Ontological Support for a Theory-Eclectic Approach to Instructional and Learning Design

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Abstract. Enhancement of learning with technology has been accelerating thanks to the advancement of information technology (IT) and the development of IT standards for learning. The purpose of this study is to build a still more advanced engineering infrastructure of utilization of instructional and learning theories for practitioners in line with such development. This paper discusses a modeling framework for instructional and learning theories based on ontological engineering and the compliance of IMS LD to theoretical knowledge.

1. Introduction

Enhancement of learning with technology has been accelerated thanks to the advancement of information technology (IT) and the development of IT standards in the areas of learning, education, and training. This includes, for example, accumulated knowledge for constructing intelligent educational systems [20] and standardization activity in IEEE LTSC, ARIADNE, ADL, ISO SC36, etc. Thus, increasingly powerful tools for developing advanced educational systems and contents are available. The purpose of this study is to build a still more advanced engineering infrastructure of utilization of instructional and learning theories for practitioners based on such development.

However, the problem of how to build a "good" system using the technologies still remains. Of course, considerable achievement has been made in instructional and learning sciences which would be expected to provide guidelines for building systems. Yet, even though some theories prescribe optimal/desirable methods of learning and instruction, many of the theories are not sufficiently articulated for the use of practitioners. Such theories allow for diverse interpretation and therefore may be difficult to use in practice. Furthermore, age-old question continues to apply: "Is it 'better' to select one theory when designing instruction or to draw ideas from different theories?" Answers to this question depend to a great extent on the purpose of considering instructional theories [17].

One of the reasons such problems come up is that the description of educational theories (learning, instructional and instructional design theories) is made in natural language, using different terminology. As Reigeluth points out, although many theories prescribe the same method for the same situation, these are described in different terminology [18]. This leads to a diversity of theories that are all open to interpretation. Even for experts, it is sometimes difficult to appropriately use theories while having a clear understanding of the similarities and differences between them. It is even more difficult to implement knowledge of the theories on computers and make it available to support instructional and learning tasks. We must first establish a common basis for understanding the theories at a conceptual level, along with organized concepts and vocabulary.

As Ertmer discusses, although there are many theories for learning and instruction, every one of them seeks to explain the “Learning” process of human beings [5]. In other words, every theory rests somehow on the common basis of explaining learning and instruction. If we reveal this common basis, we will be able to establish a foundation for comprehensively understanding and using a variety of existing theories.

This being said, 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 the 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 [2][3][14].

Another important issue that this study focuses on is sharing and reuse of the product of instructional and learning design. In this regard, IMS Learning Design (LD) specifications [9] are emerging as a dominant IT standard. IMS LD aims at providing a containment framework of elements that can describe any design of a teaching / learning process in a formal way. In addition, it can be considered as an integrative layer to many existing specifications. This being said, most of the existing LD tools have difficulty to explicitly integrate educational theories, even though the specifications underline their importance. It may be because of the lack of representation of theoretical knowledge as well as the lack of a compliance mechanism between the specifications and the theoretical knowledge. In order to make IMS LD specifications work with educational theories, this study proposes an ontology of educational theories which describes these theories and their links to the LD [16]. It further promotes the discussion of how to organize theoretical knowledge and making theoretical knowledge compliant to IMS LD.

This paper is organized as follows. The next section presents our perspective on learning and instruction. Section 3 proposes a framework for organizing instructional and learning theories. Section 4 discusses an authoring tool based on the framework, after which we conclude.

2. Ontological approach to systematization of educational theories

2.1. Theories of learning, instruction and instructional design

According to Reigeluth overview [18], instructional design is a prescriptive science because its primary purpose is to prescribe optimal methods of instruction. However,

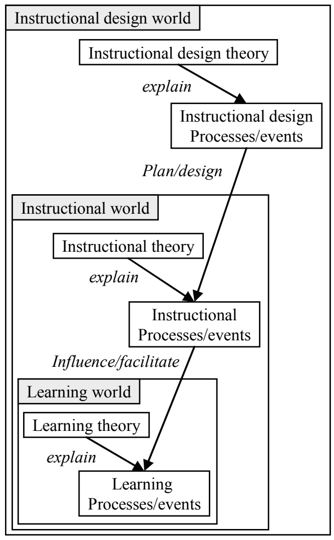

Fig. 1 A nested structure of learning, instruction and instructional design [2]

theories behind instructional design, which are learning and instructional theories, may be discussed in either a descriptive or prescriptive form[1]. In his overview, Reigeluth also summarizes the distinction between descriptive and prescriptive theories. Descriptive ones try to explain learning phenomena by investigating learning actions according to: (1) sets of conditions necessary for making the learning actions successful and (2) expected outcomes. In contrast, prescriptive ones assume sets of conditions and desired outcomes are given and prescribe the best learning actions as the variables of interest. We consider that grasping both aspects of theories is important to understand and design learning and instruction appropriately.

