau, 2007).

As for the issue of sharing learning scenarios, OMNIBUS serves to mediate between theories and standard technologies to establish "the fusion of learning/instructional theories and standard technologies" by coping with both theory-awareness and standard-compliance in the authoring system. As mentioned above, theory-neutrality is both a benefit and a drawback for standard technologies. This study addresses the compliance of the proposed scenario model with IMS LD standards. Moreover, a mechanism to convert learning/instructional scenario models into IMS LD descriptions has been developed to explicitly demonstrate the theoretical grounds and the design intentions of the authors (Hayashi, Bourdeau & Mizoguchi, 2007). In this case, the ontology provides vocabulary and guidelines regarding the "content" to be described with the IMS LD specifications. The ontology is theory-neutral and in no way intended to make a specific learning/instructional theory become a standard, yet it aims to support the development of quality learning content by providing engineers with environments that assure that theories can be easily incorporated within IMS LD scenarios.

Based on the aforementioned concepts, this paper summarizes the results of this study, an eight-year long investigation conducted after the publication of Mizoguchi and Bourdeau (2000). The results reported in this paper present a comprehensive view of OMNIBUS, whose evolution continues at the moment of this publication, as well as the implementation and feasibility demonstrations of the basic functions of SMARTIES, a solution that supports the design of learning/instructional scenarios that are based on multiple theories. This study is still at a preliminary stage and its practical benefits have

not yet been fully realized. We believe, however, that the current results of this study address high-level technical challenges in the field. Therefore, the fact that the initial version of the ontology and the authoring system presented in this paper successfully demonstrate that they have the desired functionality offers an appreciable contribution to the advancement of research in the area of authoring systems for ITSs and other areas of AIED.

This paper is structured as follows: the second section clarifies issues regarding the structuring of learning/instructional theories and presents OMNIBUS. OMNIBUS, an innovation built in the context of this study, is a full-fledged heavyweight ontology, which is rarely seen in learning support and e-Learning studies. The third section presents scenario modelling based on OMNIBUS and the fourth section pertains to its compliance with IMS LD. Then, the fifth section addresses the structure and functions of the SMARTIES authoring system in a systematic manner. SMARTIES, an intelligent system rather than a rule-based expert system working with heuristic rules, runs by relying solely on theoretical knowledge that is described in a declarative manner. In this sense, SMARTIES was built as a new type of intelligent system based on a heavyweight ontology. The sixth section considers the above results from three distinct perspectives: confirmation of the working hypothesis, blending of theories and presentation of related studies on authoring systems. Finally, the last section summarizes this paper and presents the contributions of these results to the research area of authoring systems for ITSs and the other areas of AIED.

THE BUILDING OF OMNIBUS

In general, three factors inhibit the systematization and structuring of knowledge in knowledge modelling:
- Lack of common vocabulary;
- Lack of consistent descriptions; and,
- Lack of universal/common descriptions.

In addition to these three factors, , the issue of "paradigms" adds even more challenge to structuring. Paradigms provide a knowledge theory for constructing learning theories, which can then be grouped according to these different paradigms. More specifically, the issue refers to the differences between paradigms such as *behaviourism*, *cognitivism*, and *constructivism* (Cooper, 1993): (a) *behaviourism* views learning through changes, either in the form or the frequency of observable performance; (b) *cognitivism* stresses the acquisition of knowledge and focuses on internal mental structures; and (c) *constructivism* considers that learning occurs by creating meaning from experience. These paradigms express their own theories by essentially adopting different terminology, concepts and models. In this section, the extraction of the conceptual basis that highlight the paradigm structures, as well as similarities and differences among them are discussed.

A Working Hypothesis

As mentioned above, when establishing a common conceptual basis for the structuring of learning/instructional theories, the biggest challenge lies in the extreme difficulty of finding common ground, since all paradigms have different definitions for "learning" and form their own distinctive conceptual frameworks. However, certain researchers, such as Ertmer & Newby (1993) and Reigeluth (1983) suggest that a certain level of commonality can be found. According to their studies, although

each paradigm assumes a different development mechanism and process, this study assume that the paradigms may have a certain degree of commonality among them. Given such an approach, these studies trigger the working hypothesis that a sharable "engineering approximation" related to "learning" can be found in terms of the changes that are taking place in the state of the learners. Based on the working hypothesis, such a conceptual basis was extracted, to highlight the paradigm similarities and differences, and then structuralized into OMNIBUS.

The concepts concerning learners' states are at the heart of OMNIBUS. They are the basic components of the learning/instructional process model that will be proposed in the section on "MODELLING LEARNING/INSTRUCTIONAL PROCESSES." In other words, the underlying philosophy for building OMNIBUS is that all learning/instructional actions can be defined in relation to the learners' states, which are changed by such actions. For example, cognitivism pays attention to a learner's cognitive processing while constructivism focuses on interpersonal interactions or the environment. These theories seem to deal with different types of state changes; cognitivism focuses on learners' internal changes in the cognitive process whereas constructivism treats the external state affected by interaction. However, the working hypothesis of this project is that establishing a set of states that can be used by learners across paradigms, such as a change in the cognitive structure resulting from the learning process, for example, can help link the various learners' internal and external states associated with each paradigm. Obviously, the most significant issue is related to whether or not such a cross-paradigm set of states in the learner can be established or not. Undeniably, at a detailed level, many different specific states exist for each learning theory. However, if states can be classified into several groups – such as those common to some of the paradigms, those common to all paradigms or those which are theory-specific – then based on the important golden rule of "engineering approximation," a conceptual system can be established to some extent.

OMNIBUS: an Overview

Due to space limitations, only the upper level structure of OMNIBUS is dealt with in this section. For more detailed information on OMNIBUS, its draft and commentary are available on our Website.[2] Built using the "Hozo" ontology editor,[3] OMNIBUS defines 1,084 wholeness concepts, 175 relational concepts and 4,452 slots.[4] It is also publicized in the OWL format based on the simplified OWL output function (Sunagawa, Kozaki, Kitamura & Mizoguchi, 2006) by Hozo.[5]

Figure 1 shows the basic relationship between learning, instruction and instructional design as discussed in this study. Based on the working hypothesis mentioned above and the nested structure shown in Figure 1, the relationship between learning, instruction and instructional design, as well as to associated theories are taken into consideration in OMNIBUS.

Its foundation is based on learning, and learning processes are explained by means of learning theories. In current learning theories, different mechanisms to acquire or structure knowledge are suggested according to paradigms, and learning processes are interpreted in various ways.

---

[2] http://edont.qee.jp/omnibus/

[3] http://www.hozo.jp/

[4] See Kozaki, Kitamura, Ikeda and Mizoguchi(2002) about the difference between Whole concept and Relational Concept.

[5] A final version of OWL descriptions (Kozaki, Sunagawa, Kitamura & Mizoguchi, 2006) will be incorporated in Hozo in the future.

The instruction process is the component that most affects the learning process, and it is explained by way of instruction theories. Based on such learning theories, each instruction theory suggests an effective instruction process (learning support process) for learning.

These learning and instruction processes are executed concurrently in the real world, whereas in ITSs instructional design processes are subject to a planning phase that precedes the execution. In other words, learning/instruction theories provide guidelines to structure learning/instruction scenarios that result from a design process, while instructional design theories supply principles and guidelines to the design process (i.e., how to advance the instructional design process, and how to choose appropriate strategies proposed in theories or models).

Figure 2 shows the upper level IS-A structure of OMNIBUS (for further details, refer to Mizoguchi et al., 2007). This ontology can be categorized into the following six basic concepts: *Common world*, *Learning world*, *Instructional world*, *ID-ISD (Instructional Design/Instructional System Design) world*, *World of cognition*, as well as *Theory and Model*. The concepts of the *Common, Learning, Instructional and ID-ISD worlds* and the *World of cognition* define the basic ideas behind the things and processes in their respective worlds, while *Theory and Model* defines instructional principles or guidelines.

Fig. 1. A nested structure of learning, instruction and instructional design (Bourdeau & Mizoguchi, 2002).

In this section, an outline of *Common*, *Learning* and *Instructional worlds* is described in connection with the learning/instruction theories, since they form the core model of learning/instructional processes that are the main subject of this paper. The *ID-ISD world* contains concepts related to its modelling process, and the *World of cognition* contains concepts related to general cognitive processes. These will not be addressed in this paper.

In the *Common world*, general cognitive and physical processes or concepts regarding objects are defined as the foundations of the other worlds. The key concepts are the following: (a) *State* for the stative processes, (b) *Action* for the dynamic processes, and (c) *Event*, which integrates *State*s and *Action*s in a particular context.

Internal and external *States* are defined. Internal states pertain to a person's inner conditions. This category defines one's attitudes, the level of progress in the cognitive or meta-cognitive processes, and the development of knowledge and skills. On the other hand, external states relate to interactions between agents. For example, states about whether or not actions (active or passive) have already been taken are defined.

Actions, which are independent of the context, are defined in the *Common world*. In OMNIBUS, an *Action* can be broken down into several sub-actions. Realistically, however, such a breakdown eventually ceases given the target task of the ontology. A differentiation criteria had to be found in order to identify state-based actions (*physical state* and *cognitive actions*) and those which are behaviour-based (*primitive actions*): although both are defined as elements that trigger a state change, the former can be broken down further while the latter cannot. We do not claim this classification to be universal, but we believe that it varies in accordance with the purpose of building the ontology.
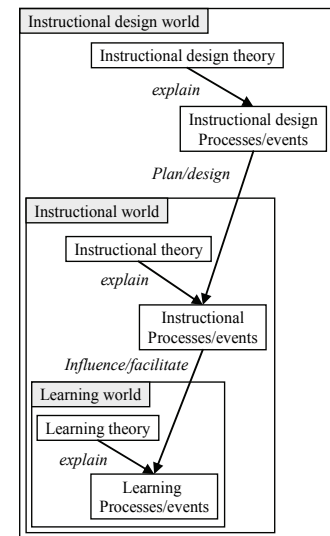
Anything
Common world
  Entity
    Concrete
      Object
        Agent
          System
          Human
          Robot
          Learning agent
        functional
          artifact
    Occurrent
      Process
        Dynamic
          Action   *Common world*   *Action*
            Composite action
            Simple action
              Multi-actor action
              Single-actor action
                Physical action
                  Object action
                    Primitive action
                    Physical state action
                  Meta action
                Cognitive action
        Phenomena
      Stative   *State*
        Context
        State
          Agent state
            Internal state
              Cognitive process state0
              Attitudinal state
              Progression state
              Developmental state
            External state
          Object state   *Event*
          Situation
      Event
        Educational event
          Learning event
            Preparing learning condition
            Effect of learning
            Interactive event
          I_L event
            Reciprocal I_L event
            Simple event
            Influential I_L event
          Instructional event
    Abstract
      Number
      Constraint
    semi-abstract
    Substrate
    Function
    property   *Learning world*
    Universal
Learning_world
  Attribute of learning
    Process related attribute
    Material related attribute
    Learner related attribute
    Learning paradigm
    Learning condition
    Learning domain
    Learning environment-related
  L.Entity
    L.Process
    Learning Object
    Learning environment
  Learning
    Behaviorism learning
    Cognitivism learning
    Constructivism learning
      Socio-constructivism learning
Instructional world   *Instructional world*
  Instructional goal
  Instruction
  Instructional attribute
  I_L scenario   *World of cognition*
  IEntity
World of cognition
  Knowledge model
  Attribute of knowledge model
  Attribute of Knowledge   *ID-ISD world*
  What to learn
ID-ISD world
Theory and Model   *Theory and Model*
  Theory
    Instructional design theory
    Instruction theory
      Constructivist Instruction Theory
      Cognitivist Instruction Theory
      unclassified
      Instruction management theory
      Behaviorist Instruction Theory
      Cross-paradigm Instruction Theory
    Learning theory
  model
    Instruction model
      Instruction management model
      Cognitivist Instruction Model
      Behaviorist Instruction Model
      Cross-paradigm Instruction Model
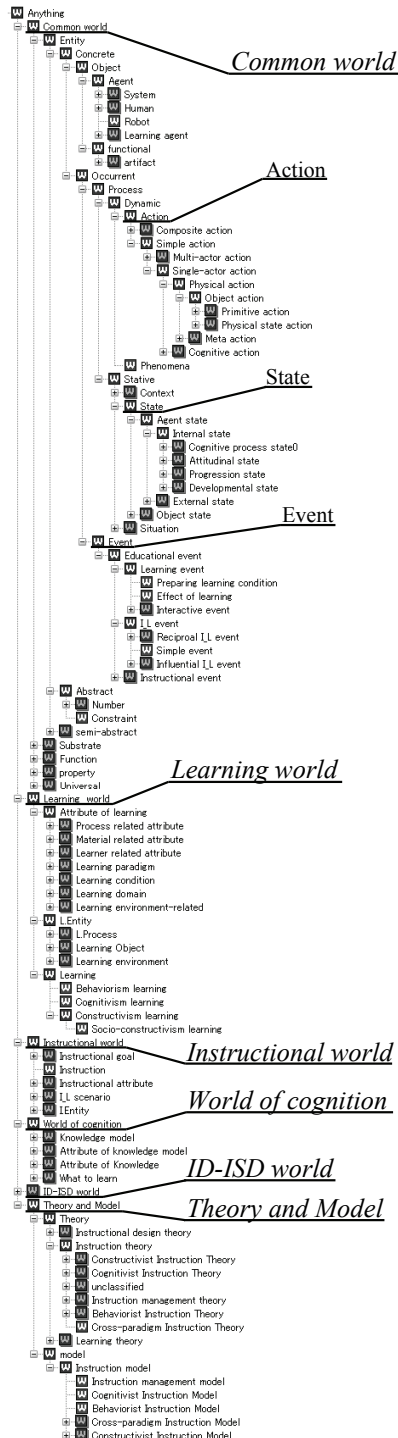   Constructivist Instruction Model

Fig. 2. OMNIBUS: Upper level IS-A structure

Regarding the *physical state* and the *cognitive actions*, the former deals with the changes that pertain to the *external state,* while the latter relates to changes to *internal states*. The significance of an *Action* in a context of learning and instruction is described within the concept of the *Educational event*. This will be discussed after describing the framework of *Learning world* and *Instructional world*.

