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Understanding the Factors Affecting Students' Ability to Solve Math Word Problems

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Word problems are a question type commonly seen in math tests and exams. Since word problems are an integral part in teaching and learning of mathematics in schools, understanding what factors that would affect students' ability to solve math word problems may help students understand where their weaknesses lie and help teachers adopt effective approaches to assess students' ability of solving math word problems. Through the data collected from a timed online math quiz and an online questionnaire survey, the present study suggests that math word problems that are not presented in participants' first language will be likely to cause disturbances to their process of solving the problems, but even when the questions are not presented in participants' first language, the difference in the length nor the complexity of sentence structure of the questions would greatly affect their understanding of the context. Participants in general have the perception that their English reading comprehension ability is a critical factor that affects their performance of solving math word problems, but surprisingly, even though the participants could extract accurate information from the question context, they might not be able to apply the appropriate math model to solve the problems.

Keywords: math word problems, online math test, question setting, math models, instructional language

INTRODUCTION

Word problems are of great importance in teaching and learning of mathematics in schools (Bernado, 2002). They are commonly and frequently used to teach mathematics and assess students' ability to apply the appropriate math models to solve the given problems.

When students do not perform well in a math assessment, they are usually assumed weak in mathematical skills. However, research suggested that in addition to students' mathematic skills, other factors such as students' attitude (Harun et al., 2021) should be considered when students fail a mathematics test. Pungut and Shahrill (2014) suggested that students' language competence attached considerable significance when students were required to solve math words problems, which are a common question type in mathematics tests. They defined math word problems as "mathematical questions expressed in sentences and it requires precise understandings over the questions in order to know what mathematical concepts is needed to solve it" (p.2). When solving a math word problem, students first need to apply their language skills to extract necessary information from the given contexts and then apply their math skills to select the appropriate math model to work out the correct answer. In other words, when students fail to solve a math word problem, it could be due to different reasons; some may lack the required mathematical skills to solve the problems, while some may have misinterpreted the questions due to their weak reading skills.

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Cabezuelo and Pavón (2019) suggested that students would find it more challenging to take math assessments that are not presented in their first language as students would face linguistic difficulty and mathematical complexity at the same time. Bernardo (2002) questioned whether not using students' first language to set the questions would influence their performance of solving math word problems. Vilenius-Tuohimaa et al. (2008) found a strong correlation between the participating Finland primary students' English reading comprehension ability and their performance of solving math word problems in a study. The study of Krawitz et al. (2022) also agreed that the reading comprehension competence of EFL (English as a foreign language) students had a positive impact on constructing math models when solving math word problems presented in English.

Contrarily, Pungut and Shahrill's study (2014) on junior secondary students in Brunei revealed that when the non-native English students were asked to solve math word problems in English, their English competence did not show significant influence on their performance on the given math task. However, it should be noteworthy that Pungut and Shahrill concluded that students do not need a good command of English to solve math words problems with less than 40 words, but good English skills are still required when students need to solve longer questions.

The contradictory conclusions resulted from the previous studies can be because of factors including not only the English competence of the EFL participants, but also other language-related factors such as the question design, the length of the questions, and the English language used by instructors in giving instructions of the math questions in EFL school contexts. Chan (2015) analyzed the common vocabulary and grammar structures in mathematical register used in Hong Kong schools, where English is commonly used as the medium of instruction for EFL students. These linguistic challenges could be the factor that affects students' performance of solving math word problems, and it was thus concluded that to help students overcome these challenges, teachers would adopt strategies, such as breaking down the questions, providing commonly used hint words, and adopting multimodal elements when setting the math word questions. In Hong Kong, English is the common medium of instruction in tertiary institutions, and students are usually expected to do the subject assessment tasks in English, even for close-book tests or exams. Chan's study provides an insight concerning the challenges that EFL students would face in the assessment tasks of non-English content subjects, such as mathematics. Whether providing students with aiding resources and the language used in instructions would have impact on their performance in subjects other than language is thus worth a discussion.

The previous studies have laid a ground for the discussion of whether EFL learners' English reading ability would have impact on their performance in solving math word problems. The proposed study is informed by the splitting conclusions of the previous research that more factors such as the English language and prompts used in the instructions, the design of the questions, the context given in the questions should be considered. The present study aims to investigate the following:

1. When math word problems are presented in the students' second language, how would the language use affect students' competence in math modelling?

