（ 続紙 1）

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論文題目	Cognitive Neuroscientific Research for Developing Diagram Use Instruction for Effective Mathematical Word Problem Solving		

（論文内容の要旨）

In his doctoral research, Mr Ayabe examined the mechanisms involved in promoting the successful use of diagrams in mathematical word problem solving. He designed and implemented an effective method for teaching junior high school students how to construct and use appropriate diagrams to match different types of mathematical word problems. Furthermore, his research revealed the relevance of cognitive load (perceived mental effort) on strategy use and problem solving. He also used brain imaging techniques (EEG and fNIRS) to examine the specific changes that occur in brain activity as a consequence of developing knowledge and skills in diagram use for problem solving.

In the dissertation, Mr Ayabe explains the importance of learning how to solve mathematical word problems in school. Such problems provide students with opportunities to apply what they have learned in mathematics to problems in the ‘real world’. However, many students find them very difficult. This is why learning how to use diagrams for solving such problems is very important, especially as previous studies have shown that diagrams are the most effective heuristics for solving them. However, as Mr Ayabe explained, research also shows that there are many problems associated with students’ use of diagrams, including lack of spontaneity in using them, tendency to choose inappropriate diagrams for the problems they are working on, and inability to draw the necessary inferences and hence derive the correct answers. While there have been many hints in previous research about how to deal with these challenges, there were no definitive answers, which was why Mr Ayabe was motivated to undertake the studies described in his dissertation.

After the preliminary chapters, Mr Ayabe’s dissertation contains five chapters that describe the five main studies he conducted. The first of those chapters examined information provided in Japanese school textbooks about the correspondence between types of math problems and kinds of diagrams. This study found that, especially where more complex problems and more abstract diagrams are concerned, there is not much guidance provided in the representative textbooks currently in use.

The second of the study chapters describes an intervention study. Mr Ayabe designed and implemented instructions for junior high school students, focusing on the their being able to use the appropriate kinds of diagrams for the types of problems that were given. Significant improvements in not only appropriate diagram use, but also correct answer rates, were found. Furthermore, Mr Ayabe found evidence that the instruction reduced students’ perceptions of cognitive effort involved in constructing and using diagrams.

The three remaining study chapters describe investigations in which Mr Ayabe provided instruction on diagram use and took brain imaging data (EEG in the third study, and fMRI in the fourth and fifth studies) to understand the impact of instruction not only on behavior and performance, but also brain activity. He obtained evidence showing that there are identifiable changes in brain activity that correspond to acquisition of knowledge and skills in diagram use, as well as differences in such activity depending on the kind of diagram being used for problem solving. The brain imaging findings provide useful indications about the cognitive mechanisms involved in diagram and strategy use during problem solving.

（論文審査の結果の要旨）

Mr Ayabe wrote his dissertation in English, and his oral defence was conducted almost entirely in English. The overall quality of the dissertation is high. Explanations are clear and easy to follow, and the research studies that have been conducted have been described largely in ways that even non-experts would be able to understand. The quality of the five research studies that have been conducted is also very high and together the studies make important contributions to theory, research, and practice in the areas of mathematics education, diagrams for educational purposes, and educational neuroscience.

The first chapter of the dissertation provides a general introduction to and context for the studies that have been conducted. The chapter is very clearly written, but the examiners felt that it may have been better if Mr Ayabe had not included the brief summaries of the research studies in this chapter as there is some duplication of purpose where the final Discussion chapter is concerned (as this chapter also includes summaries – albeit written differently – of those studies). However, the examiners did not consider this a big problem as it is one that Mr Ayabe can easily modify when he publishes this dissertation.

The second chapter of the dissertation explains the importance of mathematical word problem solving in mathematics education, the value of diagram use, and the problems that students manifest in such use that have been identified in previous research. This chapter demonstrates Mr Ayabe's capabilities in engaging with the pertinent domestic and international research literature and integrating key points from that literature to provide a concise yet fully adequate overarching background to the studies that he conducted.

