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Structure-mapping Support for Learning by Analogy with Kit-Build Concept Map

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Abstract: When people learn new things that are similar to what they already know, analogy enables them to learn faster and deeper by associating knowledge and reinforcing the network of knowledge. However, there are obstacles to using analogy correctly in learning. In this study, we attempt to support learning by analogy through structure mapping of the learning base and target. Expressing the structures of similar contents on a concept map enables learners to recognize the overall similarity by seeing the structures and the correspondence of each component in detail. We propose a learning environment in which learners can try to map the structures of base and target domains as a kit-build concept map. We experimentally used the system at an elementary school to test the feasibility of the learning activity and the learning gain. As the results, students learned with the system understood the target domain more than the students without the system. In addition to that, the students learned with the system could also retain the understanding of the base domain more than the students without the system.

Keywords: Learning by analogy, Structure mapping, Kit-build concept map

1. Introduction

Analogy is a powerful cognitive mechanism for a wide range of purposes, including problem-solving, explanations, and arguments (Gentner, 1997). Although it plays an influential role in learning, there are obstacles to using analogy correctly in learning (Gentner, 1986) (Sandoval, 1995). This study proposes an environment for learning by analogy using a Kit-Build Concept Map (KBmap) (Hirashima, 2011) (Hirashima, 2015).

There are several models of analogy: symbolic, connectionist, and hybrid (French, 2002). This study focuses on the symbolic model, especially, the structure-mapping theory of analogy (Gentner, 1983). This theory assumes that knowledge is represented as a propositional network of nodes and predicates. The similarity between base and target domains can be described as the relation between propositions. The theory defines two types of similarity involved in analogy, surface and structural, and the latter is important in the analogy. The MAC/FAC model (Forbus, 1995) is a comprehensive description model of the human analogy process as the implementation of the similarity distinctions in theory on a computer. Fobus and Hinrichs (Forbus, 2006) developed Companion Cognitive Systems based on this model and used the concept map (Novak, 2006) as a user input.

The concept map is a graphical representation of propositions as the relations between concepts. It is useful for organizing and externalizing learner knowledge and understanding (Pailai, 2017). It has significance in enabling learners to express their understanding. However, in the general concept map, evaluation is difficult because learners can freely create concept maps. On the contrary, a KBmap (Hirashima, 2011) (Sugihara, 2012) can automatically diagnose concept maps because learners create concept maps from the components that are decomposed from a concept map created by teachers. This enables learners to organize their understanding in a comprehensible way in the form of the concept map and allows teachers to confirm learners' understanding immediately (Hirashima , 2015).

This study uses KBmaps in which learners create concept maps of two topics and map the concepts. A concept map itself represents the structure of concepts. Therefore, it is helpful for learners to compare the structure because it clarifies the structure as the relationships among concepts. Also, providing components to create concept maps in KBmaps allows learners and teachers to compare concept maps and the structural mapping. For this reason, we propose a learning method for structure mapping using KBmaps.

This paper discusses the proposed learning method and the effectiveness of the system implementing the method. This paper is structured as follows. Section 2 presents the basic idea of KBmap. Section 3 presents the overview of analogical reasoning and the support functions in the KBmap system for structure mapping that is one of the sub-processes in analogical reasoning. Section 4 presents an evaluation of KBmap's function in the elementary classroom. Section 5 concludes this paper and presents future work.

2. Kit-Build Concept Map

Following are examples of learning activities with the KBmaps. They are an overview of the current systems.

2.1 The Goal Map and the Kit

In the KBmap, teachers create concept maps as a summary of the learning concepts presented to learners. The validity of the concept map is guaranteed by the teacher. The goal map represents: (1) the expected learners' understandings as the learning goal, and (2) components that the teacher provides for learners to demonstrate their understanding. The kit is the decomposition of the goal map. The teacher gives the kit to learners and asks them to compose a concept map. Figs. 1 and 2 show an example of the goal map and the kit.

