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Promoting Reflection on Question Decomposition in Web-based Investigative Learning

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Abstract: In Web-based investigative learning, learners are expected to construct wider and deeper knowledge by navigating a great number of Web resources/pages. In elaborately investigating an initial question, learners are expected to decompose an initial question into related question to be further investigated. However, it is difficult for learners to conduct question decomposition in concurrence with their knowledge construction. In our previous study, we have proposed a model of Web-based investigative learning, and developed the system named interactive Learning Scenario Builder (iLSB for short). Although iLSB could promote self-directed investigative learning, learners often decompose a question into unrelated sub-questions. This suggests the necessity of promoting reflection on question decomposition by diagnosing the appropriateness of question decomposition. Toward this issue, we have proposed a method for diagnosing the appropriateness of question decomposition with Linked Open Data (LOD). In this paper, we describe an adaptive prompting with diagnosed results for reflection on question decomposition. This paper also reports a case study whose results suggest the potential for promoting reflection on improper question decomposition.

Keywords: Web-based investigative learning, Self-regulated learning, Reflection, Diagnosis, Adaptive prompting

1. Introduction

The Web allows learners to investigate any question to learn from a great number of Web resources in a self-directed way [Hill and Hannafin, 1997]. In the Web-based investigative learning process, learners are expected to construct wider and deeper knowledge from their point of view by selecting and navigating Web resources/pages suitable for learning, and integrating the contents learned at the navigated resources/pages [Henze and Nejdl, 2001].

On the other hand, learners tend to search a limited number of Web resources/pages for investigating a question, which often results in an insufficient investigation. In elaborately investigating an initial question, learners are expected to deepen and widen the question by identifying related questions to be further investigated during navigation and knowledge construction [Hill and Hannafin, 1997]. This corresponds to decomposing the initial question into related ones as sub-questions, which would give rise to wider and deeper knowledge construction.

In addition, the Web do not provide learners with learning scenarios which implies questions to be investigated and their sequence such as a table of contents in an instructional textbook. In learning with Web resources, therefore, learners are expected to create learning scenarios by decomposing a question into sub-questions. Such learner-created scenarios could play a crucial role in self-regulating their navigation and knowledge construction process [Azevedo and Jennifer, 2004].

However, it is difficult for learners to create learning scenario in concurrence with question decomposition and knowledge construction [Land and Susan M, 2000]. In our previous work, we have proposed a model of Web-based investigative learning and developed a system named interactive Learning Scenario Builder (iLSB for short). iLSB provides scaffolds for conducting the investigative learning process as modeled [Kashihara and Akiyama 2017]. On the other hand, learners often

decompose a question into unrelated sub-questions, which could be caused by insufficient reflection on question decomposition. This suggests the necessity of promoting reflection on question decomposition by diagnosing the appropriateness of question decomposition. But, it is a challenging issue in self-directed learning since we could not define the suitability of relationships between questions in advance.

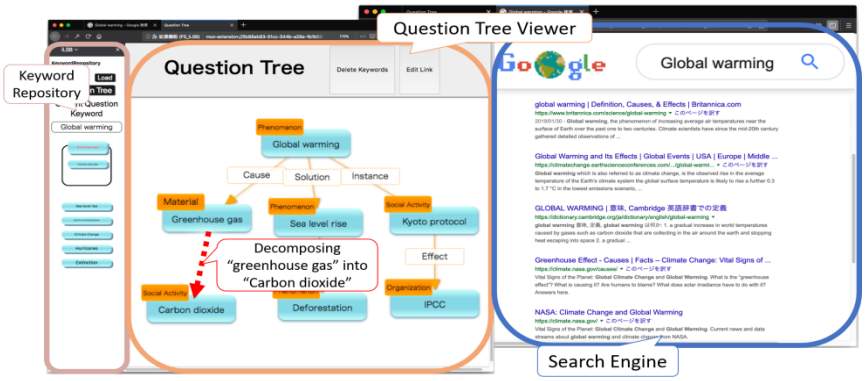

Figure 7: User Interface of iLSB

Toward this issue, we have proposed a method for diagnosing question decomposition with Linked Open Data (LOD) [Sato et. al., 2019]. In this paper, we describe adaptive prompting for reflection on question decomposition with diagnosed results, which induces learners to revise their learning scenario. This paper also reports a case study whose purpose was to ascertain whether adaptive prompting could promote reflection on question decomposition and learning scenario revision. The results suggest that it allows learners' reflection on their question decomposition.

2. Web-based Investigative Learning

Let us first describe the model of Web-based investigative learning and iLSB. We then explain the issue of how to prompt learners to reflect on their own question decomposition.