The relation among theories underlying instructional design is considered as a nested structure as shown in Fig. 1. The bottom of the structure is what we call the learning world. Learning theories explain processes and events in this world[2]. What we call the instructional world is on top of the learning world. Instructional processes influence or facilitate learning one. Instructional theories prescribe effective instructional processes for learning processes leading to desired outcomes. Instructional processes and events are parallel to learning ones. We place what we call instructional design world is on top of the instructional world. Instructional design process is the design process of instructional processes. Instructional design theories prescribe rational processes for designing instructional processes.

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 that all the processes share an essential characteristic: they all rely on the learning process which can be modeled as "state-change of a learner." Therefore, this study has built an ontology with state-change of a learner as the foundation of the conceptual system.

2.2. An ontology of learning and instruction

Roughly speaking, the ontology that this study has been developing is composed of five major concepts: concepts related to the *Common, Learning, Instructional and Instructional design worlds* and *Educational event* in the learning and the

[1] There are also instructional design theories other than learning and instructional theories. These mainly focus on the design *process* and will not be discussed here because we focus on the *product* of design.

[2] Here, learning theories include theories of knowledge, of which there are several paradigms – behaviorism, cognitivism and constructivism – according to the various views about knowledge.

instructional worlds. Fig. 2 shows the hierarchy of the upper level concepts. Concepts related to each world are those that describe processes in the respective worlds. The concept of *Educational event* is a description of process. This paper discusses ontology with a focus only on the learning and instructional worlds and the relations between them.

Concepts related to the common world are for describing general cognitive and physical processes of human beings. It includes the definition of concrete concepts such as *Object* (e.g. agent and tool) and *Process*, and abstract concepts such as *Knowledge*, *Theory* and so on.

Concepts related to learning world are for describing learning processes. The concepts include definitions of *Learning*, *Learning object* and *Learning process* as entities in the learning world*, Learning condition, Style, Paradigm* as *Attribute of learning* and so on. As shown in Fig. 1, this world is the core of the nested structure. The key issue in this world is that a learning process is defined as a change of learner's state. As mentioned before, Ertmer asserts that although behaviorism, cognitivism and constructivism each has many unique features, they describe the same phenomena (learning) [5]. In a similar line of the thought, this study sets up the working hypothesis that the phenomena can be conceptualized by change of learner's state. In other words, while the assumed mechanism of developing knowledge is different for each paradigm, the idea of states in the learning process is common[3]. It is our belief that this hypothesis makes sense as an engineering approximation to build a common ground for understanding and using existing theories.

Concepts related to the instructional world are for describing instructional processes. The concepts include definitions of *Instructional action, Instructional strategy*, *Instructional attribute*, etc. The point of the concepts in this world is that instruction is premised on learning. Instruction exists to influence learning, that is to say, to facilitate a change in learner's state. Thus, the meaning of an instructional action is defined by an achieved or intended change of learner's state. However, in this ontology, the relation between a change and an instructional action is defined by I_L event, which will be explained at the end of this section, and an instructional

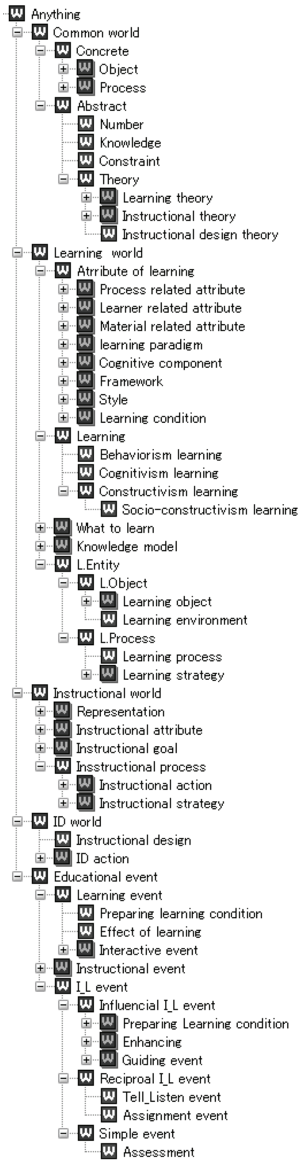

Fig. 2 the upper level concepts (Total number of concepts is 533)

3 Note that we are not saying all the learning theories share the same learning states.

action is defined independently of the change of learner's state. This is because a type of instructional action may have different effects depending on the context. Maintaining independence between instructional actions and changes of learner state is important in order to allow a variety of combinations of instructional actions and the effect.

