Strategy-centered Modeling for Better Understanding of Learning/Instructional Theories

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Abstract: Structuring learning/instructional theories suffers from the issue of "paradigms", which makes it even more challenging. This paper discusses the conceptualization of the theories and proposes a mechanism to provide perspectives for understanding and utilizing them. Two types of conceptualization proposed in this paper reveal their characteristics from a variety of viewpoints.

Keywords: learning/instructional theory, ontology, authoring system

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Introduction

The issue of “paradigms” has been one of the major difficulties in structuring of learning/instructional theories in a unified framework. Paradigms provide a theory of knowledge to construct learning theories, which can then be grouped according to different paradigms. More specifically, the resulting structure refers to the differences between paradigms such as behaviorism, cognitivism, and constructivism (Cooper (1993)). These paradigms express theories in terms of their own concepts and models not shared by others.

Several studies have been made on clarifying the characteristics of each theory/model and differences between them from various viewpoints and make it easy to utilize them. Reigeluth assembles theories, each of which is an independent and piecemeal knowledge base, and aims at building a common knowledge base that integrates them in his series of books (Reigeluth (1983a); Reigeluth (1987); Reigeluth and Carr-Chellman (2009)). These books collect the literature of theories basically by the originator and make annotations about relation between theories. Smith and Ragan organize strategies by the target such as concept, procedure, principle, problem-solving, attitude and so on (Smith and Ragan (2005)). Dick and Carey’s ID Model (Dick et al. (2001)) incorporates an eclectic set of strategies drawn from each of the theories in several paradigms mentioned above and organizes them according to learning/instructional process model. Although these are done with considerable effort, the consistency of them is still an open question because the activities are conducted independently of each other.

There are also several studies on accumulating knowledge for learning/instruction and utilizing it computationally (Meisel (2003); Harrer (2006); Hernandez (2006)). These studies propose modeling frameworks to describe learning processes and mechanisms to accumulate successful learning processes as patterns for re-use. However, these studies mainly focus on the operationality on learning management systems and have little
The purpose of this study is, through the ontological engineering approach (Devedzic (2006); Dicheva (2008); Mizoguchi and Bourdeau (2000)), to build a conceptual basis that comprehensively organizes a variety of theories/models, and to provide perspectives to understand and utilize them. So far this study has developed an ontology named OMNIBUS as such a conceptual basis and a theory-aware authoring system named SMARTIES (Mizoguchi et al. (2007); Hayashi et al. (2010)). This paper discusses the conceptualization of theories/models in OMNIBUS and proposes a mechanism to provide perspectives for in-depth understanding and better utilization of them.

The structure of this paper is as follows. Section 2 gives an overview of OMNIBUS as the foundation for modelling learning/instructional theories. Section 3 proposes a modelling framework of learning/instructional theories, especially focusing on strategies included in learning/instructional theories. Section 4 shows the model of theories based on OMNIBUS and describes a mechanism to provide perspectives to understand and utilize them. Section 5 presents theory-aware functions of SMARTIES. SMARTIES supports learning/instructional scenario design with its own understanding of learning/instructional theories based on OMNIBUS. The section describes how to support application of learning/instructional strategies to a particular scenario and investigation of theories from multiple perspectives. Although quantitative analysis results of theories/models on SMARTIES are presented, that is done for investigating the feasibility of the mechanism proposed in this paper. Note that the purpose of this paper is not to justify appropriateness of the results. The purpose is, especially at the current stage of this study, to explore the possibility of contribution by computer systems to management of theoretical and practical knowledge for learning and instruction. Finally, Section 6 concludes this paper and discusses the future work.

2 OMNIBUS ontology

Most learning/instructional theories contain a principle as the premise, versatile strategies based on the principle and so on. Utilizing the theories requires users to select a suitable theory from a variety of theories and then to apply the strategies included in the selected theory to a specific situation with the deep understanding of the relationship among them as well as each theory. In order to satisfy the requirement, it would be helpful to have a common conceptual basis for better comparison between theories.

As a solution to the problem, this study makes a working hypothesis that a certain kind of sharable “engineering approximation” related to “learning” can be found in terms of the change in the state of learners. Based on this working hypothesis we have built the OMNIBUS ontology as a conceptual basis that highlights the differences and commonalities of a variety of theories based on some paradigms.

