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Instructional Design Support System Based on Both Theory and Practice and Its Evaluation

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Abstract: In this study, we have been developing a system called FIMA (Flexible Instructional Design Support Multi-Agent System) that dynamically supports teachers in designing instruction by facilitating their thinking ways according to the characteristics of those of expert teachers. In the present study, we focused on a support to facilitate teachers' deep reflection and awareness of room for improvement of their lesson plans based on instructional/learning theories and best practices. In order to provide such support, we make use of the OMNIBUS ontology, which describes knowledge extracted from instructional/learning theories and best practices. In this paper, we describe this support function in detail and report results of an experiment carried out for evaluation of its effectiveness.

Keywords: Ontology, Instructional Design, Lesson Plan, Instructional/Learning Theories

Introduction

The educational gaps caused by differences in teachers' professional abilities are a perennial problem, especially for complex tasks like instructional design. Among the several approaches to resolving this problem, providing teachers with an efficient and usable support system is promising, since most teachers want to participate in the process of designing high-quality instruction. In order to investigate strategies to support less-skilled teachers in designing instruction, it is effective to analyze skilled teacher's thinking processes in approaching this task. Sato et al. have investigated differences in thinking processes between expert and novice teachers when they analyze existing instructional plans [1]. This investigation led us to the conclusion that the thinking way of expert teachers is characterized by the following three features: 1) multiple viewpoints thinking, 2) contextualized thinking, and 3) problem framing and reframing strategies. Because it is also important for teachers to analyze instruction objectively when they themselves design the instruction, this study aims to support teachers in designing high-quality instruction by directly facilitating these three types of thinking. In order to provide such support, we have proposed a Flexible Instructional design support Multi-Agent system, called FIMA [2]. In this paper, we focus on one of the FIMA's sub-system called "FIMA-Light" to facilitate teachers' deep reflection and awareness of some room for improvement of their lesson plans based on instructional/learning theories and best practices.

In Japan, teachers discuss their lessons with their colleagues to improve their lessons' quality in a peer-review meeting called "lesson study". The framework of such "lesson study" and the capabilities of Japanese teachers have been highly regarded throughout the world [3, 4]. One of the greatest reasons for this high regard is that Japanese teachers have formed study groups to reflect upon lessons after beginning their professional careers as teachers [5]. They have found in those groups that others' opinions and points of view are important for making teachers consider their lessons more deeply and effectively. We think that recognizing others' opinions and points of view facilitates above three types of thinking which novice teachers can rarely do. And, it is effective for them in noticing improvement points of their lesson which they cannot notice only by themselves. However, opportunities for teachers to participate in "lesson study" have been decreasing recently because they are busy. Therefore, providing a computer support that can automatically provide teachers with others' reliable opinions and interpretations of their designed lesson plans can be highly valuable.

Based on these considerations, the goal of the present study is to support teachers in designing instruction based on instructional/learning theories and empirical knowledge extracted from best practices that can be regarded as others' opinions and interpretations. We made use of the OMNIBUS ontology, which describes knowledge that is extracted from instructional/learning theories and practices from the perspective of learners' state changes in a common form using shared concepts [6]. In this paper, we discuss an automatic interpretation of the flow of lesson plans that teachers design based on the OMNIBUS ontology, and supports them in their instructional design process based on results of the interpretation. The remainder of this paper is structured as follows: In section 2, we describe an alignment with the OMNIBUS ontology. In section 3, we discuss an automatic function for producing such decomposition trees by interpreting lesson plans designed by teachers using the OMNIBUS ontology. In section 4, we report some results of an experiment carried out for evaluation of the effectiveness of FIMA-Light based on the decomposition trees followed by related work and concluding remarks.

1. An Alignment with the OMNIBUS ontology

1.1 The OMNIBUS ontology and the WAY

The OMNIBUS ontology has been built to organize a variety of instructional/learning theories and empirical knowledge extracted from best practices independently of the learning paradigms [6]. Fig. 1 shows I_L event, the core of the OMNIBUS ontology, and its use in lesson modeling. This ontology is built based on the following two principles.

