Structurization of Learning/Instructional Design Knowledge for Theory-aware Authoring systems

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Abstract. Currently, there are little guidelines on building quality standard-compliant learning courses. Although educational theories can be guidelines, there are difficulties in the practical use. An approach to the problem is to build a theory-aware and standard-compliant authoring system based on an ontology that establishes a multi-paradigm conceptual basis for learning/instructional theories. This paper discusses the feasibility of building such an ontology, as well as the functionality of a theory-aware authoring tool based on it.

1. Introduction

Standard technologies in the field of Technology-Enhanced Learning (TEL) are currently undergoing remarkable development [5]. However, a significant problem has been noted: in most of the learning/instructional design of TEL courses, learning objects (LOs) are combined with little justification, which can result in low-quality learning courses. A cause of this problem is in fact a disjunction between the learning/instructional theories and the standard technologies. Although the theories may not be always true, they can provide guidelines for quality design.

As a key to the solution of the problem, the concern with ontologies has been growing [6]. We have made a study on an ontology for educational theories and a theory-aware and standard-compliant authoring system based on it [19, 20]. Issues addressed in this study are 1) to make computers understand and utilize a variety of educational theories and 2) to keep sharability of designed scenarios with theoretical justification. To achieve the understanding and the utilization requires a conceptual basis to ensure the compatibility among representations of theories. On the other hand, the sharability with justification requires a design environment for authors to articulate the design rationale of a learning/instructional scenario and to output the resultant scenario in a standard format such as IMS Learning Design (LD) [1]. As the ongoing results we have published OMNIBUS ontology and an authoring system SMARTIES on the project website[2].

[1] http://www.imsglobal.org/learningdesign/

[2] The OMNIBUS ontology and SMARTIES can be downloaded for free from the OMNIBUS project web site (http://edont.qee.jp/omnibus/)

This paper discusses the confirmation of the working hypothesis on which the OMNIBUS ontology is built and the feasibility of a theory-aware and standard-compliant authoring system SMARTIES. This paper is structured as follows. Section 2 describes the overview of the OMNIBUS ontology and a modeling framework for learning/instruction based on it. Section 3 presents the system structure and the functionalities of SMARTIES. Section 4 considers the above results from three viewpoints: confirmation of working hypothesis, theory-blending support on SMARITES and related studies about authoring tools. Finally, the last section concludes this paper and shows other potential of the OMNIBUS ontology than SMARTIES.

2. A framework for modeling learning/instructional theories

2.1. OMNIBUS: a learning-support-related theory ontology

The underlying philosophy of building OMNIBUS ontology is that all the learning/instructional actions can be defined relying on the state of learners that has been changed according to such actions. For example, cognitivism pays attention to cognitive processing inside a learner while constructivism pays attention to interaction with others or the environment. Those paradigms seem to deal with different types of changes of state because cognitivism deals with a learner's internal changes in the cognitive process whereas constructivism treats the external state affected by interaction. In practice though, the educational strategies proposed by these theories are compatible and even complementary (e.g. [24]).

The hypothesis in this study is that establishing a multi-paradigm set of states of the learner, for example, states concerning change of the cognitive structure as a result of the learning process, can help to make a connection among the various internal and external states of learners with which each paradigm deals [9]. The most serious issue is, of course, whether such a multi-paradigm set can be found or not. It is obvious that there are many different states specific to each learning theory at a detailed level. However, if based on the important guiding principle of "engineering approximation," the states can be categorized into several groups such as those in common within some of the paradigms, those in common within all the paradigms or ones specific to each theory.

2.2. A framework for modeling learning/instructional scenario

In the OMNIBUS ontology, learning/instructional processes are modeled from two viewpoints: "what" to achieve and "how" to achieve [9]. Figure 1 shows an example of the model. The oval nodes represent *I_L events*, in which "I_L" stands for the relationship between the Instruction and the Learning. An I_L event is composed of state change of a learner and actions of the learner and the instructor related to the change. This describes what learner state is achieved by the actions. Black squares linking the macro and the micro I_L events represent ways of learning/instructional goals achievement (hereafter, WAYs). A WAY means the relation in which the macro is achieved by the micros. The micros basically have smaller grain-sized state to be

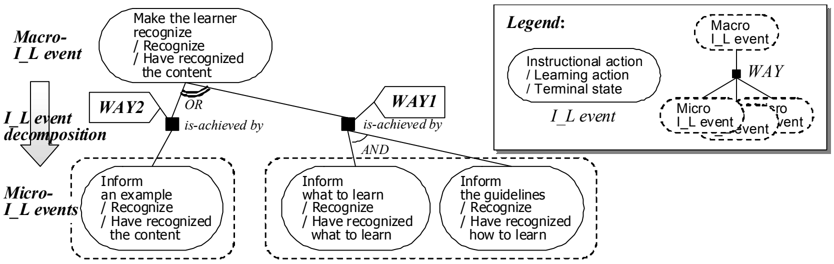

Figure 1. Example of WAY to achieve learning/instructional goals

achieved than the macro's. A WAY describes how the state in the macro can be achieved by the sequence of smaller grain-sized states.

