EFFECTS OF REAL-WORLD CONTEXTS ON MATHEMATICAL MODELLING PROBLEMS IN PRIMARY EDUCATION

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Mathematical modelling involves translating real-world situations into mathematical problems, with real-world contexts playing a central role. The challenge of transferring modelling competencies across different contexts is insufficiently explored in primary education. This study examines how various real-world contexts influence primary students' modelling performance and transfer ability. Using a mixed-methods design, 136 students solved problems constructed in parallel with private, school, and vocational contexts, followed by stimulated recall interviews with 10 students. Results reveal significant context effects and transfer issues despite students' recognition of structural similarities between problems. Findings emphasize the need for diverse authentic contexts and targeted support in early modelling education.

INTRODUCTION

The importance of mathematical modelling in mathematics education, including at primary school level, has been steadily growing. It emphasizes the use of mathematical competencies to address real-world problems and to connect mathematics with everyday life and various professional contexts (Smith & Morgan, 2016). In mathematics education, modelling problems are commonly used to introduce real-world contexts, which can vary in their degree of authenticity. A central aim of mathematics education is to enable students to apply their mathematical competencies across a variety of contexts (Niss & Blum, 2020). However, research from cognitive psychology highlights that transferring mathematical competencies from one real-world context to another is often challenging (e.g., Evans, 1999). Evidence from mathematics education further supports this, particularly for complex applications of mathematical modelling (Almuna Salgado, 2017).

Although transfer issues have been widely recognized at higher education levels, their manifestation in real-world contexts at the primary school level remains insufficiently explored. This study, therefore, focuses on the influence of different real-world contexts on the successful solving of modelling problems in primary school. Understanding these transfer difficulties at primary level is essential for fostering effective engagement with mathematical modelling problems in authentic contexts from an early age, thereby laying the foundation for solving more complex modelling problems later on.

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THEORETICAL FRAMEWORK

Real-world contexts in mathematical modelling

Mathematical modelling describes the process of using mathematics to analyse and solve problems originating from the real world. Although the modelling process can be conceptualized and represented in various ways, the translation between a real-world context and the mathematical domain—and vice versa—remains the central element of all representations of mathematical modelling (Niss & Blum, 2020). In this regard, specific real-world contexts play a crucial role within mathematical modelling. From a curricular perspective, these contexts serve as a practical application tool for mathematics in everyday life, a vehicle for learning, or as a motivating engagement with real-world phenomena (Smith & Morgan, 2016). In mathematics education, problems with real-world references frequently appear in the form of word problems. Consequently, reading comprehension plays a vital role in solving these problems, as it enables students to build an accurate model of the presented situation (Krawitz et al., 2017). Such a linkage between real-world contexts and mathematical application can thus benefit both mathematical competencies and a deeper understanding of the real-world context itself. Accordingly, Niss and Højgaard (2011) defined the *radius of action*—the range of real-world contexts—as one of three key dimensions of modelling competence, alongside the *technical level* and the *degree of coverage*.

An important aspect in characterizing mathematical modelling problems is the authenticity of both the underlying real-world contexts and the mathematical applications involved. The authenticity of real-world contexts has gained increasing attention in mathematics education research; contexts for mathematical modelling are becoming a central focus within the field (Brown, 2019). Verschaffel et al. (2020) conceptualize the degree of authenticity and reality of mathematical problems as a continuum: At one end of this continuum are word problems for which the real-world context appears to play a subordinate role in their solution. At the opposite end are problems derived from authentic real-life contexts that are approached using mathematical methods. Within this framework, word problems are considered to be simply structured problems that nonetheless require mathematical modelling competencies for their solution, although only to a relatively small extent. Therefore, in the following, word problems will be subsumed under the terminology of mathematical modelling problems.

Issues in transferring mathematical competencies across real-world contexts

Mathematical competency depends on context, and cognitive psychology shows that transferring competencies between different contexts is challenging. The cognitive flexibility theory (Spiro et al., 1988) explains transfer difficulties by emphasizing that acquiring competencies across varied situations enhances flexibility and problem-solving ability. Situated cognition theory (Brown et al., 1989) goes further, arguing

that competencies are strongly tied to their acquisition contexts, making it difficult to separate competencies from context.