Based on the findings of previous research, the third chapter then derives and explains the likely reasons for the problems that students experience in using diagrams for solving mathematical word problems. These identified reasons form the basis for the rationale of the research studies that Mr Ayabe conducted. These reasons provide new perspectives on the nature of those problems and are in themselves useful contributions to understanding in this research area. For instance, Mr Ayabe identifies a lack of instruction on problem-appropriate diagram use as a main contributor to students' failure to correctly solve mathematical word problems despite diagram use – which is an original and useful perspective on this problem.

Chapter 4 of the dissertation describes the first of the studies in which Mr Ayabe examined information provided in Japanese government-approved school textbooks about the correspondence between types of math problems and kinds of diagrams. An important finding in this study is that, especially where more complex problems and more abstract diagrams are concerned, there is not much guidance provided in the representative textbooks currently in use. This suggests that currently available school resources (textbooks), due to deficiencies in their contents, may at least in part contribute to the problem of students' general inability to use more abstract diagrams in particular.

Chapter 5 reports on the second of the studies, which is an intervention study. Mr Ayabe designed and provided instruction on problem-appropriate diagram use to junior high school students. He demonstrated that the provision of such instruction led to significant improvements not only in appropriate diagram use, but also in correct answer rates. Furthermore, Mr Ayabe found evidence that the instruction reduced students' perceptions of cognitive effort involved in constructing and using diagrams. The findings of this study can be considered as very important contributions in this research area, providing a much needed viable solution to the identified problem. This study also described a useful variation on the multiple baseline design, which can be applied especially in studies that provide instructional

interventions that may have specific parameters in expected effects.

In Chapter 6, Mr Ayabe reports on the first of three studies that gathered not only problem solving performance data from participants but also brain imaging data. In this study, he gathered EEG (electroencephalogram) data to understand the brain activity changes that occur when students learn how to correctly construct appropriate diagrams that match the requirements of the problem they are given. The most important finding from this study is that there are detectable brain activity changes – increases and decreases – that occur when students become able to correctly construct and use diagrams for problem solving, and these changes are different depending on the diagrams they use (tables or graphs).

In Chapters 7 and 8, Mr Ayabe reports on two further studies that examine brain activity that results from the provision of problem-appropriate diagram use instruction, this time using fMRI (functional near-infrared spectroscopy). In one study (Chapter 7) he examined instruction on the use of tables, and in the other (Chapter 8) on the use of graphs. These studies confirm that changes in brain activity occur following the provision of problem-appropriate instruction, and students increase in their capability to solve the problems they are given. Furthermore, these studies revealed that such instruction activated areas of the frontal lobe of the brain that are responsible for working memory activity when solving problems. Taken together, Chapters 6 to 8 make original and significant contributions to educational neuroscience research, as these are the first studies to examine the connections between strategy use instruction, corresponding changes that occur in problem solving performance, and the parts of the brain that are involved.

In the final chapter of the dissertation (Chapter 9), Mr Ayabe provides the discussion and conclusion of all the studies combined. Unfortunately, in the version of the dissertation he submitted, he made a mistake in printing and compiling the contents and, as a consequence, a number of pages of this chapter were left out. The examiners discussed this matter and concluded that, although the missing pages are noticeable when considering the purpose of Chapter 9, on the whole the missing pages do not render the dissertation deficient in any significant way, and they can easily be added when Mr Ayabe publishes his dissertation.

In addition, the examiners raised and discussed with Mr Ayabe a number of critical points about the research studies he had conducted. These points included:

- Whether the findings concerning the patterns of changes in brain activity specifically pertain to diagram use or more broadly to mathematical word problem solving;
- The low levels of correct answer rates achieved by the students in some problem types despite the instructions provided and the significant improvements they had demonstrated;
- The need to consider how the instructional methods can realistically be implemented in schools, including possible challenges in teacher professional development.

Although Mr Ayabe needs to consider these critical points as he continues his research in the future, the examiners consider the research described in this dissertation as being valuable and sufficient for the award of a doctoral degree in education.

よって、本論文は博士（教育学）の学位論文として価値あるものと認める。また、令和 5 年 1 月 24 日、論文内容とそれに関連した事項について試問を行った結果、合格と認めた。

なお、本論文は、京都大学学位規程第１４条第２項に該当するものと判断し、公表に際しては、（期間未定）当該論文の全文に代えてその内容を要約したものとすることを認める。

要旨公表可能日：　　年　　月　　日以降