Educational event is the concept for describing (1) events in each world and (2) relations between them. *Learning event* and *Instructional event* are the concepts describing events in the learning and instructional worlds, respectively. Events of each world are described by concepts of the world and explain the process. A learning event composes an agent as a learner, objects, change of learner's state, and conditions of learning. The relation among them is suggested by learning theories. An instructional event for it part composes an instructional action, its agent, its object and spatial/temporal attributes. The events describe what happens in the respective worlds independently. The important point to note is that the definition of *I_L event* links instructional events to learning events. *I_L event* defines relations between learning and instruction from two points of view. The first is the contribution of instructional events to change of learner's state. The other is the preparation for the following learning event. The role of *instructional event* is to prepare conditions of learning that make learning processes successful. Thus, I_L event also models the contribution to the subsequent learning process. This point will be examined again with examples in 3.1.

2.3. Ontological modeling framework of functional design knowledge

The ontology mentioned in the previous section provides basic concepts to describe events of learning and instruction. It has been built with a goal of establishing a basis for describing any learning and instruction. This being said, we need guidelines to determine the composition of the basic concepts. Instructional and learning theories suggest effective composition depending on the situation. This section discusses how to model the prescriptive aspect of instructional and learning theories.

This study adopts an ontological modeling framework of functional design knowledge of artifacts (devices) by Kitamura et al. [11] as a framework to model educational theories. Although the domain is different from educational knowledge, we believe that it is applicable to the systematization of theoretical knowledge for instructional and learning design.

This framework defines a device from two points of view: "behavior" and "function". A "behavior" of a device is defined as the objective independent of designer's intention, that is, the interpretation of its input-output relations

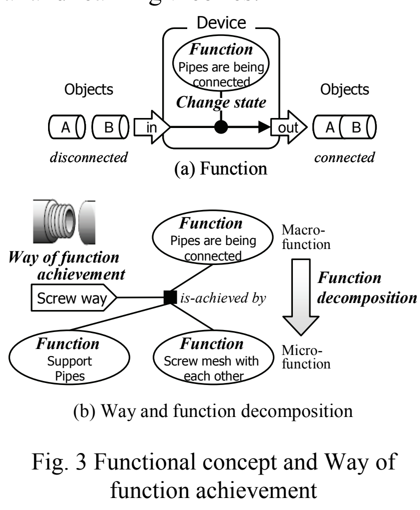

Fig. 3 Functional concept and Way of function achievement

considering the device as a black box. A "function" is defined as the teleological interpretation of a behavior given an intended goal.

The key concepts of the framework are *Functional concept* and *Way of function achievement*. The conception comes from the separation of "function" into (a) what to achieve and (b) how to achieve. The functional concept is a conceptualization of the former (Fig. 3 (a)) and the way of function achievement is one of the latter (Fig. 3 (b)). An important point is the separation between the intended/implemented state-change and the way to achieve the change. This kind of conceptualization makes it possible to provide alternative ways to achieve an intended/implemented state-change because a change is usually achieved in several ways.

Using functional concepts, the functional structure of a device is modeled as a Function decomposition tree and a General function decomposition tree. A function decomposition tree represents the functional structure of a specific device. In contrast, a general function decomposition tree is a composition of some function decomposition trees for similar devices with the same whole-function (the top-function of a function decomposition tree). A (general) function decomposition tree basically shows that a required function (called a macro-function) can be achieved by a sequence of specific sub (micro)-functions. Relations between a macro-function and sub (micro)-functions are described by the ways of function achievement. A general function decomposition tree includes alternative ways of function achievement with an OR relationship. It indicates that there are more than one possible ways to achieve a specific function.

3. Systematization of learning/instructional theories in the form of way of function achievement

In this section, let us discuss systematization of learning/instructional theories in full detail. This study proposes a framework for systematizing learning/instructional theories/models based on the modeling framework of functional design knowledge described in 2.3.

