Inside Theory-Aware and Standards-Compliant Authoring System

Riichiro Mizoguchi, Yusuke Hayashi, Jacqueline Bourdeau

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Absrtact. In their paper[14], Bourdeau and Mizoguchi foresaw a framework for ontology-based intelligent systems. Although it took longer years than their expectation, the ontology they have been developing is now released for evaluation with the help of the second author. Ontology building is a labor-intensive process and it is rarely perfect. Our enterprise is not an exception. The current ontology is still very preliminary because it has been completely reconstructed from the existing one with a few new ideas. So, we hope the readers be generous when they read the ontology. The ontology presented here is not a light-weight ontology but a heavy-weight ontology. It is built based on philosophical consideration of all the concepts necessary for understanding learning, instruction and instructional design. Although it is full of axioms, the Hozo GUI which is based on a frame structure makes it easier to read it. However, the readers are expected to have basic knowledge of ontology and preferably be aware of the theory of role and of the Hozo way of role representation. Papers [6][7] would be helpful to grasp what we are doing with this ontology. The prototype system named SMARTIES is a totally ontology-aware system which fully utilizes the merits of ontology computationally as well as conceptually. It is so preliminary that it cannot be open to public, though you can get a rough idea of what it is from the papers.

1. Introduction

Nowadays standard technologies play an important role in the development and delivery of learning contents. Standard technologies provide stakeholders with great benefits; there is however a lack of pedagogical justification of standard-compliant contents. This project focuses on educational theories as a kind of pedagogical knowledge and aims at building an information system that helps users to utilize them for instructional and learning design (Here, the term "instruction" does not have a narrow definition such as lecture but has a broad definition to include anything that fosters or suggest learning in a learning environment). This project takes an ontological engineering approach to grasp fundamental concepts of learning and instruction in order to enable information systems to be aware of the theories on the basis of such concepts.

This article introduces a comprehensive ontology which covers different theories and paradigms about instructional and learning design[1]. Note that this ontology is still a tentative result of our project. We have plans in the future to continue to make further refinement on it and we welcome your contribution to the refinement. In addition, at the current moment, this ontology focuses only on the abstract design of learning contents and has not been yet related to domain knowledge or learning objects to concretize the abstract design. This is one of the future plans of this project.

1.1 Scope: Objectives and non-Objectives

This project's objectives include:

- To find an engineering approximation that allows building of an engineering infrastructure that enables instructional designers and educational practitioners to apply knowledge derived from educational theories, and

[1] This ontology is open to the public on our web site: `http://edont.qee.jp/omnibus/`.

- To establish a method for building theory-aware systems for education.

This project's objectives do not include:

- To insist on the scientific validity of the proposed framework for organizing educational theories,
- To reconstruct existing educational theories on such a basis, nor
- To create new theories

1.2 Expected outcomes

a) Providing a sharable model of instructional design knowledge
Instructional design knowledge includes theoretical knowledge such as instructional and learning theories as well as empirical one such as heuristics and best practices. The ontology introduced in this document includes about 100 pieces of "`WAY-knowledge`" based on some theories.

b) Increasing theory-awareness in authoring tools
Based on the ontology, an authoring tool can become aware of instructional knowledge and help authors. This project has developed "SMARTIES": a prototype system of a theory-aware authoring tool based on the ontology. This prototype system provides support functions for making learning/instructional scenarios based on this ontology. To put it more completely, this system provides a modeling environment and guidelines for making theory-compliant learning/instructional scenarios. This system has the flexibility of ontologies. The upper level concepts are built-in but the lower level concepts can be imported from the ontology built in Hozo[2] [12].

c) Linking standard-technologies to instructional design knowledge
Instructional design knowledge is expected to enhance the educational justification of standard-compliant contents. The prototype system supports authors in building standard-compliant scenarios with theoretical justification because it can export a theory-based instructional/learning scenario model into IMS LD level A format [9].

1.3 Current state and Future plans

a) Updating this ontology
The current version of this ontology is the version 1.0. Comments received and discussion done on this workshop will be reflected in the modification as much as we can. In addition, we want to continue the discussion about ontologies of instructional design on our website.

b) Expansion of this ontology
We are planning to include concepts related to instructional design theories/processes and CSCL. In addition, we currently plan to put this ontology to the core of our infrastructure for instructional design knowledge sharing. This means that the ontology enables us to utilize theories for contents design through the top-down approach as well as to build new theories and to share best practices through the bottom-up approach. We believe such an infrastructure will harmonize theory and practice of instructional and learning design.

c) Link with learning objects and learning object metadata
In order to implement such abstract design as our scenarios, it is necessary to link it to learning objects. We have defined attributes of learning and instruction in the proposed ontology. To consider the relation between these attributes and learning object metadata (e.g. IEEE LOM [8])is one of the future directions of this study.

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[2] Hozo ontology editor can be downloaded from `http://www.hozo.jp`

2. Building a comprehensive ontology for educational theories

The objective of this study is building a comprehensive ontology which covers different theories and paradigms. In this section we briefly discuss the problems and our approach for building such an ontology.

2.1 Basic consideration

In building such a comprehensive ontology, there is one big problem. It is considered that, in the first place, each paradigm or theory has its own definition of “Learning” and hence we cannot organize variety of theories on a common basis. However, for example, Reigeluth [17][18] and Ertmer [4] give some observations about commonality and difference among paradigms and theories. We can summarize these statements as follows; Every theory has some sort of common basis for explaining learning and instruction, and while the assumed mechanism of developing knowledge is different for each paradigm, the idea of *states* in the learning process is common. In a similar line of the thought, this study sets up a working hypothesis that there must be an engineering approximation of the states where we can conceptualize “Learning” in terms of state change of learners [14].

Note that the purpose of this study is not to expose a scientifically valid basis for organizing theories nor to reconstruct them on this basis, but rather to find an engineering approximation that allows building of an engineering infrastructure that enables practitioners to utilize instructional and learning theories. This paper thus proposes a foundation from the view point of ontological engineering based on the results of previous research in this respect [1][14][16].

2.2 Conceptualization of the interaction between learning and instruction

We have defined a concept that we named I_L event as shown in Figure 1. An I_L event is a concept to link instructional events to learning events. In this study a learning event is composed of state-change and learning action. Learning actions cause the change of learner’s state. On the other hand, an instructional event is composed of an instructional action which affects learning events. The key points of our conceptualization include to emphasize the relations among these three and to model a contribution of instructional action on the change of learner’s state.

