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Idea Space Change Process Visualization System for Supporting Interpretation of Thinking Strategy in Research Instruction

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Abstract: In research activities, it is difficult for instructors to provide guidance to learners' thinking strategies. Since thinking depending on the thinking strategy, it is possible to infer the strategy from the thinking process for ideas (idea space change process). Therefore, in this study, we propose a system that visualizes an idea space change process from the thinkings obtained by the learners. As the result of evaluation experiment, it was confirmed that the number of instructional contents for thinking strategies increased by using system.

Keywords: Research instruction support, idea space change process, visualization

1. Introduction

In research activities, instructors often guide learners through the research outputs they produce. Research outputs do not describe the strategies that generated the thinking (thinking strategies). A thinking strategy refers to a policy of thinking to proceed with research, such as "When considering a research problem, consider various candidates." It is desirable for instructors to provide guidance for learners' thinking strategies in order to enable them to conduct research on their own.

Research consists of elements such as background, objectives, solutions, and experiments. The research output is a specific topic that corresponds to each of these elements. Since the thinking strategy indicates how to proceed with thinking in order to obtain the research output, to grasp the sequence of learners' thinking from a global viewpoint will help to understand their thinking strategy. In this study, we aim to develop a system that can help instructors become aware of learners' thinking strategies by visualizing the sequence of learners' thought.

Some systems provide information which enable learners or teachers to interpret learners' thinking strategies by estimating them. (Yoshioka, Hayashi, & Seta, 2019; Tian, et al., 2019). These systems only summarize a few consecutive thinkings, and it is difficult to estimate the strategy that contributes to the learners over all thinking. A method for visualizing process of creating outputs has been proposed to provide a global viewpoint of the entire thinking process.

A system that automatically generates Linkograph, a method that enumerates the components of outputs and expresses which components are integrated with which components in a hierarchical structure, has been proposed (Smith, et al., 2025). This representation method cannot show the order of integration. Since the thinking strategy is expressed in the process of creating outputs, it can be estimated by visualizing the process of creating outputs.

In this study, we propose a method of visualizing how the semantic clusters of topics (idea), which are candidates for outputs, have changed in a graph structure. We also aim to support instructors' estimation of learners' thinking strategies by constructing a system with a function to visualize the process of creating research outputs according to the proposed method.

2. Approach

2.1 Idea in Research Activity

People have the elements to be considered in research (research knowledge), and they differ depending on the research domain and methods. Therefore, it is considered that people use multiple types of research knowledge according to their research domains and methods.

Research outputs are the information obtained through investigation, analysis, and inference (topics), which are mapped to the research knowledge. In the process of deriving research outputs, several elements of research knowledge and topics are considered as a meaningful group, and the candidate outputs are created by developing and selecting the group. In this research, we call such a meaningful group an idea. Figure 1 shows the relationship among research knowledge, topics, and ideas.

For example, consider a researcher who has research knowledge such as "background," "problem," "method," and "technology." If the topic "programming learning" is corresponding to "background" and the topic "difficulty in understanding the grammar" is corresponding to "problem," the researcher is considered to have the idea of "research to solve the difficulty in understanding the grammar in programming learning." An idea can be only research knowledge or only a topic. For example, if a researcher is thinking of "background" because "background" is necessary for his/her research, he/she has an idea that exists only for "background," and if he/she wants to do something using generative AI because generative AI is popular, he/she has an idea for "generative AI" only as a topic. In this way, we can say that an idea is a collection of research knowledge and topics that researchers focus on in order to create a candidate outputs.