The concepts of the *Common world* are essentially built on the upper-level ontology described in Mizoguchi(2004; 2005). Meanwhile, the concepts that belong to the other worlds (i.e., *Learning, Instructional* and *Instructional Design* worlds) define particular concepts in their respective worlds.

Concepts regarding learning processes are defined in *Learning world*. The concept of "learning" is central and definitions for "learning" are categorized according to the different learning mechanisms associated with each learning theory paradigm. In addition, *attribute of learning* and *L.Entity*, which is the upper class of entities related to learning such as learning process (*L.Process*) and objects, are defined. It is important that *L.Process* is defined as a learner's state change in accordance with the aforementioned working hypothesis. This may cause certain problems with regard to achievable levels of accuracy; however, we believe that a reasonable engineering approximation can be derived at a level where computers understand existing theories enough to support its application. That is because ontological engineering investigates knowledge in terms of its origins and the elements from which that knowledge is constructed. The hierarchical nature of concepts and the 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 that knowledge engineering has faced (Mizoguchi & Bourdeau , 2000).

In *Instructional world*, concepts such as Instructional process, Instructional attribute and Instructional goal are defined. Here, it is important that instruction and learning are defined separately. As mentioned above, instructional theories are based on learning theories. However, we define learning and instructional theories separately so that combinations of a wide variety of instructional processes and learning processes are allowed, as suggested by various theories. The specific way in which learning and instruction are combined in each theory can be described by a concept called "I_L event", to be mentioned further on in this paper. Hence, the concepts defined in *Instructional world* offer the primitives to describe the relationship between learning and instruction as I_L event.

After outlining the *Learning* and *Instructional worlds*, we will return to the issue of *Event*. In *Common world, Educational event* refers to the specific event of education and defines: (a) events in each world and (b) the relationship of events among worlds. Actions, actors and objects that constitute an event are defined in each world. *Learning* and *Instructional events* are concepts used to define events in *Learning world* and *Instructional world*, respectively. Learners, their actions and their state changes are the essence of *Learning event*. Valid composition of these elements is suggested in learning theories. On the other hand, *Instructional events* consist of actions carried out by an instructor for a learner. As mentioned above, *Instructional world* is defined separately from *Learning world*, so that a learner's state change is not defined as a part of *Instructional event*. *I_L event* defines the relationship between instruction and learning by connecting *Learning event*s and *Instructional event*s. *I_L event,* the concept that constitutes the core of this study, is discussed in detail in the following section. By defining *Learning event* and *Instructional event* separately and allowing for various combinations of these events through *I_L event*, a wide variety of learning and instruction processes suggested by various theories can be described, one of the characteristics of OMNIBUS proposed by this study.

MODELLING LEARNING/INSTRUCTIONAL PROCESSES

In this section, the lower level structure of *Educational event* is discussed in detail together with the elements of learning/instruction modelling in OMNIBUS. Additionally, the ontology-oriented modelling of each theory, based on such models, is also dealt with in detail.

One of the sources of difficulty in modelling learning/instruction is that the two processes are interrelated. An instructor performs an Instructional action for a learner, expecting a specific action and change from the targeted learner. On the other hand, the learner performs a certain learning action (not necessarily the one anticipated by the Instructional action) and, as a result, the learner's state changes. Moreover, even though an Instructional action takes place, it is possible that the learner performs the learning action spontaneously in order to obtain a certain learning outcome (i.e., the learner's state changes). Although the phenomenon of "learning" is highly uncertain and it is almost impossible to obtain actual learning measurements, in order to increase the possibility of effective instruction we need a modelling framework in which the relationship between learning and instruction can be described and can serve as a basis for design, execution and validation.

This study proposes a modelling framework for the learning/instructional processes defined in OMNIBUS. This framework is based on the functional modelling framework (Kitamura & Mizoguchi, 2003), which stems from a device ontology, the effectiveness of which has been assessed by using the framework for representing the functional structure of artefacts (equipment). Its main characteristics lie in how it differentiates between what to achieve and how to achieve it, by conceptualizing the function of the equipment as the changes of the state of an object. In this study, an engineering model[6] of learning/instructional theories was constructed by associating functions and learning/instructional actions with learners' state changes, by linking the actions' results with learners' state changes, and by considering the changes as the goal of learning/instruction.

---

[6] Even though we associate humans and equipment, this model by no means treats human beings in an inhumane manner. The central aim of this study is to make effective use of a conceptual model that is polished and verified by the device ontology towards the learning/instructional worlds.
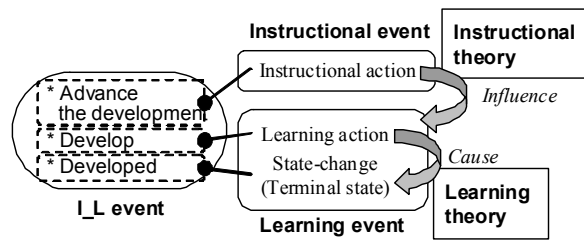
Fig. 3 The Structure of the I_L event

I_L Event

Figure 3 shows the structure of *I_L event* used as a conceptual kernel of modelling. "I_L" means that it indicates the relationship between the Instructional event and the Learning event. In this study, the main components of *Learning event* are defined as a combination of the learner's state change and the learning action with the relationship in which the learner's state change is triggered by the learning action. Also, *Instructional events*, defined as Instructional actions, affect the *Learning event*. This association is described as a relationship between the *Instructional event* and the *Learning event*. Under this *I_L event* concept, the relationships among three concepts that this study addresses (i.e., *Instructional action*, *Learning action* and the learner's state change) are conceptualized as one. This makes it possible to describe the relationships among various learning/instructional actions and state changes. Figure 3 shows a simplified case consisting of one *Instructional action*, one *Learning action* and one learner's state change where the *Instructional action* affects the *Learning action* and changes the learner's state. However, there are additional kinds of *I_L events,* such as a learner's state change that plays the role of preparation (something to meet the requirements) of other *I_L events* or other factors that triggers additional state changes. The kinds of *I_L events* are explained in the section on "Modelling Strategies from Theories," with several examples.

Another important aspect of *I_L event* concerns the fact that each learning/instructional theory explains the validity of the relationships between the *Instructional action*, the *Learning action* and the learner's state change, either in a descriptive or prescriptive manner. A further role that *I_L event* plays is that of a framework in which this theoretical knowledge is described.

How Learning/Instructional Goals Are Achieved

In this study, learning/instructional processes are structured based on two perspectives: the learner's state change process and the manner in which it is achieved. The state change expected at each step in each action can be described as a previously mentioned I_L event. This section explains how to realize such an event, composed of a sequence of finer-grained I_L events.

In the proposed model, learning/instructional processes are described as a hierarchical structure from the viewpoint of an achievement relationship. This fundamental structure is based on the framework of functional modelling (Kitamura & Mizoguchi, 2003). As mentioned above, in this framework the function of a device is interpreted as the state change of the input object. The conceptualization of the achievement relationship between a function and a sequence of sub-functions to obtain the function is defined as the functional achievement way (hereafter called "WAY"). This hierarchical structure permits the modelling of the functional structure of a device. The objects of this modelling consist of the artefacts and their functions. At first, they seem foreign to the learning/instructional processes dealt with in this study, yet an abstraction reveals the common
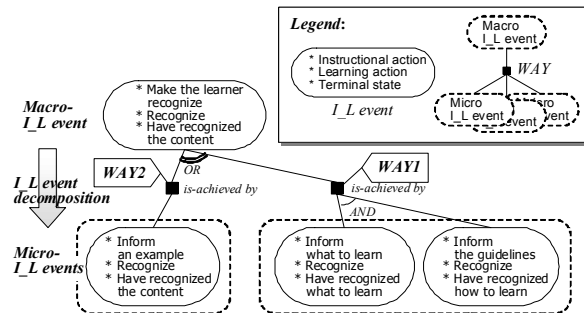
Fig. 4. Examples as to how WAY achieves learning/instructional goals

elements of the relationship between the state change and the behaviour that causes the alteration in both the device and learning processes, suggesting that they can be treated in the same manner. The framework of the functional achievement way is thus considered to be general in the sense that its applicability is not limited to the functions of the devices.

Figure 4, an example of WAYs to achieve learning/instructional goals, illustrates that there are two approaches to achieve the upper I_L event, where learners recognize what they need to learn, which is called "macro" I_L event. WAY1 is based on Gagne and Briggs' theory (Gagne & Briggs, 1979). This is an instructor-directed process in which the instructor first informs learners of the content of the learning material before providing explanations. WAY2, based on Collins's theory (Collins, Brown & Newman, 1989), is a learner-directed process in which the instructor presents pedagogical material without specifically explaining how or what should be learned. Both of these strategies have a common goal (the learner's expected state change), yet they take different approaches to achieve it. As shown in Figure 4, the "OR" relationship indicates that there are at least two possible ways. In this manner, making a distinction between "What" to achieve and "How" to achieve it will further clarify the similarities of and differences between each piece of theoretical knowledge and this will work as a guideline to clarify the relationships among the theories. Moreover, the distinction allows for the consideration of alternative learning/instructional methods in order to achieve the same goal when building scenarios.

The WAY approach can be interpreted either bottom-up or top-down. In the former, the state change in the macro I_L event is achieved by a state change sequence in the micro I_L events. This descriptive interpretation illustrates the relationship in terms of state changes. In the latter option, the action of a macro I_L event is realized by the sequence of actions of the micro I_L events. This offers a prescriptive interpretation of how learning/instructional actions are achieved.

In this study, as mentioned above and shown in Figure 5, [7] in order to clarify learning/instructional goals, learning/instructional scenarios are modelled as a hierarchical tree structure composed of I_L events from the perspective of WAY. In this paper, the hierarchical structure component is called the "scenario model" whereas the bottom I_L event structure, the sequence of the leaf I_L events, is referred to as the "scenario." The scenario represents the actual functions performed by learners and instructors, as they are executed. Currently this study focuses on individual or collective learning in which an instructor supports or facilitates the learning of a learner (individual or group), therefore a scenario is composed of the interaction between an instructor and a

---

[7] This structure is not an "is-a" structure but a "whole and parts" one based on the relationship of achievement.
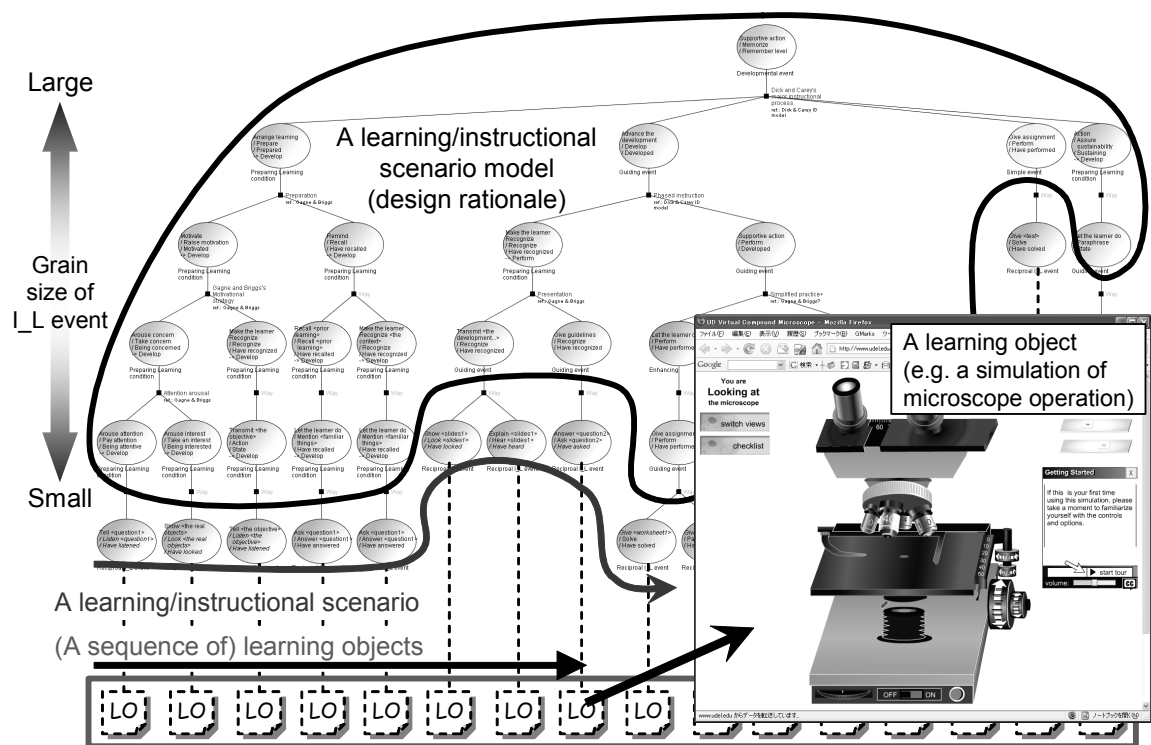
Fig. 5. An example of a learning/instructional scenario model

learner. On the other hand, the scenario model has an abstract structure that indicates the design rationale of the scenario. In other words, it indicates the types of changes the learner is targeting, and how the state change is broken down into achievement sub-processes by a sequence of I_L events as part of the scenario as a whole. The scenario model is constructed by dissolving the coarse-grained I_L event into finer-grained I_L events in a phased manner. The actions appearing on the bottom I_L events are described as "primitive actions", the lowest-level concept of the Action, one that cannot be decomposed further in OMNIBUS. However, the determination of when to stop decomposing by using the "primitive action" is arbitrary for model creators, and lies outside the scope of such modelling. Finally, the scenario is linked with learning objects attached to actions.