Empirical studies within mathematics education further support these findings. Differences in context have been investigated in several studies, which predominantly emphasize the challenges of transfer (Almuna Salgado, 2017; Orón & Lizasoain, 2023). However, these investigations have primarily focused on learners at secondary education level. For example, trainee industrial clerks exhibit different problem-solving patterns when working on mathematical problems with and without vocational contexts, despite the mathematical structure of the problems being identical (von Hering et al., 2018). In contrast, research on primary school students has yet to yield clear evidence regarding the potential influence of familiarity with a real-world context on the successful solving of mathematical modelling problems (Vessonen et al., 2024).

Mathematical modelling competencies should be acquired and applied across a wide variety of contexts (Niss & Blum, 2020). Despite the widespread endorsement of this principle, for example, within the OECD's definition of Mathematical Literacy (OECD, 2023), the specific real-world contexts in which these competencies should be developed have been relatively underexplored in a systematic way. The PISA framework classifies real-world contexts into four categories: *school*, *private*, *vocational*, and *societal*. However, in primary school mathematics textbooks, real-world demands appear almost exclusively in private or school-related contexts, while vocational and societal contexts are rarely included (von Hering et al., 2025). Whether this represents a genuine issue depends particularly on whether the cognitive psychological theories concerning the transfer issues of mathematical competencies manifest not only in secondary education but also in the simpler mathematical modelling problems encountered in primary education.

RESEARCH QUESTIONS

Real-world contexts are a crucial component of mathematical modelling problems. However, regarding primary school students, there is still no clear evidence on the transfer issues of mathematical competencies across different real-world contexts. This gap in the research leads to the following research questions:

RQ1: What influence do different real-world contexts have on the successful solving of mathematical modelling problems in primary school?

RQ2: To what extent can primary school students transfer mathematical competencies from one real-world context to another?

METHODOLOGY

Design & Sample

To answer these questions, we conducted a mixed-methods study. Initially, we developed parallel versions of mathematical modelling problems embedded in different real-world contexts. These problems were then administered as a paper-and-

pencil test and analysed quantitatively with N = 136 students from three primary schools in Northern Germany (61 female, 75 male; 63 in Grade 3, 73 in Grade 4). Subsequently, we conducted stimulated recall interviews with 10 students (3 with low overall test scores, 3 with average overall test scores, 4 with high overall test scores) to gain qualitative insights into the underlying thought processes during problem solving, thereby complementing the quantitative findings.

Instruments

To capture differences between various real-world contexts, we initially developed short, closed-ended mathematical modelling problems, systematically varying the context while maintaining a fixed mathematical structure. Alternatively, the problems can be classified as word problems embedded in real-world contexts. This resulted in four problem sets, each comprising three problems, representing the three context categories: *school*, *private*, and *vocational*. For reasons of time feasibility, we decided against including a fourth problem in a societal context for each set. Age-appropriate vocational contexts were selected, namely the occupations of farmer, postal worker, and cook. All problems involved arithmetic content. Three of the problem sets primarily targeted the domain of quantities and measurement, while one focused on numbers and operations. To ensure an authentic application of mathematics, the numerical values and quantities used were minimally adjusted where necessary. The comparability of the mathematical demands within each problem set was confirmed through an interview study involving 15 primary school mathematics teachers. Figure 1 illustrates one problem set on the topic of money, presented in three different context versions.

Figure 1: Problem set on the topic of money with one item each in the real-world contexts of *school*, *private*, and *vocational* (from top to bottom)

Class 3d wants to buy new cushions for their classroom. At the school festival, they made a profit of 50 Zeds with a sales booth. The cushions cost a total of 15.60 Zeds. How much money is left from the profit?

Lisa and Jan spend the day at the lake. Lisa received 20 Zeds pocket money from her mother. She wants to treat Jan to an ice cream with it. Lisa has to pay a total of 7.60 Zeds for this. How much money does Lisa have left?

Mr. Schröder is a farmer and sells fresh eggs. Today, he earned 40 Zeds from the sales. However, he still needs to buy new egg cartons with this money. The egg cartons cost a total of 12.20 Zeds. How much money does Mr. Schröder have left from his sales today?

The problem sets were administered as a paper-and-pencil test with an open response format. Responses to the test items were scored using a three-level ordinal scale. Background variables collected included mathematical self-concept (five items, four-point Likert scale, α = .83, M = 2.90, SD = .67) and motivation in mathematics (five

items, four-point Likert scale, α = .88, M = 3.00, SD = .79), and special educational needs (SEN) in language and mathematics.

For the conducted stimulated recall interviews, we developed an interview guide that first prompts students to recap their solution process for one of the four problem sets. Additionally, questions regarding the perceived difficulty and familiarity with the real-world contexts are posed. Furthermore, perceived differences and similarities within the problem sets are explored to determine whether the students were aware of the parallel structure of the problems and whether they utilized it during problem solving.