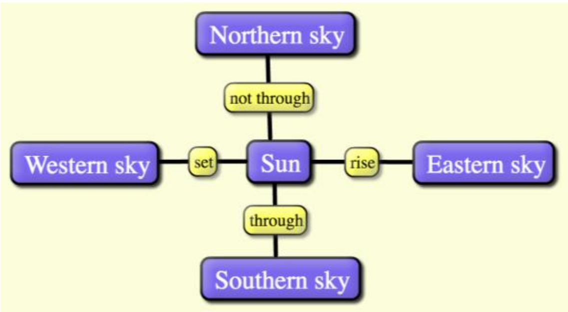

Fig. 1. A goal map

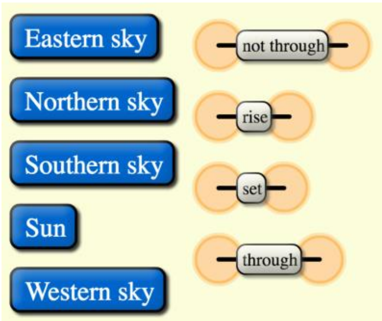

Fig. 2. The kit from the goal map

2.2 Learner Map

With KBmap, learners assemble the components in the kit to create concept maps as the representations of their understanding. Providing components helps learners' understanding process in which they first recognize the components in the learning content and then structure them as the overall understanding of the learning content.

2.3 Diagnosis and Feedback

One characteristic of KBmaps is that the teacher can check the learners' understanding as the difference between the goal map and the learner maps. The learner maps, consisting of the components of the goal map, enable a comparison between them. The differences represent the gap of understanding between the teacher and the learners as well as among the learners. The KBmap assessment method is automated, and its validity for evaluating learners' understanding has been confirmed (Wunnasri, 2018). In addition to the one-on-one comparison, it is possible to overlap the learner maps as the representation of aggregated understanding of learners. The teacher can also compare the over-lapped map with the goal map. With the overlapped map, the teacher can analyze the trend of learner understandings in the class. The analysis is helpful for the teacher to provide feedback to the learners (Pailai, 2017) (Yoshida, 2013).

2.4 KBmap System

The system for Kit-Build Concept Mapping is called the “KBmap system.” (Sugihara, 2012) The KBmap system is composed of two client systems: “KBmap editor” and “KBmap analyzer,” and the server system are “KBmap DB.” KBmap editors work on tablet computers. This allows the system to be used in ordinary classrooms. Learners use KBmap editor for creating a learner map from a kit. KBmap analyzer works on web browsers on PCs. Teachers use KBmap analyzer to assess learner maps. KBmap covers a variety of subjects: science in elementary schools (Hirashima, 2011) (Hirashima, 2015), geography in junior high schools (Nomura, 2014), learning English as a second language (Alkhateeb, 2015), and university-level social science and computer science (Hayashi, 2014) (Hayashi, 2015).

3. Structural Mapping in KBmap

3.1 Structural Mapping in Analogy

The basic process components of analogy are (1) recognizing analogous bases, (2) elaborating and extending analogical mappings, (3) evaluating the support of analogical inferences, and (4) consolidating confirmed inferences (Hall, 1989). The structure-mapping theory (Gentner, 1983) defines the mapping in the second process component as the comparison of propositions. Propositions can be described as object-attributes or relations between objects. Structural mapping requires relations between objects, rather than object-attributes. This study aims to establish the KBmap-based learning environment in which learner’s experience structural mapping of domains and find similarity between them for learning analogy.

3.2 Structural Mapping in KBmap

Structural mapping in KBmap requires the additional function for mapping two concept maps. It is possible to create each concept map of a domain in the KBmap system. The required additional function is that learners can create and associate with two different concept maps. This study proposes a procedure of structural mapping in KBmap. First, learners make a concept map of the base domain. Then, they are provided the target domain concepts and juxtapose the concepts with the base domain concepts composing the base domain concept map.

3.3 Structural Mapping Mode of KBmap System

Fig. 5 shows a screenshot of structural mapping mode in KBmap system. This mode displays the base domain concept map (fish) at the top edge of the screen. Learners cannot change the map. They can operate only the components for the target domain map (human) displayed at the bottom edge of the screen. Each concept in the base domain concept map has a slot to assign the associated target domain concept. Learners place the target domain concepts on the slots to associate the concepts with the base domain and connect the target domain concepts with the links for the target domain. After learners upload the associated maps of the base and target domains, teachers can also check the aggregation of learners' structural mapping on KBanalyzer.