Before we turn to the discussion of the systematization of learning/instructional theories, it is useful to examine the correspondence of the framework to the domain of learning and instruction. As mentioned before, in a function decomposition tree, the concept of device is defined from two points of view: "behavior" and "function". Essentially, "function" means some sort of *change of state* of the input object and "behavior" is defined as *action* that contributes to the change. In the domain of learning and instruction, this study focuses on the change of learner's state and actions that contributes to the change. The difficulty in modeling these might be that the change is achieved by two kinds of actions: instructional actions and learning actions. That is to say, an instructional action leads a learner to do some sort of learning action and the result of the learning action is the change of learner's state. The key points of our conceptualization are to emphasize the relation among the three and to model a contribution of instructional action on the change of learner's state. Consequently, an *action* is defined as a combination of instructional action and learning action and *change of state* is defined as the change of learner's state. This is the essence of definition of I_L event. This framework therefore enables us to model the structure of I_L event to achieve a certain change of a learner's state.

A structure of I_L event is connected by way of function achievement (referred to as "Way" hereafter), which is defined as a relation between a macro-I_L event and some sub (micro)-I_L events. For example, consider a situation where an instructor wants a learner to understands a piece of knowledge and the necessary condition is that the learner should be aware of prerequisite knowledge. A conceivable process to achieve this is to remind the learner of the prerequisite and then to inform him/her of the thing to learn. The former instructional action brings about the necessary condition, which is to be aware of, and the latter promotes the outcome, which is to understand. A Way is such a decomposition of the required change into the detailed changes and actions to achieve them.

A Way has two interpretations. One is, called bottom-up approach, the sum of changes of learner's state of sub-I_L event promote the changes of learner's state in view of a macro-I_L event. The other is, called top-down approach, that an instructional action of a macro-I_L event is decomposed into detailed/concrete instructional actions of sub-I_L events. The interpretation concentrating on states is descriptive. It describes which outcome is produced by a sequence of changes of learner's state. The interpretation concentrating on action is prescriptive. It prescribes which sequence of instructional actions is required for performing the intended instructional action.

Having examined the correspondence of the framework to the domain of learning and instruction, we return to the issue of the systematization of instructional and learning theories. The prescriptive aspect of Way plays a significant role to model instructional and learning theories. The theories prescribe strategies for designing instructional and learning process according to assumed situations. Therefore, this study proposes to model instructional and learning strategies as Way with not a particular situation but generic situations stated in theories. In this study such a generic Way is called Way-knowledge. Organizing Way-knowledge will contribute to clarification of the conceptual structure of each theory and to setting some flexible design guidelines according to theories.

A hierarchy of I_L event itself may look fairly similar to IMS LD [9]. IMS LD also aims to establish a framework to describe instructional and learning processes at very abstract levels. However, IMS LD is just a framework (at least right now) because the purpose of the specification is to provide a containment framework of elements that can describe any design of a teaching-learning process in a formal way. This means that it allows designers to describe any instructional and learning process without guidelines. Thus, the prescriptive aspect of Way-knowledge proposed in this study will contribute to enhance the expressiveness of IMS LD as guidelines on designing instructional and learning processes [16]. On the other hand, descriptive aspects help check the consistency of learning process influenced by the instructional processes.

3.1. Describing learning/instructional theories as Way-knowledge

Fig. 4 shows an example of Way-knowledge from learning/instructional theories. This is described using the Hozo ontology editor [12].

The fundamental definition of Way concept is represented Fig. 4 (A). Way is defined as a relational concept [12]. The relational concept is a conceptualization of the relation among concepts. It has slots of participant concepts (*participate-in* relation denoted by "p/i"). Participant concepts in a way class are "whole" or "sub". Constraint of both participants is I_L event.

A learning/instructional strategy derived from a learning/instructional theory is defined as sub-class of the Way class. Fig. 4 (B) is an example of learning/ instructional strategy defined as a Way. The Way describes a motivational strategy that comes from Gagne and Briggs's nine events of instruction [6][4]. It is composed of the first two events extracted out of the events. One is "Gain attention" (Fig. 4 (2)), whose objective is to interest the learner, and the other is "Inform the learner of the objective" (Fig. 4 (3)), whose objective is to orient the learner to learning. We consider both of these extracted events are concerned with learner motivation.