Modelling Theories and Their Procedural Interpretations

While *I_L events* are defined as a wholeness concept, WAYs refer to relational concepts that indicate the breakdown and achievements between *I_L events*. The difference between these two concepts lies in the division of What (I_L event) and How (WAY) regarding the achievement of state, as mentioned in the previous section. In addition, the fact that the Way is conceptualized as a relationship is key to modelling theories.

As stated in the introduction, it is important that modelling theories harmoniously satisfy the following two requirements:

- They contain declarative definitions which allow the system to "understand" the theory; and,
- They include a procedural interpretation for the system to "utilize" the theory.

Each theory clarifies the relevant learning/instructional methods for possible situations and expected learning outcomes. The nature of learning/instructional theories is to clarify these relationships as learning/instructional schemes. Therefore, an aggregation of such schemes can capture one of the essential properties of a learning/instructional theory. The relevant modelling of the theories would be declarative, describe these schemes (WAYs) as relationships and make them available for procedural use. They can be understood as "strategies from theories." So far, 99 WAYs have been defined, based on strategies from eleven theories such as Gagne & Briggs' "Nine Events of Instruction" (1979), Dick, Carey and Carey's "ID model" (2001), Merrill's "component display theory" (1983), Keller's ARCS model (1987), Collins et al.'s "cognitive apprenticeship" (1989), Jonassen's "design of constructivist learning environments" (1999) as well as Schwartz, Xiaodong, Brophy, and Bransford's STAR LEGACY model (1999). Such a theory-based WAY is called "WAY-knowledge."

Unlike ad-hoc WAYs described in a particular scenario model, pieces of WAY-knowledge can be used in various scenario models with theoretical justification, if the situation of a scenario fits the conditions of a piece of WAY-knowledge specified in the original theory. Of course, ad-hoc WAYs can be reusable, yet they are not related to any justification. If a WAY can be justified, it can be defined and used as a piece of WAY-knowledge.

As mentioned in the section entitled "How Learning/Instructional Goals Are Achieved," the framework of WAYs can be interpreted with either a top-down or bottom-up approach. As for the latter, by defining the schemes suggested in the theories as an achievement relationship of the state, the meaning of each strategy forms a theory that can be defined in a descriptive manner. On the other hand, considering the decomposition of actions based on a top-down interpretation allows for describing schemes in a prescriptive manner. The "use" of theories will be actualized through such a top-down interpretation. For example, a certain I_L event can be decomposed into the micro I_L events of a piece of WAY-knowledge, if such a piece of WAY-knowledge contains the macro I_L event that coincides with the I_L event to be decomposed. In other words, by unification of a macro I_L event of the piece of WAY-knowledge with the I_L event to be decomposed, a micro I_L event sequence of the piece of WAY-knowledge is derived as a partial I_L event sequence that helps realize the I_L event. Declarative definitions and procedural interpretations of theories can be made simultaneously by modelling the theories as an aggregation of pieces of WAY-knowledge.

As mentioned above, a theory can be modelled as an aggregation of strategies. Each strategy can be modelled as a piece of WAY-knowledge, meaning that a theory can be characterized by accumulated pieces of WAY-knowledge. This approach, however, is not sufficient to represent the character of the theory as a whole, although each learning/instructional scheme contained in the theory is visible. For this reason, and apart from the pieces of WAY-knowledge defined as a relational concept, each theory is also defined as a wholeness concept. In the concept definition of theories, each paradigm is structured with elements such as the learning mechanisms, the learner and the properties of the LOs. Each piece of WAY-knowledge refers to the definition of the original theory defined as the wholeness concept. Based on this relationship, the character of each theory as a whole is organized, while the learning/instructional schemes contained therein are declaratively defined as a piece of WAY-knowledge that can be used procedurally in a top-down approach.

Modelling Strategies from Theories

As mentioned above, in this study 99 pieces of WAY-knowledge are defined according to 11 theories suggested mostly by Reigeluth (1983, 1999). Table 1 reflects the number of pieces of WAY-knowledge, roughly sorted into four categories according to theory, paradigm and object, with each piece assigned to one of the corresponding theories. As shown in Table 1, in this paper, theories and models are organized into four categories: cross-paradigm, cognitivist, constructivist and instruction management. The behaviourist theory/model, another typical paradigm, is not included in Table 1 as it has yet to be defined.

The first three categories, the cross-paradigm, cognitivist and constructivist theories/models are based on differences in the "Learning (mechanism) paradigm." The Cognitivist theory/model interprets people's learning as the delivery of knowledge from the point of view of knowledge processing and considers the cognitive/thinking processes. On the other hand, the constructivist theory/model emphasizes metacognition and interactions with others and the environment rather than learners' cognitive processes. The cross-paradigm model, a category name coined in this paper, pertains to models that are independent of a particular paradigm. A typical model would be the one suggested by Dick et al. (2001).

Furthermore, the instructional management theory/model category aims at creating learning conditions such as motivation, readiness and so on, thus using a different grouping axis from the others. It goes without saying that theories that belong to the other three groups may include a similar point of view. A typical example would be Keller's ARCS model (Keller & Kopp, 1987), which deals exclusively with affective considerations, addressing attitudes and motivation (Petry, Mouton & Reigeluth, 1987). The name of this category also reflects an innovation in this study.

The content of pieces of WAY-knowledge definitions are further addressed in the section called "Testing the Working Hypothesis". Here specific examples of WAY-knowledge are presented according to the definitions in the Hozo ontology editor.

Table 1

Categories of Way-knowledge Pieces

Category of theory/model	Learning (mechanism) paradigm			Instruction management
	Cross-paradigm	Cognitivist	Constructivist	
Number of theories/models	1	3	6	1
Total pieces of WAY-knowledge	2	30	51	16
Total pieces of WAY-knowledge for each theory/model	Dick and Carey's I-model (Dick et al., 2001) 2	Component display theory (Merrill, 1983) 21	Constructivist learning environment design (Jonassen, 1999) 22	Keller's I-Theory (Keller & Kopp, 1987) 16
		Gagne's I-Theory (Gagne & Briggs, 1979) 8	STAR LEGACY model (Schwartz et al., 1999) 18	
		Merrill and Tennyson's I-Theory (Merrill & Tennyson, 1977) 1	Scaffolding theories (Hogan & Pressley, 1997; Hmelo & Guzdial, 1996) 3	
			Cognitive apprenticeship (Collins et al., 1989) 8	

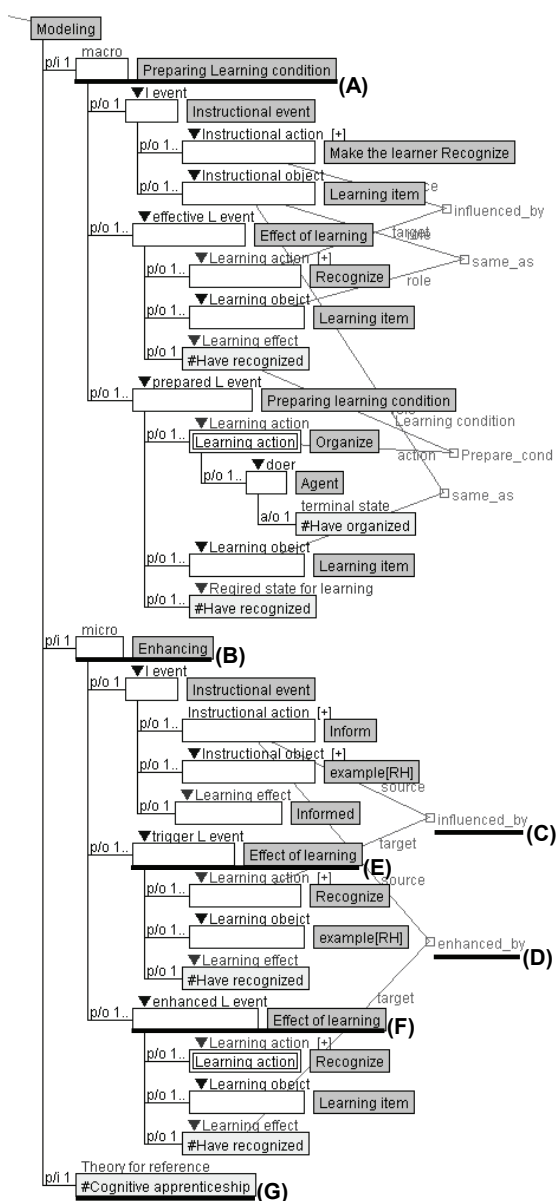Fig. 6. Definition of the piece of WAY-knowledge: Presentation

Figure 6 defines a piece of WAY-knowledge called "Presentation," based on Gagne's theory. This is the same as "WAY1" shown in Figure 4. This piece of WAY-knowledge is defined as a relational concept, that is, the relationships among "macro," "micro" and "Theory for reference" are linked with the "participate-in" (p/i) relation.

The "macro" (e.g., Figure 6-A), reflects the slot for the upper I_L event in a piece of WAY-knowledge and only one "macro" slot can be included in it, whereas more than one "micro" slot can be used for the lower I_L events (e.g., Figure 6-G, 6-I). In Figure 6, two "micro" events are defined (Figure 6-G, 6-I), meaning that the macro I_L event is broken down into two micro I_L events.

The "macro" slot is defined with a type of I_L event called "Preparing the learning condition" (Figure 6-A). This kind of I_L event indicates that the learner's state changes as a result of this event, and functions as a preparation for succeeding I_L events. Three types of slots, "I event", "effective L event" and "prepared L event" are defined by this kind of I_L event. The relationship mentioned above, in which this I_L event serves to prepare the succeeding I_L event, is described as the relation between the "effective L event" (Figure 6-B) and the "prepared L event" (Figure 6-D).

"Effective L events" (Figure 6-B) define learning events that includes the learning effect of the macro I_L event. The effect is defined by the "Learning effect" slot (Figure 6-C). In this case, the "Have recognized" state is set. This means the learner recognizes the learning item as the result of the macro event.

On the other hand, "prepared L events" (Figure 6-D) describe the type of learning actions that become possible in succeeding I_L events by way of the resultant state of the macro event. In this case, the possible action is set to "organize" (Figure 6-E), meaning that learners will be able to organize the items in

Fig. 7. Definition of WAY-knowledge: Modelling

their minds in the succeeding event since they have already recognized it.

Basically, in the aforementioned relationship, the learner's state changes serve to prepare the subsequent I_L events, as defined by the "Prepare-cond" relation (Figure 6-F) between the "Learning effect" slot (Figure 6-C) and the "Learning action" slot (Figure 6-E). In this relation, the resultant state of the macro I_L event can also be the required state of an action carried out in the ensuing I_L events.

Contrary to the "macro" slot, the two "micro" slots are both defined with the kind of I_L event called "Guiding event" (Figure 6-G, 6-I). This is a basic kind of I_L event that defines the relationship in which an instructional action simply affects the learning action. This relationship is shown by the "influenced_by" relationship (Figure 6-H, 6-J) between the Instructional action and the Learning action. "What to learn" and "How to learn" shown in Figure 4 are defined as the "Learning item" and the "Guideline", respectively, in OMNIBUS. In addition, to "Inform" these matters is defined as contributing to, or influencing, the recognition of these matters.

The original theory/model is addressed under "Theory for reference." In this example, the wholeness concept refers to the definition of Gagne's I-Theory in OMNIBUS (Figure 6-K). This type of cognitivist theory is defined as a lower-level concept of the "Cognitivist Instruction Theory."

Figure 7 provides another example as to how to define a piece of WAY-knowledge. The "Modelling" piece of WAY-knowledge is based on Collins' cognitive apprenticeship theory (Collins et al., 1989). This is the same as WAY2 shown in Figure 4.

Same as the "Presentation" shown in Figure 5, "macro" is defined by the I_L event called "Preparing learning condition" (Figure 7-A). As mentioned in the section "How Learning/Instructional Goals Are Achieved," this WAY-knowledge can be used as an alternate "Presentation" since they share the same "macro" definitions.

However, unlike "Presentation," only one "micro" is defined by a type of I_L event called "Enhancing" (Figure 7-B). It consists of materializing, rather than decomposing, the upper event. This "Enhancing" type of I_L event causes a two-step state change in learners. The instructional event

affects the first state change, which, in turn, triggers a second, spontaneous learner state change. This relationship is defined as the "influenced_by" relationship (Figure 7-C) between the instructional action and the learning action in "trigger L event" as well as the "enhanced_by" relationship (Figure 7-D) between the instructional action and the learning effect in the "enhances L event." In Figure 7-E, the "trigger L event" where the learner recognizes an example is defined as the trigger of the learner's spontaneous recognition of the learning item, which is the "enhanced L event" (Figure 7-F).

Lastly, in the "Theory for reference," the definition for "Cognitive apprenticeship" appears in Figure 7-G. This kind of constructivist theory is defined as a lower-concept of the "Constructivist Instruction Theory."