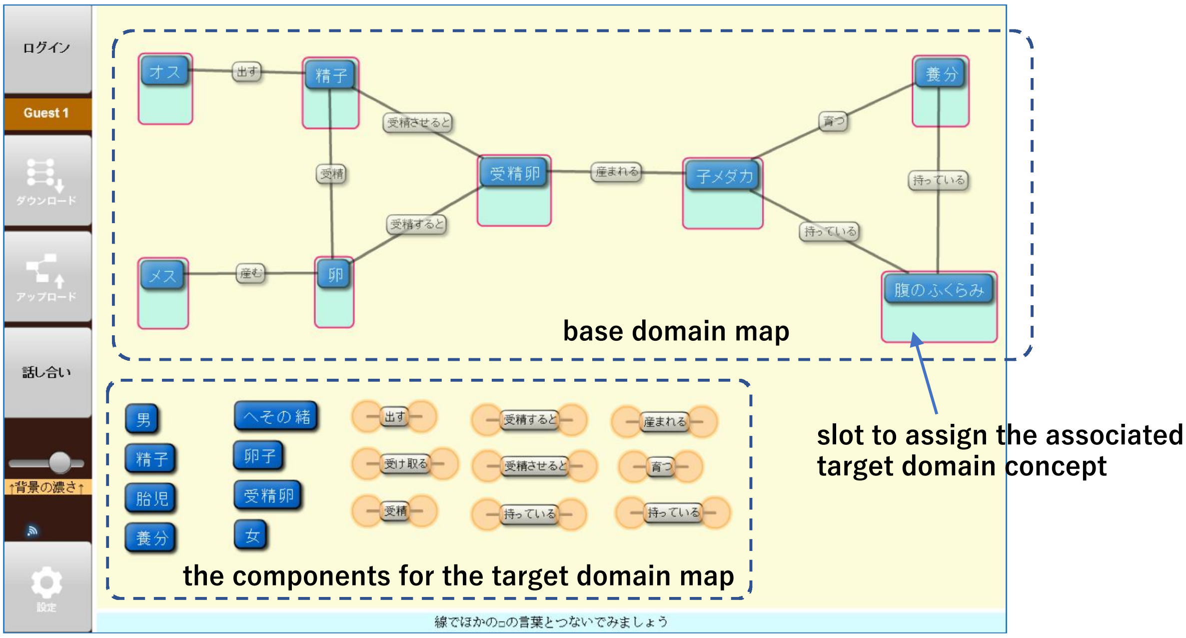

Fig. 5. Structural mapping mode of KBmap system.

4. Experimental Use of Structural Mapping Mode of KBmap system in Classroom

4.1 Participants

This study was carried out with two class-groups of 6th-year elementary school students (11-12 years old) in science lessons (n = 36 and 33, respectively). The students in both groups had used KBmap system before. The same teacher is in charge of the science lessons in these two classes. The teacher also conducts lessons in this study. There two classes are divided in such a way that there is no significant difference between the two classes regarding grades and there are no significant differences in and the score of the previous end-of-term exam. One class is the experimental group, and the other is the control group. This group assignment is decided by the teacher.

4.2 The Purpose of the Experimental Use

This study tests the hypotheses about the learning of the structural analogy described in the previous section: "learning by structural mapping with KBmap is more effective to facilitate understanding structural similarity than teaching structural mapping," also "structural mapping support function is applicable in lectures." In the experimental group, students learn with the structural analogy support functions implemented in this study. They make structural mapping by themselves. In the control group, they learn only using the standard KBmap without the new functions. They do not make structural mapping by themselves. Instead, the teacher explains the structural mapping showing the associated map. The learning content was "development of a fish" as the base and "development of a human" as the target. Although all the learners had already had classes for learning human and fish independently without KBmap system, they did not learn the association of them. The goal of the classes in the experimental use is to associate the two domains and enrich the understanding of them. The teacher created goal maps as shown in Fig. 6. In both groups, the teacher conducted the lectures for the same purpose of learning the relationship between the two topics. The effect on the learning outcome is measured by the change of learner maps and a written test.