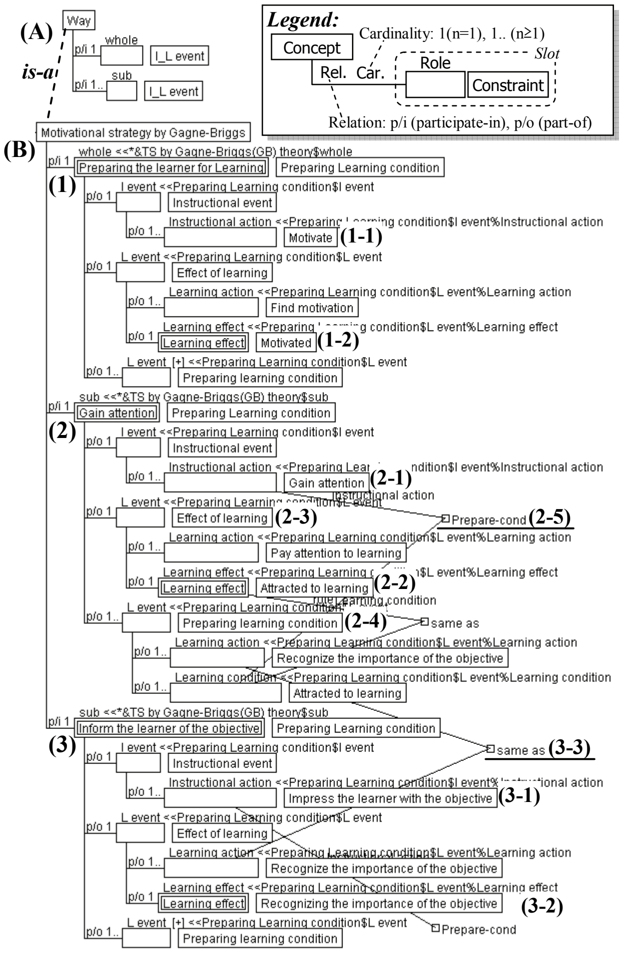

Fig. 4 Description of Way-knowledge in Hozo

The participant concept assigned to a whole (Fig. 4 (1)) is an I_L event that deals with motivation comprehensively. As mentioned in the previous section, an I_L event is composed of pair: an instructional event and a learning event. These events are defined independently of each other though when they are paired they form a meaningful I_L event. In our example, the instructional event has an instructional action "Motivate" (Fig. 4 (1-1)). The intention of the action is described not in its definition but in the coupled learning event in the I_L event. Here, the coupled

[4] The strategy shown here is not actually stated in the theory but an interpretation in this study. Gagne and Briggs have identified nine events of instruction as a simple sequence

learning event describes the achieved/intended learning condition as "Motivated" (Fig. 4 (1-2)), which means that a learner's motivational state has been modified through the event.

The sub participant concepts include necessary I_L events (Fig. 4 (2), (3)) to achieve the whole I_L event (Fig. 4 (1)). This strategy attempts to achieve the states in the whole I_L event with the following two states: "Attracted to learning" (Fig. 4 (2-2)) and "Recognizing the importance of the objective" (Fig. 4 (3-2)). That is, the required state in the whole I_L event is achieved if both of the states of sub I_L events are achieved. The sub I_L events also propose instructional actions to achieve the states: "Gain attention" (Fig. 4 (2-1)) and "Impress the learner with the objective" (Fig. 4 (3-1)), respectively.

It can be considered basically that instructional process prepares conditions of learning and succeeding learning processes. An I_L event is described as not only achieved/intended change of learner's state but also preparation of the succeeding learning events. For example, "Gain attention" (Fig. 4 (2)) is modeled with two meanings; one is to change of learner's state to "Attracted to learning" (Fig. 4 (2-2)), which is described as *Effect of learning* (Fig. 4 (2-3)) and the other is the preparation for the following I_L event "Inform the learner of the objective" (Fig. 4 (3)), which is described as *Preparing learning condition* (Fig. 4 (2-4)). The relation of preparation is illustrated in *Prepare-cond* relation between instructional action and learning condition (Fig. 4 (2-5)) and *same as* relation between learning actions (Fig. 4 (3-3)). Conceptualizing instruction with relation of preparation is characteristic of this study.