One of the characteristics of this framework is "OR" relation between WAYs. As shown in Figure 1, the macro has two WAYs; WAY1 and WAY2. It indicates that there are two alternative ways to achieve the macro (where the leaner recognizes what to learn). WAY1 is an instructor-led process in which the instructor directly informs what and how to learn, on the other hand WAY2 is a learner-led process in which the instructor gives a demonstration without explanations. These two WAYs have a common goal (expected state-change of the learner) but take different approaches to achieve it.

In this manner, making a distinction between "What" and "How" to achieve will further clarify the differences and commonalities of ways for learning/instruction. Moreover, this also works as guidelines to consider alternative ways to achieve the same goal. WAY is defined as the relational concept [16] on Hozo ontology editor[3] and an example of the detailed definition is shown in [20].

2.3. Modeling strategies from theories in the form of WAY

Each strategy from a theory (hereafter called strategy) describes relationships between relevant learning/instructional approaches for possible situations and expected learning outcome. Moreover, a learning/instructional strategy is considered as an aggregation of such relationships. The relevant modeling of the theories would be declaratively describing these relationships. Consequently, this study proposed to model the schemes described by theories as WAYs. Such WAYs are called WAY-knowledge.

In this study, a hundred pieces of WAY-knowledge are defined based on the eleven theories. Table 1 is a summary of the amount of WAY-knowledge roughly sorted into four categories of the theories/models. *Cross-paradigm*, *Cognitivism* and *Constructivism* are in the grouping axis based on the differences in the paradigm of "Learning (mechanism)" but *Instructional management* is in a different axis because it deals with preparing learning conditions such as motivation. Another typical paradigm is the *Behaviorism*, but we excluded it from Table 1 since its WAY-knowledge has not been defined currently. We discuss the content of WAY-knowledge in 3.1.

[3] Hozo ontology editor can be downloaded for free from the Hozo web site (http://www.hozo.jp/)

Table 1. Content of WAY-knowledge Definition

	Categories of theory/model			
	Cross-paradigm	Cognitivist	Constructivist	Instruction management
Number of Theories/models	1	3	6	1
Amount of WAY-knowledge	2	30	51	16
Amount of WAY-knowledge by a theory/model	Dick and Carey's I-model [7] 2	Component display theory [18] 21	Constructivist learning environment design [13] 22	Keller's I-Theory (ARCS model) [14] 16
		Gagne's I-Theory [8] 8	STAR LEGACY model [25] 18	
		Merrill and Tennyson's I-Theory [17] 1	Scaffolding theories [11, 12] 3	
			Cognitive apprenticeship [4] 8	

3. SMARTIES: a theory-aware and standard-compliant authoring tool

SMARTIES is a prototype of an authoring tool that supports authors to design learning/instructional scenarios based on the OMNIBUS ontology [20]. At the same time, this is a standard-compliant system that can output the models in the IMS LD format. All the information in scenario models designed using SMARTIES, which includes the theoretical justification of the scenario, can be referred to from IMS LD-compliant tools such as Reload LD player [10]. Unlike other systems in which theories are embedded in a procedural manner, the assistance that SMARTIES offers is provided based on the declarative knowledge defined by the OMNIBUS ontology which enables scenario generation by the flexible use of multiple theories and automatic generation of explanations about the theories and scenarios generated.

3.1. An overview of SMARITES

The current scope of SMARTIES is the design phase, one of the five major phases of Instructional design: analysis, design, development, implementation and analysis. SMARTIES assist the scenario design from the abstract level to the concrete level, in other words, from goal setting of a scenario to assignment of learning objects (LOs) to it. In SMARTIES the scenario design is done by decompositions of the goal of a scenario into sub-goals as WAYs. This process is to externalize the design rationale of the scenario as well as to specify LOs used in it. Finally, the resultant scenario model is output in IMS LD format and can be executed on IMS LD compliant tools.