2.1 Model of Web-based Investigative Learning and iLSB

This model includes three cyclic phases: (a) search for Web resources, (b) navigational learning, and (c) question decomposition. In phase (a), learners are expected to select Web resources suitable for investigating an initial question and to navigate across them using a search engine. In phase (b), the learners are expected to navigate the Web pages in the selected resources and to construct their knowledge by extracting keywords to represent the contents learned in the pages and by making the relationships among them. In phase (c), the learners are expected to find out some related sub-questions to be further investigated about the initial question, which could be obtained from the keywords extracted in phase (b). This corresponds to decomposing the initial question into sub-questions. Each sub-question is investigated cyclically in the next phases (a) and (b).

The question decomposition results in a tree called question tree, in which questions as nodes are represented with keywords (called q-keywords). This tree includes part-of relationships between the question and the sub-questions whose root represents the initial question. The question tree represents a learning scenario.

In addition, we have developed iLSB as an add-on for Firefox, which scaffolds the investigative learning process as modeled. Figure 1 shows the user interface of iLSB. iLSB provides learners with functions according to the three cyclic phases: search engine, keyword repository, and question tree viewer. Learners are expected to construct knowledge by means of keyword repository, and to decompose a question into sub-questions by means of question tree viewer.

2.2 Issue and Purpose

In Web-based investigative learning, it is important for learners to reflect on their investigative learning process. On the other hand, learners often decompose into sub-questions unrelated to the initial question even if they use iLSB, which is caused by insufficient reflection on question decomposition. A common approach to promote learners' reflection is to prompt them to review their own activities. Although such prompting could stimulate their metacognitive activities [Bannert, M& Reimann. P, 2012], it is often conducted in an ad hoc way [Narciss 07].

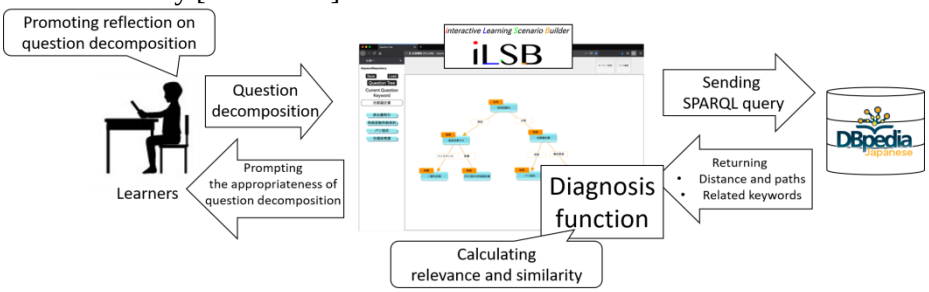

Figure 8: Framework of Question Decomposition Diagnosis

The main issue addressed in this paper is how to promote reflection on question decomposition in an adaptive way. Our approach is to diagnose the question decomposition conducted by learners, and to prompt learners to reflect on it according to diagnosed results. This allows learners to create an appropriate learning scenario. However, it is difficult to verify whether the relationships between a question and the sub-questions decomposed during self-directed investigation are appropriate, since we could not prepare a valid relationship with any question in advance. The adaptive prompting can be accordingly viewed as a challenging issue. We have proposed the diagnosis method with LOD so far [Sato et. al., 2019]. In this paper, we aim to confirm whether presenting diagnosed results could promote learners to reflect on their question decomposition.

3. Diagnosis of Question Decomposition

Let us next demonstrate the method for diagnosing and prompting the appropriateness of question decomposition with LOD.

3.1 LOD (Linked Open Data)

LOD (Linked Open Data) is a set of structured data interlinking with related ones on the Web. In this work, we use DBpedia Japanese whose data are extracted from Japanese Wikipedia [DBpedia Japanese, 2016]. The data in DBpedia Japanese are expressed as RDF (Resource Description Framework), which consists of three entities known as triples: subject, predicate, and object. Such RDF data are extracted/operated by sending SPARQL queries to DBpedia Japanese.

3.2 Framework of diagnosis

Figure 2 shows the framework for diagnosing the appropriateness of question decomposition by means of DBpedia Japanese. The diagnosis is implemented as a function of iLSB.

In this framework, learners are first expected to investigate an initial question according to the model of Web-based investigative learning, and to decompose a question into sub-questions. iLSB then sends SPARQL queries to DBpedia Japanese, and obtain paths between q-keywords and keywords related to each q-keyword. From obtained paths and related keywords, iLSB then calculates the relevance and similarity between q-keywords. Following calculated relevance and similarity, iLSB finally decides the appropriateness of question decomposition as one of three levels: appropriate, weak appropriate and unknown. The diagnosed results are presented to learners, which is expected to prompt them to reflect on the appropriateness of their question decomposition.

