Educational Externalization of Thinking Task by Kit-Build Method

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Abstract. This paper describes kit-build approach to realize educational externalization of thinking task. In this approach, a learning target is to comprehend an information structure. In order to comprehend the structure, an interactive environment where a learner is allowed to operate the structure is designed and implemented. In the operation, the learner is provided several components and operates them. So, this approach is called kit-build approach. In this paper, the framework and several past related work are introduced. Then, ongoing work and future work following this approach are reported.

Keywords: Educational externalization · Thinking task · Kit-build · Domain-specific information structure

1 Introduction

Learning is an internal change in cognitive system or knowledge as a result of learning activity. This means that it is impossible to support or promote learning itself directly. Therefore, the target of support or promotion of learning should be the learning activity. Because problem-solving is one of the most important learning activity, this paper focuses on thinking tasks as problem-solving.

Cognitive process in problem-solving can be categorized into the following four sub-processes: representing, planning/monitoring, executing and self-regulating [1, 2]. Many investigations then have already indicated that to complete these processes adequately is not easy tasks for most learners [3, 4]. In other words, the thinking activity itself is often difficult for learners and some of them fail to complete the process. Because quality of learning depends on the number and quality of learner's problem-solving experiences, the way to complete the process is one of the most important issues to support of learning from problem-solving.

Externalization of thinking tasks is proposed as a promising method to support a learner to complete the problem-solving process in this paper. If it is assumed that information structure is the processing object in the problem-solving process, the above four sub-processes are categorized into three processes for the information structure: (1) representation, (2) manipulation and (3) evaluation. Then, if we suppose that the thinking tasks are carried out in human's cognitive system as representing, manipulating and evaluating the information structure concerning the tasks, externalization of thinking tasks is able to be realized by externalization of the representation, manipulation and evaluation of the information structure. This externalization is different from

S. Yamamoto (Ed.): HIMI 2016, Part II, LNCS 9735, pp. 126–137, 2016.
DOI: 10.1007/978-3-319-40397-7_13

self-explanation or externalization of results of thinking, because the processes of thinking tasks themselves are carried out outside of the cognitive system. Although similar ideas can be found in the earliest studies of intelligent tutoring systems in the 1970s, the goal has not been achieved even now.

From a viewpoint of artificial intelligence, simulation of excellent thinking process of human, for examples, abstraction, analogical reasoning or metacognition, is one of the most important research goals that has not achieved even now. However, even for human, especially for a learner who is just learning, to complete such excellent thinking processes is often uneasy task. In artificial intelligence, the main difficulty of realization of the simulation is in generalization of the thinking process realized in the simulation. However, it is often claimed that human thinking is domain-specific [5]. Therefore, domain-specific realization of thinking process would be enough to use for learning support. Neither a computer nor a learner can adequately complete the thinking process alone, the process would be able to be carried out adequately if both engage in the process cooperatively. In this research, we have proposed a research approach composed of the following three steps: (1) building a domain-specific model by researchers as representation, (2) rebuilding the model with provided components by learners as manipulation, and (3) diagnosing the rebuilt model and giving feedback to the rebuilt model as evaluation. Preparing components by decomposing a domain-specific model and rebuilding the model by a learner are the most characteristic features of this approach. Because of these characteristics, the rebuilt model is diagnosable. We call this approach “kit-build approach” [6].

In this paper, I introduce several past major investigations with the similar goal with this proposal and indicate that the goal has not been completed yet even now. Then, a series of ongoing case studies is reported. Finally, potential of this challenge is discussed.

2 Past Studies

2.1 Past Trials to Externalization of Thinking Tasks

The idea to externalize thinking process had been proposed several times in the history of research of education and learning. The most important two frameworks related to this idea are “Galperin’s theory of the stepwise formation of mental actions” [7] and “Microworld” in Papert’s Mindstorms [8]. In Galperin’s theory, learning is a process to acquire mental action (that is, intelligent thinking) and the process is organized as stepwise formation composed of the following four distinctive steps: (1) orientation by instruction, (2) physical material action, (3) verbal action and (4) mental action.