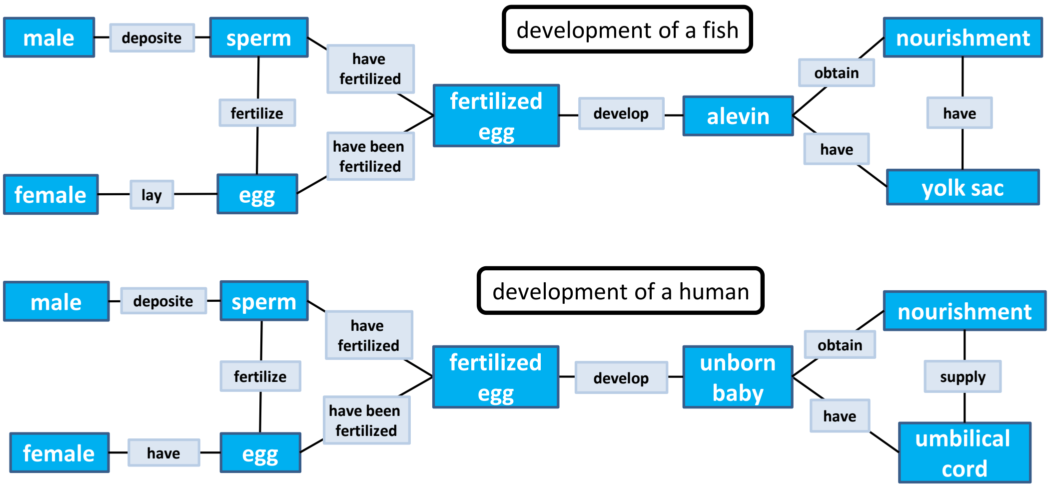

Fig. 6. Goal maps of "development of a fish," (base) and "development of a human" (target).

4.3 The flow of the Experimental Use

The learning demonstrated during class is almost the same in the experimental and the control group. As shown in Fig. 7, the difference is whether the use of the structural mapping support functions in KBmap or not in expressing the structural similarity between the two topics.

The class takes 90 min using two class-units. This includes the pre- and post-test and does not include a delayed test. First, students create learner maps of "development of a human" on the KBmap editor as the pre-test. Second, students receive an explanation of "development of a fish" and then create learner maps of it on the KBmap editor. Third, the teacher analyzes the results of learner maps of "development of a fish" on the KBmap analyzer and then provides feedback on the points that the learners have misunderstandings or a lack of understanding. Finally, students create learner maps of "development of a human" again on the KBmap editor as the after-fish-test. Note that the teacher does not provide any explanation about "development of a human."

This is where the experimental and the control group have a different activity to demonstrate an understanding of "development of a human." The experimental group created the corresponding relationship between “development of a fish” and “development of a human” with the structural mapping mode in KBmap and receives feedback on the result from the teacher. On the other hand, the control group did not create a structural mapping of the two maps by themselves but just receives the lecture by the teacher on the corresponding relationship between "development of a fish" and "development of a human" with the structural mapping of the two concept maps. Through this phase, both groups have looked at the correct mapping of the two concept maps and have received the explanation by the teacher. The teacher’s explanation for each group is by the structural mapping of two concept maps. After that, both groups create learner maps of "development of a human" again on the KBmap editor as the post-test.

Two weeks later, students create learner maps of "development of a fish" and "development of a human" again as the delayed test. Also, they answer a written test to measure their understanding. Between the post- and delayed-test, there is no class about this topic and no use of KBmap system. The delayed-test is not announced in advance.