By defining pieces of WAY-knowledge with the relations explained above, the theories that satisfy both of the following requirements, as described in the previous section, have been successfully modelled:

- Declarative definitions that allow the system to "understand" the theory; and
- Procedural interpretations for the system to "utilize" the theory.

MERGING LEARNING/INSTRUCTIONAL THEORIES AND STANDARD TECHNOLOGIES

Although theories can be modelled in a declarative and procedural manner, much work remains to be done before modelling results can be easily used in actual educational practices. In order to address this challenge, it is essential to make user friendly scenario models for educational practices (Psyché, Bourdeau, Nkambou & Mizoguchi, 2005).

This study considers IMS Learning Design specifications (IMS, 2003), a standard format that is increasingly used by TEL engineers who develop learning/instructional scenarios. Furthermore, we propose converting an OMNIBUS-based scenario to the IMS LD format (Hayashi, Bourdeau & Mizoguchi, 2007). By doing so, the design rationale and its theoretical grounds stored in the scenario model can be operational with IMS LD specifications. This clearly demonstrates the scenario's theoretical grounds and validity, which tend to be lost in actual practice, promoting "knowledge-sharing" between the theoretical study and practice to fill the gaps between the two.

Overview of the IMS Learning Design

Up to now, a variety of Educational Modelling Languages (EMLs) have been proposed to establish a standard for learning/instructional scenarios. IMS, one of the standard-setting organizations, adopted EML (OUNL-EML, 2001) created by the Open University in the Netherlands(OUNL), as a basis and it has been standardized as an IMS Learning Design specification.

The learning/instructional scenarios at the core of the IMS LD consist of the following three elements:

- **Role:** The participant's role. Roles are classified into *learner* or *staff* (such as teachers and mentors) at the top level. In the IMS LD, a scenario is modelled by setting actions to be executed for each role.
- **Activity/Activity-structure:** The actions to be executed for each role and their structural descriptions. The *Activity-structure* is a single level hierarchical structure to decompose a given action into several sub-actions. As for the *Activity* that cannot be decomposed further,

the *learning-activity* and the *support-activity* elements are defined for the *Learner* or *Staff* role respectively.

- **Environment:** Learning objects and services to be used in order to carry out the activities. This includes textbooks and pedagogical material used for learning/instruction, as well as communication tools such as e-mail or BBS.

In the IMS LD standards, these elements are used to describe learning/instructional scenarios through a theatrical metaphor. They define the design of learning/instructional scenarios by specifying the roles assigned to each participant in the learning/instructional activities and which activity each role can perform in which environment. In addition, they allow for the description of learning/instructional processes performed by numerous participants and in various forms, including individual learning or collective learning such as lectures.

Mapping Between the IMS LD Specifications and a Scenario Model

In order to make an IMS LD description compatible with the suggested scenario model, a decomposition (WAY) in a scenario model is separately described as two Activity-structures (Hayashi et al., 2007) based on the fact that the tree structure of the scenario model corresponds to the Activity-structures of the learners' and staff's roles. With this correspondence, individual learning described as a scenario model based on OMNIBUS can be compatible with IMS LD specifications.

Figure 8 shows an example of such a correspondence: the right-hand section indicates a segment of a scenario model, while the left-hand shows a data structure of the scenario model converted into the IMS LD. The basic formation of an Activity-structure consists of a single-level hierarchical structure, composed of an activity to be broken down and its sub-activities, whose structures are identical to those of a WAY. Each WAY contained in a scenario model is described as an Activity-structure, while a Leaf I_L event is described either as a Learning-activity or a Support-activity. The WAY shown in Figure 8-1 is separated into Activity-structures for instructors (defined as a Staff role) and learners (Figure 8-2, 8-3). The relation between the participants' roles and activities are specified in the Role-part element (Figure 8-4). For example, the Role-part element describes the relation between the Activity-structure for an instructor and the instructor's role in reference to such elements. In addition, the explanation generated from the scenario model is linked to the Activity-structure as an information element. Yet, the leaf I_L event (Figure 8-5) is not converted into Activity-structures but rather, into a combination of a Support-activity and a Learning-activity (Figure 8-6, 8-7), which cannot be decomposed further. In the scenario model (Figure 8-9), the link between the leaf I_L event and a LO is converted into the reference from each Activity to an Environment referring to the LO (Figure 8-8).

As mentioned above, IMS LD descriptions and scenario models are compatible and they can be mutually interchangeable since they can share a common structure. However, one of the problems with IMS LD is that the elements used to describe learning goals are defined for the entire scenario, and are defined as Learning-objective elements of Learning Design (Figure 8-10). Moreover, Learning-activity, which defines leaf activities for learners, can also contain the Learning-objectives element (Figure 8-7). Therefore, although the scenario model can be mapped to the Activity-structure, only the Activity-structure that indicates the root (i.e., the whole scenario) and the Learning-activities (i.e., actions corresponding to the leaf I_L event) can describe the learning goal (i.e., learners' expected changes). However, the Activity-structures at the intermediate levels cannot describe the learning goal, thus failing to preserve the design rationale in the IMS LD descriptions of scenario

Fig. 8. Learning/Instructional process decomposition tree and its correspondence to LD

models. On the other hand, the proposed scenario model can describe the learners' state changes at each node (event) and manage information such as the specific WAY that was (not) applied or the theory on which the WAY is based.

Therefore, by linking the IMS LD and the scenario model in a complementary style, the interoperability and the assurance of content validity is met and "knowledge-sharing" between the theoretical study and the practical study is supported, thus filling the gap between theory and practice. The description content in a scenario model will be output and linked to the IMS LD description through the mechanism that explains its generation, a topic addressed in the section entitled "Overview of the Support Functions."

SMARTIES: A LEARNING/INSTRUCTIONAL SCENARIO-DESIGN SUPPORT SYSTEM

This section describes and illustrates SMARTIES, the learning/instructional scenario-design support system prototyped in this study.

SMARTIES is a theory-aware authoring system that can understand and make use of theories from OMNIBUS. It also supports designers to build scenarios that conform to theories. Moreover, this is a standard-compliant system that can output its deliverables in the IMS LD format. Unlike other systems with theories embedded in a procedural manner, the support provided by SMARTIES is based on the declarative knowledge defined by the OMNIBUS, which is built apart from SMARTIES.

System Architecture

The current scope of this system deals only with the design phase, one of the five major phases of instructional design: analysis, design, development, implementation and evaluation, such as the ADDIE model (Leshin, Pollock & Reigeluth, 1992). SMARTIES supports a design from its most abstract level to its most concrete level. In other words, it spans the goal setting of a scenario up to the Learning Objects (LOs) that are assigned to it. In SMARTIES, scenarios are designed by decomposing the scenario goal into sub-goals, as in WAY. This process externalizes the design rationale of the scenario and specifies LOs used in it. Finally, the resultant scenario model is produced in an IMS LD format that can be executed with IMS LD compliant tools.

Figure 9 shows the system architecture of SMARTIES. It supports three kinds of authors: ontology, scenario and knowledge authors. Ontology authors maintain OMNIBUS through the Hozo ontology editor (Kozaki et al., 2006), which is located outside SMARTIES. Scenario authors are instructional designers or teachers, for example, who design scenario models through the scenario editor, with reference to the concepts defined by OMNIBUS and by the educational theories described as pieces of WAY-knowledge. Knowledge authors describe learning/instructional design knowledge
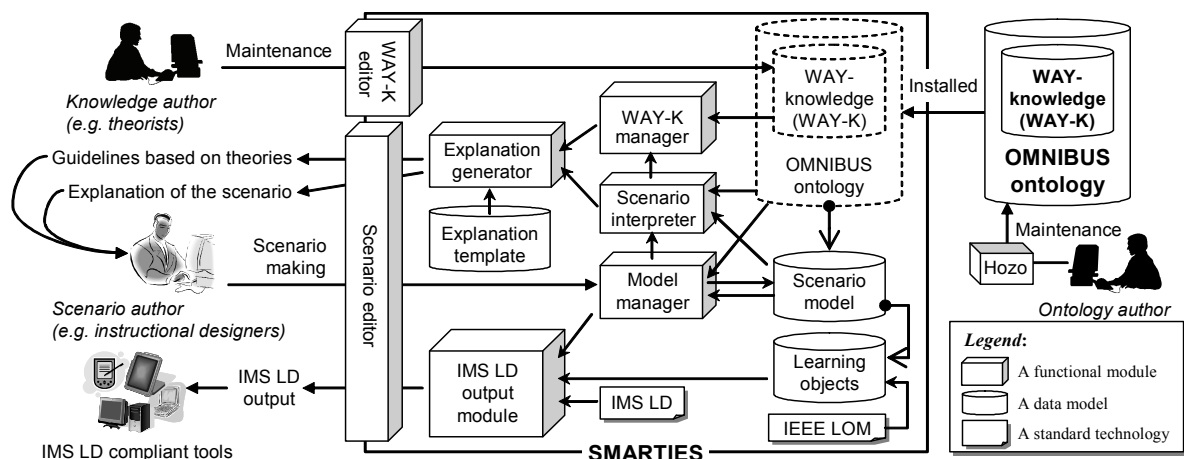
Fig. 9. SMARTIES: System Architecture

such as theories, best practices and their own heuristics as a set of pieces of WAY-knowledge. The WAY-knowledge editor supports the task and stores the resultant pieces of WAY-knowledge, which can be edited on the Hozo ontology editor.

Scenario authors create scenario models through Scenario editor, which supports the following functions available to the scenario authors:

- Providing a modelling environment
  - ➢ Concepts and vocabulary based on OMNIBUS
  - ➢ Graphical user interface to build scenario models
- Generating explanations of scenarios and theories
- Providing a modelling guideline based on multiple theories
  - ➢ Applying theories to scenarios
  - ➢ Providing alternative WAYs based on other theories
  - ➢ Providing theories which are similar to WAY, as defined by users
- Storing design rationale
  - ➢ Keeping the scenario model structures
  - ➢ Recording the theoretical legitimacy
  - ➢ Recording the design history
- Scenario validation function
  - ➢ Checking the consistency of scenarios
- Learning object search support
  - ➢ The link to a learning object repository (GLOBE[8])
- Scenario output
  - ➢ In text format
  - ➢ In the IMS LD format.

These functions are provided by the modules shown in Figure 9. The core module, the Model Manager, manages the descriptions of the author's scenario as a scenario model based on OMNIBUS. The scenario interpreter decodes the scenario model and queries the WAY-knowledge Manager in search of a piece of WAY-knowledge that is applicable to the model. The WAY-knowledge Manager launches a search of each I_L event in the scenario models. The interpretation and search results obtained by the above process are sent to the Explanation generator, which turns out explicative texts that are presented to the authors through the Scenario editor. Scenario authors can refer to the system's interpretation of the scenarios that they created in order to: (a) validate whether their intention is appropriately reflected in the scenario model, (b) confirm which piece of WAY-knowledge is suggested, and (c) confirm which theory supports the suggested piece of WAY-knowledge.

Overview of the Support Functions

This section addresses the three following support functions for the scenario authors (hereafter "authors") mentioned above:

- Providing a modelling environment
- Generating explanations for scenarios and theories
- Scenario output

---

[8] http://www.globe-info.net/en

As mentioned above, scenario models created in SMARTIES remain at an abstract level, so the description of the control structures is out of its scope at this moment. Since the current system can only create simple scenario sequences, a more sophisticated scenario model, including the conditional branches about the state of the learner, needs to be described in order to be adapted for each learner when the scenario is played. In addition, how learners' states are obtained is beyond the scope of this paper.

Providing a Modelling Environment

Figure 10 shows the SMARTIES user interface. The scenario editor (Figure 10-1) is the main interface. The author creates a scenario model (Figure 10-a) in a graphical way through the interface. In principle, the scenario author can freely describe I_L events and decompose them to create the scenario model. The I_L event description window (Figure 10-3) and WAY description window (Figure 10-4) have fields which correspond to the slots of each concept definition. Authors can fill out these fields in their own words or through a concept defined by OMNIBUS. When the ontology is referenced to, the IS-A structure of the available concepts is displayed thanks to the class restriction in the concept definition that corresponds to the fields (Figure 10-2). This example shows the case where an author is setting an Instructional action and an IS-A structure of candidate actions is displayed. As shown in this example, only the necessary elements extracted from the IS-A structure of OMNIBUS are displayed to the author. If authors find no relevant actions or states in the ontology, they can describe I_L events in their own words. In such cases, however, the support provided by the SMARTIES is more limited, since the system cannot interpret words not included in the ontology.

By using the concepts and vocabulary defined by OMNIBUS, SMARTIES interprets the content of a scenario model and offers an intelligent response such as generating explanations or suggesting applicable pieces of WAY-knowledge. The detailed mechanism that generates explanations will be presented in the following section, while suggestions of applicable pieces of WAY-knowledge are briefly explained here. The WAY-knowledge proposition window (Figure 10-5) displays the applicable pieces of WAY-knowledge (Figure 10-d) for the I_L event selected in the Scenario editor. This list displays pieces of WAY-knowledge that match the selected I_L event sorted by the matching score[9] along the IS-A structure of the theories, classified according to the paradigms discussed in the section on "Modelling Theories and Their Procedural Interpretations." When a piece of WAY-knowledge is selected, its structure after application (Figure 10-e) and its explanation (Figure 10-f) are displayed. All of these contents are created dynamically, based on OMNIBUS. Referring to this information, the author can select the piece of WAY-knowledge that seems most relevant. In other words, based on the theories, the author can design a learning/instructional sequence of actions that achieves a certain learning goal by referring to and selecting the piece of WAY-knowledge displayed.