Basically, in this theory, the objects of action, that is, objects of thinking, should be materialized previously. In the first step, a learner is taught how he/she acts on the materialized objects. Then, in the step of physical material action, the learner learns the way to use the actions to specific objects and representations of them. In the step of verbal action, dialogical thinking is requested as a complement of the previous step. At the final step, an action has become a pure mental act. In this theory, it is assumed that thinking can be performed as action to materialized objects and the result of learning is modelled as internalisation of the external and materialized action. Therefore, this theory provides theoretical base to trials of externalization of thinking tasks. However, although many practical lessons based on the theory had been reported in the past, there were significant difficulties in materialization of the objects and in supporting the learning process. Information technology has potential to overcome these difficulties.

In MINDSTORMS [8], Papert emphasized the importance of having a well-defined model of a learning object and to build an environment where a learner is able to manipulate the learning object. Then, he also indicated that the model should be composed of “mind-sized bites”. In this framework, it is expected that the learner is promoted to comprehend the learning object through the manipulation. This comprehension means that the construction of the model in his/her mind. This is also a trial to externalize thinking tasks that are difficult for a learner. Then, he indicated that the promising contribution of information technology and conceptualization based on artificial intelligence in order to realize such learning environment. He named such learning environment “microworld”. LOGO developed by Papert as a method to manipulate learning objects in the microworld is a programming language that can deal with general learning objects. Although it is very famous and popular programming language, the language itself is not optimal one as externalization of thinking tasks.

Both Geometry Tutor in geometry proofs [9] and Algebraland in algebra equation-solving [10] were the first and important trials to realize domain-specific computer-based microworld. In Algebraland, a problem space of algebra equation-solving is visualized. In the problem space, a learner is provided an equation as a problem and allowed to manually perform all the calculations associated with different algebraic operations. The problem space presents a visual representation of all previous problem status and applied operations. Also in Geometry Tutor, a problem space to visually construct a proof graph is provided to a learner. In this space, a learner is able to work either forward from given conditions (forward chaining) or backward from what is to be proved (backward chaining) by applying geometry theorems manually. Because these problem spaces were designed based on a model of cognitive system of problem-solving, they are examples of trials of externalization of thinking tasks. Unfortunately, during the period when these studies were conducted, there was not enough hardware and software infrastructure of information technology. Therefore, they were not able to produce practical results. Besides, in the target tasks of them, that is, geometry proof and algebra equation-solving, basic representation of the problem-solving process have been already formalized. Nowadays, we have already significantly advanced infrastructure. Based on the infrastructure, we would be able to challenge thinking task that is not basically carried out inside of cognitive system and produce fruitful results.

2.2 Domain-Specific Information Structure

Modelling a learning object as an information structure is the most important task to realize “externalization of a thinking task”. An approach to model a learning object as an information structure has been a traditional way to design an intelligent tutoring system. SCHOLAR [11] that is widely considered as the first intelligent tutoring system was designed based on well-defined information structure of a learning object, the geography of South America. The information structure was represented by a semantic network representation [12] that was the latest cognitive model at that time. Carbonell called this approach "information structure oriented approach" and emphasized that the information structure processed in an intelligent tutoring system should be the same one in learner's cognitive system.

A series of researches of GUINDON and NEOMYCIN [13] insisted that the knowledge that can be taught to the learner should be described with transparent or glass-box representation. GUIDON was developed to teach expert knowledge (rules) of MYCIN that was a rule-based expert system to identify bacteria causing severe infections. The results of GUIDON suggested that the knowledge of computers or expert systems was difference from the knowledge for a learner. Based on this consideration, NEOMYCIN was developed as a reconfiguration of MYCIN. The main component of NEOMYCIN was a psychological model of diagnostic thinking. The model is used to interpret learner's behaviour and teach diagnostic strategies. This reconfiguration is regarded as the shift from a performance-oriented design to a knowledge-engineering design, that is, to describe knowledge with transparent or glass-box representation. Although the series of researches were oriented to realize general framework of expert systems and tutoring systems, such as GUNIDON2, the contribution of the domain-specific model for diagnostic thinking was significant to the success of NEOMYCIN. Therefore, these researches are also regarded as successful examples of information structure oriented approach.