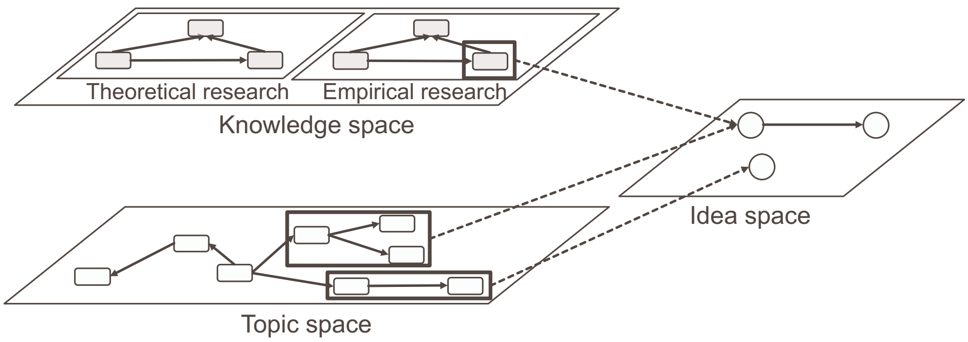

Figure 1. Relationship among Research Knowledge, Topics, and Ideas

2.2 Thinking Strategy and Its Estimation

In order to derive the research outputs, it is important to know what kind of thinking is to be done. In this study, a thinking strategy is a policy of thinking to achieve an objective. The objectives include generating certain elements of research knowledge and topic that corresponds to an element of research knowledge, such as "deriving a research approach" or "determining a research problem." Thinking strategies include divergent thinking and convergent thinking (Guilford, 1967), which are strategies for expanding ideas, and data-driven thinking and goal-directed thinking (Russell & Norvig, 2010), which are strategies for how to proceed with reasoning.

Thinking transforms the idea space by updating or deriving ideas. Since thinking is carried out according to a thinking strategy, we can estimate the thinking strategy by looking at the process of changes of idea space by the implemented thinking strategy. For example, when thinking is done in such a way that a number of derived ideas are created in response to certain existing idea, it can be estimated that divergent thinking was used as a thinking strategy. If the thinking that updates the existing ideas one after another is performed, it can be estimated that convergent thinking was used as a thinking strategy. If we can visualize the idea space change process, we can support the estimation of the thinking strategy.

2.3 Research Instruction Support Environment

In this study, we construct a research instruction support environment consisting of a thinking externalization system, an idea space change process visualization system, and a thinking database. The thinking externalization system provides an interface that enables learners to organize their ideas while expressing their own research knowledge and topics. The idea space change process visualization system has an idea space map generation function that generates a graph representing the idea space change process (idea space map) based on the learner's thoughts, and an interface for displaying the generated idea space map. The thinking database is a database that stores the learner's thinking.

The following describes the procedure for using the research instruction support environment. The learner expresses his/her research knowledge and topics on the interface of the thinking externalization system. The operations of expressing research knowledge and topics are stored in the thinking database. The instructor selects a learner whose thinking strategy he/she wants to estimate on the interface of the idea space change process visualization system. The idea space change process visualization system acquires the selected learner's operation series from the thinking database and generates idea space map with the idea space map generation function. The interface of the idea space change process visualization system displays the generated idea space map. The instructors estimates the learner's thinking strategy based on the visualized idea space map and provided guidance.

3. Thinking Externalization System

The thinking externalization system provides an interface for representing one's own research knowledge (knowledge externalization interface) and an interface for representing topics and mapping topics to research knowledge represented by the knowledge externalization interface (thinking externalization interface). Since knowledge and topics can be expressed in terms of elements and their relations, they are represented in a graph structure with the elements of research knowledge and topics as nodes and their relations as edges. The knowledge externalization interface is operated in the same way as the thinking externalization interface, so only the thinking externalization interface is described below.

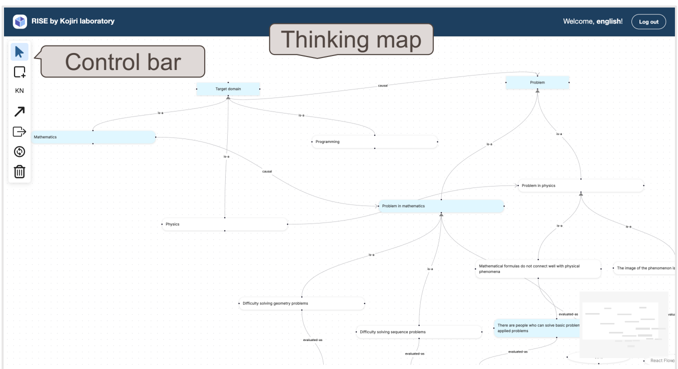

Figure 2. Thinking Externalization Interface

A thinking externalization interface must be able to represent and relate topics and research knowledge. As thinkings for representing topics and research knowledge, we have prepared operations for creating topic nodes and research knowledge nodes, and topic nodes with edges. The creation of a node with an edge is an operation to add a new topic node that is connected to an existing topic node by a specific relation. As mapping topics and research knowledge, we have prepared an operation to add edges between topic nodes and research knowledge nodes. As types of relations between topics, we define the part-of relation, which is a detailing relation, the causal relation, which is a premise-conclusion relation, and the is-a relation, which is an abstraction relation. The is-a relation, which represents correspondence, defined as a relation between a topic node and a research knowledge node.