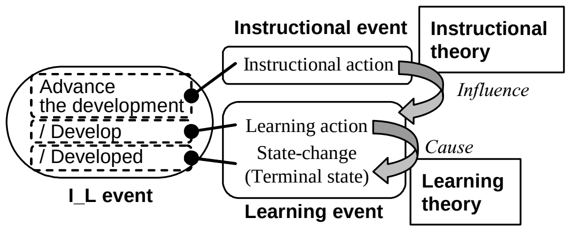

Figure 1 An I_L event

2.3 Conceptualization of the abstract structure of instructional/learning scenario

In our modeling framework, a scenario can be modeled as a hierarchical structure of I_L events for achieving a certain change of a learner state. We call it an “I_L event decomposition tree”. The basic idea of an I_L event decomposition tree is to relate a macro-I_L event to the lower (micro) ones that collectively achieve the upper (macro) I_L event as a way of achievement of the change of a learner state (referred to just as “WAY” hereafter). Figure 2 illustrates an example of an I_L event decomposition. This shows that there are two WAYs to achieve the macro-I_L event, which is to introduce a content for making a learner recognize it. WAY1 is based on Gagne and Briggs’s theory [5]. This firstly presents what to learn and then gives guidelines. The other is based on Collins’ [2]. This gives only demonstrations and no explanations. In this case the macro-I_L event is not decomposed

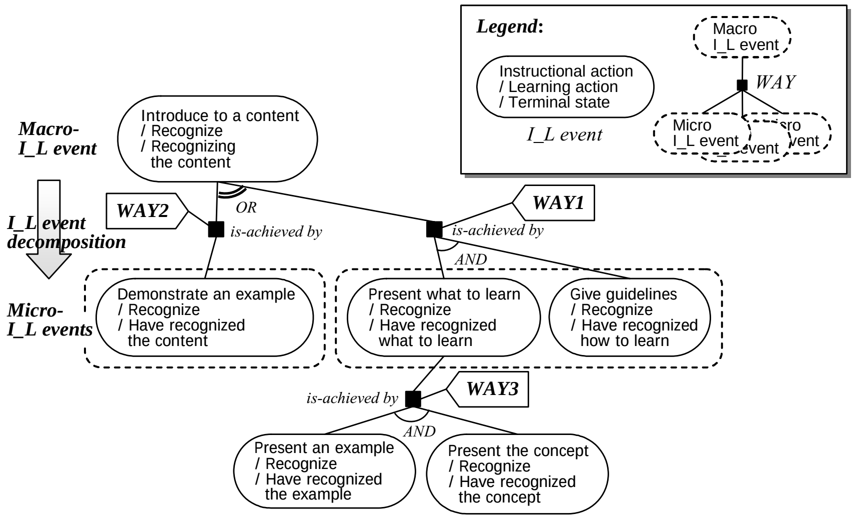

Figure 2 An example of an I_L event decomposition by WAYs

but concretized. These ways can be thought to have the same goal but achieve it by different strategies. Such relation between WAYs is described by OR relation like between WAY1 and WAY2. In the proposed modeling framework, a scenario is described as a sequence of the leaves in the tree structure and the tree-structure model layered multiply with WAYs accounts for the design intention.

2.4 Conceptualization of strategies suggested by instructional/learning theories

Theories prescribe strategies for planning the instructional and learning process according to supposed situations. In our modeling framework, a learning and instructional strategy is modeled as a WAY in view of generality which can be adapted to the specialized concrete application situations. Such a generic WAY is named "`WAY-knowledge`". Currently, we have organized about 100 pieces of "`WAY-knowledge`" based on some theories: Gagne's nine events of instruction [5], Dick and Carey's ID theory [3], Merrill's Component display theory [13], Keller's ARCS model [11], Collins's cognitive apprenticeship [2], and Jonassen's Design of constructivist learning environments [10]. These are defined as relational concepts (see 3.4).

Organizing "`WAY-knowledge`" is expected to contribute to the clarification of the conceptual structure of each theory and to theory-eclectic design guidelines for the

Table 1. A classification of the properties (not exhaustive)

Categories	Properties	values
Learner characteristics	- Age (type) - Language - Prior knowledge: fact, concept, rule	- child, adult - Japanese, English, French - learned, not learned
Domain/topic characteristics (what to learn, content)	- Concreteness - Complexity - Causality - Prerequisiteness	- concrete, abstract - simple, complex - causal, not causal - prerequisite, not prerequisite
Context characteristics	- Context of learning - Testing - Instruction mode - Delivery mode	- School, workplace, university - summative, formative, Assessment, certification - individual, group, community -classroom, distance, distributed
I_L event characteristics (scenario)	- Event kind - Authenticity - Interaction kind	- I_L, assessment - authentic, artificial, virtual- - action, interaction, social interaction
Learning object characteristics	- Language - Language level - Representation mode	- Japanese, English, French - child, adult - text, graphics, image, video, simulation, game

modeling learning and instructional processes. Through this process, we have tried to classify the properties of the theories. Table 1 shows the current classification of the properties. These properties are common to learning/instructional scenarios and models, the pieces of "WAY-knowledge" and concepts of theories in the OMNIBUS ontology. One of the contributions of this is to enable authoring tools to understand the relation between theories and a scenario and to explain it to the authors. Using these properties, such an authoring tool can suggest theories that have the same properties as a scenario to the authors, or can provide the accordance of properties between a scenario and a theory as the justification of a scenario for the authors. We have implemented authoring supports of this kind. This is discussed in 4.4.

3. Concepts defined in the ontology

Among various types of concepts defined in the ontology, we are here concerned only with the main concepts related to the instructional/learning scenario models introduced above. This section describes what are defined in this ontology and how to read it using Hozo ontology editor.

3.1 The basic principle of conceptualization in the Hozo ontology editor

Although the ontology is presented in two versions - Hozo and OWL -, we recommend to read the Hozo version, since it represents the full semantics of the ontology. However, you need to know the basics of the Hozo way of representation.

The Hozo ontology editor handles the following two concepts separately:

- Wholeness concept: A concept of a thing considered as a whole (e.g. bike), which is composed of multiple concepts (e.g. wheel, handle, etc.), each of which makes up a part of the whole,
- Relational concept: Conceptualized relationship between multiple (usually two) concepts.

This distinction is done based on the following consideration [12]. For example, let us consider a "brothers" and a "brotherhood". Assume that there are two brothers, Bob and Tom. "The Smith brothers" could be a conceptualization as a whole, which is a pair of two persons. On the other hand, "brotherhood between Bob and Tom" is conceptualized as a relation. On the basis of the observations that most of the things are composed of parts and that those parts are connected by a specific relation to form the whole, wholeness concept and relational concept are distinguished in Hozo ontology editor. In this example, the "brothers" can be considered as a wholeness concept and the "brotherhood" as a relational concept. Theoretically, every thing that is a composite of parts can be conceptualized in both perspectives as a wholeness concept and a relational concept.

In the ontology, two types of relations are defined: pure relation such as "same as" and "before-after", and "WAY-knowledge" (strategy) such as "Educational strategy". While the former is used as constraints on the wholeness concepts(normal classes), the latter is not used that purpose but used for representing "WAY-knowledge". Details are explained in relational concept.