A student model as a basic component of intelligent tutoring systems is also based on modelling of cognitive process and a learning object. For example, bug model [14] was developed as a model of cognitive procedure for solving computational exercises in subtraction and succeeded in reproducing learner's erroneous answers in subtraction by adding a bug as a wrong partial procedure. REPAIR theory [15] was a generation theory of the bug from the correct cognitive procedure. STEP theory [16] was a learning model of bug generation that explains the reason why a learner obtained the bug. Because one of the most important outcomes of this series of researches was the excellent domain-specific model of the cognitive process and the learning object, they were also very important previous researches about information structure.

Externalization of a thinking task is realized by visualizing such information structure and enabling direct operations to the structure. In the above information structure oriented approach, the information structure is used as a reference model of system design or as an internal mechanism for diagnosis and feedback for learner's behaviour. In contract, in externalization of thinking tasks, the structure is used as the objects of learner's behaviour. Therefore, the approach to externalization of thinking process is a kind of revival of information structure oriented approach.

3 An Ongoing Case Study

In order to realize externalization of thinking tasks, domain-specific model of information structure is indispensable. Besides, evidence of being usable in practical learning or teaching situation is strongly required. Therefore, an investigation aiming to externalization of thinking tasks is not popular in late years. In this section, a series of ongoing case study conducted by the author is introduced.

3.1 Learning by Problem-Posing in Arithmetic Word Problems

In this subsection, externalization of problem-posing task of arithmetic word problems designed on “triple sentence model” is introduced [17]. An interactive problem-posing environment of arithmetic word problems [18, 19] (we call it MONSAKUN, that is, Problem-Posing Kid in Japanese) has been developed and practically used in arithmetic classes in several elementary schools at the first grade (addition and subtraction) [20], the second grade (multiplication) [21], and the third grade (multiplication and division) [22].

Several investigations have already indicated that problem-posing of arithmetic word problems are promising learning activity [23, 24]. However, this activity gives heavy load to both a learner and a teacher. It is usually hard for a learner to make sentences from scratch. The learner often feels difficult how to write sentences, select story or numbers that are not so important from arithmetical point of view. Although posed problems and their posed processes are different in each learner, it is impossible for a teacher to diagnose posed individual problems in real time. Therefore the learner is not able to receive individual support. Even if the teacher gives up diagnosing the posed problems in real time, to diagnose all problems posed by a set of learners is a time-consuming task. Moreover, it is not easy for the teacher to use the diagnosed results for teaching effectively because of time lag between the class of problem-posing and the class of feedback based on the results. Because of these difficulties, it was rare that a class of learning by problem-posing was carried out. Agent-assessment is a solution of this issue [25, 26]. To realize the agent assessment, kit-build approach is a promising approach.

In this subsection, firstly, in order to give an image of externalized task of problem-posing by kit-build approach, MONSAKUN is introduced. Then, the model of information structure of an arithmetic word problem is explained.

