

An Analysis of Students' Difficulties in Processing of Scientific Experiment Manuals

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Abstract

The purpose of this study is to analyze the difficulty encountered in the processing of scientific experimental manuals and to suggest implications for effective handling of experimental manuals. For this, it was gathered that eye-movement, CVP, RVP, experimental behavior of 5 university students who participated in the practical work of 'making electromagnet' accepting experimental manual. The collected data were analyzed and categorized by qualitative analysis method. As a result of the study, the students' difficulty in handling the experimental manual was categorized into the understanding step and the execution step, the difficulty was categorized as 'conflict situation', 'insufficiency situation', and 'inconsistency situation' depending on the processing steps of the procedure and the clearness of the representation. These results suggest that the way to solve difficulties differs according to each situation.

Keywords: Science practical work, Scientific experimental manuals, Qualitative case study, Making electromagnet, Eye-tracking

1. Introduction

Science practical works are unique instruction methods that only science disciplines have [1]. Students can develop important skills in science education, such as the development of scientific concepts and principles as well as development of inquiry skills and scientific attitudes through science practical works [2]. Particularly, the experience of science practical works of learners is important because specific learning objectives can only be achieved in this context [3].

In science practical works, an experimental procedure describing the order of experiments is required [3]. However, it is difficult for students to design their own experiments [3]. Therefore, in general classes, an experimental manual describing the experimental procedure is used [4], and it helps to control the practical work of the students to carry out the experiment effectively [5].

However, the students have difficulty in handling the experimental manual. According to the previous studies, students do not remember the experimental procedure, so it is difficult to connect the experimental procedure to the performance or confuse the experiment sequence [6]. Also, students have difficulty understanding the terms presented in the experimental manual [7]. Therefore, it is also difficult for the

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teacher to make effective practical works because of the difficulty in handling the manuals.

Previous studies to identify and improve the causes of lack of effectiveness of practical works have focused on emphasizing higher-order thinking beyond simple 'recipe-like experiments'[8] and emphasizing the aspect of inquiry in scientific experiments [2]. However, they did not focus on the difficulty of handling experimental manuals, and only the experimental manual has been discussed as one of the material to improve the readability [9][10][11].

Experimental manuals play an essential role in scientific experiments [4] and the effective handling of manuals is highly correlated with the effectiveness of practical works [11]. However, there are no studies that analyze the difficulties or the cognitive process of the manual reading. So, in this study, we analyze the difficulties in the processing of scientific experiment manuals and try to get some implications for the effective manual handling of experimental manuals.

The situation in which the students process the experimental manual should go through a complex process of thinking that selects and organizes the information from the surrounding environment, experimental manuals, etc. [12]. And they have to constantly interpret the various situations and make quick decisions. Therefore, this study examines two research problems through qualitative case study in order to grasp the various context of science practical work. First, what are the difficulties that students have in the processing of scientific experiment manuals? Second what are the categories of difficulties in the processing of scientific experiment manuals?

2. Methods

The purpose of the case study is to gain an in-depth understanding of the phenomena and the complex implications involved in the phenomenon [13]. In order to analyze the difficulties encountered in the processing of scientific experiment manuals, the students' behaviours should be observed during the actual practical works. In addition, if the observations do not include the student's thoughts and behaviours on the changing environment during the experiment, the phenomenon cannot be described and analyzed comprehensively. So, in this study, the case study method is used to understand deeply the students' behaviours using the experimental manual.

Participants were 5 undergraduates (2 males and 3 females) majoring in elementary education, geography education, and home education at university. They were selected considering the fluency of aloud thinking and the possibility of eye tracking. And 'Making electromagnet' was selected as the task. The tasks were modified in terms of description of the sentence, structure of the experimental manual, and the name of the tool in consideration of the performance time and the level of the participant. In addition, the task was commissioned by 4 science education experts to review the content validity. The final CVI value was confirmed to be 0.91.

In order to increase the validity of qualitative research, a number of data sources were collected and diversified [14]. Collected data were eye movement data, CVP (Concurrent Verbal Protocol), experimental behaviour data, and RVP (Retrospective Verbal Protocol). Participants were asked about 20 minutes of thinking aloud training. After that, they were asked to do concurrent think aloud while conducting scientific experiments. And eye movement data were also collected using Tobii Glasses 2, and all experimental behaviours were recorded in video camera. After completing the task, we

asked to make a retrospective think aloud using the collected eye movement data as a clue.

The collected data were transcribed. And the researchers repeatedly read the data and tried to understand the key features revealed in the experimental manual process. Based on this, it was possible to categorize the difficulties in the processing of experimental manual and analyze the characteristics of categorized difficulties. In addition, in order to obtain the validity and reliability of all the courses, the consultation of two science education experts, review of the collected data, and consultation of peer researchers were repeated. In addition, we received advice from 2 science education experts for the high validity and reliability in this study repeatedly.

3. Results

3.1. What are the difficulties in handling the scientific experiment manual?

3.1.1. Difficulties in understanding experimental manual

Difficulties due to insufficient information: Participant D wraps the whole nail without cutting the given A4 paper to nail size. And then he does not know what to do. If there is no description of how to manipulate the material in the manual, students will follow the given manual simply. In other words, they are passive because they lack confidence in how to perform when they do not understand the procedure because of insufficient information about the environment and the manual.

