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Towards Better Understanding of Learning/Instructional Design Knowledge with Strategy-centered Structuring

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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 theories/models 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: ontology, knowledge modeling, learning/instructional theory

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 these different paradigms. More specifically, the resulting structure refers to the differences between paradigms such as *behaviourism*, *cognitivism*, and *constructivism* [2]. 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 the independent and piecemeal knowledge base, and aims at encouraging building a common knowledge base that integrates them in his series of books starting from [17]. These literatures collect the explanation 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 [19]. Dick and Carey's ID Model [5] incorporates an eclectic set of strategies drawn from each of theories in several paradigm mentioned above and organizes them according to learning/instructional process model. However, these are done separately with considerable effort and the consistency of them is still an open question.

There are also several studies on accumulating knowledge for learning/instruction and utilizing it computationally [7][11]. 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 semantics to keep the appropriateness and consistency of knowledge described on the framework.

The purpose of this study is, through the ontological engineering approach [3][4][15], 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 [16]. This paper discusses the conceptualization of theories/models in OMNIBUS and proposes the mechanism to provide perspectives for understanding and utilizing them.

The structure of this paper is as follows. Section 1 gives an overview of the conceptualization of theories/models in OMNIBUS. Section 2 proposes a mechanism to manage the viewpoints on theories/models based on OMNIBUS. Section 3 presents quantitative analysis results of theories/models on SMARTIES, which 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 4 concludes this paper and presents the future work.

1. 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, learning/instructional theories and models are conceptualized from the following two viewpoints;

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

From the former viewpoint, each theory or model is conceptualized by its properties such as the principle, the hypothesis and the evidence, and categorized according to paradigms, such as behaviorism, cognitivism, and constructivism [2]. These paradigms provide theories of cognition to construct learning/instructional theories and model, 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 Fig. 1.

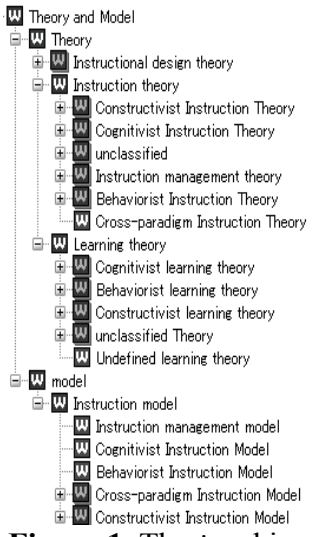


Figure 1. The *is-a* hierarchy of theories and models

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 categorized them independently of the paradigms. Then the strategies can be aggregated again into each theory or model. Thus, each theory or model is modeled as a set of strategies.

Based on the combination of these two types of conceptualization, theories and models are structured in OMNIBUS. This structure brings out the characteristics of theories, such as which paradigm a theory belongs to, what strategies compose the theory, which kinds of state the theory covers, and so on. This section discusses the conceptualization and categorization of strategies independently of the paradigms.

1.1. Conceptualization and categorization of strategies

As mentioned above, each strategy provides how to learn/instruct in a context. In OMNIBUS, this is conceptualized as a combination of *what-to-do* and *how-to-do*. What-to-do represents state change of learner in learning/instruction, and how-to-do represents a way to achieve the state change. This conceptualization is called a WAY, and especially, a WAY based on a theory/model is called WAY-knowledge [16].

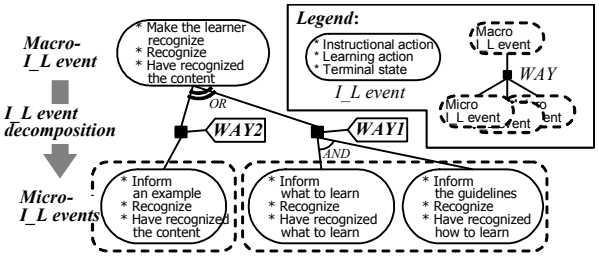


Figure 2. The conceptualization of strategies

A WAY is described as an achievement/decomposition relation of state changes of a learner. Fig. 2 shows the examples of a WAY which is represented as the relation between the upper node and the lower nodes, which are called I_L event. Each node represents what-to-do, that is, what state is achieved. WAY can be interpreted in two directions. The bottom-up interpretation is that the micros are the requirement for achieving the macro, and the top-down is that the macro is achieved by the micros. The former represents descriptive aspect of strategies and the latter represents the prescriptive aspect of them. Based on these interpretations, this study tries to strike a balance between knowing what kinds of strategies exist and utilizing them [10].

The pieces of WAY-knowledge are categorized in the *is-a* hierarchy independently of the paradigms. Fig. 3 shows portion of *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 Fig. 3 represent the top-level categories of WAY-knowledge: *Organizational strategy*, *Developmental*, *Communication strategy*, *Component strategy*, *Management strategy*, and *Delivery strategy* [8]. 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 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.