MONSAKUN: Interactive Environment for Learning by Problem-Posing. The workspace of the problem-posing activity is shown in Figs. 1 and 2 shows a scene where a student is using MONSAKUN for problem-posing. In the upper left side of the interface, a calculation “7-3” and a type of arithmetic story (change problem: increase) [27, 28] are assigned (these words were translated from Japanese into English). A learner is required to pose a problem that can be solved by the calculation and belongs to the specified type of arithmetic problem by using sentence cards provided in the right side of the interface. The set of sentence cards includes not only the necessary ones but also unnecessary ones (the unnecessary card is called dummy card). In the lower left side, there are three blanks where a learner puts sentence cards in order to complete a problem. In Fig. 1, two cards have been put in the blanks. In this case, required problem is composed of {“Tom has 3 pencils.” “Tom buys several pencils.” “Tom has 7 pencils.”}. By pushing the “Check the problem” button, the posed problem is diagnosed and the learner is able to receive feedback based on the diagnosis.

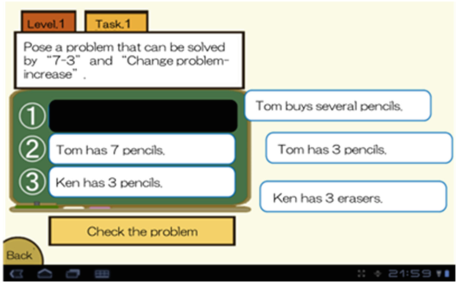

Fig. 1. Workspace of problem-posing

Fig. 2. A scene of practical use

In MONSAKUN, the task to pose a problem is externalized as (1) selection of sentence cards and (2) ordering the selected sentence cards based on the model of information structure of arithmetic word problem. In other words, a learner can operate information structure of an arithmetic word problem by operating sentence cards. In usual problem-posing situation, only a posed problem appears as the result of thinking of a learner. Therefore, the problem-posing is a typical thinking task in mind. In contrast, in MONSAKUN, components of a problem are visualized for a learner as operatable ones. Then, the learner is able to compose a problem through visual operations of the components. Therefore, it is possible to say that the MONSAKUN is an example of externalization of a thinking task.

3.2 Triplet Sentence Model

In MONSAKUN, problem-posing task is designed based on a model of an arithmetic word problem called triplet sentence model [17]. In the model, a basic arithmetic word problem is composed of three sentences. Then, the problem-posing task is designed as combination of the sentences. An arithmetic word problem should be solved using one or more basic arithmetic operations. A problem that can be solved by one basic operation is called basic arithmetic word problem. Since one operation composed of three numerical values, that is, two operands and one result, the basic arithmetic word problem includes three arithmetic concepts corresponding to the three numerical values. By writing a pair of the arithmetic concept and its value in a sentence, it is possible to express a basic problem by using three sentences. In the triplet sentence model, the sentences are categorized into two types, that is, (1) existence sentence and (2) relation sentence. The existence sentence includes an independently existing arithmetic concept and its numerical value. For example, "there are six apples" or "there are two dishes" are existence sentences. The relation sentence includes an arithmetic concept and its value that expresses a relation between other two existence sentences. For example, "two apples are eaten" expresses the relation between the number of apples before eating and after eating. "There are six apples" and "there are four apples" is able to be connected by the relation sentence. By arranging the three sentences in the following order: "there are six apples", "two apples are eaten" and "there are four apples", an arithmetic story is formed. The story is transformed to a problem by changing a numerical value to unknown one and requesting to derive the value from other two values.

Based on this model, it is possible to derive several problems from one existence sentence as shown in Fig. 3. Bold rectangles are relation sentences and others are existence sentences. An existence sentence can be used in all kinds of stories/problems although its role is different depending on the type of stories/problems. The types of arithmetic word stories/problems solved by addition or subtraction are categorized into following four stories: change-increase, change-decrease, combine, compare. Compare stories are often classified into compare-more story and compare-less story. As for the stories/problems solved by multiplication or division, there is only one story and the story is composed of three factors, that is, “base quantity”, “proportion quantity”, and “comparison quantity”. Relation between them are expressed “base quantity” * “proportion quantity” = “comparison quantity”. In both multiplication story and division story, three arithmetical concepts are assigned to one of them. In the story of multiplication or division, an existence sentence plays a role of the proportion quantity or the comparison quantity. The base quantity is assigned only relation sentence. In Fig. 3, “one apple is 80 cents” and “2 apples on one dish” are relation sentences that play the role of base quantity. The existence sentence “there are 6 apples” expresses the portion quantity when the relation sentence is “one apple is 80 cents”, and it expresses the comparison quantity when the relation sentence is “2 apples on one dish”.