3.2 Ontological approach to the systematization of educational theories

3.2.1 Fundamental viewpoint

The relation among theories behind instructional design is considered as a nested structure as shown in Figure 3. The bottom of the structure is the "learning world". Learning theories explain processes and events in the world. The "Instructional world" is on top of the learning world. The instructional process influences or facilitates the learning process. Instructional theories prescribe the effective instructional process for the learning process with the desired outcome. The instructional process happens in parallel with the learning process. Moreover, the "Instructional design world" is on top of the instructional world. Instructional design process is the design process of the instructional process. An instructional design theory prescribes the rational process for designing the instructional process. One of the major differences among the three kinds of processes is that while the lower two are real world processes, the other is a planning or design process of real world processes/events. However, thinking along the nested structure, we see an essential characteristic that all the processes rely on the learning process which can be modeled as a state-change in a learner. Therefore, based on our working hypothesis stated in 2.1, we built this ontology with the state-change in a learner as the foundation of the conceptual system.

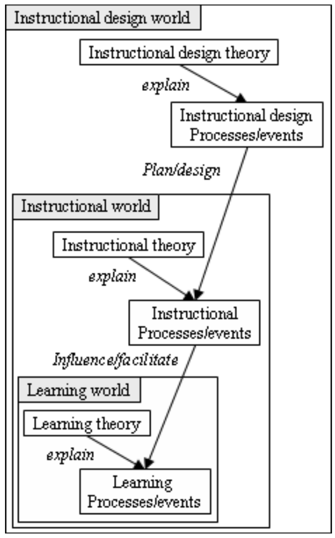

Figure 3 A nested structure of learning, instruction and instructional design

3.2.2 Upper level structure

The upper level structure of this ontology is shown in Figure 4. Roughly speaking, the OMNIBUS ontology is mainly composed of concepts related to the "Common", "Cognition", "Learning", "Instructional" and "Instructional design /Instructional system design (ID-ISD)" worlds, and "Event". We would like to emphasize that our policy of conceptual distinction between "Event" and the other process-related concepts is based on context-dependence. Concepts related to each world are defined as those necessary to represent processes in the respective worlds with minimal context-dependence. On the other hand, "Event" and its subclasses are defined as those for representing (1) events with maximal context-dependence on education referring to those defined in other worlds and (2) relations between them. We discuss the distinction and the context- dependence of them in a bit more detail in 3.3.3.

This paper discusses OMNIBUS ontology with a focus only on the learning and instructional worlds and the relations between them. In the following sections, we mainly explain "State" and "Action" that are defined in the common world and that are shared among the learning and instructional worlds in order to describe learning and instructional process, "Educational event" as a contextualized description of process, and "WAY" as the relational concept.

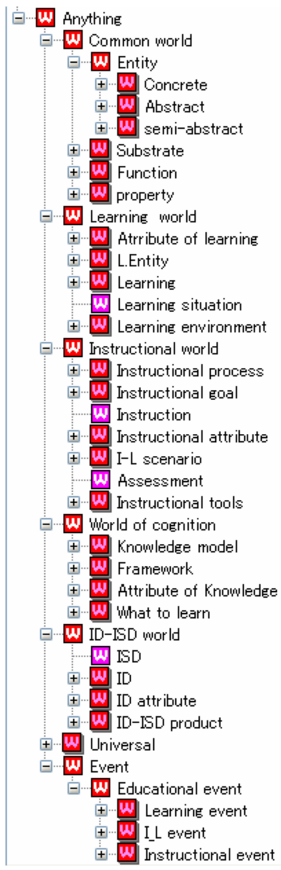

Figure 4 The upper level structure of OMNIBUS ontology

3.3 Main wholeness concepts

This sub-section introduces the main wholeness concepts in this ontology.

3.3.1 State

As discussed in 2.1, *states* in the learning process are the most important factor for building the comprehensive ontology. Each description of educational theories uses its own terminology. Hence each theory has different concepts of states from the other theories at a glance. However, Reigeluth points out that many theories are described in different terminology although some of them describe or prescribe the same method for the same situation (states as the precondition and the outcome) [18].

In accordance with our working hypothesis stated in 2.1, we have collected such states from several theories and categorized them under an is-a hierarchy from the view point of the conceptual meaning (Figure 5). States in the OMNIBUS ontology are mainly classified into the following two types of classes.

- Internal state: This is a state about the inside of agents. This includes “`Cognitive process state`”, “`Attitudinal state`”, “`Progression state`”, “`Developmental state`”.
- External state: This is a state locating between internal state and situation and is an aspect of the agent’s engagement/participation in an action.

In this ontology, these states are common to any theory and learning is described by changes of learner state. Therefore the difference between theories is described as the difference of states used or not used in the theories, process of changes of the state supported in the theory, and the relation between changes of states and learning actions.

In the following, we explain the definition of actions and discuss the relation between changes of states and learning actions.

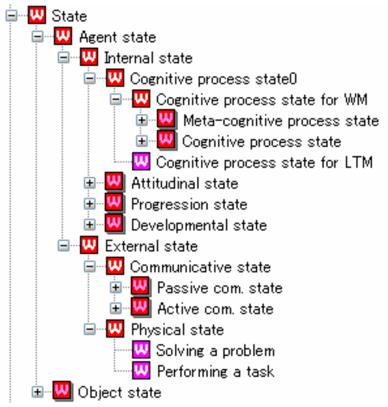

Figure 5 Is-a hierarchy of “`State`”

3.3.2 Action

Actions are defined in common with learning and instruction (Figure 6). All actions are decomposed into some subactions and the decomposition can be repeated almost endlessly. However, in most cases, the decomposition should be stopped at a certain granularity level under which

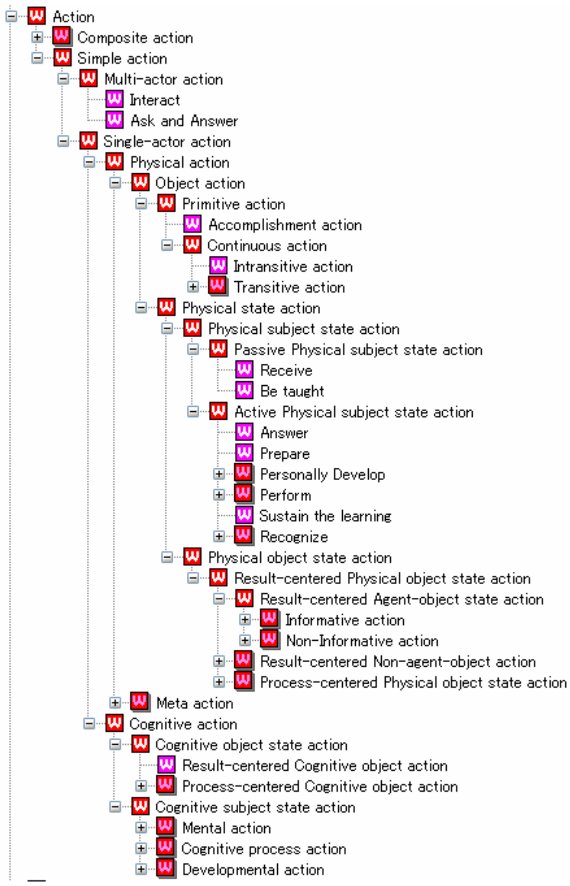

Figure 6 Is-a hierarchy of “`Action`”

finer grain actions are meaningless in the context. The finest grain actions are called primitive actions.