– Learning is defined as state changes of a learner
– "What" and "How" of state changes are separated

The core concepts of the OMNIBUS ontology are an I_L event and its decomposition structure. An I_L event is a basic unit of learning and instruction and is composed of the state change of a learner, instructional action, and learning action. Such an I_L event shows what state change a learner is expected to realize. A method for how to realize the state change (macro-I_L event) is expressed by a decomposition relation with micro-I_L events, called a WAY. By this decomposition, various methods that can achieve an educational goal can be described as WAYs. In the OMNIBUS ontology, 100 WAYs extracted from 11 instructional/learning theories and 10 WAYs extracted from best practices have been described. A macro-I_L event is decomposed into a couple of micro-I_L events by applying a WAY. A decomposition tree is developed by applying such decomposition recursively to other micro-I_L events as shown in Fig. 1.

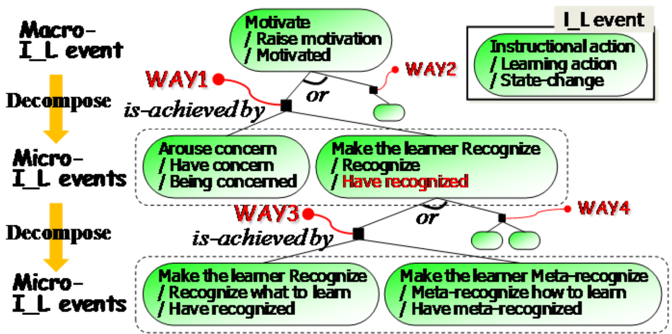

Fig. 1 The modeling framework in the OMNIBUS ontology

With this modeling framework, the flow of a lesson is modeled as a tree structure of I_L events that is called an I_L event decomposition tree. The root node of an I_L event decomposition tree is an I_L event that shows a learner's state change, which should be realized in a whole lesson. In addition, teachers' strategies to achieve the goal of a lesson are expressed as a hierarchical structure by decomposing a macro-I_L event into smaller grained I_L events using WAYs. In this decomposition tree, leaf nodes are descriptions of learning and instructional activities executed by teachers and learners, and the tree structure above the leaf level explains teachers' design intentions for the lesson. In this study, FIMA-Light reasons about teachers' intentions from their lesson plans based on 110 WAYs, which are described in the OMNIBUS ontology at present, and automatically produces relevant I_L event decomposition trees in a bottom-up manner by interpreting a given lesson plan. Then, FIMA-Light facilitates teachers' deep reflection and awareness of room for improvement of their lesson plans by providing them with decomposition trees that are regarded as others' opinions and interpretations of their designed lesson plans.

1.2 Description of relationships between FIMA and the OMNIBUS ontology

In order to support teachers based on their lesson plans input to FIMA by them, FIMA has several original concepts and let teachers select these concepts in instructional design process according to their design intention. We have worked to prepare the concepts which teachers are familiar with. For example, one of the authors has proposed a classification of the goals (the Goal List) of IT education in terms that are familiar to teachers [7]. To make use of the results of this research which has already been so widely used by teachers, we have built our ontology of IT education goals and have identified the relations between the Goal List and our ontology. FIMA allowed teachers to use the concepts of the Goal List by exploiting the function of FIMA which translates the concepts of the Goal List into the concepts of the ontology of IT education goals. See [8] for details. About instructional and learning activities, for FIMA, we have also prepared a set of 36 concepts which teachers are familiar with, through discussion with a couple of teachers. And, we classified the FIMA's activity concepts into one type of concepts of instructional activities and two types of concepts of learning activities ("shallow-level learning activities" and "deep-level learning activities"). By shallow-level learning activities, we mean concrete actions which often appear in lesson plans (e.g. "Discuss," "Listen"), and by deep-level learning activities, we mean cognitive actions which rarely appear in lesson plans (e.g. "Raise motivation," "Recognize state of learning"). In the instructional design process using FIMA, FIMA asks teachers to select a concept from 10 concepts prepared as instructional activities (e.g. "Explain," "Ask"), a concept from 11 concepts prepared as shallow-level learning activities, and a concept from 15 concepts prepared as deep-level learning activities, for each step in the flow of lesson plans. Here, FIMA allows them to select nothing as shallow-level and deep-level learning activities at each step. The purpose in asking teachers to select concepts for the deep-level learning activities is to let teachers reflect on their own instructional intentions for each step in the whole lesson through letting them select a concept that shows the cognitive action of learners that they rarely explicitly describe in usual lesson plans. FIMA-Light makes use of the FIMA's activity concepts which teachers select in the instructional design process using FIMA.