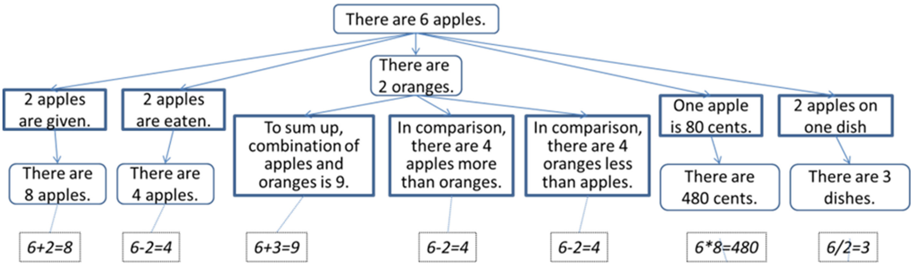

Fig. 3. Various problems derived by the same existence sentence

Based on this model, it is possible to design various kinds of activities to manipulate the structure of arithmetic word problems and to implement diagnosis and feedback function for the activities. Through practical use of MONSAKUN reported in the previous subsection, it has been confirmed that operating the sentence cards doesn’t disturb learners’ thinking process and promotes the task of problem-posing. Moreover, learning effect for structural comprehension of arithmetic word problems has been observed. Therefore, it is possible to say that the investigation about MONSAKUN is a promising example of externalization of thinking tasks. These researches deal with a basic problem that can be solved by one arithmetic operation. In order to deal with more complex problem that can be solved several operations, triangle block model and interactive learning environment based on the model have been investigated [29]. Because of page limitation, they are not introduced in this paper.

4 Targets of the Challenge

In this section, as examples, several thinking tasks that would be targets of the externalization are discussed. In order to externalize a thinking task, it is indispensable to visually represent information structure. Although the information structure is built from scratch in usual thinking process, if we pay special attention that the structure is built by connecting components, it is possible to divide the building process of the structure into (1) generation of the components and (2) connection of the components. If the components are provided to a learner, the task to build the information structure becomes (1') recognition and selection of the components and (2') connection of selected components. If this framework of building of information structure is acceptable, it is possible to express the externalization of thinking process as representation, manipulation and evaluation of information structure. This framework is called "kit-build" framework and has been used in several schools practically [30–32]. In this section, several targets of the externalization are considered based on the kit-build framework, that is, it is allowed to provide components of information structure. The framework where a learner is requested to use only provided components might constrain a learner strong and impede learner's flexible thinking. Solving this trade-off, enabling and constraining, is an open question now.

4.1 Analogy

Analogy is one of the most popular research targets of cognitive science/psychology or artificial intelligence as an excellent and creative thinking task that a human can do better than a computer [33]. Various cognitive models of the analogical thinking have been proposed and several computational simulations have been also developed. The way to use them in education is also discussed [34]. However, it is also well known that to make an analogy adequately is very difficult for usual human [35, 36]. It is also difficult to let a learner make analogy following an ideal thinking process in a cognitive model [37].

Several models of analogy that deal with the process as representation, manipulation and evaluation of information structure have already been proposed, for example, structure-mapping [38, 39], where it would be a promising target of the externalization of the thinking tasks in analogy. In the structure-mapping, (1) building of structural representation of base object, and (2) mapping the structure of the base to the structure of the target, are the two main tasks. By adopting kit-build framework, the two main tasks are able to be externalized by providing a learner with the components beforehand and requesting to build the structures with them.