Under the top-level categories, the pieces of WAY-knowledge are further categorized 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" (Fig. 3(1)) and "Inquisitive CmS4Hr" (Fig. 3(1)). Both are the sub-classes of *CmS for Have recognized,* which is *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.

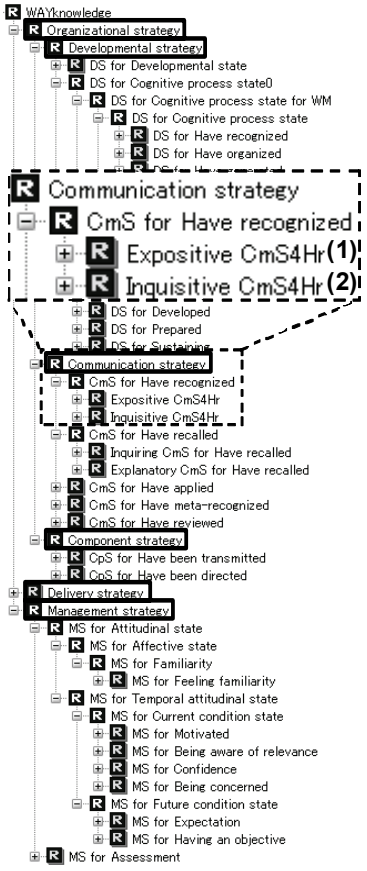


Figure 3. The *is-a* hierarchy of WAY-knowledge

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 Fig. 3. Currently 105 strategies are extracted from 11 theories/models and defined in OMNIBUS.

1.2. 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. Fig. 4 summarizes these relationships.

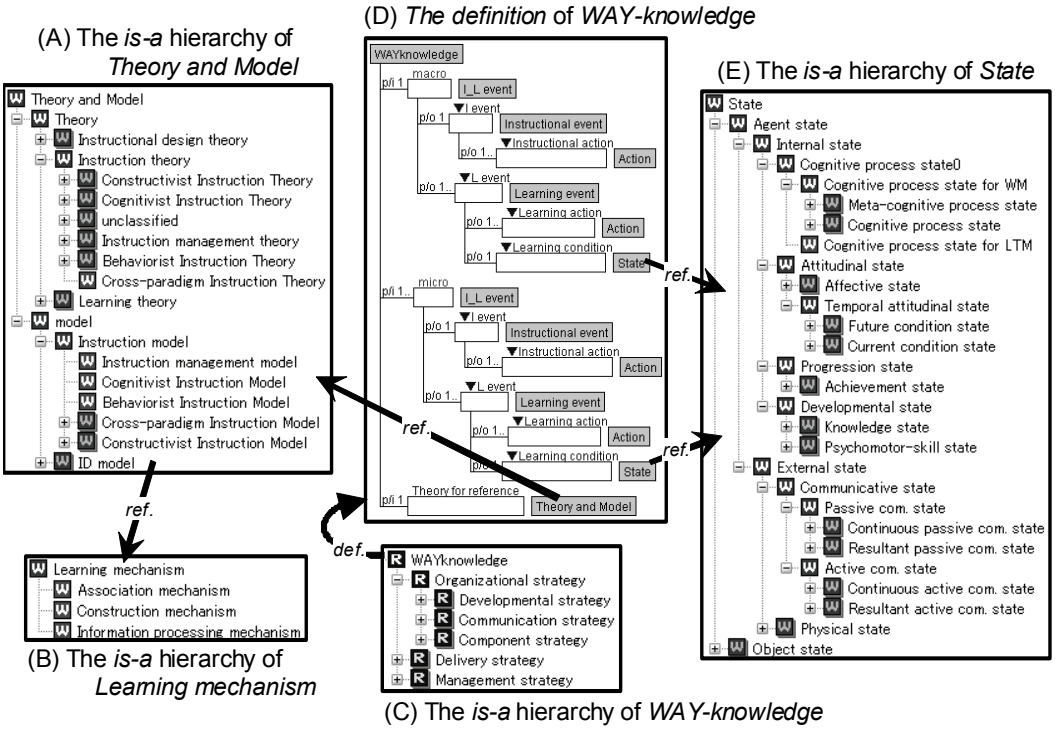


Figure 4. Relation among theory/model, WAY-knowledge and state

Theories themselves are structured in an *is-a* hierarchy of "theory and model" (Fig. 4(A)) according to the paradigms (Fig. 4(B)). Strategies are also structured in the *is-a* hierarchy of WAY-knowledge (Fig. 4(C)). The link between them is in the definition of WAY-knowledge (Fig. 4(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 the reference to state, which is organized in the *is-a* hierarchy (Fig. 4(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 state through WAY-knowledge. Therefore, WAY-knowledge plays the role of 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 on Hozo. Following such relations among the concepts in OMNIBUS bring out the characteristics of theories/models.