There are two kinds of actions: one which has a unique decomposition into subactions like "walk" and the other which has multiple ways of decomposition according to the context/goal under which actions are being performed like "teach". The former case is a normal case so that subactions are defined using (part-of) slots. The latter case needs special care to grasp its rich meaning properly, that is, to uncover its deep implications underlying the ways of performing the sequence of subactions. This is why we don't use part-of slots but instead introduce "`WAY-knowledge`" (way of decomposition) together with "`Event`" for the latter kind of actions. Needless to say, the distinction between these two kinds of actions is relative. Furthermore, we introduce the idea of "`Event`" to capture the latter kind of actions. By event, we mean a large chunk of actions full of contextual stuff such as "`learning event`" and "`instructional event`". "`Event`"s refer to "`Action`"s at particular situations which require particular actions to achieve their goals.

3.3.2.1 Primitive action

This action changes the "`Communicative state`" of the doer or of the object. In this ontology, actions of this type cannot be decomposed into some sub actions. That is to say, they are primitive actions.

3.3.2.2 Physical state action

This action also changes Communicative state of the doer or the target object. In contrast to primitive actions, this action can be decomposed into some sub actions to achieve the state change intended in the action. However, the decomposition is not defined in the definition of the action. It is defined as a "WAY" that will be explained in the later section: WAY: prescriptive model derived from strategies defined in theories.

d) Example1: Inform (Figure 7)

This class defines the action "`Inform`" as the state change of the recipient of the "`Inform`" action, which is an Agent, to the state of "`Informed`" which is a sub-class of communicative state.

a) Example2: Remind (Figure 8)

This class defines "`Remind`" as the state change of recipient of the action to the state of "`Led`", which is a sub-class of communicative state, to "`Recall`" action. Note that it is out of the scope whether the action led is actually done or not. This definition intends to describe the intention of the doer of the action. The action of "`Recall`" is defined as a sub-class of the "`Cognitive action`" which is explained below.

3.3.2.3 Cognitive (state) action

This action changes the internal state of the doer or the object. This action can be also decomposed into some sub actions to achieve the state change intended in the action.

a) Example 1: Recall (Figure 9)

This defines that the action of "`Recall`" changes the state of doer of the action to the state of "`Have recalled`", which is a sub-class of the internal state. This is illustrated below.

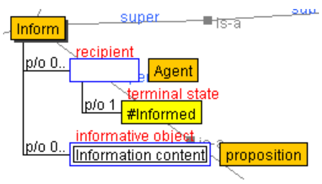

Figure 7 Definition of "`Inform`" in Hozo

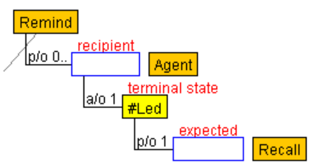

Figure 8 Definition of "`Remind`" in Hozo

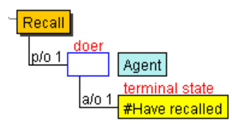

Figure 9 Definition of "`Recall`" in Hozo

3.3.3 Educational event

"`Educational event`" is the concept for representing (1) events of learning and instruction, and (2) relations between them. Its is-a hierarchy is shown in Figure 10. "`Learning event`" and "`Instructional event`" are the concepts for representing events of learning and instruction. "`I_L event`" is a concept for relating "`instructional event`" to "`learning event`".

In this ontology, the instructional and learning process is defined as a process with a goal related to the situation. A process can have different meanings in different contexts, which are composed of goal, situation, etc. For example, informing a topic has an intention to afford better understanding of a learner in a context but has an intention to just call a learner's attention in another context. Based on such considerations, this ontology focuses on describing the instructional and learning process with the context clearly. The concept to describe such a process is "`Event`". Basically, "`Event`" is defined as composition of "`process`" and the contextual information of it such as "`participant`", "`time`", and "`location`". In "`Educational Event`", "`process`" is specified by "`Action`". You may wonder why we define "`Action`" and "`Event`" separately. The definition of "`Action`" also has "`participant`" as explained in the previous section and "`time`" and "`location`" will be fixed when an instance of "`Action`" is made. But what we can say here is that our policy of conceptual distinction between "`Action`" and "`Event`" in this ontology is context-dependence as mentioned in 3.2.2, especially the relation to the goal of "`Action`": "`Event`" is defined to be dependent on a context. On the other hand, "`Action`" is defined independently of the context, and just defined as the change of states with no relation to any intention.

3.3.3.1 Learning event

A "`learning event`" is composed of an agent as a learner, a learning action, its objects, effects and conditions of learning, and spatial/temporal attributes. The relation among them is suggested by learning theories.

3.3.3.1.1 Effect of learning

By "`Effect of learning`", we mean that a learning theory can tell us what effect is expected after this learning action. This meaning is described by the "`Action result`" relation among "`Learning action`", "`Learning effect`" and "`Learning theory`" slots as shown in Figure 11.

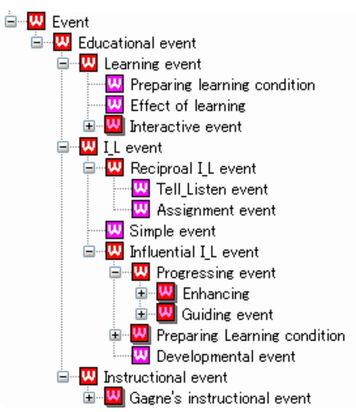

Figure 10 Is-a hierarchy of "`Educational event`"

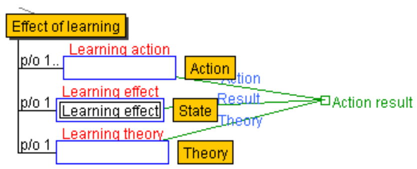

Figure 11 Definition of "`Effect of learning`" in Hozo

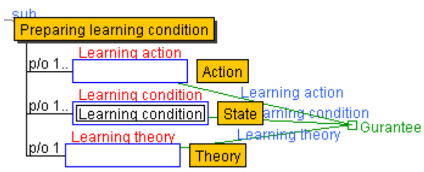

Figure 12 Definition of "`Preparing learning condition`" in Hozo

3.3.3.1.2 Preparing learning condition

By “Preparing learning condition”, we mean that when learning conditions are satisfied, the learning theory assures that the learning action should be successful. This meaning is described by the “Guarantee” relation among “Learning action”, “Learning condition” and “Learning theory” slots as shown in Figure 12.