2.1 The core concepts

One of the characteristics of the OMNIBUS ontology is to conceptualize learning/instruction processes from two viewpoints: what to achieve and how to achieve (Hayashi et al. (2006)). These viewpoints are defined as the concepts named “I_L event” and “WAY”. I_L event, in which “I_L” stands for the relationship between the Instruction
Author

and the Learning, is the concept to describe what learner state is achieved by what types of action. WAY is the concept to describe how the state can be achieved by the sequence of the states of smaller grain-size.

Figure 1 shows an example of a learning/instructional process model based on these concepts. In Figure 1, the oval nodes represent I_L events, and black squares linking the macro and the micro I_L events represent WAYs. The macro I_L event has two WAYs; WAY1 and WAY2, and there is an “OR” relation between them. This indicates that there are two alternatives to achieve the macro I_L event.

These concepts give a conceptual scheme to model strategies included in learning/instructional theories. We have extracted 104 strategies from 11 theories and defined them as WAYs in the OMNIBUS ontology. Such WAYs based on learning/instructional design knowledge, which include learning/instructional theories and best practices, are called “WAY-knowledge” in the OMNIBUS ontology. WAY-knowledge is an engineering model of strategies and works as the source of theory-awareness for SMARTIES.

Figure 1 I_L event and WAY

2.2 Scenario model

Based on these concepts, a learning/instructional scenario model is described as a tree structure of I_L events decomposed by WAYs as shown in Figure 2 and WAY-knowledge works as theoretical guidelines for the modeling. The leaf level is a description of a learning/instructional scenario executed by instructors and learners, and is linked with LOs used in the execution. The tree structure on top of the leaf level explains the design rationale of the scenario and it works as the specifications of the attached LOs. This idea is close to the idea on the LOCO-Cite ontology (Knight (2005)). The ontology aims at describing the context of usage of learning objects in each scenario with e-learning and semantic web standards. This conceptual framework to describe the context by the LOCO-Cite ontology is complementary to the theoretical guidelines provided by the OMNIBUS ontology in order to record the context of learning objects used in a scenario and its theoretical validity.
3 Structuring learning/instructional theories

The final goal of this study is to structure the existing learning/instructional theories and models, and to enable both of humans and computers to understand them, in other words, humans and computers know what theories and models exist and how to utilize them based on the structured knowledge of them.

In order to achieve the goal, in OMNIBUS, we organize learning/instructional theories and models from the following two viewpoints (Hayashi et al. (2009));

1) a theory as a whole, and
2) a theory as a set of strategies.

From the former viewpoint, each theory or model is characterized according to its properties such as the principle, the hypothesis and the evidence, and organized according to paradigms, such as behaviorism, cognitivism, and constructivism. These paradigms provide theories of cognition to construct learning/instructional theories and models, which are then grouped according to these different paradigms. In OMNIBUS learning/instructional theories and models are classified according to the paradigms and organized in an is-a hierarchy as shown in Figure 3.
Figure 3 The is-a hierarchy of theories and models

On the other hand, the latter viewpoint focuses on strategies included in theories and models. Each strategy provides how to learn/instruct in a context, which includes topics, learning goals, characteristics of learner, and so on. In OMNIBUS, we extract such strategies from theories and models, and then organize them independently of the paradigms. Then each theory or model can be characterized in terms of those strategies. Based on the combination of these two types of characterization, theories and models are structured in OMNIBUS with richer implications. This structure brings out the characteristics of theories, such as which paradigm a theory belongs to, what strategies compose a theory, which kinds of state a theory covers, and so on. This section discusses such conceptualization and categorization of strategies independently of paradigms.

3.1 Categorization of strategies

According to Reigeluth (Reigeluth (1983b)) instructional strategies are composed of three different aspects: organizational strategy characteristics, delivery strategy characteristics and management strategy characteristics. Organizational strategies refer to how an instruction will be sequenced, what particular learning object will be chosen for presentation, and how the object will be presented. Delivery strategies are concerning what instructional medium will be used and how learners are grouped. Management strategies include the scheduling and allocation of resources to implement the instruction that is organized and delivered as planned within the previous two strategy aspects (Smith and Ragan (2005)). In addition, by Merrill’s definition, management strategies involve motivational techniques, individualization schemes and so on (Merrill (1983)). These categories are considered to be useful as the guidelines for abstracting and organizing knowledge.