3.2. Correlating learning/instructional theories by ways of function achievement

It was pointed out above that each theory is respectively organized as a set of Way-knowledge. Such a set can provide guidelines for instructional designers in view of the underlying theory. This section will expand this idea into theory-eclectic guidelines for instructional designers according to multiple theories.

Dependence between instructional theories is best illustrated in the book edited by Reigeluth: "Instructional Theories in Action: Lessons Illustrating Selected Theories and Models" [19]. He asked several authors to design a lesson based on a specific theory, having in common the subject matter, the objectives, and the test items. The objectives included both concept learning and skill development. The lesson is an introduction to the concepts of lens, focus and magnitude in optics. The book offers eight variations of the lesson, each one being an implementation of eight existing and recognized theories.

One of the problems of using theories is best expressed by Reigeluth: "*There are many commonalities among these theories: that is, many theories prescribe the same methods for the same situations (all in different terminology, though!). Most of the differences in methods prescribed by the theories are due to differences in the situations for which they are prescribed.*" This clearly shows that it is highly necessary to analyze theories and to discriminate what the terminology essentially refers to. It is further important to differentiate the situations to which each theory pertains. We believe an ontological engineering approach has the potential for solving this problem because it focuses on making "things" clear at a conceptual level. The

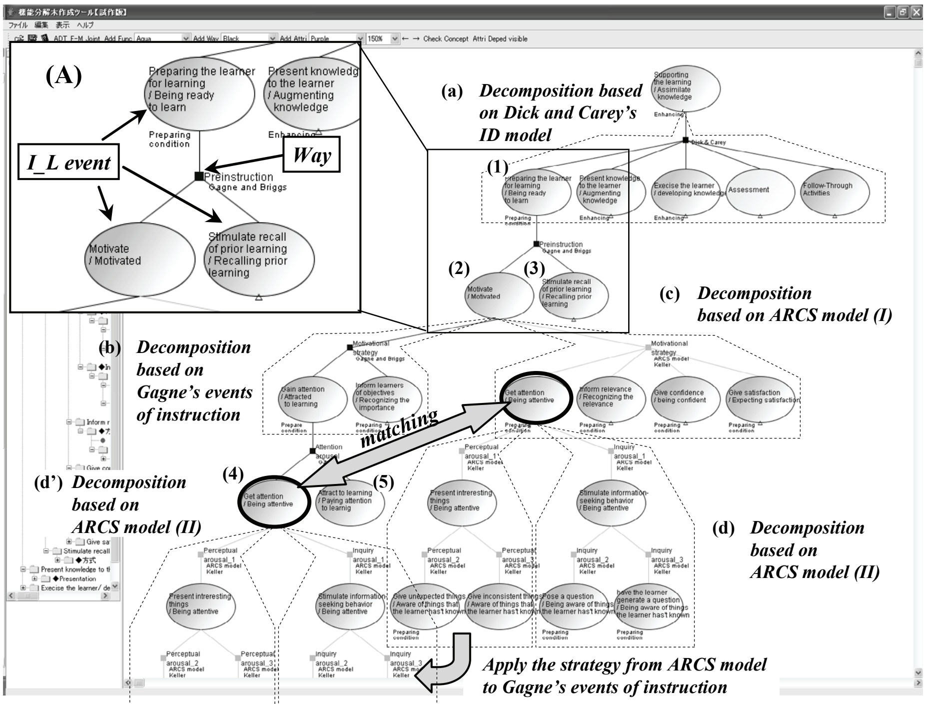

Fig. 5 A part of a general function decomposition tree of learning and instructional design

idea of Way-knowledge and general function decomposition tree based on ontologies is a solution to the problem.

As mentioned in 2.3, a general function decomposition tree includes alternative Ways corresponding to multiple possible Ways to achieve a specific I_L event. In this framework a strategy prescribed in a theory/model is described in terms of Way-knowledge. Matching desired outcome and required condition in a Way makes it easy to find points in common among theories/models.

Figure 5 shows a part of a general function decomposition tree of learning and instructional design. An oval node represents an I_L event. Its label expresses combination of instructional action and state-change of learner in the form of "instructional action/state-change of learner". For example, in Fig. 5 (A), "Preparing the learner for learning" is the instructional action and "Being ready to learn" is the state-change of learner[5]. Ideally, this tree provides every possibility of decomposition of I_L events. I_L events in this tree have alternative Ways of function achievement in an OR relationship.