Basically, scenario models are created by repeating this operation. The hierarchical structure of a scenario model indicates the design rationale and the theoretical validity of the scenario. A sequence of I_L events at the leaf level of the scenario model is represented through the piece of WAY-knowledge it uses. The section coloured in gray (Figure 10-c) in the scenario model indicates that it was set before and changed into another WAY. In addition to these displays, authors can record the reasons behind the changes, thus saving the design history and reasons for the changes.

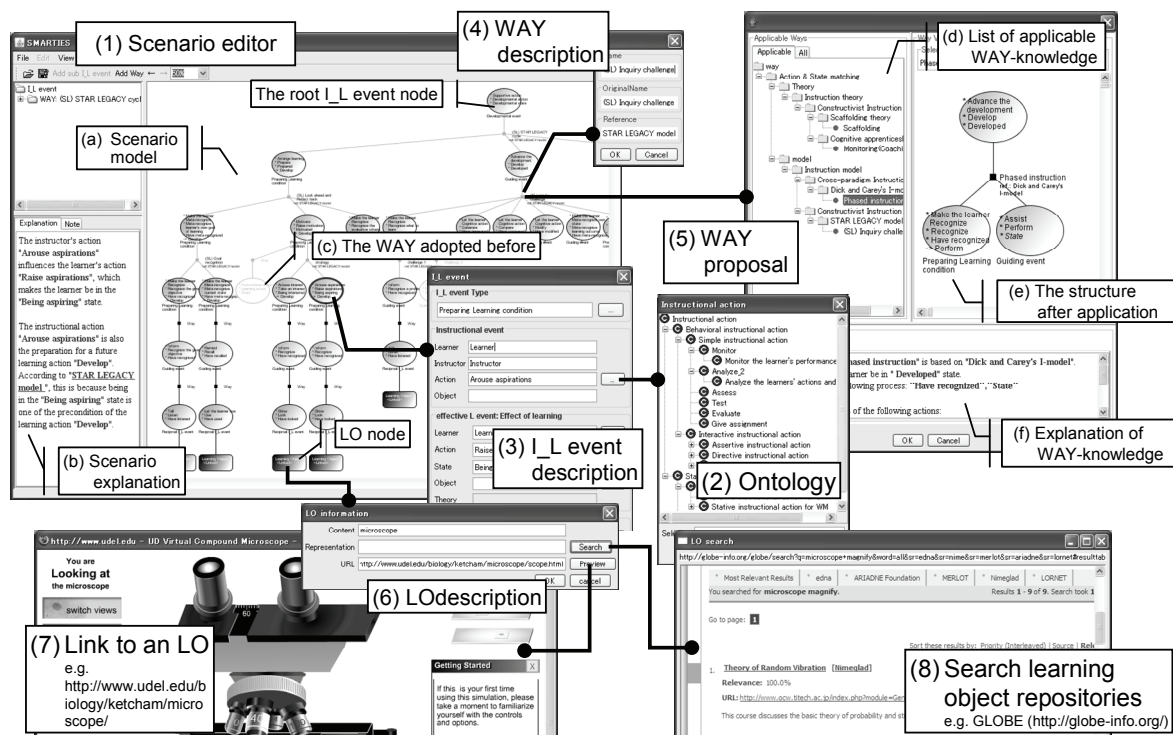[9] Matching occurs between the I_L event and the upper I_L event of the WAY-knowledge.

Fig.10. Screenshot of SMARTIES

Once a scenario is designed, learning objects are linked to the resulting scenario. The leaf nodes depicted by rectangles in the scenario model represent LOs. In this example, a microscope is simulated (Figure 10-7) in order to materialize the leaf I_L event. This is because the goal in this I_L event is to remind learners of the procedure (manipulating a microscope) and the transformational media. Actually, pictures illustrating changes over time or space are appropriate for such content according to Clark & Mayer's multimedia principle (Clark & Mayer, 2007). Authors can set an LO that they made or know or search for the most appropriate LOs in LO repositories, given the set requirements. Using keywords for content and representations set by the authors (Figure 10-6), SMARTIES can query an LO repository. For example, SMARTIES is currently connected to GLOBE. Authors can browse through query results (Figure 10-8) and copy the URL to SMARTIES (Figure 10-6) if an appropriate LO is found. The LO set in SMARTIES is displayed on the preview window (Figure 10-7) as mentioned above. In searching the LO repository for appropriate LOs the problem of keeping consistency between the characteristics of the leaf node and the specification of LOs is still an open one. Although only keywords are used to discuss LO requirements in the current implementation, many more properties should be considered to be used to specify the requirements, such as learners' characteristics (e.g., age, prior knowledge), the domain characteristics of the content and context characteristics such as mode of instruction and delivery (Mizoguchi et al., 2007). Work is currently in progress to enumerate such properties and to link them to LOM elements for LO searches.

The procedure to create scenario models has thus been explained in the case of concepts defined by OMNIBUS and of the WAY-knowledge. However, if authors cannot find relevant definitions for
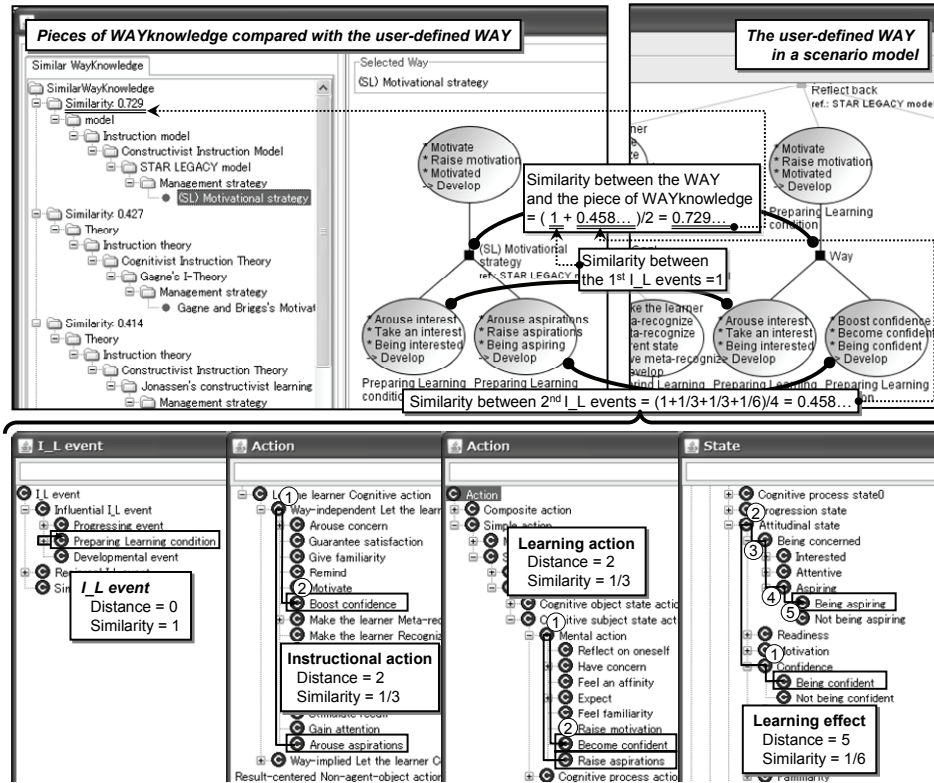
Fig. 11 Degree of similarity between a user-defined WAY & pieces of WAY-knowledge

actions or states in the ontology, they can describe an I_L event in their own words, although it limits the support that can be provided by SMARTIES. Nevertheless, at least the design rationale is stored as the hierarchical structure of the I_L events in the scenario model, and also in the description of the WAYs. Scenario authors can think of a decomposition as a WAY even if the decomposition is not defined as a piece of WAY-knowledge. In such a case, applicable pieces of WAY-knowledge will be provided upon further decomposition as far as the micro I_L events of the user-defined WAY are described in terms of the concepts defined in the ontology.

The validity of a WAY, as defined by the scenario author, can be examined by measuring its degree of similarity with the pieces of WAY-knowledge found in SMARTIES. When they are very similar, we can consider that the defined WAY is likely to be theoretically sound to the extent of the WAY-knowledge contained in SMARTIES. The level of similarity is calculated as follows. Concepts used in the WAY components are first compared with one of the target pieces of WAY-knowledge. The similarity value for each component is added together and the total is then normalized, resulting in a final value between zero and one. Currently, the similarity value between the concepts is obtained by measuring the distance between them along the IS-A structure of OMNIBUS, regarding the kinds of I_L events, instructional action and state of each I_L event included in the WAY or the piece of WAY-knowledge. S(A, B) is the similarity value between concept A and B, and D(A, B) is the distance between them.

$$S(A,B) = \frac{1}{D(A,B)+1} \qquad (1)$$

The distance between concepts is measured by the number of IS-A relations traced from one concept to the other and the degree of similarity equals the reverse of that number plus one. Figure 11 shows an example of similarities between a user-defined WAY and pieces of WAY-knowledge. In this case, the piece of WAY-knowledge with the highest degree of similarity is "(SL) Motivational strategy," with a level of similarity of 0.729. This value represents the mean similarity between the constituent micro I_L events of the author-defined WAY and the constituent micro I_L events of "(SL) Motivational strategy." In this example, the first micro I_L events are exactly the same, yielding a degree of similarity of 1. The second micro I_L events have a similarity value of 0.458, as calculated from the distances between the micro event's sub-types: *I_L event*, *Instructional action*, *Learning action,* and *Learning effect*. For example, the types of both *I_L events* are identical, so the distance between them equals 0 and the degree of similarity 1. At the same time, the types of *Instructional actions*, which are *Arouse interest* and *Boost confidence*, are different and have a distance of 2 along the IS-A hierarchy in OMNIBUS.

We acknowledge that this method of calculation leaves plenty of room for improvement and plans are underway to develop a more effective calculation method.

Explaining Scenarios and Theories

One of the characteristics of SMARTIES is that it can explain scenarios and theories. This feature can interpret scenarios and the definition of theories based on the ontology and the pieces of WAY-knowledge held by SMARTIES. As the result of the interpretation, the content of each I_L event or WAY described by the scenario author or the theory on which the WAY-knowledge is based (if pieces of WAY-knowledge are used) is presented to scenario authors in natural language. The theory definition is also presented. Table 2 lists these types of explanations.

The explanation of a scenario model is generated by using templates and is materialized by using the ontology and pieces of WAY-knowledge employed in the scenario model. To be more precise, the necessary data for each explanation are given by the Model Manager and the WAY-knowledge

Table 2
Types of Explanations (non exhaustive)

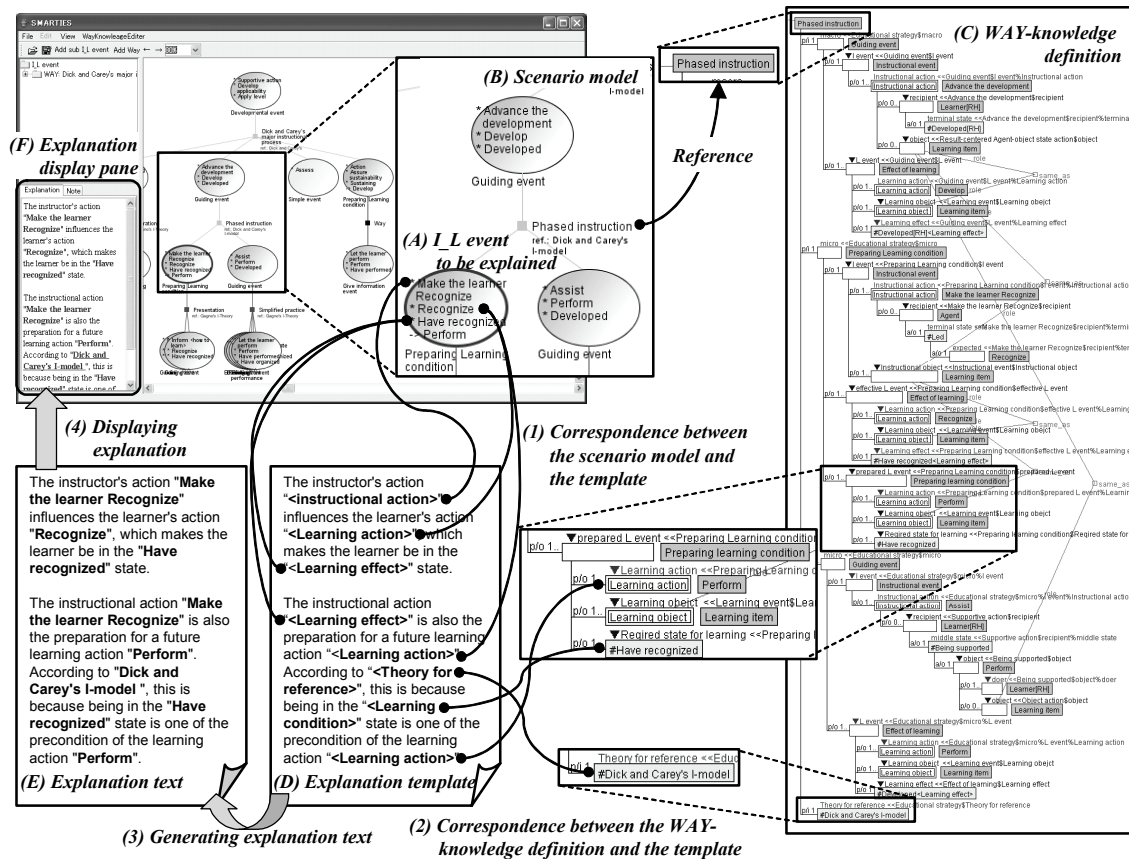| Types	Explanation
Scenario interpretation	The system's interpretation of the scenario model described by the author. There is no correspondence to the theory. e.g., The goal of the macro I_L event is to make the learner be in "*Prepared*" state. This is achieved by the following process of learner's state-change: "*Have meta-recognized,*" "*Motivated,*" "*Have recognized.*"
Theory explanation	Explanation of each piece of WAY-knowledge defined by the theory. e.g., This WAY-knowledge "*(SL) Motivational strategy*" is based on "*STAR LEGACY model.*" The goal is to make the learner be in "*Motivated*" state. This is achieved by the following process: "*Being interested,*" "*Have aspirations.*"
Theoretical legitimacy	It explains the scenario model described by the author based on the theory. e.g., This WAY may be inconsistent with the previous events.