According to these categories, this study proposes categories of strategies summarized in Table 1 as the upper level concepts of WAY-knowledge (Hayashi et al. (2008c)). Basically, these categories are defined according to Reigeluth’s definition while Organizational strategy is further divided into three more detailed sub-categories; Developmental strategy, Communication strategy and Component strategy. These categories are different in the target state of decomposition. In other words, the combinations of types of state in the macro I_L event are different. Using these
upper level categories of WAY-knowledge, this study proposes the structuralization of instructional design knowledge from theory and practice. Actually, those at the upper level are to some extent independent of each theory and WAY-knowledge from each theory or best practice will be placed under the upper level in the is-a hierarchy. An example of the is-a hierarchy of WAY-knowledge is shown in Section 4.

Table 1 Categories of strategies

<table>
<thead>
<tr>
<th>types</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type of macro state</td>
</tr>
<tr>
<td>Organizational strategy</td>
<td>To specify the sequence of learning/instruction</td>
</tr>
<tr>
<td>Developmental strategy</td>
<td>To specify the development process of learner</td>
</tr>
<tr>
<td></td>
<td>Internal state</td>
</tr>
<tr>
<td>Communication strategy</td>
<td>To specify the communication between learner and instructor.</td>
</tr>
<tr>
<td></td>
<td>Internal state</td>
</tr>
<tr>
<td>Component strategy</td>
<td>To specify the content to be presented to learner</td>
</tr>
<tr>
<td></td>
<td>Communicative state</td>
</tr>
<tr>
<td>Delivery strategy</td>
<td>To specify the medium used in the communication</td>
</tr>
<tr>
<td></td>
<td>Communicative state</td>
</tr>
<tr>
<td>Management strategy</td>
<td>To specify the cultivation of attitude of learner</td>
</tr>
<tr>
<td></td>
<td>Internal state</td>
</tr>
</tbody>
</table>

3.2 Layering a scenario model

In this study, as mentioned in 2.2, a learning/instructional scenario is modeled as a hierarchical tree structure composed of I_L events from the viewpoint of WAY to achieve learning/instructional goals\(^1\). The hierarchical structure is called the “scenario model” whereas only the bottom structure (the sequence of the leaf I_L events) is called a “scenario.” Such a scenario shows an actual sequence of events performed by the learner and the instructor when executed.

This scenario model can be separated into three layers; Rationale layer, Communicative layer, and Presentation layer as shown in Figure 4. Presentation layer corresponds to a scenario. This layer is linked to LOs and specifies which medium should be used for presenting the LO to learners. Physical state related to the LOs is focused here, for example, Have looked, Have read, and so on (in this section italic words denote concept defined in the OMNIBUS ontology). The communicative layer is an abstraction of Presentation layer in terms of communication between the learner and the instructor participating in the scenario execution. This layer deals with Communicative state, for example, (has been) Informed, Asked (questions/to do an action) and so on. Rationale layer presents the design rationale of the other two layers. This layer deals with Internal state, for example, have recognized, have recalled and so on, therefore this can explain why the Communicative and Presentation layers are planned in the scenario model from the perspective of the internal change of learners.

\(^1\) This structure is not an “is-a” structure but a “whole and parts” one that is based on the relationship of achievement.
According to the types of states dealt with at each layer, the categories of strategy usable in each layer can be specified. For example, Rationale layer deals with Internal state, hence Developmental, Communication and Management strategies can be used to decompose I_L events in the layer according to Table 1. This would be useful not only for abstracting and categorizing WAY-knowledge from both of theoretical literature or scenarios in best practices but also for characterizing each theory and best practice. To put it little more concretely, each theory and best practice can be characterized by which layer of the scenario model the theory or best practice covers.