Figure 2 illustrates the system structure of SMARTIES. SMARTIES supports three kinds of authors: Scenario authors, Knowledge authors and Ontology authors. Scenario authors are instructional designers or teachers for example, who designs scenario models through the scenario editor with reference to concepts defined by the ontology and the educational theories described as WAY-knowledge. Knowledge

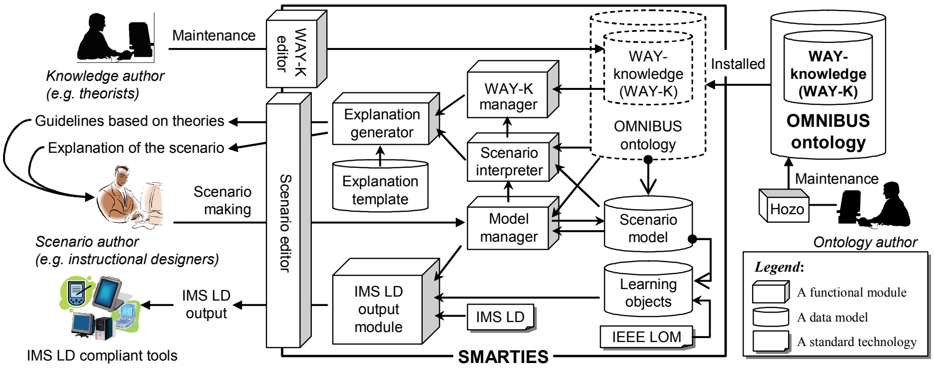

Figure 2 the system structure of SMARTIES

authors describe learning/instructional design knowledge such as theories, best practices and their own heuristics as a set of WAY-knowledge based on the ontology. The WAY-knowledge editor supports the task and stores the resultant pieces of WAY-knowledge are stored in WAY-knowledge base. Finally, ontology authors maintain the OMNIBUS ontology through the Hozo ontology editor, which is located outside of SAMRTIES.

3.2. The scenario design support in SMARTIES

Figure 3 shows the screen shots of the scenario editor where the author designs a scenario model for learning micro scopes based on STAR Legacy model [25]. This screen shot shows how an author makes a scenario model using “WAY-knowledge”. The scenario editor (Fig. 3(1)) is the main window, which provides a scenario author (hereafter, author) with an environment to describe a scenario model (Fig. 3(a)) as a tree structure of I_L events in which the root describes the goal of the whole scenario. In this window, the author decomposes the root I_L event step-by-step. For each I_L event, the setting panel is provided to the author (Fig. 3(2)). In the panel he/she can refer to the ontology and choose concepts to describe I_L event (Fig. 3(3)). The authors can describe the decomposition of each I_L event by the author-defined WAY (Fig. 3(4)) or WAY-knowledge stored in SMARTIES.

The Way proposal window (Fig. 3(5)) provides an author with applicable WAY-knowledge in order to assist the author to decompose each I_L event in the scenario model. The list of applicable pieces of WAY-knowledge is shown in Fig 3(d). This is the result of the I_L event pattern matching based on OMNIBUS ontology. The I_L event selected in the scenario editor is compared with the macro I_L event of all the pieces of WAY-knowledge. If these match up, the WAY-knowledge is applicable. When the author chooses one of them, a proposed decomposition by the WAY-knowledge is displayed on the viewer (Fig. 3(e)). If the author decides to adopt the selected Way, the proposal is applied to the scenario editor. By repetition of such a process, an author makes scenario model from abstract levels to concrete ones.

At the end of the scenario design, learning objects are linked to a scenario model. The leaf nodes depicted by rounded rectangles in the scenario model stand for LOs. In