As evaluating topics, we have prepared operations for creating evaluation criterion nodes and evaluation value nodes. The evaluation criterion node describes from what point of view the topic is evaluated, and the evaluation value node describes the evaluation value from that point of view. As a selection of topics, an operation to label the topic nodes as adopted or rejected is provided.

Figure 2 shows the thinking externalization interface. The thinking externalization interface consists of a thinking map and a control bar. On the thinking map, research knowledge and topics are represented as nodes, and the relations between them are represented as edges. Nodes and edges are created and edited using the control bar.

4. Idea Space Change Process Visualization System

The idea space change process can be represented as a graph structure in which ideas are nodes and changes of ideas are edges. This graph is called an idea space map. The idea space map supports the estimation of thinking strategies from the shape of the graph structure by representing the idea space change process as a shape of the graph structure. There are two types of idea change: derivation and renewal. The operation of creating a different idea from an existing idea is called "derivation," and the operation of updating an existing idea by adding new elements is called "renewal." To express these two types of changes, we prepare two types of edges in the idea space map: derivation and renewal.

In order to generate idea space map, it is necessary to identify how operations on the thinking map transform the idea space. Operations on the thinking map are performed on specific research knowledge nodes or topic nodes (target node). The target node is included in one of the ideas. Therefore, we can say that the operations on the thinking map are operations that change the ideas that contain the target nodes. The idea space map can be created by three steps: 1. Identifying the nodes and edges targeted by the operations on the thinking map, 2. Identifying the ideas that contain those nodes and edges, 3. Adding new ideas to the idea space map and adding edges that represent changes between the ideas that contained the target nodes and edges. When an operation is performed that does not target other ideas, such as “adding a topic node,” a new idea is added to the idea space map.

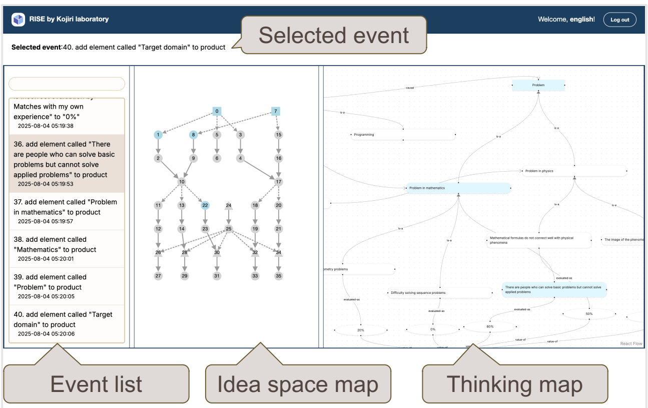

Figure 3. Interface of Idea Space Change Process Visualization System

The interface of the idea space change process visualization system is shown in Figure 3. This interface consists of three parts: an event list that displays the learner’s operations in one glance, a thinking map created by the learner, and an idea space map that displays the idea space change process generated from the learner’s thinking process. The nodes on the idea space map represent the ideas, and the edges represent the change between ideas caused by operations on the idea. Nodes are assigned the order of the operations that caused their state. By checking the node orders, the instructor can see in what order the operations were performed.

5. Evaluation Experiment

5.1 Experiment Settings

We have conducted an experiment whether the proposed idea space change process externalization system is effective in supporting research instruction. The effectiveness of research instruction is evaluated by comparing the instruction without using the proposed system with that when considering instruction using the proposed system.

The participants in the experiment were 9 graduate students (A-I) who can provide research instruction to undergraduate students. The following is the experimental procedure. First, the participants were presented with the research output that the authors had prepared in advance and the thinking map on which the research output was based, in a setting in which they had been created by a fictional learner. The prepared research output and the process for creating it included parts that may require instruction on thinking strategies, such as "deep consideration of the research topics, but neglecting to consider the consistency between the topics." The research output was a slide in which the adopted parts of the thinking map ware listed.