![Figure 4 Layers of a scenario model](image)

### 4 Modeling instructional/learning strategies as WAY-knowledge

#### 4.1 Is-a hierarchy of WAY-knowledge

The pieces of WAY-knowledge are organized in the *is-a* hierarchy independently of the paradigms. Figure 5 shows portion of the *is-a* hierarchy, in which pieces of WAY-knowledge are classified according to firstly the strategy types, secondly the types of learner state to be decomposed, thirdly the composition of micro-I_L events, and then the leaves are the pieces of WAY-knowledge extracted from particular theories. The marked nodes in Figure 5 represent the top-level categories of WAY-knowledge: Organizational strategy, Developmental strategy, Communication strategy, Component strategy, Management strategy, and Delivery strategy. Difference between them is defined as the combination of states in macro- and micro-I_L events. For example, developmental strategy decomposes an internal state of a learner into much smaller grain-sized one, that is, both of the macro- and micro states are internal states. On the other hand, Communication strategy decomposes an internal state into external states related to communication with the instructors or other learners.
Figure 5 The is-a hierarchy of WAY-knowledge

Under the top-level categories, the pieces of WAY-knowledge are further classified according to the types of state to be decomposed. This level of the is-a hierarchy is almost the same as the one of state. Following the type of state to be decomposed, WAY-knowledge is categorized.

Then, types of WAY-knowledge are specialized according to the composition of micro-I_L events. That is to say, at this level, WAY-knowledge is categorized in terms of how-to-do. The examples are Expositive CmS4Hr (Figure 5(1)) and Inquisitive CmS4Hr (Figure 5(2)). Both are the sub-classes of CmS for Have recognized, which is a Communication strategy. The difference between them is how to achieve the learning goal. The essence of the former is straightforward explanation and, by contrast, the essence of the latter, is suggestion as indirect assistance.

Finally the leaves of this hierarchy are the pieces of WAY-knowledge extracted from particular theories. Due to the limitation of space the leaves are not presented in Figure 5. Currently 104 strategies are extracted from 11 theories/models and defined in OMNIBUS.

Figure 6 shows a portion of the is-a hierarchy of WAY-knowledge in detail. In this figure only instructional action is described in I_L events of each piece of WAY-knowledge. The classification of WAY-knowledge in this is-a hierarchy is independent of the classification of paradigms and theories. In Figure 6 three theories/models are
While these are seemingly different, there is a common feature between them if these are further decomposed. For example, *Arouse concern* in Gagne & Briggs’s theory (Figure 6(a)) can be decomposed further into two I_L events with *Arouse attention* and *Arouse interest* (Figure 6(d)). The part *Arouse attention* is common to the first micro I_L event of *Keller’s strategy to Motivate* (Figure 6(b)). This I_L event can be decomposed by two pieces of WAY-knowledge from Keller’s theory (Figure 6(e, f)) in common. In this manner, through the lines of *is-a* links and the reference to the other WAY-knowledge (heavy lines in Figure 6), it becomes clear which pieces of WAY-knowledge can be applied to decomposition of the micro I_L event of a piece of WAY-knowledge. For example, both of *Keller’s strategy to Motivate* (Figure 6(b)) and Gagne & Briggs’s *strategy to Motivate* (Figure 6(a)) can be decomposed by *Strategy to Arouse attention*, which has two sub-classes, that is to say, there are two alternatives.

### 4.2 Relation among concepts in OMNIBUS

As discussed above, theories and models can be viewed from two perspectives: a theory/model as a whole and as a set of strategies. This is realized by the relationship between the definitions of theories/models and WAY-knowledge. Through the relationship the characteristics of theories and models are brought out, for example,
which paradigm a theory belongs to, what strategies compose the theory, which kinds of state the theory covers, and how the states are achieved. Figure 7 summarizes these relationships.

Theories themselves are structured in an *is-a* hierarchy of theory and model (Figure 7(A)) according to the paradigms (Figure 7(B)). Strategies are also structured in the *is-a* hierarchy of WAY-knowledge shown in Figure 7(C). The link between them is in the definition of WAY-knowledge shown in Figure 7(D), which has the reference to the underlying theory/model. Through the relation the theory/model that a strategy belongs to is defined in OMNIBUS.