2. Do common technical prompts in math help students achieve the target math model?

3. When students are not hinted at, which areas do students perceive would be the root cause(s) of their incompetence of solving the word problems, their language competence or math ability?

METHOD

Quantitative analysis was adopted in the study. The data were collected by a timed online math quiz and an online questionnaire. The math quiz was designed to collect data about participants' application of math modelling when they solved math word problems, while the questionnaire was

mainly aimed at soliciting information about participants' educational background and information about what kinds of tools or resources they had used when doing the math quiz.

On-site math test is always regarded as one of the common and fair ways to assess students' math ability, but "too often, students see the knowledge taught by teachers as mathematical procedures and they failed to apply the importance of such knowledge to their daily lives" (Pungut & Shahrill, 2014, p.1). In math tests, they would have trouble in choosing the appropriate mathematic techniques to solve daily life problems if no prompts are given to them. In real-life contexts, when students encounter problems, they would seek assistance. However, in on-site test settings in schools, students are usually not allowed to seek help nor to use other resources to solve the test questions. It would make solving math word questions a more difficult task for them. The proposed study provides a setting that allows participants to show their initiative to seek help when solving problems in a real-life situation, and the types of resources they seek help from will also provide important implications on identifying the problems they would have, for example, problems related to their English competence or math ability, when solving math word problems.

Participants

Students from a local tertiary institution in Hong Kong were recruited to sit an online timed math quiz on a voluntary basis. The students were taking sub-degree programmes at that institution and had completed 6 years secondary school curriculum or attained equivalent education level before they were admitted to the institution. To ensure the participating students were taught the target math topic, the research team chose the students who were taking the same mathematics subject in that semester. All the participating students were clearly told that their results in this study would not have any impact on their academic results. The students were required to complete a common online math quiz and a questionnaire within the specific time. 93 students participated in the study, while 88 of them duly completed both the quiz and the questionnaire.

Data Collection Instruments

Online data collection instruments were adopted because the data collection was done in late 2022, when many face-to-face school activities were suspended in Hong Kong. The data were collected by a common timed online math quiz and an online questionnaire.

The Timed Online Math Quiz

In the timed online math quiz, only simple instructions written in both Chinese and English were provided on the question paper to let students know the duration of the test and how to submit the quiz. They were also reminded to handwrite their answers and clearly show every calculation step for the researchers to understand their ability to extract information from the given questions. The question paper consisted of three math questions. All the questions asked the participants to apply the same math model, the probability model, to work out the answers. The first question was presented in the format of a math formula, with the same set of math symbols that were used in their class notes. The second and third questions were word problems. The same context (election of class monitor, monitress, and class committee members) was used in the two questions. The second question was presented in only 45 words with simple sentence structures. The length of each sentence was between 10 and 13 words. Simple English phrases and an explicit hint "what is the probability" was given in this question. The last question was a longer word problem in 134 words. The length of sentences varies from 10 to 27 words. The relevant contextual factors, such as the change in number of eligible voters, were presented in various complicated sentence structures including but not limited to compound sentences, subordination, and embedded clauses. No explicit hints about computing probability were given to students in this question.

Participants were asked to download this question paper from the college online teaching platform and were given 30 minutes to complete the test. After the quiz, for the sake of lowering the risk of network congestion, they were given 15 minutes to upload their answers to the same platform. Participants were required to log in to the platform with their own unique student numbers and switch on their camera throughout the quiz. The two responsible researchers and two assistants were monitoring the whole process during the quiz. No participants reported that they had encountered technical difficulties in the process.

The Online Questionnaire

After submitting their answers to the math test, the participating students were invited to complete a questionnaire via an online survey platform. In addition to soliciting information about participants' educational background, the questionnaire served two other major purposes. First, the participants were asked to comment on the level of difficulty of the three questions. They were asked "When doing the timed online mathematics quiz, did you think Question X was difficult?" and they were asked to further explain why they thought that question was difficult. Following were semi-closed questions that asked participants to report what kinds of tools or resources they had used when doing the math quiz. As participants' preferences for choosing the tools and resources during the math quiz could reflect where they perceived their weaknesses lied when solving math problems, it was worth to investigate which kind of tools or resources participants preferred to use when they encountered difficulties in solving math problems. The online questionnaire was not a timed task. Students had been reminded to complete all questions before they submitted the questionnaire.