Conflicts due to differences between the contents of the manual and the thoughts: Participant A has a conflict whether the number of enamel lines in the electromagnet should be exactly 150. Because she thought that it would take a lot of effort and time to count exactly 150 times. So he does not count the exact number of enamel lines, but just rolls the enamel lines until the nails are fully covered. She decided that the exact number of times she had to wrap the enamel line was meaningless. Students usually follow the instructions given in the experimental manual throughout the course. However, when the contents presented in the manual are different from my thoughts, the students have conflicts and choose one of them.

Difficult to connect the objects presented in the manual with the actual environment: Participants D and E cannot find what the term 'electromagnet' in the manual refers to in the actual environment. A student who does not have background knowledge about electromagnet cannot recognize that the object he is making during experiment is 'electromagnet'. So he looks for 'electromagnet' among the things that are given and the things he is working on. And he inferences what 'electromagnet' is by removing it from his own 'list of electromagnet' that he thinks 'electromagnet' is absolutely not. If students connect the term "electromagnetism" with an object through inference without knowing what an 'electromagnet' is, he shows a lack of confidence.

3.1.2. Difficulty in executing an experimental manual

No scale to evaluate completion of execution: Participant A repeats the process of removing the enamel line because she does not know the state that it can evaluate that the enamel line is peeled off. Then she abandons the experiment when she observes that there is no response to the electromagnet manipulation. As such, knowing the expected outcome of the procedure is important because it is a scale to evaluate completion of

execution. When students do not know the expected outcome, they do not know whether or not the procedure has been executed, so it executes repeatedly and shows a lack of confidence in the performance of the next procedure.

Inefficient way: Participant C is not satisfied in terms of the accuracy and speed of the method of winding the enamel line. Since then, he has repeated his method, and has shown a better way to modify it through continuous evaluation. In this way, students reflect on their performance in a reflective way, and perform iteratively by taking into account their goals.

Derive outcomes that differ from expected outcomes: Participants continue to verify that the expected and actual results are consistent. Since some of the participants have background knowledge about the magnets, they think the electromagnet will act as a magnet. Therefore, they expect that the electromagnet will stick to the office pin. However, when the expected outcomes are not shown, they are repeatedly executed to solve the problem or behave again from the previous procedure.

Accumulation of incorrectly executed outcomes: Participant D wrapped the entire nail without cutting the given A4 paper to the nail size when wrapping the paper in the nail. Since then, he judges that his performance is intuitively wrong due to the difference in the size of paper and nails and the incomplete outcomes. Because of these wrong executions, students may find it difficult to understand the procedures in the following procedures or lead to the accumulation of erroneous performance. Because students use the final outcomes of the previous procedure to understand the next procedure.

3.2. What are the categories of difficulties in the processing of scientific experiment manuals?

As a result of analyzing students' experimental manual processing cases, first, students seem to think about the contents of the procedure and the expected results accordingly and then continuously evaluate how closely the expected and actual outcomes are achieved during actual execution. Thus we use the notion of 'representation' to analyze this cognitive processing more analytically. A 'representation' is a hypothetical and inner mental representation in the mind, which tells what kind of reality comes to mind[15]. That is, students represent the content and outcomes of the procedures and continuously evaluates whether they match the actual results.

At each stage of understanding and executing the procedure, students process the manual through this process. In this process, we were able to categorize the difficulties experienced by students with and without representations.

First, we can categorize it as a 'conflict situation' or 'insufficiency situation', depending on whether the representation is clear or not at the stage of understanding the procedure. A 'conflict situation' is a situation in which the representation of a procedure is clear, but there is a conflict between the information of the manual and the information of the background knowledge, and therefore one of them must be selected. An 'insufficient situation' is that the given information is insufficient and the representation is not clear.

Also, we can categorize it as 'inconsistent situation' or 'insufficient situation' depending on whether the representation is clear or not at the stage of executing the procedure. An 'inconsistent situation' is that the representations at the stage of

understanding the procedure are clear, but the outcomes are not consistent with the expected outcomes. An 'insufficient situation' is that the information given in the process understanding stage is insufficient and the representation is not clear, and thereafter the insufficient representation in the execution is not clear.

The categories of difficulty, conflict, and insufficiency, and inconsistency, situation can be classified according to the processing steps of the procedure and the clearness level of representation. So it seems that the way to solve the difficulties differs according to each situation. In A 'conflict situation', the information presented in the manual and the background knowledge provides different information. Therefore, there is a problem-solving method in which information is selected in consideration of the situation.

And in An 'insufficient situation', the representation of the procedure is not clear. Therefore, there is a problem-solving method of collecting information and inferring procedural contents to clearly represent the procedure. An 'inconsistency situation' shows a problem-solving method that makes various attempts to correct the expected outcomes or to match the expected and execution outcomes.

4. Conclusion

Based on the results obtained in this study, the following conclusions can be drawn.

First, as a result of analyzing the difficulties in the processing of scientific experiment manual, in the understanding experimental manual stage, "Difficulties due to insufficient information," "Conflicts due to differences between the contents of the manual and my thoughts," and "Difficult to connect the objects presented in the manual with the actual environment" appeared. In the executing experimental manual stage, "No scale to evaluate completion of execution," "Inefficient way," "Derive outcomes that differ from expected outcomes," and "Accumulation of incorrectly executed outcomes" appeared.

Second, as a result of categorizing the difficulties in the processing of scientific manuals, we could categorize them into 'conflict situation', 'insufficiency situation', and 'inconsistent situation' depending on the stage of understanding, the stage of execution, and the clearness of representation, and the way of solving problems according to each situation changed according to the characteristics of the situation.

Through these results, it is possible to find out the cause of the difficulties in the processing of the manual and solve the problems, and it can contribute to enhance the effectiveness of scientific practical works.

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