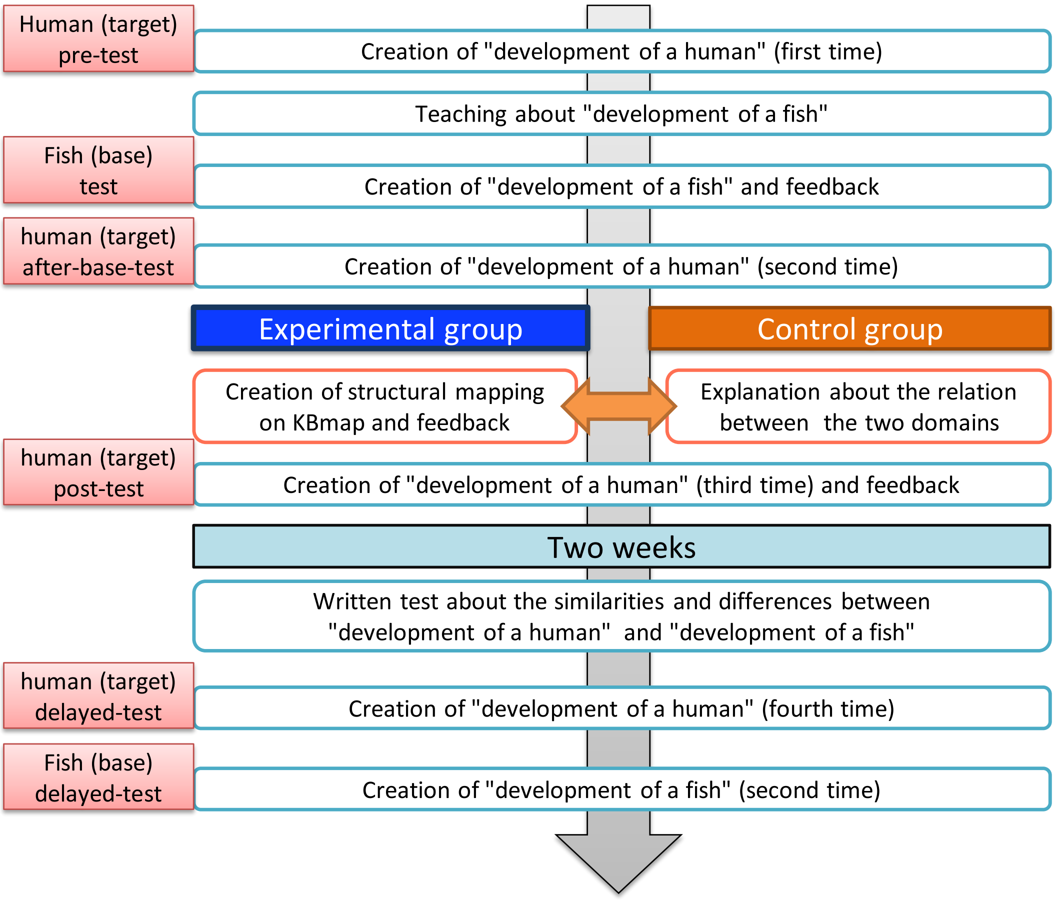

Fig. 7. The flow of the experimental use in the elementary school.

4.4 Analysis Results and Discussion

These classes are conducted for testing hypotheses based on the objectives of this study;
Objective A: to test whether learning by structural mapping with KBmap is useful for understanding structural similarity, and
Objective B: to test whether the structural mapping support function can help learners to understand structural similarity.
This study sets five hypotheses corresponding to the objectives as follows:
Hypothesis A: learning "development of a fish" facilitates learning "development of a human,"
Hypothesis B1: the experimental group that learns with the structural mapping support function can understand "development of a human" better than the control group,
Hypothesis B2: the experimental group that learns with the structural mapping support function can retain the understanding of "development of a human" after the classes better than the control group,
Hypothesis B3: the experimental group that learns with the structural mapping support function can understand "development of a fish" fish" better than the control group, and
Hypothesis B4: the experimental group that learns with the structural mapping support function will score higher on the written test than the control group.
This section illustrates and considers the result of the classes. Figs. 8 and 9 and Tables 1 and 2 shows the score, and the differences between the groups by Wilcoxon signed-rank test within groups or Wilcoxon rank sum test between groups with Bonferroni correction.

Table 1. Scores of learner maps of human (target).

group		pre	after-base	post	delayed
experimental	mean	21.7	79.3	96.5	86.1
(n = 36)	sd	14.0	21.2	8.59	18.8
Comparison with the previous test	adjusted p-value		0.0000 **	0.0001 **	0.0597 +
	effect size (Cohen's d)		3.85 (huge)	0.80 (large)	-0.36 (small)
control	mean	34.7	71.6	77.4	67.5
(n = 33)	sd	15.6	20.6	19.2	25.7
Comparison with the previous test	adjusted p-value		0.0000 **	0.4979 n.s.	0.1591 n.s.
	effect size (Cohen's d)		2.77 (huge)	0.45 (medium)	-0.36 (small)
difference between groups	adjusted p-value	0.0100 *	1.312 n.s.	0.0000 **	0.0102 *
	effect size (Cohen's d)	-0.46	0.29 (small)	0.97 (large)	0.71 (large)