[1] http://www.ei.sanken.osaka-u.ac.jp/hozo/eng/index_en.php

2. Viewpoint Management for Better Understanding of Theories

Based on the structure of theory/model, WAY-knowledge and state, 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 conceptualized as a set of WAY-knowledge, which is defined by the reference to the definition of theories and states. Following the relations between concepts in an ontology flexibly, that is, following it in the normal or opposite directions, any concepts related to the focused concept in the ontology can be extracted [13]. In the OMNIBUS ontology, through this mechanism, the range of states that a theory covers or theories that a state covers can be revealed.

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 among 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 (Fig. 4(A_1)) we can pick up the pieces of WAY-knowledge included in it (Fig. 4($D_{1\sim2}$)). Although, in Fig. 4, 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 Gagne's theory comes out from these pieces, for example, "have recognized" and "motivated" in Fig. 4($B_{1\sim2}$). Therefore, the scope of the theory for types 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 at the beginning. For example, from "motivated" state, the pieces of WAY-knowledge related to the state can be picked up. Fig. 4($D_{2\sim3}$). These come from the different theories; one comes from Gagne' theory (Fig. 4(A_1)) and the other comes from Keller's theory (Fig. 4(A_2)). Such interdependency of the concepts from a state shows the scope of the state for theories/models.

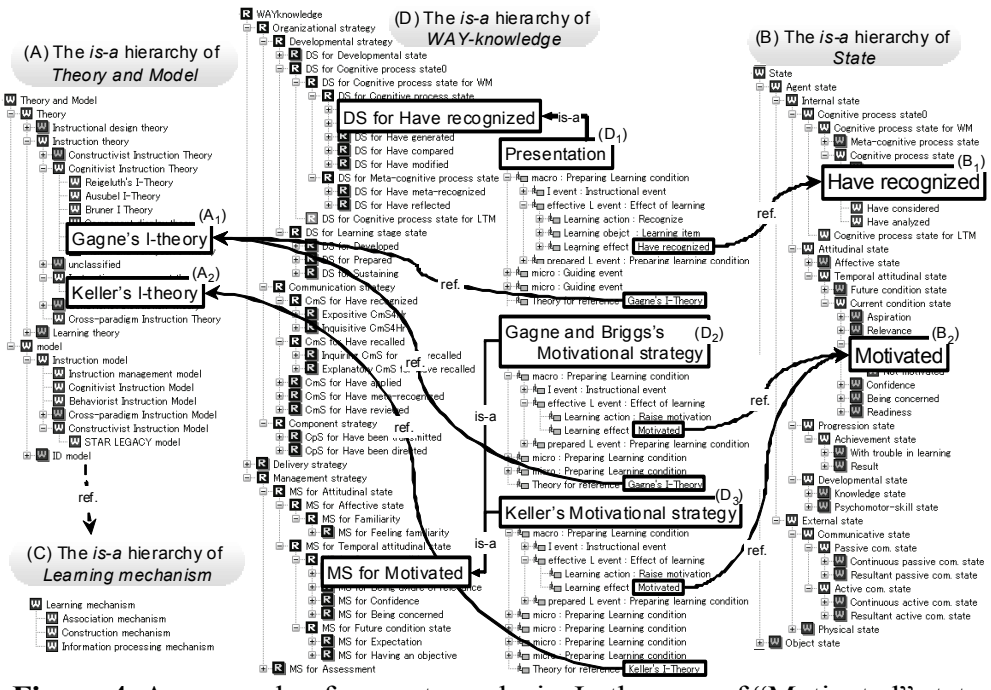


Figure 4. An example of separate analysis: In the case of "Motivated" state

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 types 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 type of theory/model or WAY-knowledge. Examples of the comparative analysis will be shown in the next section.

3. Analyses of theories on SMARTIES

In this study a theory-aware authoring system SMARTIES has been developed based on OMNIBUS. The main support functions of SMARTIES are the following; to support learning/instruction scenario design based on theories and to afford a panoramic view of theories included in OMNIBUS [10]. This section discusses the latter with results of comparative analyses of paradigms and of theories/models on SMARTIES.

Currently OMNIBUS includes 105 pieces of WAY-knowledge from 11 theories/models. However, as mentioned in Introduction, the present goal of this study is not to validate the result of analyses but to look into the feasibility of functions for such analyses.

3.1. A comparison of paradigms

Figure 5 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. [5]. 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.