3.3.3.2 Instructional event

An “Instructional event” is composed of an agent as an instructor, an instructional action, its objects and spatial/temporal attributes. The definition of this event itself is defined independently of the definition of “Learning event”; therefore an “instructional event” does not include how the instruction affects learning. The effect of instruction on learning is described within “I_L event” as presented below.

3.3.3.3 I_L event

An “I_L event” defines the relation between a “Learning event” and an “Instructional event“. That is to say, an “I_L event” describes how an “Instructional event” contributes to a “Learning event”. This relation is defined from two points of view. The first is the contribution of “Instructional event”s to the change of a learner’s state. The other is the preparation for the following “Learning event”.

3.3.3.3.1 Example 1: Preparing learning condition and Remind event

Figure 13 shows the definition of “Preparing learning condition”, which is a sub-class of “I_L event”, and Figure 14 shows “Remind event”, which is a sub-class of “Preparing learning condition”.

“Preparing learning condition” is composed of one “I event” slot and two “L event” slots (one is constrained by “Effect of learning” and the other is constrained by “Preparing learning condition”). This defines the following two kinds of relation between learning and instruction:

1. An “instructional action” influences a “learning action” that causes an expected “learning effect” (Of course, this never means that the learner always does the intended learning action and changes to the intended state).

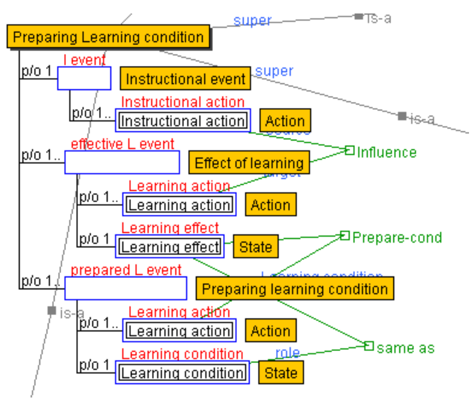

Figure 13 Definition of “Preparing Learning condition” in Hozo

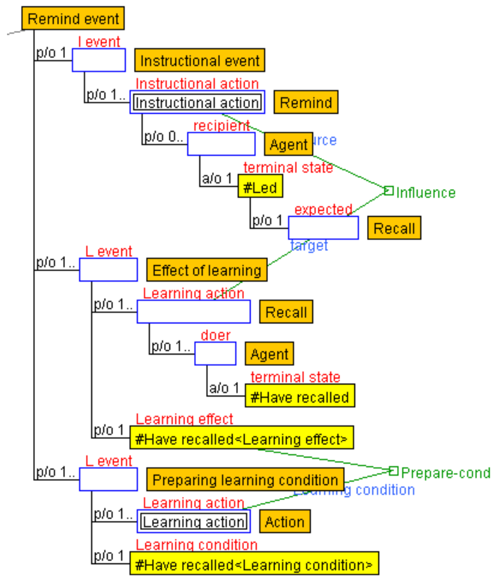

Figure 14 Definition of “Remind event” in Hozo

This is defined as the "influence" relation between the "instructional action" slot in the "I event" slot and the "learning action" slot in the "L event" slot constrained by "Effect of learning" ("Learning event").

2. "learning action" is a preparation of the other "learning action". That is, "learning effect" satisfies the condition of the other learning action ("learning condition"). This is defined as the relation between the "learning action" slot in the "L event" slot constrained by "Effect of learning" slot and the "L event" slot constrained by "Preparing learning condition".

These are defined as three slots (one "I event" and two "L event") and by the relation between them ("Influence" and "Prepare-cond").

In "Remind event", these are defined more concretely as shown in Figure 14:

1. A "Remind" action of an "instructor" influences a "Recall" action of a "learner", which causes a change of learner state to the "Have recalled" state. This relation is defined as the "Influence" relation. (In the Figure 14, the "Influence" relation in the "Remind" event appears just in order to make the explanation easy to understand. It is not necessary to define this link in the "Remind event". "Remind event" is a sub-class of "Preparing learning condition" so that the "Influence" relation is inherited.) You may think that the "learning effect" slot of "L event" slot and the "terminal state" slot of "doer" slot in "learning action" are redundant descriptions. However the "learning effect" slot of the "L event" slot describes only a notable state in this event picked from states defined in the learning action.
2. The "Have recalled" state as the "effect of the learning" is a preparation of the other future learning action of the learner. That is, the effect satisfies the condition of a future learning action. This relation is defined as the "Prepare-cond" relation and "same as" relation.

3.4 Relational concepts

In this ontology, we define the following two types of relational concepts in HOZO:

- Pure relational concepts: This is a concept to define a relation among slots in a wholeness concept. In this ontology, relational concepts other than sub-classes of "WAY" are pure relational concepts.
- "WAY" and "WAY-knowledge": "WAY" is a special relational concept to describe a way of achievement of the state change in a learner. This type of relation is not used for defining the relation among slots in a wholeness concept. "WAY-knowledge" is a specified concept of "WAY" based on theories as of now. In the future, we are planning to extend this definition not only to theory but also to empirical knowledge.

In OWL, both of them are defined as a sub-class of "RelationalConcept", which is a sub-class of owl:Thing. Note that they are not defined as sub-classes of owl:Property.

3.4.1 Pure relational concept

In this ontology, some pure relational concepts are defined. For example, "less-than", "same as", "Influence", "prepare-cond", etc. Please see in detail in the Hozo or OWL-compliant ontology editor. These pure relational concepts are used in order to define the relation among slots of a wholeness concept as shown below.

3.4.2 *WAY: prescriptive model derived from strategies defined in theories*

As mentioned above, "`WAY`" is a relation between an "`upper (macro) I_L event`" and one or several "`lower (micro) I_L event`"s that achieve the upper one. That is to say, a "`WAY`" is a description of an educational strategy. Theories prescribe strategies for planning the instructional and learning process according to supposed situations. In our modeling framework, a learning and instructional strategy is modeled as a "`WAY`" in view of generality which can be adapted to the specialized concrete application situations. Such a generic "`WAY`" is named "`WAY-knowledge`". Figure 15 illustrates examples of the description of "`WAY-knowledge`" named "`Presentation`" WAY. This is based on a part of Gagne and Briggs's nine events of instruction. The key of this strategy is to tell directly to a learner the content and way of learning. This "`WAY-knowledge`" describes this learning and instructional process as the sequence of two "`micro I_L event`". One is to inform the content of learning as a learning item in order to let a learner recognize it and the other is to inform guidelines for learning to the learner in order to let a learner recognize the guidelines. These processes are described by "`Guiding event`", which is a sub-class of "`I_L event`". "`Guiding event`" focuses on the continuous interaction between an instructor and a learner. In this "`I_L event`", the interaction is taking place from the start to the end. On the other hand, there are the other types of "I_L event", for example, "`Enhancing`". This focuses on a non-continuous interaction. In this type of "`I_L event`", basically the interaction between an instructor and a learner is taking place only once at the beginning. Then the learner does by him/herself.