To make use of WAYs described in the OMNIBUS ontology, FIMA-Light has to translate FIMA's activity concepts into the action concepts defined in the OMNIBUS ontology (approximately 250 concepts). For realization of the translation, we described the mapping relation between FIMA's concepts and OMNIBUS action concepts. For example, the mapping relation between the concept "Raise motivation" in FIMA and 11 concepts ("Raise aspirations," "Recognize the relevance," "Feel familiarity," and so on) which are defined in the OMNIBUS ontology was described. Based on the description of the mapping relation, FIMA-Light can translate FIMA's activity concepts selected by teachers into OMNIBUS action concepts.

2. Producing I_L Event Decomposition Trees

Usually, I_L event decomposition trees are made by teachers by decomposing how to achieve learners' state change in the whole lesson in a top-down manner. In contrast, FIMA-Light produces I_L event decomposition trees in a bottom-up manner by interpreting the sequence of concrete-level instructional and learning activities described in usual lesson plans. Analogically, we can say that FIMA-Light builds a syntax (parse) tree of an action sequence in the lesson plan as a sentence by parsing it. So, when FIMA-Light produces I_L event decomposition trees, it is important to automatically add hypothetical I_L events showing underlying intention than is described in usual lesson plans. FIMA-Light produces I_L event decomposition trees following the procedure described below after translating FIMA vocabulary selected by teachers into several related concepts defined in the OMNIBUS ontology. FIMA-Light

1. extracts WAYs relevant to each step in the flow of the lesson plan, and develops decomposition sub-trees that have hypothetical root nodes by applying the WAYs,
2. produces all I_L event decomposition trees appropriate for the given lesson by configuring appropriate sub-trees developed above, and
3. determines three I_L event decomposition trees that fit well with the lesson plan by calculating degrees of similarity of every decomposition tree to the lesson plan.

In this section, we describe an outline of each process of this procedure and the structure of an example I_L event decomposition tree produced by FIMA-Light.

2.1 Extraction of WAYs and Decomposition Sub-Trees Related to Each Step

In each step of the lesson, FIMA-Light translates three concepts that teachers selected as an instructional activity, a shallow-level learning activity, and a deep-level learning activity into several related concepts defined in the OMNIBUS ontology. Based on the principle of the WAY, the relation between the three kinds of activity concepts of FIMA can be interpreted as the teacher's intention to realize a state change (a deep-level learning activity) in the learner by micro-I_L events, which include an instructional activity and a shallow-level learning activity. In addition, a deep-level learning activity can also be interpreted as one of the micro-I_L events for achievement of a macro-I_L event that aims a deeper state change in the learners. Therefore, in this step, FIMA-Light not only extracts relevant WAYs but also develops decomposition sub-trees that have hypothetical root nodes by applying the related WAYs. Here, extracted WAYs have to include an I_L event relevant to the deep-level learning activity because it is the key concept to reason teacher's intention. Based on this consideration, patterns of the structure of WAYs and decomposition sub-trees which FIMA-Light develops for each step of a lesson are shown in Fig. 2. In Fig. 2, ① shows an I_L event that is relevant to a deep-level learning activity, ② shows an I_L event that is relevant to a shallow-level learning activity, and ③ shows an I_L event that is relevant to an instructional activity described in a step of the flow of the lesson.

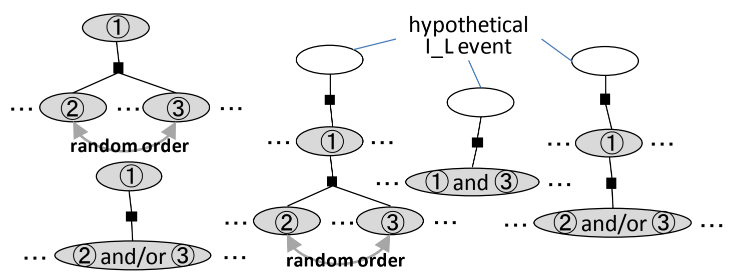

Fig. 2 Patterns of developed WAYs and decomposition sub-trees

2.2 Producing All I_L Event Decomposition Trees Relevant to the Whole Lesson

FIMA-Light tries to produce all I_L event decomposition trees that are appropriate to the whole lesson by configuring WAYs and decomposition sub-trees that are developed from every step of the lesson plan based on the following rules.