Besides the reference to a theory or a model, WAY-knowledge also has references to states, which is organized in the *is-a* hierarchy shown in Figure 7(E). The reference from the macro I_L event represents the state to be achieved and the ones from the micro represent the states required to achieve it. This reference makes the relation between theories/models and states through WAY-knowledge. Therefore, WAY-knowledge plays the role of a mediator among concepts related to theories/models.

Although, in the definition, the reference is from WAY-knowledge to theories/models or state, these relations also can be dealt with bi-directionally with HozoCore\(^1\), which is JAVA API to utilize ontologies built in Hozo. Such relations between the concepts in OMNIBUS bring out the characteristics of theories/models.

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\(^1\) [http://www.ei.sanken.osaka-u.ac.jp/hozo/eng/index_en.php](http://www.ei.sanken.osaka-u.ac.jp/hozo/eng/index_en.php)
**4.3 Viewpoint Management for Better Understanding of Theories**

Based on the inter-related organization of theories/models, WAY-knowledge and states, this paper proposes a mechanism to generate multiple viewpoints for the support of understanding a variety of theories. As discussed in the previous section, each theory can be characterized as an aggregation of WAY-knowledge, which is defined by the reference to the definition of theories and states. Following the relations between concepts in an ontology in either of the two directions, any concepts related to the focused concept in the ontology can be extracted (Kozaki et al. (2008)). In the OMNIBUS ontology, using this mechanism, the range of states that a theory covers or theories that a state covers can be revealed.

![Diagram of Viewpoint Management](image)

*Figure 8 An example of separate analysis: In the case of “Motivated” state*

Two types of analysis are proposed; one is an individual analysis of theory/model, state and WAY-knowledge, and the other is a comparative analysis of them. The individual analysis discloses the characteristics of interdependency between the three kinds of concepts. The comparative analysis discloses such characteristics from the macroscopic perspectives in comparison with each other.

In the individual analysis, the characteristics of interdependency between the three kinds of concepts are disclosed through the relation between them. If a theory is focused on, the pieces of WAY-knowledge included in the theory come out. Then, from each of the pieces, the kinds of state related to the theory can also come out. For example, if we focus on Gagne’s theory (Figure 8(A1)) we can pick up the pieces of WAY-knowledge included in it (Figure 8(D1~2)). Although, in Figure 8, only two pieces are shown, nine pieces of WAY-knowledge are actually defined in OMNIBUS. However, note that this is not the total number of strategies in the theory but just the number defined in OMNIBUS.
Furthermore, the states related to the Gagné’s theory comes out from these pieces, for example, *have recognized* and *motivated* in Figure 8(B1~2). Therefore, the scope of the theory for kinds of state can be disclosed as one of the characteristics of interdependency between theory/model, state and WAY-knowledge.

Likewise, a state also can be focused first. For example, from *motivated* state, the pieces of WAY-knowledge related to the state can be picked up (Figure 8(D2~3)). These come from the different theories; one comes from Gagne’ theory (Figure 8(A1)) and the other comes from Keller’s theory (Figure 8(A2)). Such interdependency of the concepts from a state shows the scope of the state for theories/models.

On the other hand, the comparative analysis discloses the difference among types of theories/models, WAY-knowledge or state throughout the accumulation of the results of the individual analysis of them. For example, accumulating the results of individual analysis of states, the difference of them can be disclosed as the scopes of them for the related theories/models. Some types of states may be dealt with in many kinds of theories/models however others may be dealt with in only a few. Of course, although the analysis is done from state in this example, as mentioned above, the analyses also can be done from the kind of theory/model or WAY-knowledge. Examples of the comparative analysis will be shown in Section 5.2.

5 Theory-awareness of SMARTIES

As discussed in 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 paradigmatic issues. We have developed SMARTIES as a prototype of theory-aware system and WAY-knowledge discussed thus far can be the source of the authoring system. This is not an authoring system that provides theoretical support to authors by incorporating a single learning/instructional theory (e.g. CREAM (Nkambou et al. (1996)), CTAT (Koedinger et al. (2003))) but an authoring system that understands a variety of learning/instructional theories. Such 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.