FINDINGS

Participants' answers to the three questions in the math quiz were analyzed by one of the responsible researchers and two assistants. Before the analysis, they discussed and agreed on the common coding system. They read and coded the scripts of all 88 participants individually. They then compared their coding, discussed the discrepancies found, and cleaned up the data. Five points were allocated to each of the three questions in the quiz. Since the presentation of the first question was presented in a math formula, all the five points were given based on students' calculation accuracy; three points were given if the participant could apply the correct math model, and they could get another two points when they could provide the correct answer. Questions 2 and 3 were word problems. Participants were required to understand the details given in English sentences to extract the information for calculation. For each of these two questions, three points (information score) were given if students could successfully understand the given context presented in English and extract the correct information (the numbers) for calculation, while another two points (calculation score) were given if the students could apply the correct math model (probability model) and work out the correct answer. The participants' scores in each of the three questions were analyzed and compared by one-way anova. The average scores were significantly different among these three questions (p-value = 4.4048×10^{-16} = < 0.05). Table 1 shows the mean scores of the three questions of all participants.

Table 1
Mean scores of the three questions in the math quiz

	Question 1	Question 2	Question 3
mean	4.42	3.53	2.39
stdev	1.00	1.86	1.51

The mean score of question 1 was 4.42, which means most of the participants could apply the correct math model when computing the answer. It also indicates that most of the participants could manage to apply the target math model (probability model). The results obviously show that among the three questions, question 3 was the most challenging one for the participants. In the questionnaire, participants were asked if they thought each of the three math questions was difficult. Responses from

the participants well matched with the mean scores of the three math questions. 5.68% of the participants thought the first question was difficult, while 12.50% and 40.91% of the participants, respectively, thought the second and the third question was difficult.

In the questionnaire survey, only three participants reported that they did not know what math models they should apply when answering question 2. Rather, eight participants believed that they could not solve the question because they had problems in understanding the English expressions in the question. For question 3, nine participants (about 10%) reported that they were not sure what math models should be used, while 27% of the participants reported they could not understand the question because they could not comprehend the English words and phrases used in the question. The breakdown of the information score and calculation score in the two word problems, i.e. question 2 and 3 were analyzed separately. The mean scores of question 2 and 3 are shown in Table 2.

Table 2
Mean scores of Question 2 and Question 3

	Question 2	Question 3
Information score (maximum 3 points)		
mean	2.33	2.07
stdev	0.93	1.07
Calculation score (maximum 2 points)		
mean	1.20	0.32
stdev	0.98	0.74

Participants' scores in the two questions showed contradictory results. From the results, there was no significant difference in participants' understanding of the two questions (p-value = 0.0857 > 0.05). They scored 2.33 and 2.07 out of 3 points respectively in extracting the information from the questions. It showed that the difference in the length nor the complexity of sentence structure of the questions would greatly affect their understanding of the context. On the other hand, a significant difference was observed between the calculation score of the two questions (p-value = 1.9453×10^{-10} < 0.05). It could be explained by the difference in the language used in the question setting. When an explicit hint word "probability" was given in question 2, participants would perform better in solving the math word problems, whereas in question 3, no hint at what math model should be applied, and participants were expected to choose the appropriate model by themselves.

That participants perceived their weak proficiency in English would critically affect their ability in solving math word problems could be evident in their preferred aiding resources in the quiz. As mentioned, the researchers deliberately did not prompt participants to use any types of tools or resources during the quiz. Although it was not deliberately stated in the instructions, a considerable number of participants (82%) used calculators during the quiz. Among these participants, 59.7% assumed that they could use calculators in math quizzes in normal circumstances. Another 33.3% used calculators because they believed that using calculators during the quiz could improve their accuracy of answering the questions. Other than calculators, 11 participants had used online dictionaries or translation tools, and only 2 reported that they had referred to the math course notes. A substantial proportion of participants (81.8%) had not used any aiding resources. 54% of participants explained that they did not use any resources other than calculators because they had confidence in answering the questions accurately. Some participants explained that they did not do so because they were not told that they could use aiding resources (27.8%) or they did not know what tools should be used (13.9%).