3.3 Diagnosis Procedure

We have designed the procedure for diagnosing the appropriateness of decomposition into any q-keyword *i* in a question tree as shown in Figure 3 [Sato et. al., 2019]. This procedure decides the appropriateness level of question decomposition by calculating the relevance and similarity between q-keywords. The relevance is calculated as three levels: relevant, weak relevant, and unknown. The similarity is also calculated as three levels: similar, weak similar, and unknown.

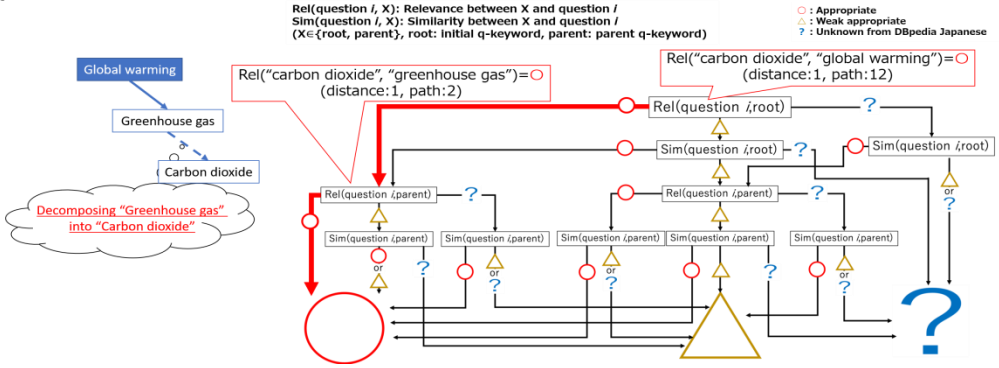

Figure 9: Diagnosis Procedure

This procedure first calculates the relevance and similarity between q-keyword *i* and the root q-keyword. It then calculates the ones between q-keyword *i* and the parent q-keyword. Depending on the calculated levels of relevance and similarity, as shown in Figure 3, it finally decides the appropriateness level as one of the three levels.

In calculating the relevance between q-keywords, iLSB first sends a SPARQL query to DBpedia Japanese, and obtain paths between q-keywords in DBpedia Japanese. Depending on the distance and the number of paths, the relevance is determined based on thresholds. In case the distance is 1, the relevance level is suggested as relevant. In case the distance is 2 and the number of paths is more than 30, the relevance level is suggested as weak relevant. In case the distance is more than 3 or the number of paths is less than 30, the relevance level is suggested as unknown.

In calculating the similarity between q-keywords, iLSB first sends the SPARQL query to DBpedia Japanese in order to obtain keywords related to each q-keyword. iLSB then creates two sets each of which consists of words to be extracted from the obtained keywords by means of morphological analysis. iLSB finally calculates the overlap coefficient which indicates the similarity between the two sets. The similarity level is determined based on thresholds depending on the calculated overlap coefficient. In case the overlap coefficient is more than 0.3, the similarity of the keywords is suggested as similar. In case the overlap coefficient is between 0.1 and 0.3, it is suggested as weak similar. In case the overlap coefficient is less than 0.1, it is suggested as unknown.

In our previous work, we had a case study for evaluating the validity of the designed procedure shown in Figure 3 [Sato et. al., 2019]. In this study, we compared the appropriateness of question decomposition diagnosed with this procedure and with the one diagnosed manually. The results suggest that the accuracy of diagnosis with this procedure toward manual diagnosis was 77.8%, which seems high.

3.4 Prompts with Diagnosed Results

iLSB calculates the appropriateness of question decomposition with the designed diagnosis procedure whenever learners decompose a question into sub-questions. After their question decomposition, iLSB provides prompts on their demand in the question tree viewer, which include the appropriate levels diagnosed. The learners are expected to reflect on the decomposed questions particularly diagnosed as weak appropriate and unknown with the prompts. They are then expected to re-investigate the question and sub-questions to revise their question tree.

4. Case Study

4.1 Purpose and Procedure

We have conducted a case study whose purpose was to ascertain whether prompts with diagnosed results could promote reflection on question decomposition.