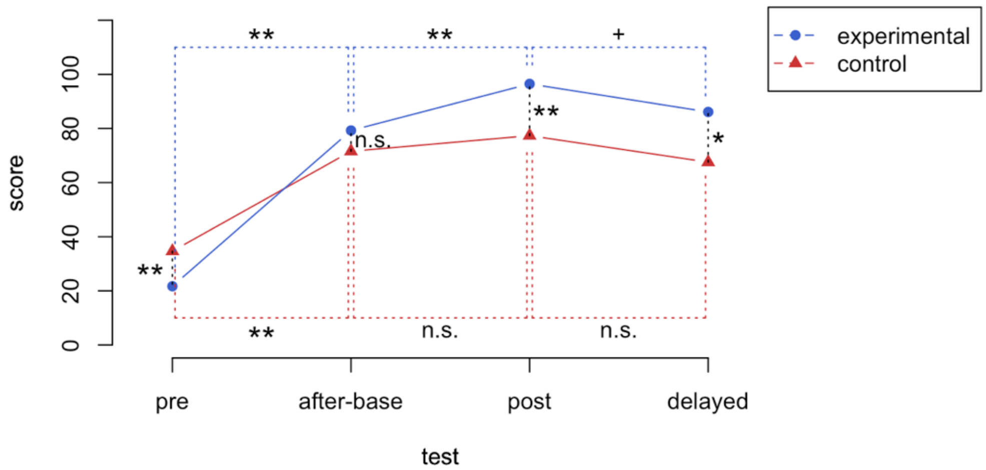

Fig. 8. Scores of learner maps of human (target).

Table 2. Scores of learner maps of fish (base).

group		test	delayed-test
experimental	mean	88.0	90.8
(n = 36)	sd	18.2	17.0
Comparison with	adjusted p-value		1.54 n.s.
the previous test	effect size (Cohen's d)		0.31 (small)
control	mean	91.0	76.4
(n = 33)	sd	16.6	24.7
Comparison with	adjusted p-value		0.0709 +
the previous test	effect size (Cohen's d)		-0.36 (small)
difference between groups	Adjusted p-value	1.46 n.s.	0.0237 *
	effect size (Cohen's d)	-0.13 (negligible)	0.53 (large)

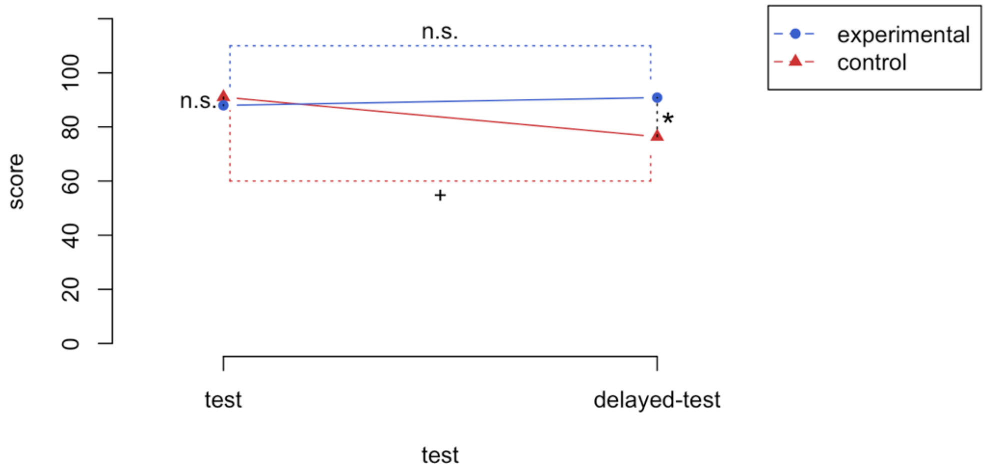

Fig. 9. Scores of learner maps of fish (base).

Consideration of Hypothesis A

Hypothesis A is that learning "development of a fish" facilitates learning "development of a human." To test this, we analyze the change in the learner maps of "development of a human." As shown in Tables 1 and 2, both the experimental and the control group show significant improvements. Although there was no learning activity on "development of a human" between the pre- and after-fish-tests, they produced significant effects. These results support Hypothesis A.

Consideration of Hypothesis B1

Hypothesis B1 is that the students in the experimental group who learn with the structural mapping support function can understand "development of a human" better than the control group. As shown in Tables 1 and 2, the after-fish-test result has no significant difference, and the post-test results of the experimental group are higher than the control group. This result shows that the use of the function is useful for understanding "development of a human" in the classes.