DISCUSSION

The findings showed that math word problems that are not presented in the participants' first language are likely to cause disturbances to their process of solving the problems. The high mean score of question 1 reflected that most participants could manage the target probability math model, while the lower mean scores in question 2 and 3 showed that participants did not perform as good as they did in question 1, even though they were in fact required to apply the same math model in all three questions.

Whether the participants could extract the useful information from the given context in question 2 and question 3 was considered to further investigate if participants' English competence would affect their performance in solving the problems. Although the overall mean score of question 2 was higher than that of question 3, when the breakdown of information scores was compared, no significant difference between the two questions was observed. This observation aligned with the findings of Pungut and Shahrill (2014) that students' English competence does not have significant impacts on their performance in doing math word problems. It should be noted that the word problems used in their study were limited to 40 words. In the present study, the two word problems varied in length and level of difficulty. In this study, nevertheless, participants might use aiding resources, and they had a higher education level than the participants of Pungut and Shahrills' study.

Krawitz et al. (2022) argued that provision of multimodal reading comprehension aids such as pictures and photos for students could effectively improve their understanding of the context of math word problems so as facilitate them to apply appropriate math modelling to solve the problems. However, the findings of the present study did not align with this claim. Instead, it is shown that even when students could comprehend the question context, they might not be able to apply the appropriate math model. The mean calculation score of question 2 is remarkably higher than that of question 3, which means more participants could apply the correct math model when doing question 2. When there is no significant difference in the participants' ability to extract the context information from the two word problems, it could be explained by the provision of an explicit hint word "probability" in the question. This hint word is commonly used in math context and can be found in the participants' class notes. Previous studies suggested that the language used in a math word problem, for example, the application of math vocabulary, serves various functions that could facilitate individuals' word problem solving performance (Cartwright et al, 2022; Chan, 2015). Csíkos et al. (2022) suggested that students tended to apply a straightforward strategy that they would focus on the hints given and associate them with the arithmetic operations taught in the course when solving math problems. The findings of the present study reflected that the use of common technical math vocabulary could improve students' math modelling competence, but the results of this study also showed that even though an explicit hint word was provided, some participants would still have problems in finding the appropriate math model.

In addition to the provision of explicit hint in word problems, the weak relationship (ρ = 0.2565) between participants' information score and calculation score can also be attributed to the participants' choice of aiding resources. It is interesting to note that when participants found themselves have problems in solving math word problems that are presented in English, they would usually assume that their problems come from their weak English reading comprehension ability rather than their math competence, and therefore they would find help from language-related resources, such as online dictionaries or translation apps. On the other hand, when participants were working on math word problems, they would focus more on the accuracy of calculation results instead of the application of appropriate math models. In view of it, it could explain why most participants preferred to use calculators, either online or offline, as their aiding resources for solving the questions in the quiz. Only a very limited number of students would refer to their course notes when they had doubts about the application of math models. It would be because in Hong Kong, students are usually not allowed to refer to their course notes in quizzes or exams, even though referring to course notes would be a useful and manageable resource to help students apply the appropriate math models.

CONCLUSION

Interestingly, students in general have the perception that their English reading comprehension ability is a critical factor that affects their performance of solving math word problems. In contrast, the findings of the present study showed that for Hong Kong ESL students, their English reading comprehension ability may not be the most significant factor that affects their math word problem solving competence. Rather, whether the students can apply the appropriate math model would be a more influential factor. If students can identify the proper aiding resources, it would be more helpful and effective for them to solve the problems. Moreover, clear instructions, such as inclusion of explicit and common hint words would be helpful to students. Teachers may also consider providing students with aids that can help them to recall the math models taught in the course, such as a summary of various math models.

It is believed that more meaningful results can be obtained if more data could be collected and compared with the findings of the present study, for example, the data collected from a face-to-face setting, word problems presented in students' first language, or word problems that require students to apply different math models. Nevertheless, the findings of the present study have given teachers some insights into setting assessments and preparing students to solve math word problems that are not presented in their first language.

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