Fig. 12. Mechanism to generate explanation text

Manager in XML format. Then, the XSLT transforms the data into an HTML file that is displayed on SMARTIES and supplemented with IMS LD descriptions. The mechanism by which such explanation texts are generated is shown in Figure 12. In this example, the content of the I_L event indicated in Figure 12-A is displayed in the explanation display pane 12-F. This content was generated by the Scenario model (Figure 12-B), the definition of the piece of WAY-knowledge (Figure 12-C) and the Explanation template (Figure 12-D). As shown in Figure 12-1 and 12-2, templates have fields for variables (the parts marked with angle brackets "<, >" in Figure 12-D) in which the definitions of concepts to be referenced to are set once materialized. For example, <Instructional action> is set to refer to the value of the Instructional action slot of the I_L event to be explained. Based on this reference definition, each variable in the Explanation template is materialized and an Explanation text (Figure 12-E) is generated. Specifically, as mentioned above, the contents of the Scenario model (Figure 12-B) and the definition of the piece of WAY-knowledge (Figure 12-C) are generated as a temporary XML file which is transformed using two XSL files that work as the content generation template and the display generation template in the HTML file of Explanation text (Figure 12-E). When the author selects any I_L event or WAY on SMARTIES, Explanation texts generated as an HTML file are posted in the Explanation display pane (Figure 12-F).

Most of the intelligent SMARTIES functions were developed based on OMNIBUS which defines learning and instruction in a declarative manner. In other words, these functions are not based on ad-hoc knowledge embedded in a procedural manner. Therefore, even if the content of OMNIBUS were updated or modified, there is no need to change the SMARTIES software, and the explanation text associated with the change can be provided to the author. This feature makes it possible to dynamically generate a great variety of the detailed explanations described above. Furthermore, such templates are created in compliance with the relatively upper-level concept of OMNIBUS (the I_L event and the WAY, for example). By creating such templates that include generalities in terms of superordinate concepts, various models can be dealt with. Furthermore, when a specialized template is required to deal with a more specialized concept, this can be handled by a minimal expansion of the template because the basic nature of the superordinate concept is inherited along the IS-A structure.

IMS LD Output Functions

Based on the correspondence with the IMS LD specifications mentioned in the section on "MERGING LEARNING/INSTRUCTIONAL THEORIES AND STANDARD TECHNOLOGIES," scenario models made with scenario authors can be converted into the IMS LD format. Figure 13 shows a screen shot in which the output was executed with the Reload LD player,[10] an IMS LD execution environment and viewer developed by the Reload project. It displays items such as the activity structures of the scenario models described in the IMS LD, descriptions of all activity elements and their related files, the LOs displayed to learners or additional descriptive information. It can be used as an execution environment to display LOs along the storyline of a scenario or as a viewer to provide references to the design information of each activity by displaying the description content.

We confirm that the scenario model content is correctly converted into the IMS LD description by feeding the IMS LD player with the scenario output in the IMS LD format from SMARTIES. By correlating explanation text generated by SMARTIES with the IMS LD description, users can refer to the theoretical grounds generated according to the ontology as the design rationale attached to a standard-compliant scenario structure. The explanation text also includes links to Web pages in which theories are explained so that more detailed information can be accessed.

All information pertaining to a scenario model designed in SMARTIES can be referred to by the Reload LD player, which is practically a standard-compliant tool. As discussed in the section "Mapping between the IMS LD Specifications and a Scenario Model," the decomposition structure of a scenario model is converted into an IMS LD activity-structure. In
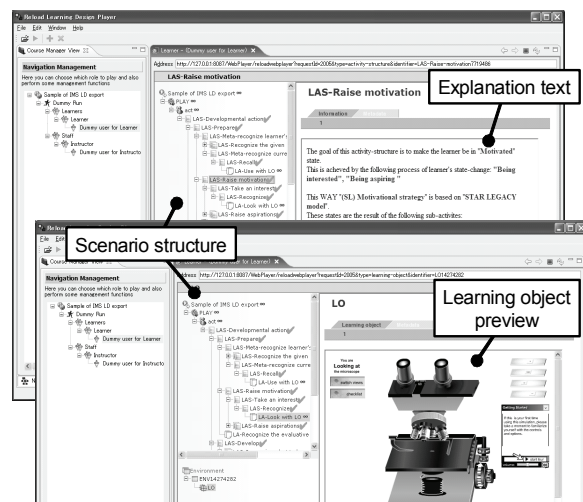

Fig. 13. Execution using the Reload LD player

[10] http://www.reload.ac.uk/ldplayer.html

addition, explanations generated by SMARTIES are converted into an HTML file and its links are made in the manifest file using the *information* element of IMS LD. The assigned LOs and the scenario model are also linked to the manifest file. Through this mechanism, theoretical information justifying scenario models is preserved in spite of the translation into IMS LD. Moreover, "knowledge-sharing" between theoretical and practical study is supported, thus filling the gap between theory and practice.

SMARTIES Characteristics

Given the functions presented so far, including the provision of guidelines or explanation text, SMARTIES may seem like an expert system. That is not the case, as SMARTIES' versatile functions are simply supported by these two basic operations:

- A simple read/write operation from/to the ontology
  (SMARTIES just needs to know which concepts are defined, what are their "parts," "attributes," what are their constraints, etc.)
- Pattern matching between I_L events
  (Matching of each I_L event described in the scenario model against the macro I_L event described in the piece of WAY-knowledge is executed to find the WAY-knowledge applicable to the scenario model.)

The following two aspects enable these two operations to realize the versatile functions described thus far:

- the declarative definition of concepts in the ontology
- the modelling based on the ontology.

By defining WAYs as relational concepts in a declarative manner, in addition to the wholeness concepts such as actions, states or events, SMARTIES can generate explanations concerning the scenario model theories and content described by the author. The possible decomposition structure of the I_L event from the scenario model is derived by unifying an I_L event from a macro I_L event of a piece of WAY-knowledge and an I_L event from a scenario model in SMARTIES. In other words, the applicability of the theories and their possible results can be indicated.[11] In this manner, SMARTIES processes the support function in a procedural manner, not based on heuristic rules but on declarative concept definitions extracted from learning/instructional theories.

However, describing theoretical knowledge in a declarative manner is not always sufficient to provide the required support. Therefore, the use of empirical knowledge must also be considered. For example, a learning/instructional scenario based on multiple theories can be created in SMARTIES. Nevertheless, as mentioned above, discrepancies between paradigms and theories imply different philosophies of learning/instruction, to a greater or lesser extent. Hence, using too many alternate theories within a single scenario may result in a lack of consistency as far as instruction or learning is concerned, confusing learners who use the scenario. It is important to keep a certain level of consistency, yet consistency verifications cannot be easily defined by the ontology in a declarative way since no theory supports the verification criteria. When dealing with such content, the use of a

---

[11] This mechanism is not something based on production rules from heuristics. In other words, it is not capable of grasping the changes of the object world by updating the working memory through the WAY-knowledge. This mechanism derives applicable WAY-knowledge by unifying the WAY-knowledge and the scenario model when the author plans learning/instructional processes.

Table 3
Support Functions that Require Rules (non exhaustive list)

Types of function	Explanations
Detecting insufficient goals	Detect the lack of sub-events that are essential or effective within the scenario model
Detecting excessive goals	Detect excessive events in the scenario model (does not contribute to achieving upper events)
Checking the balance of scenarios	Check the balance of scenarios to ensure that sufficient motivation is given and a learning review section is included at the end
Checking the consistency of scenarios	Detect a lack of consistency in the scenarios (e.g., paradigms change often)
Checking sustainability of events	Difficulties of sustaining state change (e.g., it made the learner remember something, yet the actual use of that information takes a long time.)

certain amount of heuristic rules is required. By storing the rules defined by the ontology in a rule base separately from the ontology and using them, we can manage the agreed and well-understood knowledge and ad-hoc, heuristic knowledge separately. Table 3 lists the possible support functions, the rules of which need to be defined separately from the ontology. Their implementation remains to be addressed in the future.

OBSERVATIONS

This section reports on the tests conducted to assess the validity of the proposed model of learning/instructional theories, based on the initial working hypothesis. Furthermore, SMARTIES is compared to other authoring tools.

Testing the Working Hypothesis

In order to test the working hypothesis put forth, the 99 pieces of WAY-knowledge defined so far were classified into roughly four groups based on theory, paradigm and object. Then, the usage of "state" was summarized in the pieces of WAY-knowledge at the macro and micro I_L events (Table 4) (Hayashi, Bourdeau & Mizoguchi, 2008). This section examines the characteristics and common elements of each paradigm in order to determine whether they are properly extracted.

As described in Table 1, pieces of WAY-knowledge can be classified into four theory/model categories: cross-paradigm, cognitivist, constructivist and instructional management. States are roughly classified into six groups. (a) The *Learning stage* relates to the learning process, such as "Preparation," "Development" and "Assessment." The other categories of states describe the learners' changes at each learning stage. (b) The *Cognitive process state* pertains to the learners' cognitive process, which includes recognition, recall, the learners' application of knowledge or skill and so on. (c) The *Meta-cognitive process state* is associated with metacognitive activities, such as self-regulation, reflection and so on (Kayashima, Inaba & Mizoguchi, 2005). (d) The *Attitudinal state* concerns the learners' attitude and interest, such as "Motivation." (e) The *Developmental state* relates to the developmental stages of knowledge and skills, defined according to Bloom, Hastings, and Maclaus' taxonomy (1971). This state is mainly changed in the "Development" learning stage and assessed in the "Assessment" learning stage. (f) Lastly, the *External state* pertains to learners' communication with others or the environment through subclasses such as "Informed" or "Asked."

Table 4
Distribution of the States used in the Pieces of WAY-knowledge

		Theory/Model Categories			
		Learning (mechanism) paradigm			Instruction management
		Cross-paradigm	Cognitivist	Constructivist	
Statistics on theory /model	**Number of theories/models**	1	3	6	1
	Pieces of WAY-knowledge (quantity)	2	30	51	16
	Number of I_L events	7	77	128	39
State categories	**Percentage of Learning stages**	**71.4**	4.8	6.3	0.0
	Percentage of Cognitive process states	14.3	**61.9**	36.7	35.9
	Percentage of Meta-cognitive process states	0.0	15.9	**41.4**	12.8
	Percentage of Attitudinal states	0.0	9.5	4.7	**43.6**
	Percentage of Developmental states	**14.3**	0.0	0.8	0.0
	Percentage of External states	0	7.9	**10.2**	7.7

In Table 4, the theory/model classification mostly used in each state classification appears in bold. This result indicates that various learning/instructional strategies extracted from each theory reflect their characteristics. For example, cognitivist theories/models use many *cognitive process states* since they focus on knowledge processing; constructivist theories/models use many *meta-cognitive states* related to meta-cognition processes; cross-paradigm theories/models use numerous *learning stages* as they pertain to general learning/instructional processes in which paradigm differences are minor. As for the *external state*, the distribution is similar, except for the cross-paradigm model. However, its use in the constructivist theories/models is somewhat greater than that in the others. Although these theories are similar in terms of dealing with somewhat concrete processes, the constructivist theory/model focuses on interactions between people and their environment.

As mentioned above, by modelling strategies extracted from theories as learner state-focused pieces of WAY-knowledge, paradigm similarities and differences are highlighted. As shown in Table 4, minor state classifications are also used in all theory groups, meaning that certain uses of state classifications overlap with theory groups. Therefore, even if a scenario comprises different paradigms and theories, such components can be blended into a single scenario with the common state concept working as the common ground. Since theories that support theory-blending have yet to be established, the validity of blending cannot always be confirmed. However, we consider that its feasibility can be presented by the framework of WAY-knowledge proposed in this study and the theory-blending function discussed below will provide useful information for instructional designers and teachers.

Blending Theories in Scenarios

To investigate the feasibility of theory-blending support in SMARTIES, a scenario included in (Reigeluth, 1987) was modelled using SMARTIES and the possibility of theory-blending was investigated. The scenario is based on Gagne and Briggs' theory (1979). The original book introduces eight theories and different learning/instructional scenarios for the same learning content and goal (understanding the principles that pertain to the use of the microscope). Scenarios are designed by experts, based on the respective theories, before they are explained and compared. The original scenario design comprises eleven steps. On the other hand, the scenario model built on SMARTIES contains 15 leaf nodes (I_L events), therefore, 15 steps. The reason for this difference is that several steps in the original scenario include multiple interactions between the instructor and the learner. One interaction is described as one I_L event in the scenario model therefore one step of the original scenario may be decomposed into several steps in the scenario model depending on the level of granularity of the interaction.

It was possible to describe most of the WAYs in the scenario model with pieces of WAY-knowledge extracted from Gagne and Briggs' principles. The only part that could not be described is the lowest layer of the scenario model, which consists mainly of an I_L event where actions are decomposed into concrete actions, such as *Tell* and *Listen* for instance, which cannot be further decomposed in OMNIBUS. Therefore, the pieces of WAY-knowledge prepared for this study were appropriate to build an overall storyline for the scenario.