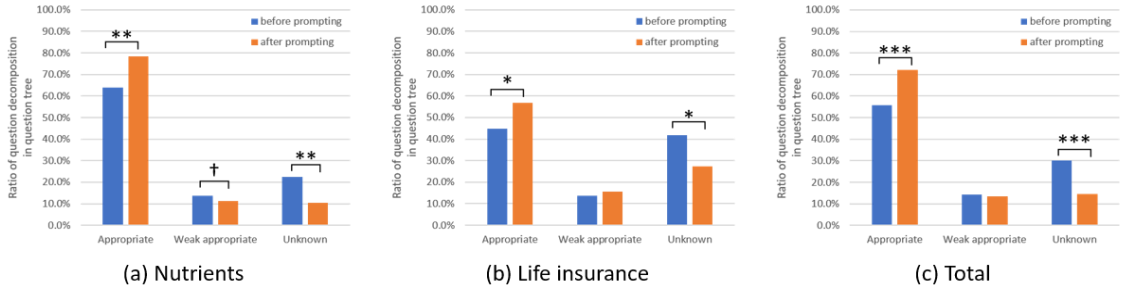

Figure 10: Ratios of Diagnosed Results

Participants were 16 graduate and undergraduate students in science and technology. Half of the participants were given "What is nutrients?" and the others were given "What is life insurance?" as an initial question. The participants were first required to use iLSB to investigate the initial question without diagnosis for 30 to 60 minutes. After their investigation, iLSB diagnosed each question decomposition in the question trees the participants created, and presented it as prompts on the question tree viewer. If necessary, they could re-investigate to revise their question trees by means of iLSB by means of diagnosis within 30 minutes. After the tree revision, the participants were finally required to answer a five-point scale questionnaire for assessing the effectiveness of prompts. In order to ascertain whether prompts could promote reflection on question decomposition, we set the following hypothesis:

Hypothesis: The ratio of question decomposition diagnosed as appropriate increases, and the one diagnosed as unknown decreases.

4.2 Results

Figure 4 shows the ratios of diagnosed results in question trees obtained from each initial question and the total ratios of diagnosed results obtained from the two initial questions. In order to ascertain whether these results support the hypothesis, we compared the ratios of diagnosed results before prompting and the ones after prompting. Regarding each initial question in Figure 4, the question decomposition diagnosed as appropriate significantly increased (Nutrients: $t(15)=-3.99$, $p<.01$, Life insurance: $t(15)=-2.21$, $p<.05$) as the results of one-sided t-test. The one diagnosed as unknown also significantly decreased (Nutrients: $t(15)=3.89$, $p<.01$, Life insurance: $t(15)=2.68$, $p<.05$). These results support the hypothesis. As for the total ratios, the question decomposition diagnosed as appropriate significantly increased ($t(15)=-3.90$, $p<.001$), and the one diagnosed as unknown significantly decreased ($t(15)=4.52$, $p<.001$).

Table 1 shows the results of the questionnaire. All average points obtained were over 3.5 which seems high. As for Q1, Q2 and Q4 asking about the effectiveness of reflection with prompts, the average points were over 4.0 that was higher than the others, and the variances were all under 1.00. As for Q5 asking about their self-directed investigation and Q3 asking about how easy it was to understand prompts, in addition, the average points were over 3.6 which seems high. On the other hand, the variances were 1.35, which seems large in answer among the participants.

4.3 Discussion

Overall, the results of this case study suggest that iLSB could adaptively promote reflection on question decomposition on the Web, which is ill-structured and difficult to scaffold for learners. Let us first discuss the effectiveness of prompts for reflection. The results shown in Figure 4 indicate a significant increase in question decomposition diagnosed as appropriate and a significant decrease in the one diagnosed as unknown by means of prompts. This suggests prompts could promote reflection on question decomposition, which is also supported by the results of Q1, Q2 and Q4 in Table 1.

In addition, the results of Q3 in Table 1 suggest that it is easy to understand prompts presented as the three levels. We accordingly asked the participants who selected "1" or "2" the reason why they had difficulty in understanding. They answered that they could not know why iLSB diagnosed question decomposition as unknown. This suggests the necessity for providing some evidence for prompts.

Table 1: Averages and Variances of Questionnaire Results

Question number	Question with five-point scale	Average	Variance
Q1	How helpful were prompts for reflection? (5: Very helpful …… 1: Not at all)	4.0	0.98
Q2	How effectively prompts improved question tree? (5: Very effectively…… 1: Not at all)	4.1	0.86
Q3	Was it easy to understand prompts indicating three levels? (5: Very easy to understand .. 1: Not easy to understand at all)	3.6	1.35
Q4	Did prompts allow you to reflect on the contents learned? (5: Yes, they did. …… 1: No, they didn't at all.)	4.0	0.69
Q5	How much did you feel that prompts prevented you from self-directed investigative learning? (5: Not at all …… 1: Very prevented)	3.8	1.35

As for self-directedness with prompts, the average of Q5 in Table 1 suggests that prompts could not prevent learners from self-directed investigative learning, but it seems to depend on learners since the variance was large. This suggests that learners who have more question decomposition diagnosed as unknown tend to feel more restriction on their self-directed investigative learning process.

5. Conclusion

This paper has addressed the issue how to promote reflection on question decomposition in an adaptive way. Toward this issue, we have proposed an adaptive prompting that includes the results of diagnosing the appropriateness of question decomposition with LOD.

This paper has also reported a case study for ascertaining whether the adaptive prompting could be effective for learners to reflect on question decomposition. The results suggest that prompts could promote reflection on the question decomposition. On the other hand, we found out the necessity of providing learners with some evidence for prompts presented, which is one of our future work.

Acknowledgements

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