Figure 9 shows an overview of theory-aware support of SMARTIES. There are two kinds of users of SMARTIES: scenario author and theory organizer. Scenario authors are instructional designers or teachers for example, who design scenario models through the scenario editor, with reference to the educational theories described as pieces of WAY-knowledge. Theory organizers describe and maintain pieces of WAY-knowledge derived from learning/instructional design knowledge such as theories, best practices and their own heuristics.

SMARTIES supports scenario authors to build scenarios that conform to theories and the support is based on the declarative knowledge defined by the OMNIBUS that is built apart from SMARTIES. In designing scenarios, concepts defined by OMNIBUS, such as I_L event and WAY, provide a conceptual scheme for scenario making and pieces of WAY-knowledge supply guidelines as models of strategies from theories.

Such pieces of WAY-knowledge are accumulated through the two paths as shown in Figure 9 (a) and (b). One is the extraction from theories in literature, which has been done in this study so far (Figure 9(a)). The other one is the extraction from practice. It is also
important to abstract practical knowledge as best practice in order to organize it as useful heuristics (Figure 9(b)). Although SMARTIES has a WAY-knowledge editor it is currently just a simple graphical editor. In order to accumulate WAY-knowledge from theory or practice effectively, guidelines are required for the abstraction and for organizing knowledge as WAY-knowledge.

Figure 9 Two paths for WAY-knowledge accumulation

This section describes support functions of SMARTIES for scenario authors. Firstly, we discuss how scenario design can be investigated based on OMNIBUS and how it is supported by SMARTIES. Secondly, we discuss what kind of information scenario authors can be provided by SMARTIES in order to better understand learning/instructional theories and the results of comparative analysis of paradigms and theories on SMARTIES are exemplified.

5.1 Scenario design support

Based on OMNIBUS a learning/instructional scenario is modeled as a hierarchical tree structure of I_L event decomposition. Figure 10 shows an example of a portion of a scenario model. This hierarchical tree structure is not is-a structure as shown in Figure 2 but the part-whole structure of I_L events using WAYs as a relational concept. Each node is an I_L event and the hierarchical relations of them depicted as a square are WAYs.

The decomposition tree shown in Figure 10 includes some alternatives to decompose some I_L events. For example, the learning goal set in the root I_L event is that a learner is motivated to learn, and there are three WAYs to achieve this goal: strategies to Motivate based on Gagne & Briggs’s theory, Keller’s theory and Star legacy model. These WAYs are defined as sub-classes of “Strategy to Motivate” shown in Figure 6. The goals of them are the same, which is to motivate learner, therefore these strategies can be related to the root I_L event with OR relationship. These are also sub-classes of Management strategy, which is as one of the top-level concepts of WAY-knowledge and decomposes an attitudinal state to other internal states of learner. Based on this top-level categorization, each WAY in a scenario model is articulated in terms of the design decision. For example, choosing a management strategy here means that the designer
does not design communication to achieve it between the learner and the instructor but tries to consider learners internal states in detail and then proceed to design communication.

Designing a scenario with OMNIBUS is basically to select a strategy from alternative pieces of WAY-knowledge derived from theories (or to describe the author’s own strategy as a new WAY). The decomposition tree in Figure 10 poses a possibility in scenario design as the OR relation of WAYs, in this example, Figure 10(a), (b) and (c). The decomposition tree presented with heavy lines is one of the results of decision making in scenario design. Firstly the Gagne & Briggs’s strategies are selected at (a) and (d), and then the Keller’s strategy is selected for further decomposition at (e). Consequently, scenario design with OMNIBUS can be said pruning of alternative WAYs for each I_L event in the decomposition tree.

Another characteristic of scenario design with OMNIBUS is that the WAY-knowledge selected by the author is automatically integrated into the scenario model. That is, selection of an intended strategy from the theories and integration of it into an instructional context is done at the same time. Such a mechanism is realized on the declarative definition of strategies as WAY-knowledge, which is a relational concept between the macro and the micro I_L events, and its procedural use based on the top-down interpretation of WAY-knowledge (Hayashi et al. (2008b)).