- In each I_L event decomposition tree, the node relevant to a step is on the left side of all nodes related to its later steps.
- In each I_L event decomposition tree, the node relevant to a step has no descendant node relevant to a later step.

The latter rule shows that it is impossible to realize the I_L event (node) relevant to a step by a sequence of I_L events that includes any I_L event (descendant node) relevant to a later step. At present, it is difficult to construct I_L event decomposition trees that include WAYs relevant to all steps of the lesson plan, because 110 WAYs currently defined in the OMNIBUS ontology cannot cover all possible strategies in the instructional/learning world.

2.3 Calculating Similarity of I_L Event Decomposition Trees to the Lesson Plan

In the case of a lesson plan that has six steps, more than 1,000 I_L event decomposition trees are often developed. In order to decide the I_L event decomposition trees with which FIMA-Light provides teachers, FIMA-Light calculates the degree of similarity of every developed I_L event decomposition tree to the corresponding lesson plan. In this study, we consider the following three viewpoints to calculate the degree of the similarity.

- A rate of steps of the lesson plan which correspond to WAYs that are included in the decomposition tree
- A rate of FIMA's concepts selected as instructional and learning activities which correspond to I_L events that are included in the decomposition tree
- A rate of leaf nodes of the decomposition tree which are relevant to the lesson plan

We have set weights (2:1:1) in each factor based on the experiences of the practical use of FIMA-Light. FIMA-Light selects three decomposition trees that have the highest degrees of similarity calculated from these three viewpoints and provides teachers with them.

2.4 Structure of an I_L event Decomposition Tree and Support Functions

One of the I_L event decomposition trees that FIMA-Light produced by interpreting an actual lesson plan designed by a teacher is shown in Fig. 3. In this example, nine WAYs that were extracted from the "Gagne's I-Theory," "Component display theory," and so on, are included. An I_L event decomposition tree includes two kinds of nodes. One includes nodes that show I_L events which FIMA-Light judged corresponding to the lesson plan. An example of these nodes is shown at ① in Fig. 3. In the case of this kind of node, a step number of the step corresponding to the node is shown on the upper right side. The other includes nodes that show I_L events that FIMA-Light judged not corresponding to any steps explicitly described in the lesson plan. An example of these nodes is shown at ② in the figure. By the two kinds of nodes, teachers can confirm points corresponding to their lesson plans and points not corresponding to their lesson plans (not explicitly described in their lesson plans). We think that this confirmation has a role which lets teachers be aware of similarity and differences between their design intentions and others' opinions and interpretations. So, FIMA-Light expects that they will deeply reflect on their intentions regarding instructional design through this confirmation process. To facilitate this awareness, FIMA-Light provides teachers with the following two types of messages when any node of the latter kind is clicked as shown at ②, ③ and ④ in Fig. 3.