Three theories/models appear in Fig. 5: Dick and Carey's instructional design (ID) model [4], Gagne's nine events of instruction and the ARCS model [10]. The fundamental structure of this tree is based on Gagne's events of instruction. Introducing Dick and Carey's ID model into Gagne's makes the latter more abstract.

[5] A state-change of learner is usually expressed in achieved/desired state of learner because it implies the previous state, that is, a learner has not been in the achieved/desired state.

ARCS model reinforces the I_L event for pre-instruction from the aspect of motivation.

The decomposition of the top I_L event (Fig. 5 (a)) is done by a Way based on Dick and Carey's ID model. In this model Gagne's events are summarized into five events. These abstract events are expected to provide pivots for inter-theory relationship at a more abstract level than Gagne's events of instruction.

The first I_L event in the second level, "Preparing the learner for learning/Being ready to learn" (Fig. 5 (1)), can be decomposed into two I_L events: "Motivate/ Motivated" (Fig. 5 (2)) and "Stimulate recall of prior learning/Recalling prior learning" (Fig. 5 (3)). The decomposition is based on Gagne's events of instruction but the first two events are put together as an I_L event related to learner's motivation in this tree. Gagne has not himself made it abstract in this way but introducing the abstract event enables learning and instructional designer to have alternatives.

In this tree "Motivate/Motivated" (Fig. 5 (2)) is given two alternative motivational strategies in order to decompose it: based on Gagne's events (Fig. 5 (b)) and based on ARCS model (Fig. 5 (c)). According to ARCS model, learner's state related motivation depends on the following four attributes: Attention, Relevance, Confidence, and Satisfaction. Hence motivational strategy by ARCS model provides four kinds of sub I_L event for each element and detailed strategies to realize the sub I_L events. On the other hand, matching Gagne's motivational strategy with elements in ARCS model, Gagne's theory takes up only Attention and Relevance.

Both Gagne's events and ARCS model have strategies related to learner's attention but these strategies have an important difference. ARCS model is motivational theory so its concern is for getting attention. On the other hand, Gagne's theory is information–processing theory, so its goal is not only for getting attention but also for directing attention to that which is to be learned[10](p. 293). What this statement suggests is that Gagne's strategy for attention is composed of two sub I_L events, which are for "get attention/being Attentive" (Fig. 5 (4)) and "attract to learning/Paying attention to learning" (Fig. 5 (5)). Moreover the I_L event for attention in ARCS model can be same as the former I_L event in Gagne's model. The I_L event for attention in ARCS model can be decomposed into two strategies: "Perceptual arousal" and "Inquiry arousal" (Fig. 5(d)). Consequently, these strategies can be applied to the I_L event based on Gagne's theory (Fig. 5 (4)). The application is shown in Fig. 5 (d').

In this manner, analyzing strategies for desired change of a learner's state not at a terminology level but at an ontological level clarifies intersections of theories and models.

4. Building a theory-aware design support system for instructional and learning design

This section discusses the application of the ontology of learning and instruction and the framework of function decomposition tree. The usefulness of ontology-based educational systems reported by some studies, for example, [1][7] are for design support and [8] for analysis support. Here, let us focus on design support and discuss the utility of the framework of function decomposition tree with the ontology of learning and instruction.

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 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. The developer, not the system, knows the theory. It causes concealment of relation between the system's functionalities and the theories they are based on.

This study aims to build a theory-aware design support system [14] that understands theories. Such a system has the capability of explaining an author which theory or strategy underlies any suggestion it makes, 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

Fig. 6 shows a block diagram illustrating SMARTIES, which has been under development in this study based on Hozo Core [13]. 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 design authors, which includes instructional designers, educational practitioners and occasionally learners. The other is knowledge author, which mainly includes researchers and theorists.

A design authors makes a particular instructional and learning process model using the authoring interface. The model manager manages a model design 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. Besides, generated instructional and learning process model could be finally exported according to IMS LD specification. Briefly put, the structure of a function decomposition tree is reflected in accordance in

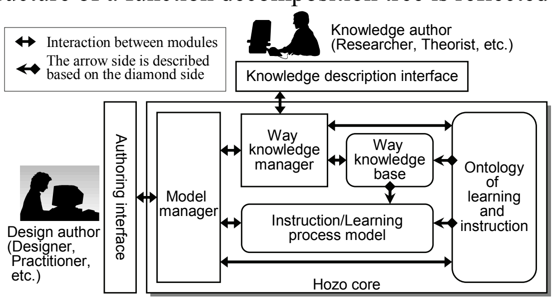

Fig. 6 Block diagram of the design support system: SMARTIES (under development). This diagram focuses only on support for abstract design of learning contents and does not show domain knowledge and learning objects to realize the abstract design.

the activity-structure of IMS LD; instructional actions are compatible with support activities in IMS LD and learning actions are compatible with learning activities in IMS LD.