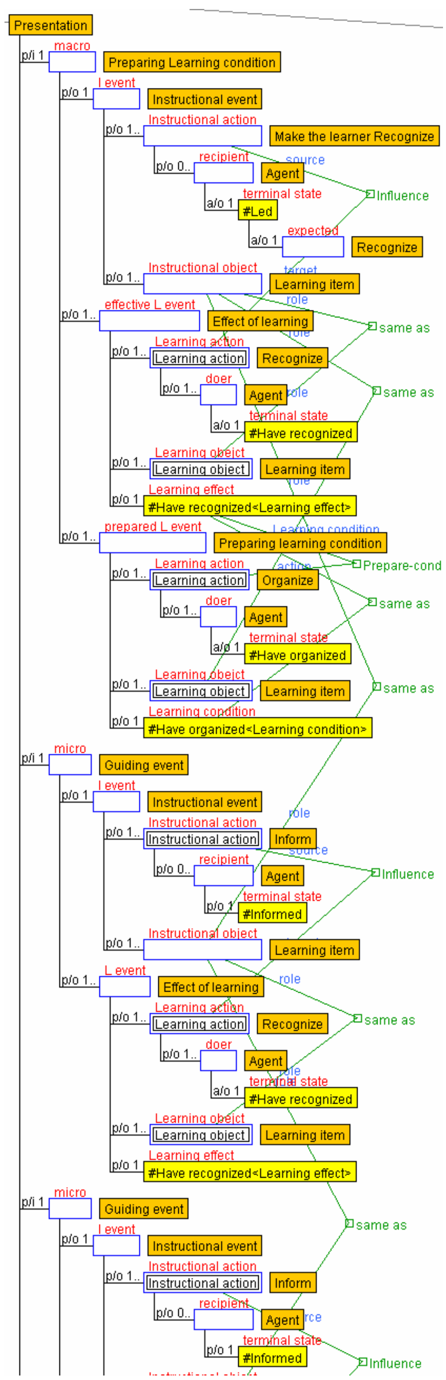

Figure 15 Definition of "`Presentation`" WAY-knowledge (a portion)

4. A theory-aware and standards-compliant authoring system: SMARTIES

This section discusses the application of the ontology of learning and instruction and the framework of function decomposition tree.

Existing authoring environments for learning support systems aim at combining authoring tools and knowledge representation [15]. Most of the systems have functionalities to support instructional and learning design based on some sort of fixed theories (or empirical knowledge). Of course, such systems provide designers with guidelines and

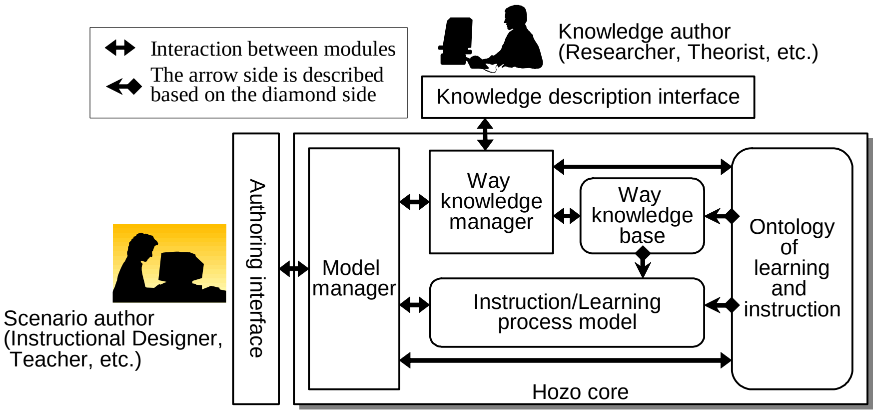

Figure 16 Block diagram of the design support system: SMARTIES
(This diagram focuses only on support for abstract design of learning contents and does not show domain knowledge and learning objects to realize the abstract design.)

improve the consistency of design on this basis. However, all of knowledge from the theories in many of the theory-based systems is built in the procedures. It is the developer, not the system, who knows the theory. It causes concealment of the relation between the system's functionalities and the theories they are based on.

Our study aims to build a theory-aware design support system that understands theories. Such a system has the capability of explaining which theory underlies any suggestion the system makes to authors, as opposed to a system in which the theories are implemented as built-in procedures. The following sub-sections present our idea of a design support system called "SMARTIES: SMART Instructional Engineering System", which we have been developing.

4.1 An overview of a theory-aware design support system

Figure 16 shows a block diagram of SMARTIES, which has been under development in this study. The scope of support is limited to the design phase of ID process, rather than the analysis and development phases.

SMARTIES helps two types of users; one is scenario authors, which includes instructional designers, educational practitioners and occasionally learners. The other is knowledge author, which mainly includes researchers and theorists.

A scenario author makes a particular instructional and learning process model using the authoring interface. The model manager manages a model that scenario authors made. In addition, the model manager provides the author with guidelines for making a model. Based on the ontology, basic guidelines for modeling instructional and learning process are supplied; concepts and a vocabulary representing them, and the basic structure of concepts. In addition, based on "`WAY-knowledge`", instructional and learning strategies from theories are supplied. Finally a scenario is generated as the leaves of an instructional and learning process model. The model can also be finally exported according to IMS LD specification [9].

A knowledge author describes instructional and learning strategies as "`WAY-knowledge`" with an understanding of theories and put them to the Way-knowledge base. The Way-knowledge manager manages Way-knowledge base and provides knowledge authors with the ontology as basic guidelines as well as the model manager. Describing "`WAY-knowledge`" makes it possible for scenario authors to retrieve strategies for inter-theory cooperation and apply multiple theories to a particular instructional and learning process model.

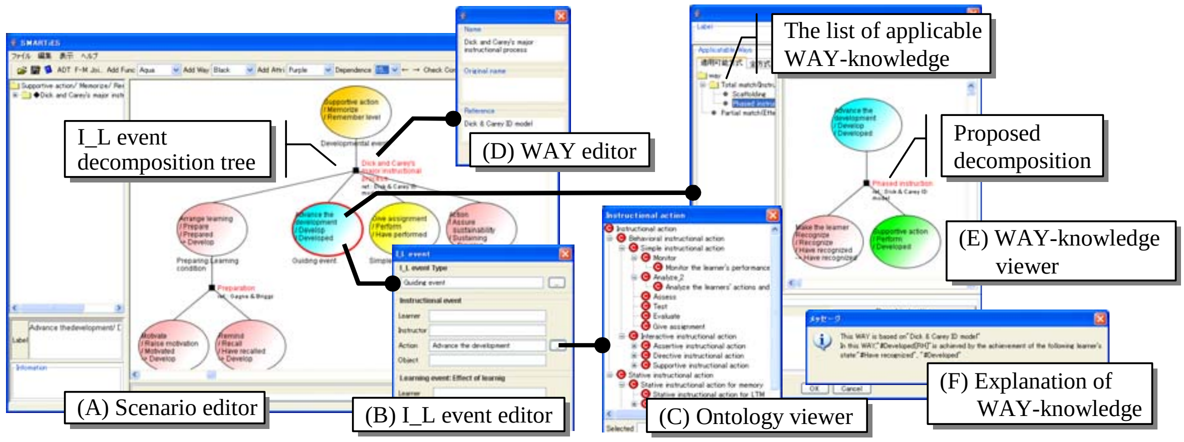

Figure 17 Screenshot of SMARTIES

4.2 Scenario description support

Figure 17 shows a screen shot of SMARTIES. This scene shows how a scenario author makes an instructional and learning scenario using "`WAY-knowledge`".