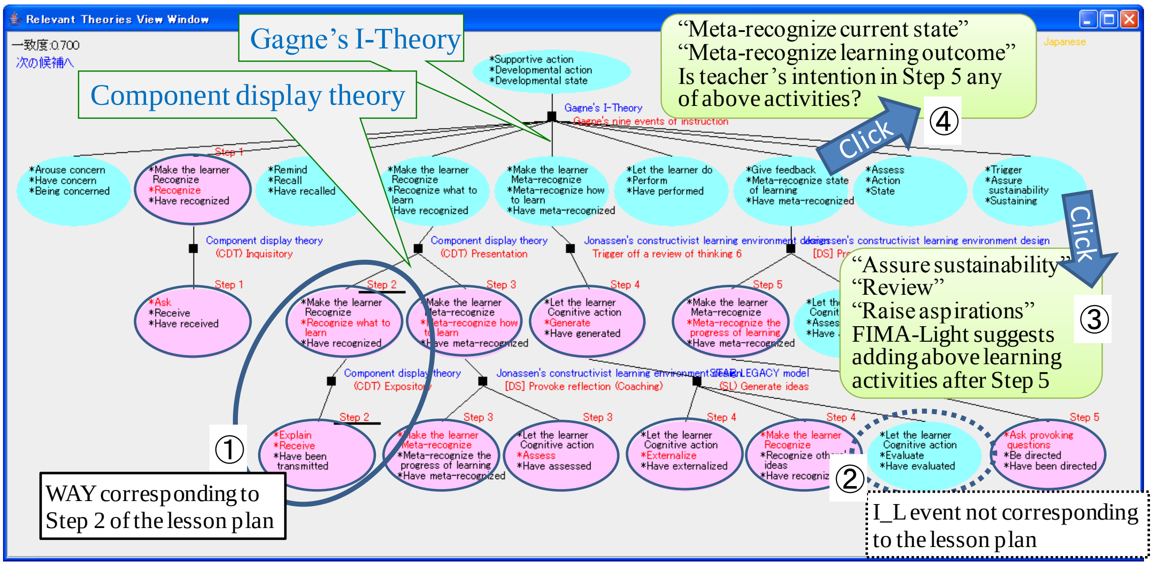

Fig.3 An example of an I_L event decomposition tree and its structure

– When a teacher clicks leaf nodes, FIMA-Light lightly suggests adding instructional and learning activities that correspond to the node into the flow of the lesson plan (for example, at ③ in Fig. 3).
– When a teacher clicks other nodes, FIMA-Light confirms that teacher's intention (deep-level learning activity) in corresponding steps of the lesson plan (for example, at ④ in Fig. 3).

Whenever teachers design instruction using FIMA-Light, they can utilize I_L event decomposition trees. Teachers can design and improve lesson plans through referring to I_L event decomposition trees which are dynamically produced from their lesson plans as others' opinions and interpretations.

3. Evaluation of FIMA-Light through the Practical Uses

In this study, we have evaluated FIMA-Light described in this paper through the practical uses by two teachers. FIMA aims at supporting teachers dynamically in their instructional design processes. However, the main aim of FIMA-Light proposed in this paper is to support teachers by automatically interpreting the flow of whole lesson plans (it is also possible to interpret the flow of part of lesson plans). To evaluate domain independence of FIMA-Light, we prepared eight lesson plans (Each of the two teachers designed four lesson plans) for several subjects (National language, Mathematics, Science, Social studies, and Physical education). Because the teachers were not yet well experienced in operating FIMA-Light and did not yet sufficiently understand FIMA's concepts, the first author of this paper helped them select FIMA's concepts and input data of their lesson plans to FIMA. And, we evaluated the quality of I_L event decomposition trees and the effectiveness of FIMA-Light. Here, though FIMA-Light provides the teacher with three I_L event decomposition trees for each lesson plan, in this evaluation we found that most teachers selected the tree of the highest score and made use of it. So, for every lesson plan, we analyzed and evaluated one decomposition tree selected by the teacher. The result of the analysis of eight I_L event decomposition trees selected by the teachers is shown in Table 1.

First of all, note that it is not necessary for produced I_L event decomposition trees to correspond fully to the lesson plans represented in FIMA-Light, because these trees have roles as different opinions of their colleagues. However, it is necessary for the I_L event decomposition trees to correspond to the lesson plans to a certain extent so that these trees can be helpful for teachers. On average, FIMA-Light produced I_L event decomposition trees

Table 1 The result of the analysis of eight I_L event decomposition trees

<table>
<tr><th></th><th>Total number of steps of a lesson plan</th><th>Number of steps included in a tree</th><th>Total number of FIMA's activity concepts in a lesson plan</th><th>Number of FIMA's activity concepts included in a tree</th><th>Total number of nodes in a tree</th><th>Number of nodes related to the lesson plan</th><th>Number of nodes led the teacher to realize his design intention</th><th>Number of nodes led the teacher to improve his lesson plan</th></tr>
<tr><td rowspan="2">Average (Rate)</td><td rowspan="2">6.1</td><td rowspan="2">5.1 (83.7%)</td><td rowspan="2">16.1</td><td rowspan="2">12.8 (79.1%)</td><td rowspan="2">23.8</td><td rowspan="2">20.9 (87.9%)</td><td>6.5 (27.4%)</td><td>2.4 (10.0%)</td></tr>
<tr><td colspan="2">8.9 (37.4%)</td></tr>
</table>