Figure 4 are the image of the externalization of analogical thinking tasks with Rutherford analogy, that is, "the hydrogen atom (composed of electron and nucleus) is like our solar system", used in [38]. Figure 4 shows a set of components of the information structure of "solar system". A learner is required to build the information structure of the solar system by using the components. The information structure of the solar system that has been built is shown in Fig. 4. These are the phase of building the structural representation of the base object. In the structure mapping phase, by corresponding "planet to electron" and "sun to nucleus", the structure between "planet and sun" is used as the structure between "electron and nucleus". In this phase, the learner is required to build the structure related to electron and nucleus by copying the structure shown in the middle of Fig. 4. Right side of Fig. 4 shows the goal structure of this analogical thinking task. In this framework, it is possible to diagnose learner's behaviour and support his/her behavior based on the diagnosis.

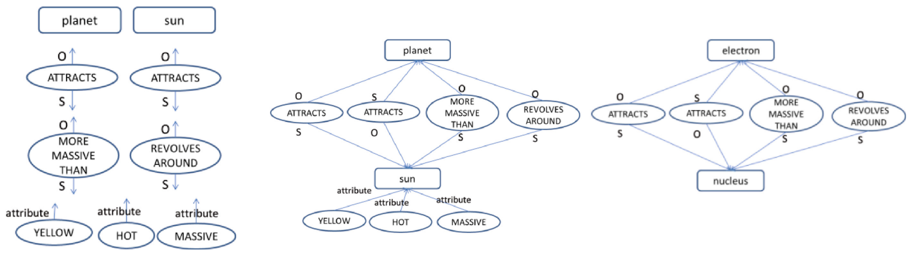

Fig. 4. Components of information structure, base structure and target structure

4.2 Reading Comprehension

Reading comprehension is defined as construction of meaning of a written or spoken communication [40]. If we can prepare explicit representation of meaning, the task is also able to be externalized as the construction of the components of the representation of the meaning. A semantic network is a network which represents semantic relations between concepts and often used as a representation of meaning. SCHOLAR [11] adopted Quillian's semantic network [12] to represent information structure of the geography of South America as the learning object. Concept map [41] that has the same representation has been also popularly used as mental representation in educational context. So, it would be reasonable to use the representation of the meaning as the result of reading comprehension. By decomposing the representation, the components of the representation can be generated. By using the components, the task to construct the meaning with the components is externalized. Learners who accomplished this externalized task are able to share the same comprehension for the communication. Therefore, when we hope learners to have basic and common comprehension about a text or communication, this externalization task would be reasonable. A trial with kit-build concept map for reading comprehension has been already started. The results of the early stage have also reported [42, 43].

In this externalized task, however, the sub-task to extract concepts, that is, components of the representation, from a text or communication is replaced to selection from the provided ones. Moreover, since the origin of the components specified in one representation, it would guide a learner to accomplish the specific comprehension and it would impede the learner to attain his/her own comprehension. Therefore, although this externalization would have advantage to let a learner experience the task of reading comprehension and share common understanding, it would have disadvantage that the learner is impeded to think and understand flexibly. Overcoming this disadvantage is the common challenge of the externalization of thinking tasks.

5 Conclusion Remarks

Thinking activity itself is often difficult for learners and some of them fail to complete the process. Since quality of learning depends on the number and quality of learner's thinking experience, the way to support the thinking process is one of the most important research issues in technology enhanced learning. The main difficulty to think is (1) it should be conducted in leaner's mind, and (2) the task itself is often unclear for his/her. Externalization of thinking tasks is a promising and challenging approach to solve these difficulties. In this paper, as an example of approaches to the externalization, kid-build approach is introduced. Although kit-build approach enables a learner to think externally by operating components, his/her thinking is restricted within the prepared components. In other words, there is a trade-off between "enabling" and "constraining". Solving this trade-off is an open question now. Although this question would be a true challenge, I hope the considerations in this paper would contribute as a step to solve it.

Acknowledgement. This work was supported by JSPS KAKENHI Grant Number 15H02931.

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