This mechanism has been implemented in SMARTIES. Figure 11 shows a screenshot of SMARTIES, in which an author is selecting a piece of WAY-knowledge from the candidates SMARTIES proposes. The target I_L event to be decomposed is shown at Figure 11(a) and the applicable pieces of WAY-knowledge are displayed in the tree structure and sorted by categories of paradigms, theories, and strategies, in that order (Figure 11(b)). Displaying not only the categories of paradigm but also the ones of strategies, the author can select a much better piece of WAY-knowledge reflecting his/her intention as discussed above. In addition this can be guidelines for design providing possible decision making. The leaves are applicable pieces of WAY-knowledge. On the right side of the window (Figure 11(c)), the author can see the

1 Although currently there is no piece of WAY-knowledge to decompose “Motivate” to communication directly in OMNIBUS, it is possible for an author to describe such a WAY in his/her way.
proposed decomposition by each piece of Way-knowledge. When the author chooses one of them, the proposed decomposition is embodied in the scenario model (Figure 11(d)).

![Strategy selection and integration on SMARTIES](image)

**Figure 11** Strategy selection and integration on SMARTIES

### 5.2 Affording a panoramic view of theories for better understanding of them

Although, in the previous section, it is simply stated that a piece of WAY-knowledge is integrated within a scenario model if one is selected, the difficulty is to select an appropriate one from applicable pieces of WAY-knowledge. As mentioned in Section 5.1, SMARTIES shows the applicable candidates with background information such as category of paradigms and theories to which the strategies belong. In order to utilize such information effectively, it is important to know the features of each category of paradigms and theories in general. From this standpoint, a tool to allow users to browse the pieces of WAY-knowledge from combinations of several viewpoints is implemented in SMARTIES (Hayashi et al. (2009b)).

Figure 12 shows a screen shot of the tool, WAY-knowledge browser. In this window, users can choose a viewpoint to browse pieces of WAY-knowledge. Three viewpoints can be chosen here: type of theory, state and strategy (Figure 12(a)). For example if “theory” is selected as viewpoint 1, the is-a hierarchy of theories is shown (Figure 12(b)). The bold letters in the is-a hierarchy mean that some pieces of WAY-knowledge related to the concept are defined in OMNIBUS. When a concept in the is-a hierarchy is selected, a list of WAY-knowledge related to the concept is shown below (Figure 12(c)).

These viewpoints can be combined. In this figure, for example, the viewpoints are selected according to the order of *instructional theory*, *communicative state* and *component strategy*. This order of combination means which instructional theories deal with communicative states and how the communicative states are achieved in each WAY-knowledge. At the request of users SMARTIES dynamically finds out pieces of WAY-knowledge fulfilling such a requirement and displays on the window.

The lower half of the window displays structure of each piece of WAY-knowledge (Figure 12(d)) and its explanation (Figure 12(e)). In addition to such detailed information, statistical information about distribution of each viewpoint is also provided to users.
In this manner, this tool provides users with panoramic view of learning/instructional theories. WAY-knowledge plays a pivotal role in such perspective management.

Figure 12 Screenshots of WAY-knowledge browser

5.2.1 A comparison of paradigms

Figure 13 shows the result of a comparative analysis on the five top-level categories of theory/model world in OMNIBUS: behaviourism, cognitivism, constructivism, cross-paradigm and instruction management. The first four categories are based on the differences in the “learning (mechanism) paradigm.” The last one of the four, cross-paradigm, was coined in this study and pertains to models which are independent of a particular paradigm. A typical model would be the one suggested by Dick et al. (Dick et al. (2001)). The last one of all, instructional management, aims at creating learning conditions such as motivation, readiness and so on, and uses a different grouping axis from the others.

The wider bars in the bottom of Figure 13 represent the amount of pieces of WAY-knowledge belonging to each of the categories. Although there is the name of Behaviorist theories/models, this doesn’t have the bar. That is because theories/models in this paradigm have not been included in OMNIBUS yet. In addition, there are some narrower bars in each wider bar. They represent the amount of states referred to in the pieces of WAY-knowledge belonging to the theory/model category.