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 design authors to retrieve strategies for inter-theory cooperation and apply multiple theories to a particular instructional and learning process model. The implementation of the retrieval process is being considered using OWL [21] and SWRL [22]. Hozo core can translate ontologies and models into OWL with a set of Hozo features: role concepts, relational concepts and so on. That makes it possible to make ontology and Way-knowledge sharable.

4.2. An example of design support through theory-eclectic approach

Fig.7 shows a screen shot of SMARTIES. This scene shows how a design author makes an instructional and learning design task using Way-knowledge.

The main window provides an author with an environment to describe a function decomposition tree for an instructional and learning design. Nodes represent I_L events in instructional and learning processes and the decomposition is represented from top to bottom. In this window, an author determines a function decomposition tree: firstly, an author decides upon the whole-function and then decomposes it step-by-step by choosing applicable ways.

The Way-knowledge window helps an author to choose a Way-knowledge to decompose a function from applicable Way-knowledge candidates. It displays applicable Ways appropriate to the selected function the author wants to decompose. Fig. 7 (a) shows two applicable candidates of Way-knowledge. When the author chooses one of them, a proposed decomposition is displayed, as shown in Fig. 7 (b). 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 design author makes instructional and learning design, moving from abstract levels to concrete ones.

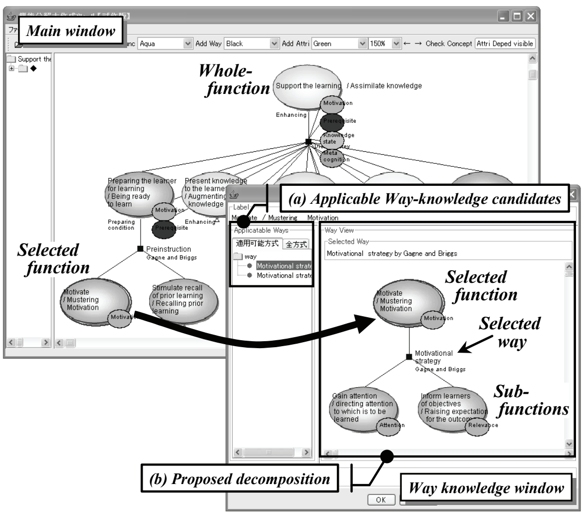

Fig. 7 Screenshot of SMARTIES (under development)

5. Conclusion

We have discussed a modeling framework for instructional and learning theories based on ontological engineering. To summarize, the characteristics of this framework include (1) a theory/paradigm-independent ontology of learning and instruction, (2) a prescriptive model derived from learning/instructional theories, and (3) theory-awareness and compliance with standards for semantic web and e-learning.

Firstly, the independence of an ontology from theories/paradigms allows us to have a common basis for understanding and comparing theories. In this paper, we have discussed the theory-independence of the proposed ontology with the example of Gagne's and Keller's theories in 3.2. The inter-theory relations derived in terms of change of learner's state is one of the key points of the proposed ontology. Although the paradigm-independence has not been discussed, it can be also shown in terms of change of learner's state. From now on, deepening the ontology through organizing many more theories is necessary to examine the effectiveness of modeling in terms of change of learner's state and the paradigm-independence of the proposed ontology.

Secondly, model of theories as Way-knowledge provides us with guidelines for designing instruction/learning at an abstract level. It prescribes which sequence of instructional actions is required to achieve the intended change of learner state. In order to implement such abstract design, 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 is one of the future directions of this study.

Lastly, this paper also proposes requirements for more advanced support systems for instructional/learning design as well as theory-awareness and compliance with standards. An ontology and Way-knowledge enable systems to understand theories to some extent. The theory-aware support based on this understanding will a facilitate theory-eclectic approach to instructional/learning design. Furthermore, compliance with standards for semantic web and e-learning will make instructional/learning design be interoperable among standards-compliant systems. To develop design support systems such as SMARTIES remains critical. Further research on such a development of the system would contribute to building an engineering infrastructure that enables practitioners to utilize instructional/learning theories.

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