In order to assess the applicability of other theories to this scenario model, all WAYs in the scenario model were verified in order to find out whether other pieces of WAY-knowledge were applicable. This experiment was conducted with SMARTIES and the results obtained appear in Figure 14. If a WAY displays alternate multicoloured shadows on the scenario editor, where colour differences represent paradigm discrepancies, the author can view the detailed information pertaining to the alternatives in the WAY proposal window. Results show that a minimum of one substitutable piece of WAY-knowledge was detected out of 99 pieces of WAY-knowledge, against 23 out of the 27 WAYs in the scenario model.

In addition, the same experiment was carried out with the scenario model based on the STAR LEGACY model (Schwartz et al., 1999), in which one or more substitutable pieces of WAY-knowledge were detected in 21 out of 24 WAYs. These alternatives include some pieces of WAY-knowledge extracted from other theories or paradigms. Such results suggest that SMARTIES can provide possibilities for applying theories other than the target theories/models, Gagne and Briggs's and STAR LEGACY models in this case, to this scenario model. Obviously, as mentioned in the previous section, not all alternatives are assured to be pedagogically relevant for usage in this scenario model, yet they can provide helpful information for scenario authors. Given this perspective, we may suggest the possibility of designing learning/instructional scenarios based on the multiple theories beyond paradigms through the modelling framework based on OMNIBUS.

Related Studies on Authoring Systems

A number of authoring systems have been suggested in the field of learning/instruction support systems (Murray, Blessing & Ainsworth, 2003). This section compares SMARTIES to other major authoring systems from two perspectives: the ontology-based and theory-based systems.
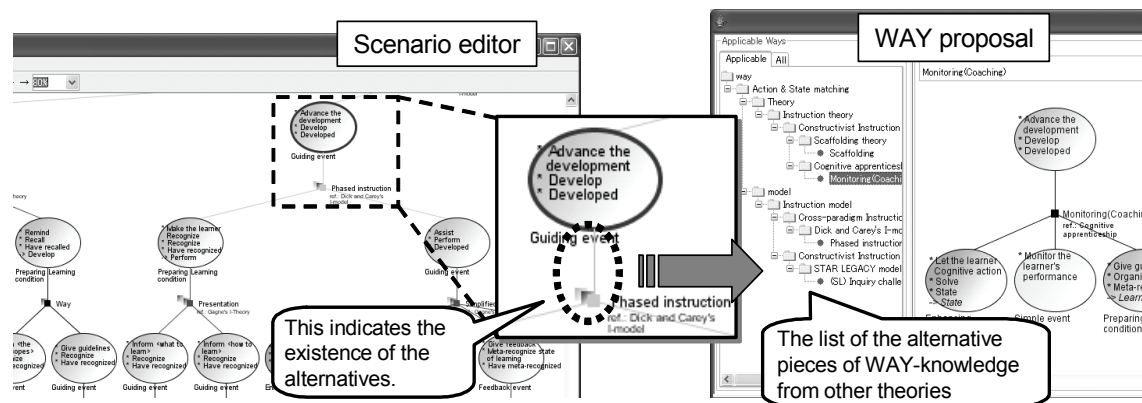
Fig. 14 Experimental result displayed on SMARTIES

EON (Murray, 1998) and the *i*Designer (Hayashi, Ikeda & Mizoguchi, 2004) are the most typical ontology-based authoring systems. These systems systematize the learning/instructional actions and the concepts regarding the objects as a task or domain ontology and then, based on that systematization, provide assistance to design the targeted learning/instructional scenarios at a conceptual level. Here, "conceptual level" means describing the educational significance of an LO rather than the flow and control structure (hereafter called "implementation level") of such an LO to be presented to learners engaged in learning activities. The characteristics of these authoring tools are that they provide the basic concepts to be used to create learning/instructional scenarios by the ontology. They also enable authors to specify design intentions at the implementation level.

The *i*Designer provides a function to verify the relevance of the process designed, along with such a specific design intention. This function, called "conceptual level simulation," verifies the relevance of the learning/instructional process by executing the process for the targeted learner model on a simulation basis. On the other hand, EON enables the authors to clearly describe the objectives and the applicable conditions of the various processes that the author designed by setting a meta-strategy. The meta-strategy comprises the combined condition descriptions based on the ontology and the strategy descriptions by way of parameter-setting. When executed, it is used to change the process dynamically, to better suit learners.

This meta-strategy is also adopted by REDEEM (Major, Ainsworth & Wood, 1997) although it is not ontology-based. The meta-strategy adopted by REDEEM is simpler than that of EON; moreover, it enables the author to easily set a meta-strategy by selecting a combination of quantitative parameters tailored to the characteristics of the targeted learner. Since the aim of REDEEM is to enable teachers who may be unfamiliar with computer technology to easily create learning materials, its setting and interface are much simpler. As this example shows, ontology-based systems tend to increase the burden on the author due to the complexity of the content to be described, yet they enable more detailed descriptions of learning/instructional processes.

The main assistance provided by the aforementioned tools is that they offer modelling frameworks. However, authors need to understand the learning/instructional theories to design relevant learning/instructional scenarios. As for the authoring systems that include theoretical knowledge, tools such as CREAM (Nkambou, Gauthier & Frasson, 1996) and CTAT (Cognitive Tutor Authoring Tools) (Koedinger, Aleven & Heffernan, 2003) can be cited as examples. They are based

on Gagne & Briggs' theory (1979) and Anderson's work (1993), respectively. By designing the assistance functions according to each theory, these tools can provide authors with detailed assistance. However, both are based on a single theory and authors who wish to design materials based on other theories must use another authoring tool since the contents of only a single theory are embedded in the assistance functions. Furthermore, the clear correspondence between the assistance functions and the theory is unavailable to authors who use the system. It is possible to explain how the system reached such a conclusion or why certain processing tasks need to be executed by showing the history or the conditional part of the selected rules when considering a conventional expert system. However, although this merely traces the links between rules which are applied superficially, this does not prove its "legitimacy." In order to prove legitimacy, an interpretation based on the fundamental knowledge of the object is required.

SMARTIES encompasses the advantages of these authoring tools and complements their drawbacks. By using the concept of events, actions and states defined by OMNIBUS, SMARTIES provides an environment in which authors can describe their own learning/instructional scenarios at a conceptual level (see Figure 9). It also offers design guidelines based on multiple theories by accumulating theories as pieces of WAY-knowledge. Obviously, focusing on a single theory has the advantage of achieving an authoring system that is theoretically consistent with the system behaviour and the user interface. However, in order to make the authoring tool continuously usable and to be able to respond to changes in theories, the accumulation of knowledge and a general-purpose framework based on the foundation of systematizing theories is required, such as is elaborated in this study. The pieces of WAY-knowledge are expandable and the number of theories to be dealt with can be augmented by increasing the number of pieces of the WAY-knowledge.

Although the ontology-based system problem of complex descriptions in the tools has not been solved, the current goal of this study is to implement and verify the basic functions for learning/instructional scenarios that is based on multiple theories. The user-friendliness of the interface and its effectiveness in practice will be addressed in the future.

Furthermore, OMNIBUS suggests other possibilities of theory-awareness than SMARTIES. CIAO (Psyché, 2004) is another system that takes an approach that is similar to SMARTIES. This system generates the scenario models based on OMNIBUS, same as SMARTIES. It outputs it in IMS LD format and it can analyze and validate the scenario. However, this is not an authoring system but a scenario analysis agent that interprets scenarios described in the IMS LD format in a bottom-up manner. This approach to dealing with scenario models is the opposite of SMARTIES, which assists scenario designing in a top-down manner. Therefore, the two systems are complementary to each other. Wang and Kim (2007) propose an Intelligent Tutoring System (ITS) based on OMNIBUS. In this ITS, the pieces of WAY-knowledge are converted to SWRL rules and used by the ITS to select an instructional strategy that is appropriate to the learner.

CONCLUSION

This paper documents the OMNIBUS ontology, as well as SMARTIES, a learning/instructional scenario-design support system that uses this ontology. By taking an ontology engineering approach, SMARTIES provides a solution to the following three challenges linked to building a theory-aware and standard-compliant authoring system. These three challenges, which were brought up at the beginning of this paper, are as follows:

i) to make computers "understand" a variety of learning/instructional theories;
ii) to "utilize" such theories to develop learning scenarios conducted by instructional designers; and
iii) to make it possible to "share" the scenarios that are created in standard technology compliant formats.

As for the first issue, we built OMNIBUS as a conceptual basis to clarify the similarities and differences among various theories. This basis was used to structure a variety of theories in a declarative manner.

As for the second issue, we proposed a mechanism that keeps the consistency between the declarative definition of theories and their procedural utilization on the basis of WAY-knowledge defined in OMNIBUS. This makes it easier for system developers to manage a knowledge base according to the modification of knowledge as well as the evolution of theories.

SMARTIES was developed based on both "understanding" and "utilization," a concrete example of atheory-aware authoring system that helps scenario authors understand the theories and utilize them to build learning scenarios.

As for the last issue, correspondences were identified between the proposed scenario model and the IMS LD specifications. Moreover, a conversion mechanism of the suggested learning/instructional scenario model was developed into an IMS LD description that explicitly demonstrates the intention of the design and the theoretical bases. OMNIBUS is located midway between theories and standard technologies to establish "the fusion of learning/instructional theories and standard technologies" by coping with both theory-awareness and standards-compliance in the SMARTIES authoring system.

The results of this study can contribute to the research area of authoring systems for ITSs and other areas of AIED, based on the various aspects described below. Although the evaluation is far from complete in terms of practical use, the authors believe all of the results of this study were considered difficult to achieve from the viewpoint of the current state of the art. Therefore, the fact that the initial version of the ontology and the authoring system successfully demonstrate that they have the desired functionality offers an appreciable contribution to the advancement of research conducted in each area related to those aspects. As part of an informal evaluation, demonstrations of OMNIBUS and SMARTIES were held at the SWEL'07[12] workshop in conjunction with AIED2007[13] and a demo session at ITS2008,[14] where positive comments were received. A special introduction to OMNIBUS and SMARTIES was given to two theorists whose theory has been modelled in the ontology, David Merrill (I2LOR'07 Conference[15]) and Alan Collins (ITS2008), and their feedback has been incorporated. Needless to say, OMNIBUS and SMARTIES must be formally evaluated with the three kinds of Authors that have been identified as users: Scenario Authors, Knowledge Authors and Ontology Authors.

Structuring Theories based on Ontology Engineering

As far as OMNIBUS is concerned, we consider that the declarative modelling of learning/instructional theories and their procedural usage was successfully executed (see the section on

---

[12] http://compsci.wssu.edu/iis/swel/SWEL07/swel07-aied07.html
[13] http://www.isi.edu/AIED2007/
[14] http://gdac.dinfo.uqam.ca/its2008/
[15] http://www.lornet.org/i2lor07

"OBSERVATIONS") by building the ontology based on the learner's state as the core concept under the working hypothesis mentioned in the section on "A Working Hypothesis." Although definitions need to be refined from the perspective of experts of learning/instructional theories, their significance lies in the fact that they present the feasibility of structuralizing various learning/instructional theories.

As discussed in the section on "THE BUILDING OF THE OMNIBUS ONTOLOGY," learning/instructional theories are diverse due to the issue of paradigms. It is, thus, particularly difficult to structure these theories. Achieving the structuring of such difficult objects owes a great deal to both the building of the upper-level ontology (Mizoguchi, 2004, 2005) and the functional modelling based on the device ontology (Kitamura & Mizoguchi, 2003), which were being developed concurrently with this study. Although the upper-level ontology that is object-independent and the device ontology that deals with artificial objects do not have much in common with the learning/instructional theories, they work as a successful platform to concretize the concepts that dominate the targeted world. This study can be an example that demonstrates the generality of upper-level ontology and functional modelling.

Implementing a Theory-aware Authoring System

As discussed in the introduction, high expectations are placed on learning/instructional theories to assure the quality of learning content, yet the interpretation and usage of the theories is difficult for practitioners, due to their abstractness and the paradigm issues. This theory-aware authoring system was built not merely as a database of theories but rather, to achieve two goals: to "explain" the content of theories and to "apply" such theories when authors construct learning/instructional scenarios.

The key to realizing such "explanation" and "application" is the combination of the declarative definition and the procedural usage of theories based on the ontology engineering method described in the section on "Modelling Theories and Their Procedural Interpretations." Since a piece of WAY-knowledge is originally defined in a declarative way, the explanation of scenarios and theories can be generated by interpreting the piece of WAY-knowledge in a declarative manner. However, it can be also interpreted in a procedural manner and based on that interpretation, we can check specifically if each theory can be applied to the scenario model or not. This will provide the modelling guidelines based on multiple theories. As we observed in the section on "Related Studies on Authoring Systems," current authoring systems embed only one learning/instructional theory, even if they are the best of their kind. SMARTIES is the only system that accumulates multiple learning/instructional theories in a way that allows computer processing.

Next-generation Knowledge Processing System: an Applied Study of Heavy-weight Ontology

Although ontology has been attracting significant attention because of the activities related to the semantic Web, many ontology studies deal with "light-weight" ontologies that aim at being metadata for searches. There are several studies on "heavy-weight" ontologies that seem to be used as the platform for higher-level intelligent systems, but most of them focus on theoretical research (Guarino, 1998). Very few studies, including the herein study, built a system leading to application. SMARTIES is a so-called ontology-aware application entirely based on the ontology. Its basic function is a reference to the concepts simply defined by the ontology, while the matching of the scenario models

and the pieces of WAY-knowledge are based on the ontology. As mentioned in the last part of the section on "Related Studies on Authoring Systems," this system remains a prototype and many challenges must be overcome before it is brought into practice. However, SMARTIES can be positioned as a model for a next-generation ontology-based knowledge-processing system that evolved from expert systems.