Consideration of Hypothesis B2

Hypothesis B2 is that the students in the experimental group who learn with the structural mapping support function can retain their understanding of "development of a human" after the classes better than the control group. As shown in Tables 1 and 2, the result of the experimental group is higher than that of the control group. This shows that, even after two weeks, students in the experimental group have a better understanding than the control group. However, there is no significant difference in the reduction of the results between the groups after two weeks. It was found from the results that the understanding was not temporal. However, this result does not show that a student who learns with the structural mapping support function can retain the understanding better than the control group.

Consideration of Hypothesis B3

Hypothesis B3 is that the students in the experimental group who learn with the structural mapping support function can also understand "development of a fish" during class better than the control group. This hypothesis means that the activity the experimental group students mapped by them with the structural mapping support function helps to enrich their understanding. As shown in Tables 2, the result of the learner map of "development of a fish" as the post-test during class shows no significant difference ($p = 0.252$) between the groups. However, the result of the learner map of "development of a fish" as the delayed test does show a significant difference ($p = 0.005$) between the groups. The only difference in the activities between the groups was the use of the structural mapping support function. This shows that the function helps the learners to retain the understanding of "development of a fish."

Consideration of Hypothesis B4

Hypothesis B4 is that the students in the experimental group who learn with the structural mapping support function can score higher on the written test than the control group. The written test asked the learners about their understanding of "development of a fish," "development of a human," and the relationship between them. The average score of the experimental group on a 9-point scale was 4.36 (sd = 2.34), and the control group was 3.18 (sd = 2.30). There is a significant difference between them ($p = 0.0342$) by Wilcoxon rank sum test, and the effect size (cliff's delta) was 0.29. This result also shows that the experimental group gains a better understanding than the control group.

4.5 Summary of the Experimental Results

The objectives of the experimental use in classrooms are to test the five hypotheses mentioned in Section 3.3. The improvement of Hypothesis A shows that learners can enrich their understanding of "development of a human" through the review of "development of a fish." The improvement of Hypothesis B1–B4 shows the effectiveness of the structural mapping support function for learning structural similarity between "development of a fish" and "development of a human." It is also interesting that the consideration of hypothesis B4 says the learners in the experimental group could have enriched their understanding of "development of a fish." This is also considered as the effect of learning structural similarity between the domains.

The difference between the experimental and control groups are that the learners make the structural mapping by themselves or that the teacher provides the structural mapping with the learners. Pepart emphasizes the importance of working with concrete materials in learning as Constructionism (Papert, 1991). Learners in the experimental group could not get instruction from the teacher but consider the relation between "development of a fish" and "development of a human" by themselves. According to Constructionism, this is the important factor of learning in this case. This reflects on learning of not only the target domain but also the base domain. In the experimental group, their understanding of it also improved because structural mapping by learners requires the review of the base domain for the association of the domains.

5. Conclusion

This paper proposed a method for learning structural similarity using KBmap, the implementation of its support function, and the validation thereof. The results show that learning by structural mapping using KBmap is beneficial to learn the structural similarity between two adjacent domains.

The characteristic of the result is that the proposed system has been effective for learners to enrich and retain their understandings about both of the base and the target domains. We could consider the results as the *organization* of the target and the *elaboration* of the base with the category of learning strategies (Weinstein, 1896). About the effect for the understanding of the target domain, it is the ordinary goal of learning by analogy and the original goal of this study. Creating KBmaps is a kind of guided *organization* of the learning contents with the provided components. In the experimental use, the students enriched their understandings through the creation of maps of human (target) and fish (base) and interaction with the teacher and the other students as we expected. The difference between the groups is to create the structural mapping or not. Both groups received an explanation from a teacher with completed structural mapping. Creating the structural mapping by themselves is more effective to enrich and retain their understandings than receiving a lecture from the teacher.

From the result of the delayed test, the student retained not only the target but also the base. In the classes, the students are required to not just understand two domains independently but associate the target (human) with the base (fish). This could be the *elaboration* of each domain as the extension of it with the other. This is now just a hypothesis, and it is necessary to investigate in the future. In future work, it is necessary to investigate the effectiveness in dissimilar domains in which only some of the concepts correspond to each other. Furthermore, it is necessary to consider the case of structural mapping in which the structure is not identical.

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