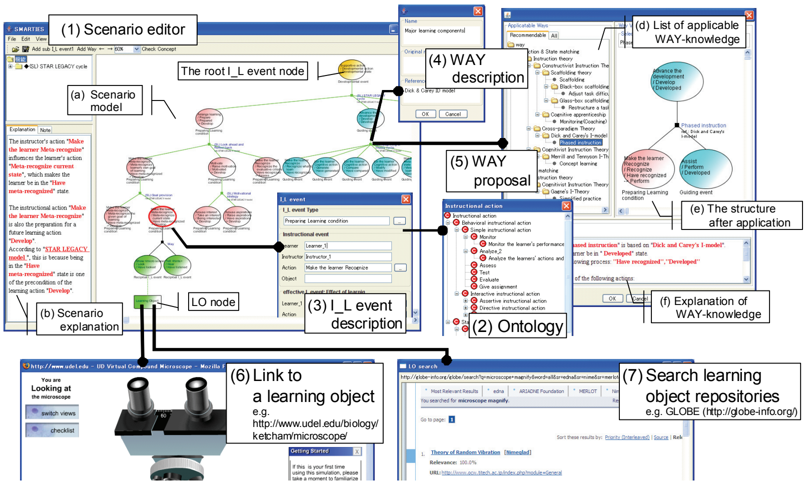

Figure 3. Screenshot of SMARTIES

this example, a simulation of a micro scope (Fig. 3(6)) is set in order to materialize the leaf I_L event. This is because the goal in this I_L event is to remind the learners of the procedure (the manipulation of micro scopes) and the transformational media, which are visual images illustrating changes in time or over space, is appropriate to such content according to Clark's multimedia principle [3]. Authors can set an LO that they made or know as well as search LO repositories for LOs appropriate to the requirement (Fig. 3(7)). Although just the content type is used to discuss the requirement of LO in the current implementation, much more properties are considered to be used to specify the requirement, for example, learner characteristics such as age and prior knowledge, domain characteristics of the content and context characteristics such as mode of instruction and delivery listed in [20]. Enumerating such properties and linking them to LOM elements for LO search is currently in progress.

4. Discussion

In this section, we discuss the confirmation of the working hypothesis of the OMNIBUS ontology and the feasibility and the advantages of SMARTIES.

4.1. Confirmation of the working hypothesis

In order to confirm the working hypothesis discussed in 2.1, we summarized the usage of "state" in WAY-knowledge in Table 2. In this section, we examine if the characteristics and the common ground of each paradigm are properly extracted.

The states are classified roughly into six groups. The *Learning stage* is a state related to the progress of learning such as "Preparation," "Development" and "Assessment." The *Cognitive process state* is a state regarding the learner's recognition process. The *Meta-cognitive process* state is a state regarding the metacognition process.

Table 2. Distribution of the States used in the WAY-knowledge

		The categories of theory/model			
		Cross-paradigm	Cognitivism	Constructivism	Instruction management
The statistics of theory/model	Number of Theories/models	1	3	6	1
	Amount of WAY-knowledge	2	30	51	16
	Number of states	8	77	132	39
Percentage of each category of states	Learning stage	**71.4**	4.8	6.3	0.0
	Cognitive process state	14.3	**61.9**	36.7	35.9
	Meta-cognitive process state	0.0	15.9	**41.4**	12.8
	Attitudinal state	0.0	9.5	4.7	**43.6**
	Developmental state	**14.3**	0.0	0.8	0.0
	External state	0	7.9	**10.2**	7.7

The *Attitudinal state* is a state regarding the learner's attitude and interest such as "Motivation." The *Developmental state* is a state regarding the developmental stages of knowledge and skills and is defined following Bloom's taxonomy [2]. Lastly, the *External state* is a state regarding the learner's communication with others or the environment and has the subclasses such as "Informed" or "Asked."

In Table 2, the theory/model classification mostly used in each state classification is depicted in boldface. This result indicates that various learning/instructional strategies extracted from each theory reflect their characteristics. For example, the cognitivism uses many *cognitive states* because it focuses on the knowledge processing process while the constructivism uses many *meta-cognitive states* that are related to the meta-cognition process. The cross-paradigm theory uses many *learning stages* because it is directed to general learning/instructional processes in which the differences in paradigms are minor.

As discussed above, by modeling strategies extracted from theories as WAY-knowledge focusing on the learner state, the similarities and differences in paradigms are clarified. As Table 2 shows, there are the overlaps of the usage of state categories among paradigms. Therefore, multiple theories from multiple paradigms might be blended in one scenario with the common state concept working as the common ground. Since there do not exist theories that support theory-blending, the validity of blending is not always assured. However, we consider that its feasibility can be presented by the framework of WAY-knowledge that we propose in this study and the theory-blending function discussed below will provide useful information for the instructional designers and teachers.

4.2. Consideration of the alternative strategy applicable for a scenario model

To consider the feasibility of the theory-blending support of SMARTIES, we have modeled a scenario on SMARTIES and examine the possibility of theory-blending. This scenario is from [24] and based on the theory by Gagne and Briggs [8]. The original scenario consists of 11 steps. On the other hand, the scenario model built on SMARTIES has 15 leaf nodes (I_L events) therefore consists of 15 steps. The reason for the difference is that several steps in the original scenario include multiple interactions between the instructor and the learner. One interaction is described as one I_L event in the scenario model therefore one step of the original scenario may be decomposed into several steps in the scenario model depending on the granularity of interaction.