The participants were asked to review the research output and thinking map provided to them and consider instructional contents (Step 1). Participants were instructed to think not only the presentation of research, but also the contents of research and the thinking behind them. Next, we asked them to consider instructional contents using the proposed idea space change process visualization system (Step 2). The idea space map corresponding to thinking map is shown in Figure 4. In this idea space map, thinkings about the "research background" and thinkings about the "research approach" are carried out independently, without any consideration of the consistency between them. In Step 2, in addition to instructional contents they had thought up in Step 1, we asked them to think of new instructional contents using the idea space map. In addition, if the participants felt that the instructional contents, they had considered in Step 1 were unnecessary or needed to be changed based on Step 2, they were asked to delete or change them. Finally, they filled out a questionnaire asking what they had been conscious of when considering the instructional content.

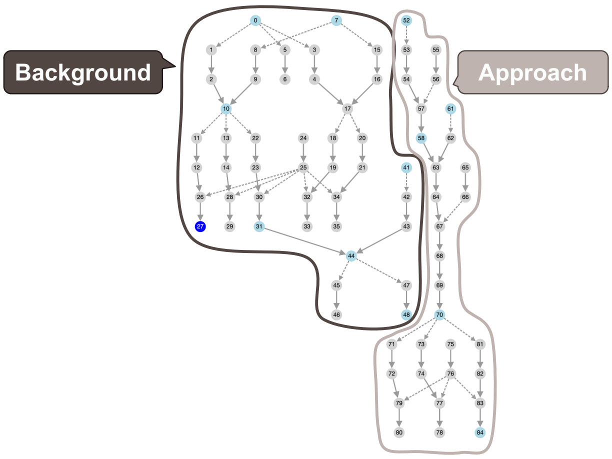

Figure 4. Idea Space Map Used in Experiment

5.2 Result and Discussion

To evaluate the effectiveness for supporting instruction for thinking strategies, we categorized the type of instructional contents. Since the research output provides instruction on the presentation of research, the thinking map provides instruction on the contents of research, and the idea space map provides instruction on thinking strategies, the classification was made into three types: 1. Instructional contents for presentation of research, 2. Instructional contents for contents of research, and 3. Instructional contents for thinking strategies. The number of instructional contents by type in Step 1 and Step 2 is shown in Table 1. Since Step

2 newly uses an idea space map, it is expected that the number of instructional contents for thinking strategies increased in Step 2.

A t-test was conducted to check whether there were significant differences between the number of instructional contents in Step 1 and Step 2 for each type. There was no significant difference in the number of instructional contents for presentation of research ($p > 0.05$), but there was a significant difference in the number of instructional contents for contents of research and thinking strategies ($p < 0.05$). This suggests that the idea space map provided insight into contents of research and thinking strategies. Example of instructional contents by referring to the idea space map included, “When thinking about your research approach, you should consider whether it is likely to fit the research problem,” and “The learner now has some understanding of what should be considered and in what order in research.” This can be said to be an example of how we were able to provide instructors with an awareness of learners’ thinking strategies.

Table 1. *The Number of Instructional Contents by Type in Step 1 and Step 2*

Type	Step	A	B	C	D	E	F	G	H	I	Avg.
1	1	2	1	1	0	7	0	4	1	0	1.78
	2	2	1	1	0	7	0	6	1	0	2.00
2	1	5	11	5	5	1	6	3	2	6	4.89
	2	6	15	7	7	1	10	5	2	7	6.67
3	1	1	0	2	1	2	0	0	1	0	0.78
	2	2	0	4	2	3	0	0	2	2	1.67

6. Conclusion

In this paper, we proposed a system that can express a learner’s thinking and a system that visualizes learner’s idea space change process as a graph structure to help instructors provide guidance to learner’s thinking strategies in research activities. The result of the evaluation experiment showed that by referring to the idea space map, the number of instructional contents for thinking strategies increased.

In the evaluation experiment, instruction was given to fictional learner. In order to verify whether proposed system can also provide an awareness of learner’s thinking strategies, and whether the derived instructional contents are useful to leaners, we need to conduct experiments with real learners. In the future, we will conduct an evaluation experiment in situations where instructors actually provide instruction to real learners.

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