States of a learner are classified into six groups at the top-level in OMNIBUS: learning stage, cognitive process state, meta-cognitive process state, attitudinal state, developmental state, external state (Hayashi et al. (2008a)). Here, note that the proportion of cognitive process state and meta-cognitive process state in the categories of cognitivism and constructivist. The cognitive process state accounts for about 40% of the total in both categories. On the other hand, although the meta-cognitive process state also accounts for 40% in the category of constructivist, it is included less often in the cognitivist theory/model. This result agrees with what constructivism emphasizes the meta-cognitive activities for self-knowledge-construction.
5.2.2 A comparison of theories/models

Figure 14 shows the result of the comparison of Gagne’s theory (the nine events of instruction) (Gagne, 1979) and Merrill’s theory (Component display theory) (Merrill, 1983). While both can be categorized into cognitivism, there are some differences between them. Figure 14(a) is about Gagne’s theory and Figure 14(b) is about Merrill’s theory. There are three pie charts in each window. The middle one indicates the proportion of the types of WAY-knowledge and the right one indicates the proportion of the types of state. In the result, Gagne’s theory is composed of Developmental, Management and Communication strategies, and Developmental strategy makes up a substantial portion of the total. On the other hand, Merrill’s theory is composed of Component strategy in addition to those types of strategies and Component strategy makes up a substantial portion of the total. The types of WAY-knowledge are defined related to the types of state. Therefore the proportion of the kinds of state follows the ones of WAY-knowledge. While Merrill’s theory deals mainly with the external states in the macro I_L event of WAY-knowledge, Gagne’s theory deals sparingly with such. From this result, we could conclude that Gagne’s theory mainly focuses on the relatively abstract learning/instruction processes, which are cognitive processes inside learners, while Merrill’s theory focuses on concrete interaction processes between learners and instructors. This agrees with the purpose of Merrill’s theory, which is a still much narrower theory than Gagne and Briggs’s (Reigeluth (1987)).
6 Conclusion

This paper discusses the conceptualization of learning/instructional theories/models in OMNIBUS and the mechanism to manage the viewpoints on theories/models based on it. Two kinds of conceptualization of theories/models in OMNIBUS reveal the characteristics of them from a variety of viewpoints.

In order to investigate the feasibility of the mechanism, the characteristics of some paradigms and theories/models are analyzed in SMARTIES. These results fit with earlier findings of theories/models. However, the results might be changed depending on theories/models included in OMNIBUS and the interpretation of them. Thus the robust verification is required for ensuring the appropriateness of the results. However, the purpose of this study at the current stage is to explore the possibility of contribution by a computer system to management of theoretical and practical knowledge for learning and instruction. As for this point, it can be considered to show the feasibility of functions to support for understanding and utilizing theories/models systematically.

As summarized above, this paper gives qualitative consideration at the current stage of this study. We plan to explore the possibility of information systems with ontological engineering. Needless to say, however, proper evaluation is necessary and qualitative or quantitative analysis of OMNIBUS and SMARTIES should be conducted. In general,
evaluation of an ontology can be done in two ways: One is to show its consistency and the other is to show its validity. Although the former is important, it is not convincing enough for evaluating its utility. Therefore, OMNIBUS and SMARTIES should be validated from the viewpoints of users: scenario authors and theory organizers shown in Figure 9. The validity of OMNIBUS will be investigated in terms of appropriateness of models of theories in OMNIBUS and of effectiveness of the theory-awareness through the practical use of SMARTIES. For this reason the evaluation tends to be mainly performed qualitatively, though some aspects can be measured quantitatively.

In order to check the appropriateness of the theory models in OMNIBUS we demonstrated OMNIBUS and SMARTIES to a few theorists who are the creators of the theories modelled in OMNIBUS and received positive comments (Hayashi et al. (2010)). We understand such an informal evaluation with theorists needs further evaluation as well as that of the description capability of the proposed modelling framework of theories. In addition to the demonstrations we are currently under experimental use of SMARTIES with actual teachers and teacher candidates. In the experimental use the examinees describe their own scenarios and try to improve them with the help of theoretical knowledge modelled in OMNIBUS. We expect such experiments allows us to get data about effectiveness of OMNIBUS qualitatively as well as quantitatively.

The other future work of this study includes further investigation of the characteristics of theories/models on the proposed mechanism and development of useful functions for better understanding and utilization of theories/models. Especially the last one is important. This paper proposes just a mechanism for analyzing theories and does not discuss how to support users in understanding theories through the analysis results. This remains as a topic to be investigated further.

References


Title