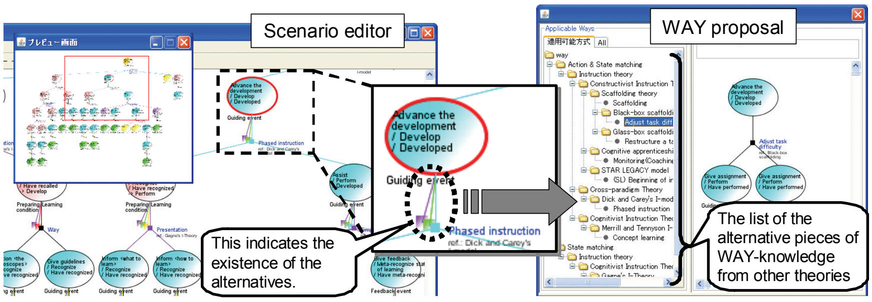

Figure 4 the experimental result displayed on SMARTIES

Most of the WAYs in the scenario model were able to be described by the pieces of WAY-knowledge extracted from the principles by Gagne and Briggs. The only part that was not described by the pieces of WAY-knowledge is the lower layer of the scenario model, which mainly consists of an I_L event where actions are decomposed into concrete actions (i.e., Tell and Listen, which cannot be decomposed more in the OMNIBUS ontology.) Therefore, we believe the WAY-knowledge prepared for this study was sufficient to build an overall storyline of the scenario.

In order to know the applicability of other theories to this scenario model, we checked all the WAYs in the scenario model to see if they had any other pieces of WAY-knowledge applicable to themselves. This experiment was conducted on SMARTIES and Figure 4 shows the result displayed on SMARTIES. The result showed that one or more substitutable pieces of WAY-knowledge were detected from 99 pieces of WAY-knowledge for each of the 23 WAYs out of the 27 WAYs in the scenario model. These alternatives include some pieces of WAY-knowledge extracted from other theories or paradigms. This can be considered that SMARTIES can pose the possibility for the application of other theories than the Gagne and Briggs's to this scenario model. Of course, as mentioned in the previous section, not all the alternatives are assured to be pedagogically relevant to be used in this scenario model, but they can work as helpful information for scenario authors. From this point of view, we may suggest the possibility of designing learning/instructional scenarios based on the multiple theories beyond paradigms through the modeling framework based on the OMNIBUS ontology.

4.3. Related Studies concerning the authoring systems

A number of authoring systems have been suggested in the area of learning/instruction support systems [21]. In this section, concerning the support functions for learning/instructional scenario design, we make a comparison between SMARTIES and the other major theory-based authoring systems.

As for the authoring systems that include theoretical knowledge, the CREAM tools [22] and CTAT (Cognitive Tutor Authoring Tools) [15] can be named as representative examples. They are based on the theories by Gagne [8] and by Anderson [1] respectively. By designing the support functions based on each theory, these tools can provide the author with detailed support. However, these two are based on a single theory and the author has to use another authoring tool if he/she wishes to use other theories because the content of the single theory is deeply embedded in the functions. Furthermore, the clear correspondence between the assistance functions and the theory is kept only in the system developer's head and the authors cannot come to know it clearly when using the system.

SMARTIES has the advantages of these authoring tools as well as complementing their disadvantages. It can provide design guidelines based on multiple theories accumulated as WAY-knowledge. Focusing on only one theory, of course, has the advantage that an authoring system has theoretical consistency from the behavior of the system to the user interface. However, the problem is the scalability concerning the accumulation of knowledge. Some sort of general-purpose framework to systematize theories is required in order to make the authoring tool continuously usable in response to the change of theories. The WAY-knowledge is scalable in SMARTIES and knowledge authors can increase the number of the theories to be dealt with by increasing the number of pieces of the WAY-knowledge.

5. Conclusions

We have discussed the feasibility of building a multi-paradigm conceptual basis for learning/instructional theories, as well as the functionality of a theory-aware authoring tool based on it. As discussed in Section 4, the OMNIBUS ontology works as a conceptual basis for describing learning/instructional strategies from theories and SMARTIES has the scalability concerning theories to be dealt with. Although the definitions of the ontology need to be refined from the experts' perspective of learning/instructional theories, its significance lies in the fact that it presented the feasibility of structurizing various learning/instructional theories. In addition, it is considered that the framework of WAY-knowledge can deal with not only theories but also some other types of design knowledge such as best practices and teachers' heuristics.

Furthermore, the OMNIBUS ontology suggests other possibility of the theory-awareness than SMARTIES. CIAO [23] is a scenario analysis agent that also works based on the OMNIBUS ontology. This interprets the scenario described in the IMS LD format and infers the design rationale of it. [26] proposes an ITS based on the OMNIBUS ontology. In the ITS, pieces of WAY-knowledge are converted to SWRL rules and used by the ITS to select an instructional strategy appropriate to the learner.

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