which include nodes corresponding to 5.1 out of 6.1 (83.7%) steps of the flow of the lesson plans, and include OMNIBUS action concepts corresponding to 12.8 out of 16.1 (79.1%) FIMA's activity concepts selected by the teachers for every step of their lesson plans. These correspondence relations were judged by FIMA-Light. On the other hand, for evaluation of the decomposition trees, FIMA-Light cannot judge the correspondence of the nodes which are so-called hypothetical I_L events that were added in the process of producing the trees. So, we asked the two teachers whether or not every node of the decomposition trees was relevant to their designed lesson independently of explicitly or implicitly. Here, the nodes related to the lesson plans include not only nodes corresponding fully to the lesson plans but also nodes that teachers can regard as others' opinions or interpretations about the lesson plans. They answered that on average 20.9 out of 23.8 (87.9%) nodes were relevant to designed lessons. These results show that the method proposed in this paper can produce I_L event decomposition trees which have rich information to facilitate their awareness of helpful opinion from the colleagues or theories.

Next, we discuss the effectiveness of the instructional design support of FIMA-Light based on the I_L event decomposition trees. We asked the two teachers how many nodes of the decomposition trees led them to change their awareness of their design intentions or of the contents of their lesson plan. They answered that on average 6.5 out of 23.8 (27.4%) nodes led them to realize their design intentions that they were not explicitly aware of. We expect that they will put their lesson plan into practice more effectively by the explicit awareness of their intention. Furthermore, they answered that on average 2.4 out of 23.8 (10.0%) nodes led them to improve their lesson plans. In other words, thanks to the I_L event decomposition trees, teachers found 2.4 improvement points in each lesson plan on average. Here, we show a concrete example of improvement points that a teacher found in his lesson plan. The I_L event decomposition tree shown in Fig. 3 is one of the decomposition trees which FIMA-Light created through reasoning about teacher's design intention from the lesson plan of the mathematics education for the sixth grade in the elementary school. The flow of this lesson plan had five steps. By the node and message as shown at ③ in Fig.3, he was aware of the importance of learning activity that aims at connecting next lesson. After the experiment, he added a new learning and instructional activity to let learners be aware of new problem and to have interest in this problem as the sixth step in the lesson plan. We think that the result of the evaluation experience shows that producing I_L event decomposition trees and support function based on the trees proposed in this paper can effectively support teachers in designing instruction. Furthermore, the fact that all the lesson plans dealt with in the evaluation come from five different subjects shows that our proposed support function work very well across various domains.

4. Related Work and Concluding Remarks

Through the consideration of thinking ways of expert teachers, this study aims to support teachers in designing high quality instruction through facilitating the three types of thinking. In this paper, we focused on the sub-system called FIMA-Light, to facilitate their deep reflection and awareness of room for improvement of their lesson plans based on instructional/learning theories and best practices. In order to provide such support, we proposed a couple of functions that automatically interpret the flow of teacher-made lesson plans based on the OMNIBUS ontology, and produce I_L event decomposition trees as others' opinions and interpretations.

Here, we would like to discuss related work, SMARTIES [6] to contrast FIMA-Light with it. SMARTIES is an authoring system that aims to support designing learning/instructional scenarios based on the OMNIBUS ontology and compliant with the standard technology of IMS Learning Design. By using SMARTIES, teachers can make I_L event decomposition trees compliant with instructional/learning theories through deeply reflecting their design intentions of their lessons. In addition, SMARTIES can suggest WAYs described in the OMNIBUS ontology as strategies for achievement of each state change in learners. In this approach, in which they employ a so-called top-down way, when teachers design scenarios, they have to think deep-level intention that they usually explicitly are not aware of. For such instructional design, it is necessary for teachers to think from contextual and multiple viewpoints. So, though this approach is effective for expert teachers who can think from these viewpoints, it is very difficult for novice teachers.

On the other hand, our approach employs a bottom-up way and can automatically produce I_L event decomposition trees through reasoning about teachers' design intentions from given lesson plans that they usually design. By providing teachers with thus produced I_L event decomposition trees, this study expects that they will notice/recognize their underlying intentions that they were not explicitly aware of. In our approach, even novice teachers can participate in easily. This is one of the characteristics of our approach. In addition, in our approach, FIMA-Light does not directly improve or tell how to improve lesson plans by itself, because such support would prevent teachers from training their professional skills. So, FIMA-Light aims at letting teachers themselves think how to improve their lesson in what respects. This is why the current FIMA-Light is implemented so. To the best of our knowledge, there is no system which can automatically interpret teachers' deep-level intentions from their designed lesson plans, and can support them based on results of the interpretation.

Acknowledgements

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