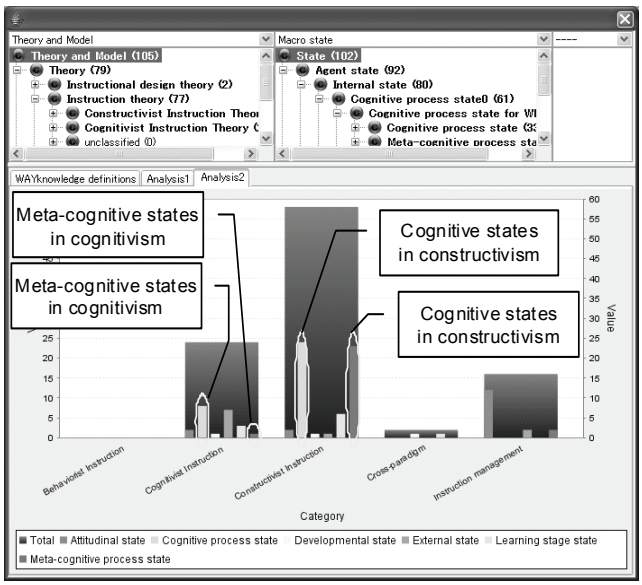


Figure 5. Comparison between cognitivism and constructivism

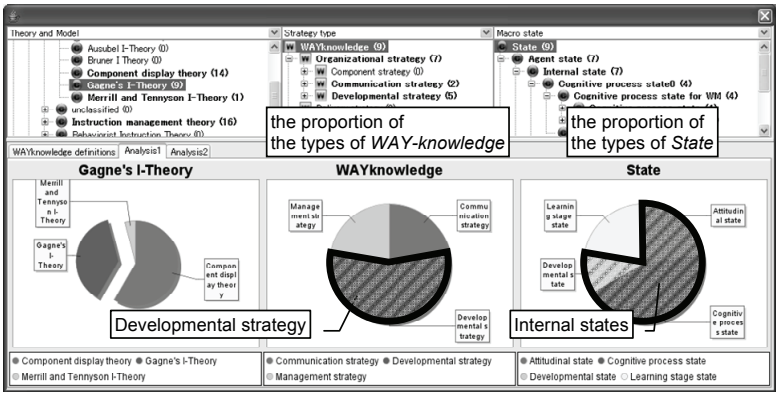
The wide bars in the bottom of Fig. 5 represent the amount of pieces of WAY-knowledge belonging to each of the categories. Although there is the name of Behaviorist theories/models, this doesn't have the bar. That is because theories/models in this paradigm have not been included in OMNIBUS yet. In addition, there are some narrow bars in each wide bar. These represent the amount of states referred to in 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* [9]. Here, note that the proportion of *cognitive process*

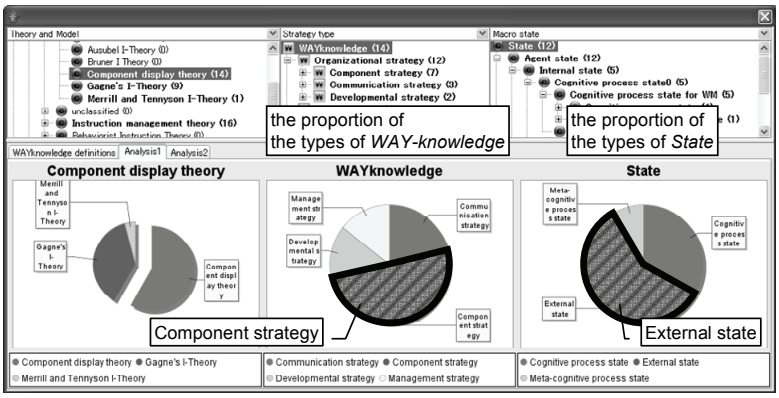
state and *meta-cognitive process state* in the categories of cognitivism and constructivist. The cognitive process state accounts for about 40% of the total in both categories. On the other hand, although the meta-cognitive process state also accounts for 40% in the category of constructivist, it is included less often in the cognitivist theory/model. This result agrees with what constructivism emphasizes the meta-cognitive activities for self-knowledge-construction.

3.2. A comparison of theories/models

Fig. 6 shows the result of the comparison of Gagne's theory (the nine events of instruction) [6] and Merrill's theory (Component display theory) [14]. While both can be categorized into cognitivism, there are some differences between them. Fig. 6(a) is about Gagne's theory and Fig. 6(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 types of state follows the ones of WAY-knowledge. While Merrill's theory deals mainly with the external state 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, and 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 [18].



(a) The proportion of types of WAY-knowledge and state in Gagne's theory



(b) The proportion of types of WAY-knowledge and state in Merrill's theory

Figure 6. Comparison between Gagne's and Merrill's theories

4. Conclusions

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 types 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 studies 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 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.

The future work of this study includes 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 not discusses how to support the users in understanding theories through the analysis results. This remains as a topic to be investigated further.

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