Content-oriented Approach to Standard Technologies

Currently, people tend to pay attention only to the format in terms of standard technologies. This is somewhat important in view of establishing interoperability. In the future, however, building a mechanism to distribute relevant content within a standardized framework will be required in addition to providing data to be shared and reused on various standard-compliant systems. In that sense, "content-oriented" study based on ontology engineering plays an important role. In this study, we gave the scenario description in the IMS LD format a common vocabulary conceptually systematized by OMNIBUS, and the theoretical validity of the structure by converting the scenario model into IMS LD. In addition, information concerning validity will be output and can be referenced using IMS LD-compliant tools. This means that SMARTIES can help authors design scenarios with theoretical validity as well as leaving the linkage to theories in the IMS LD description. This drives the utilization of theories and at the same time, enables sharing and reusing case studies in which theories are applied to each scenario. All of this will contribute to filling the gaps between theories and practice. In the future, this study will aim at dealing with not only the theories but also best practices to establish a framework of knowledge systematization that ensures the sharing and the reuse of both the format and the content of learning objects.

ACKNOWLEDGMENTS

References

Anderson, J. R. (1993). *Rules of the Mind*. Hillsdale, NJ: Erlbaum.

Bloom, B.S., Hastings, J.T., & Maclaus, G.F. (1971). *Handbook on Formative & Summative Evaluation of Student Learning*. New York: McGraw-Hill.

Bourdeau, J., & Mizoguchi, R. (2002). Collaborative ontological engineering of instructional design knowledge for an ITS. In Cerri, S.A. Gouarderes, G. & Paraguacu, F. (Eds.) *Intelligent Tutoring Systems (ITS2002)* (pp. 399-409). Berlin: Springer-Verlag.

Bourdeau, J., & Mizoguchi, R. (2004). Selecting theories in an ontology-based ITS authoring environment. In Lester, J.C. Vicari, R.M. & Paraguacu, F. (Eds.) *Intelligent Tutoring Systems (ITS'2004)* (pp. 150-161). Berlin: Springer-Verlag.

Clark, R.C., & Mayer, R.E. (2007). *E-learning & the Science of Instruction*. 2nd ed., San Francisco: Preiffer.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing & mathematics. In L. B. Resnick (Ed.) *Knowing, Learning, & Instruction: Essays in Honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cooper, P.A. (1993). Paradigm shifts in designed instruction: From behaviorism to cognitivism to constructivism, *Educational Technology*, 33(5), 12-19.

Dicheva, D. (2008). O4E: Ontologies for Education. http://compsci.wssu.edu/iis/nsdl/ .

Devedzic, V. (2006). *Semantic Web & Education*. Berlin: Springer-Verlag.

Dick, W., Carey, L., & Carey, J. O. (2001). *The Systematic Design of Instruction*, Fifth edition. Addison-Wesley Educational Publisher Inc.

Ertmer, P. A., & Newby, T. J. (1993). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly*, 6 (4), 50-70.

Gagne, R. M., & Briggs, L. J. (1979). *Principles of Instructional Design* (2nd Ed.). New York: Holt, Rinehart & Winston.

Guarino, N. (1998). Some ontological principles for designing upper level lexical resources. In *Proceedings of the First International Conference on Lexical Resources & Evaluation* (pp. 527-534).

Hayashi, Y., Ikeda, M., & Mizoguchi, R. (2004). A design environment to articulate design intention of learning contents. *International Journal of Continuing Engineering Education & Life Long Learning*, 14 (3), 276-296.

Hayashi, Y., Bourdeau, J., & Mizoguchi, R. (2006a). Ontological Modelling Approach to Blending Theories for Instructional & Learning Design. In *Proceedings of ICCE2006* (pp. 37-44).

Hayashi, Y., Bourdeau, J., & Mizoguchi, R. (2006b). Ontological Support for a Theory-Eclectic Approach to Instructional & Learning Design. In *Nejdl W. and Tochtermann K.(Eds.) Innovative Approaches for Learning and Knowledge Sharing (Proc. of First European Conference on Technology Enhanced Learning(EC-TEL2006))* (pp. 155-169). Berlin: Springer-Verlag.

Hayashi, Y., Bourdeau, J., & Mizoguchi, R. (2007). Theory-aware Explanation Support for Standard-compliant Scenario Building. In *Proceedings of the workshop on Semantic Technology for Education* (held in the 15th Int'l. Conf. Computers in Education (ICCE2007)) (pp. 104-109). http://www.ei.sanken.osaka-u.ac.jp/hayashi/ICCE2007WS-CR-hay-final.pdf

Hayashi, Y., Bourdeau, J., & Mizoguchi, R. (2008). Structurization of Learning/Instructional Design Knowledge for Theory-aware Authoring systems. In Woolf, B.P., Aimeur, E., Nkambou, R. & Lajoie, S.(Eds.) *Intelligent Tutoring Systems (ITS2008)* (pp. 573-582). Berlin: Springer-Verlag.

Hmelo, C.E., & Guzdial, M. (1996). Of black & glass boxes: Scaffolding for doing & learning. In Edelson, D.C. & Domeshek, E.A. (Eds.) *International Conference on the Learning Sciences* (pp. 128-133). Charlottesville, VA: Association for the Advancement of Computing in Education (AACE).

Hogan K., & Pressley M. (1997). *Scaffolding Student Learning: instructional approaches & issues*. Cambridge: Brookline Books.

IEEE LTSC (2002). IEEE Standard for Learning Object Metadata, IEEE Product No.: STDPD95001 (Print)/STD95001 (PDF). (PDF version of the final draft is available on http://ltsc.ieee.org/wg12/files/LOM_1484_12_1_v1_Final_Draft.pdf)

IMS Global Learning Consortium, Inc. (2003). IMS Learning Design. Version 1.0 Final Specification. http://www.imsglobal.org/learningdesign/

Jonassen, D. (1999). Designing constructivist learning environment. In C. M. Reigeluth (Ed.): *Instructional-design Theories & Models: A New Paradigm of Instructional Theory* (pp. 215-239). Mahwah, New Jersey: Lawrence Erlbaum Associates, Inc.

Kayashima, M., Inaba, A., & Mizoguchi, R. (2005). What Do You Mean by to Help Learning of Metacognition? In Looi, C.-K., McCalla, G.I., Bredeweg, B., Breuker, J. (Eds.) *Artificial Intelligence in Education* (pp. 346-353). Amsterdam: IOS Press.

Keller, J.M., & Kopp, T.W. (1987). An application of the ARCS model of motivational design. In C. M Reigeluth (Ed.) *Instructional theories in action: Lessons illustrating selected theories & models* (pp.289-320). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Koedinger, K.R., Aleven, V.A.W.M.M., & Heffernan, N.T. (2003). Toward a Rapid Development Environment for Cognitive Tutors. In Hoppe,U., Verdejo, F. & Kay, J. (Eds.) *Artificial Intelligence in Education* (pp. 455-457). Amsterdam: IOS Press.

Kitamura, Y., & Mizoguchi, R. (2003). Ontology-based description of functional design knowledge & its use in a functional way server. *Expert Systems with Application*, 24 (2), 153-166.

Kozaki, K., Kitamura, Y., Ikeda, M., & Mizoguchi, R., (2002). Hozo: An Environment for Building/Using Ontologies Based on a Fundamental Consideration of "Role" & "Relationship." In Gmez-Prez, A. & Benjamins, V.R. (Eds.) Proceedings of the 13th International Conference on Knowledge Engineering & Knowledge Management (EKAW2002) (pp. 213-218).

Kozaki, K., Sunagawa, E., Kitamura, Y., & Mizoguchi, R. (2006). Fundamental Consideration of Role Concepts for Ontology Evaluation. In *Proceedings of EON2006*.

Leshin, C. B., Pollock, J., & Reigeluth, C. M. (1992). *Instructional Design Strategies & Tactics*. Englewood Cliffs, NJ: Educational Technology Publications.

Major, N., Ainsworth, S.E., & Wood, D.J. (1997). REDEEM: Exploiting Symbiosis Between Psychology & Authoring Environments. *International Journal of Artificial Intelligence in Education*, 8 (3/4), 317-340.

Merrill, D. (1983). Component display theory, In C. M. Reigeluth (Ed.) *Instructional-design Theories & Models: An Overview of their Current Status* (pp. 279-333). Hillsdale, New Jersey: Lawrence Erlbaum Associates, Inc.

Merrill, M.D., & Tennyson, R.D. (1977). *Concept Teaching: An Instructional Design Guide.* Englewood Cliffs, NJ: Educational Technology.

Mizoguchi, R., & Bourdeau, J. (2000). Using Ontological Engineering to Overcome Common AI-ED Problems. *International Journal of Artificial Intelligence in Education*, 11 (2), 107-121.

Mizoguchi, R. (2004). Tutorial on ontological engineering - Part 3: Advanced course of ontological engineering. *New Generation Computing* 22 (2), 198-220.

Mizoguchi, R. (2005). *Ontology engineering*, Tokyo: Ohmsha Ltd. (in Japanese).

Mizoguchi, R., Hayashi, Y., & Bourdeau, J. (2007), Inside Theory-Aware & Standards-Compliant Authoring Systems. In *Proceedings of SWEL'07: Ontologies & Semantic Web Services for Intelligent Distributed Educational Systems* (pp. 1-18).

Murray, T. (1998). Authoring Knowledge-Based Tutors: Tools for Content, Instructional Strategy, Student Model, & Interface Design. *Journal of the Learning Sciences*, 7 (1), 5-64.

Murray, T., Blessing, S., & Ainsworth, S. (2003). *Authoring Tools for Advanced Technology Learning Environments: Toward Cost-Effective Adaptive, Interactive & Intelligent Educational Software* Berlin: Springer.

Nakabayashi, K. (2004). e-Learning Technology Standardization - Make It Converge!! In *Proceedings of 12th International Conference of Computers in Education (ICCE2004)* (pp. 33-39).

Nkambou, R., Gauthier, G., & Frasson, C. (1996). CREAM-Tools: An Authoring Environment for Curriculum & Course Building in an Intelligent Tutoring System. In *Proceedings of CALICSE'96* (pp. 186-194).

Koper, R. (2001). Modelling Units of Study from a Pedagogical Perspective,. http://hdl.handle.net/1820/36.

Paquette, G., Rosca. I., Mihaila S., & Masmoudi A. (2006). TELOS, a service-oriented framework to support learning and knowledge Management. In S. Pierre (Ed) *E-Learning Networked Environments and Architectures: a Knowledge Processing Perspective*. Berlin: Springer-Verlag.

Petry, B., Mouton, H., & Reigeluth, C.M. (1987). A Lesson Based on the Gagne-Briggs Theory of Instruction. In C. M Reigeluth (Ed.) *Instructional theories in action: Lessons illustrating selected theories & models* (pp. 11-44). Hillsdale, N. J.: Lawrence Erlbaum Associates.

Psyché V. (2004). CIAO, an Interface Agent Prototype to facilitate the use of ontology in intelligent authoring system. In Proceedings of the *Annual Scientific Conference of the LORNET Research Network*.

Psyché V., Bourdeau, J., Nkambou, R., & Mizoguchi, R. (2005). Making Learning Design Standards Work with an Ontology of Educational Theories. In Looi, C.-K., McCalla, G.I., Bredeweg, B., Breuker, J. (Eds.) *Artificial Intelligence in Education* (pp. 539-546). Amsterdam: IOS Press.

Reigeluth, C. M. (1983). Instructional-design: What is it & why is it? In C. M. Reigeluth (Ed.) *Instructional-design theories & models: An overview of their current status* (pp. 3-36). Hillsdale, N.J.: Lawrence Erlbaum Associates, Inc.

Reigeluth, C. M. (Ed.) (1983). *Instructional-design Theories & Models: An Overview of their Current Status.* Hillsdale, N.J.: Lawrence Erlbaum Associates, Inc.

Reigeluth, C. M. (Ed.) (1987). *Instructional Theories in Action: Lessons Illustrating Selected Theories & Models.* Hillsdale, N.J.: Lawrence Erlbaum Associates, Inc.

Reigeluth, C. M. (Ed.) (1999). *Instructional-design Theories & Models A New Paradigm of Instructional Theory.* Mahwah, N. J.: Lawrence Erlbaum Associates, Inc.

Schwartz, D,L., Xiaodong, L., Brophy, S., & Bransford, J.D. (1999). Toward the Development of Flexibly Adaptive Instructional Designs. In C. M. Reigeluth (Ed.). *Instructional-design Theories & Models A New Paradigm of Instructional Theory* (pp. 183-213) Mahway, N. J.: Lawrence Erlbaum Associates.

Sunagawa, E., Kozaki, K., Kitamura, Y., & Mizoguchi, R. (2006). Role organization model in Hozo. In *Managing Knowledge in a World of Networks: 15th International Conference, EKAW 2006* (pp. 67-81). Berlin: Springer-Verlag.

Wang, E. & Kim, Y.S. (2007). Issues in integrating teaching strategies from learning theories & extended SWRL rules. In *Proceedings of the workshop on Semantic Technology for Education* (held in the 15th Int'l. Conf. Computers in Education (ICCE2007)) (pp. 110-113). http://credits.skku.edu/credits/publications/Wang Kim STfL07 Issues Integrating.pdf