The scenario editor provides a scenario author with an environment to describe an I_L event decomposition tree as an instructional and learning process model. I_L events are represented as nodes and the decomposition of them is represented from top to bottom. In this window, an author decomposes the learning goals of the scenario step-by-step by choosing applicable "`WAY-knowledge`".

The Way-knowledge window provides an author with applicable "`WAY-knowledge`" candidates in order to help him/her decompose each I_L event. It displays applicable pieces of "`WAY-knowledge`" appropriate to the selected I_L event that he/she wants to decompose. When the author chooses one of them, a proposed decomposition is displayed on the window. If the author decides to adopt the selected Way, the proposal is applied to the main window. By repetition of the process mentioned above, a scenario author makes instructional and learning process model, moving from abstract levels to concrete ones.

4.3 IMS LD export

In order to enhance sharability and reusability of the scenario descriptions, we have mapped I_L event decomposition tree onto IMS LD specifications. Briefly speaking, each unit of

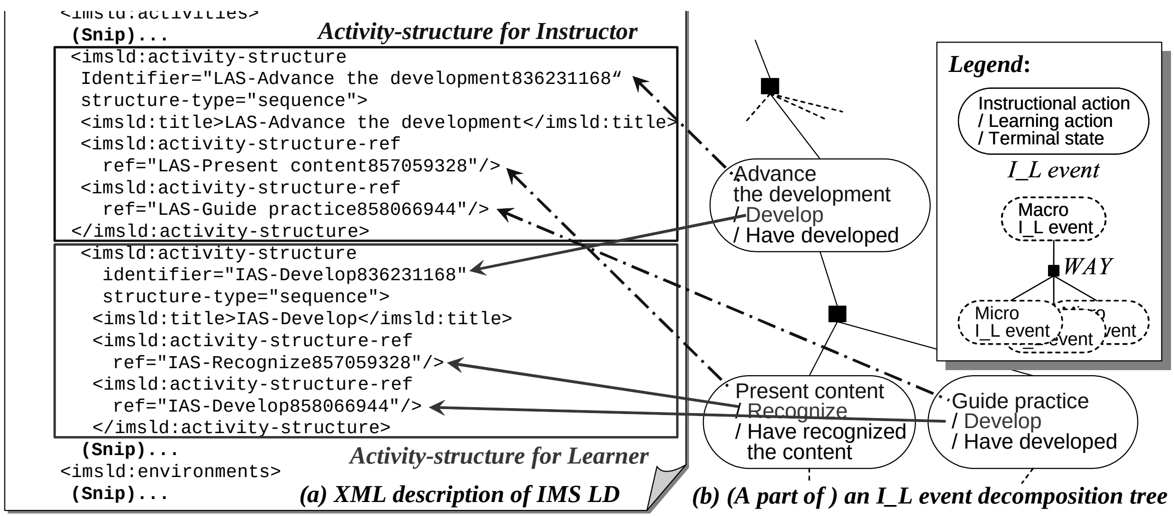

Figure 18 Mapping an I_L event decomposition tree into IMS LD

decomposition in an I_L event decomposition tree can be converted to two `activity-structure`s for `learner` and `instructor` in an IMS LD description as shown in Figure 18.

In IMS LD, only top and leaf activities have the description of the objective while the others do not have. Therefore only a part of the design intention can be converted to the IMS LD description although it keeps sharability and executability of learning/instructional scenarios. On the other hand, an I_L event decomposition tree keeps the whole design intention together with theoretical justification of it. For these reasons, IMS LD and our modeling approach are complementary to each other.

4.4 Scenario explanation support

One of the characteristics of theory-aware systems is the ability to interpret learning/instructional scenarios in terms of theories. An I_L event as a descriptive concept and "`WAY-knowledge`" as a prescriptive concept enable information systems to explain theories and scenarios described as an I_L event decomposition tree and to give suggestions for scenario design/improvement.

4.4.1 A classification of explanation types and cases

In this study, we have classified explanation of a scenario into two types. Table 2 summarizes the classification. Each type covers some cases of explanation about interpretations of learning/instructional processes or problems in achievement of the goals. These types of explanation are based on the properties of theories discussed in 2.4. I_L event decomposition tree, "`WAY-knowledge`" and the definition of theories in the OMNIBUS ontology are characterized by the properties. Such scenario explanation can be done by comparison between their properties.

Interpretative explanations report interpretation result of a scenario based on the ontology and "`WAY-knowledge`". Scenario comprehension uses the scenario model and the descriptive concepts in the ontology. Even if an author does not use any pieces of "`WAY-knowledge`" for scenario authoring, this interpretation can be done. Theory exposition uses only "`WAY-knowledge`". This just tells what each theory proposes independently of a particular scenario. A theoretical justification of scenarios is a combination of them. This explains both interpretation of a particular scenario and its

Table 2. A classification of explanation types and cases (not exhaustive)

Type	Case	Notes
Interpretative explanation	Scenario comprehension	Explaining just interpretation of relation among events in a scenario without theoretical justification. E.g. An event is preparation of another event.
	Theory exposition	Explaining theory itself independently of a specific situation.
	Theoretical justification	Explaining interpretation of relation among events in a scenario with theoretical justification. E.g. An event is preparation of another event and the necessity is guaranteed by a theory.
Suggestive explanation	Insufficiency of necessary goals	It seems learners can't achieve the goal because necessary (sub) goal is insufficient in the scenario.
	Insufficiency of supplementary goals	It seems learners can achieve the goal but not so effective. If some supplementary goals are added, it will be better.
	Excess of goals	It seems that it is difficult for learners to achieve the goal because there are too much unnecessary goals in the scenario.
	Disproportion in process	The scenario doesn't have proper proportion of process. E.g. lack of motivating, too much assessment, etc.
	Inconsistency of principle	The principle of learning and instruction isn't stable. A scenario needs some extent of sustainment of principle. E.g. too many suggestions in inquiry learning.
	Unsustained state	A state doesn't sustain until when it is required. E.g. an event reminds a learner of prerequisite knowledge but another event that needs it is far ahead.

justification based on pieces of “`WAY-knowledge`”. These kinds of explanations are expected to be useful for authors to review their own scenario or to know the deign intention of those made by others.

Suggestive explanations generate suggestions for improvement of scenarios. This is used when scenario authors did not use applicable “`WAY-knowledge`” suggested by SMARTIES but decomposed the tree using their own way knowledge in terms of the system vocabulary. In such a case, scenarios would lack theoretical validity but the system can infer the authors’ intention to some extent. This type of explanation is based on the interpretation of a scenario and includes improvement suggestions of a scenario. Cases that suggestive explanations cover are listed in Table 2. Note that it is intended not to force authors to follow but to recommend alternative ways or different viewpoints. These explanations are expected to be useful to check the validity of authors own scenarios.

4.4.2 Generation mechanism of scenario explanation

In order to generate scenario explanation we made message templates whose vocabulary comes from the ontology and whose structure is partly based on an `I_L` event decomposition tree. Comparing scenario models with the ontology and pieces of “`WAY-knowledge`” enables a theory-aware system to make interpretation and to generate explanation messages.

Figure 19 illustrates an example of explanation generation. Figure 19 (d) shows an example of explanation message about *Insufficiency of necessary goals* of *Suggestive explanation*. This message is generated from the message template (Figure 19 (a)). Italic words in the template are specified by the scenario model (Figure 19 (b)) and a definition of a piece of “`WAY-knowledge`” (Figure 19 (c)) in the ontology. This message template is composed of two parts, which are a scenario interpretation part and a theoretical justification part. The former is related to a scenario model and the latter related to “`WAY-knowledge`”. Each part has some blank entries to be filled and each blank is related to a

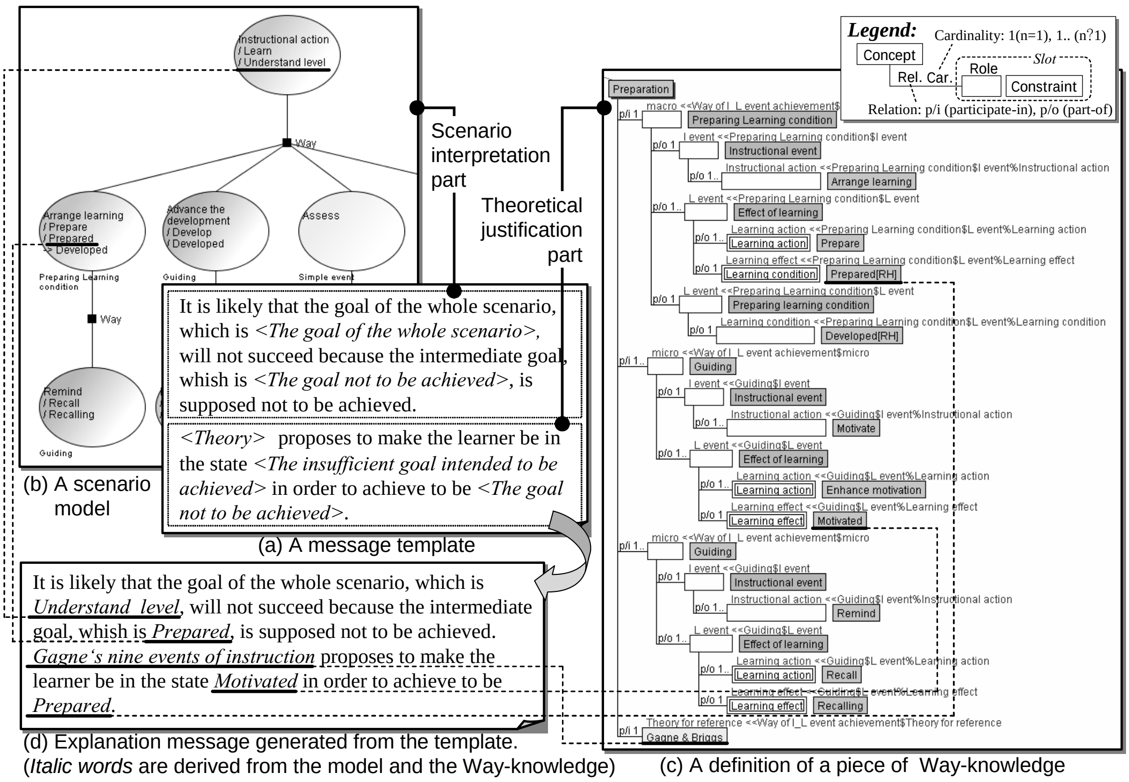

Figure 19 A generation mechanism of scenario explanation

required model structure or pieces of "`WAY-knowledge`". This relationship enables a theory-aware system to generate specific messages using templates according to a scenario.

When a system generates a message, firstly, a system compares descriptions of learner's state-changes in a scenario model with ones of "`macro I_L event`" in pieces of "`WAY-knowledge`". If a state-change is the same in both but "`micro I_L events`" are different, the system checks the difference and generates explanation messages to notify the estimated problems. Note that this comparison cannot work if a user describes state-changes by his/her own words instead of the system vocabulary because this function is based on the concepts defined in the ontology.

The first half of the message explains the current state of the scenario model. In this case, it points out that it seems learners cannot achieve the entire goal of the scenario because one of the sub-goals is unlikely to be achieved. The blank entries in the template are filled using the scenario model (Figure 19 (b)). In this case the necessary information is <*The goal of the whole scenario*> and <*The goal not to be achieved*>. These goals are detected from the model, and words representing the goal are put into the template.

The last half explains the reason of the problem and an improvement suggestion based on a theory. The template is embodied as a message using the definition of a piece of "`WAY-knowledge`" (Figure 19 (c)). In this case, this message is based on Gagne and Briggs's theory. The insufficient goal in the scenario, which is "`Motivated`", is identified with the piece of "`WAY-knowledge`" and fills the blank of the template.

We are currently developing the explanation function in our prototype. Figure 17 (F) is an example of generated explanation messages.

5. Concluding remarks

We have discussed the OMNIBUS ontology together with its application to building a theory-aware authoring tool, SMARTIES. Especially, the stress has been put on the details of design rationale and how the ontology is used at the computational level. We are just in the middle point of our long-term project. Because we already summarized what are left undone in 1.3, we only confirm here that there remain a number of problems to solve. The authors would like to kindly ask your warm help and feedback.

Ontology engineering is the key technology whose roles should be apparent. While the problem attacked in OMNIBUS project looks very AI-oriented, it is essentially different from the traditional AI in which people try to build problem solvers for humans. In other words, people try to make performance systems such as ITSs intelligent. Ontological engineering is different. It helps people solve problems by providing useful, long-lasting and reusable fundamental concepts and knowledge. It tries to make authoring tools (meta systems) intelligent rather than performance systems (ITSs). Hidden goals of OMNIBUS project include showing this new direction of AI technology application in AIED community.

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