Data analysis

To examine whether the different context versions of the items (*school*, *private*, *vocational*) influence the rating scale of the paper-pencil test, a Cumulative Link Mixed Model (CLMM) with a logistic link function was employed and fitted to the data (Christensen, 2022). In Model 1, only the context version was included as a fixed effect. In Model 2, additional fixed effects were added: mathematical self-concept, motivation, SEN in language, SEN in mathematics, and grade level. Individual variability was modelled by including a random intercept for each participant in both models. Model convergence was deemed satisfactory for both models, with a maximum gradient norm below .001.

For the analysis of the stimulated recall interviews, a qualitative content analysis following Mayring (2022) was conducted. The deductive-inductive coding system included the main categories of *problem-solving process*, *familiarity with the real-world context*, and *perceived difficulties in solving* for each of the three differently contextualized problems, as well as a main category addressing *perceived similarities and differences* within the problem set. All interviews were double-coded, achieving a high interrater reliability (κ = .85).

RESULTS

Quantitative results

Table 1 presents a comparison of Model 1 and Model 2. Model fit improved from Model 1 to Model 2 significantly ($\chi^2(5) = 65.72$, $p < .001$), as indicated by a decrease in AIC and an increase in McFadden's Pseudo-R^2. Additional models were tested to examine potential interactions between the variables. However, these models did not reveal any significant interaction effects, nor did they improve model fit significantly.

In Model 1, both the privately and vocationally contextualized items showed a significant negative effect compared to the school-context reference category, indicating lower odds of higher scores in these contexts. Model 2 confirmed these effects for the private and vocational contexts even after controlling for additional predictors. Among the added covariates, grade level had a strong positive effect, suggesting that students in higher grades had substantially higher odds of achieving

better scores. SEN in mathematics was associated with significantly lower odds of higher scores.

Table 1: CLMM results predicting overall test score (school context as reference; β = estimate, *SE* = standard error, *OR* = odds ratio; * $p < .1$, ** $p < .01$, *** $p < .001$)

	Model 1			Model 2		
	β	*SE*	*OR*	β	*SE*	*OR*
Context version *private*	-.51***	.14	.60	-.50***	.14	.60
Context version *vocational*	-.54***	.14	.58	-.54***	.14	.58
Mathematical self-concept				.29	.25	1.33
Motivation				.20	.20	1.22
SEN in language				-.28	.30	.75
SEN in mathematics				-1.37***	.39	.26
Grade level				1.63***	.24	5.10
AIC	2497			2441		
McFadden's Pseudo-R^2	.007			.036		

The variance of the random intercept for participants was 2.24 logits (*SD* = 1.50) in Model 1 and 1.27 logits (*SD* = 1.13) in Model 2, reflecting substantial individual differences in response tendencies.

Qualitative results

The results of the stimulated recall interviews indicate, on the one hand, that more students reported greater familiarity with the school and private contexts than with the vocational contexts. Additionally, of the 10 students interviewed, 8 stated that they recognized the structural similarities between the tasks within the problem set. Two of these eight students solved the parallel problems in a comparable manner.

P8, lines 182–184	Just like the others, I did. I realized it's always the same principle. And then I wrote it down the same way as the others. So, just with different numbers.

Despite perceiving structural similarities between the problems, the other students showed differences in how they approached the parallel problems.

DISCUSSION

This study investigated the influence of different real-world contexts on the successful solving of mathematical modelling problems in primary school and explored how students' approaches vary depending on these contexts. Regarding RQ1, the quantitative results indicate that real-world contexts can have a significant impact on

the successful solving of mathematical modelling problems even at the primary school level. Moreover, different real-world contexts exert varying degrees of influence. The subsequent stimulated recall interviews revealed that, although students recognized the designed parallelism in the mathematical structure of the problems, the transfer of mathematical competencies across these real-world contexts was not straightforward (RQ2).

This aligns with situated cognition theory (Brown et al., 1989), which posits that competency acquisition and application are deeply intertwined with context, and suggests that explicit scaffolding may be necessary to foster transfer across contexts. It is important to note that the tasks used in this study can be classified as word problems embedded in real-world contexts or, alternatively—and not mutually exclusively—as simple modelling problems. Regardless of this classification, the observed context effects remain evident. This finding is particularly noteworthy because context effects appeared even in very simply structured tasks, where the mathematical modelling demands are presumed to be relatively low-level. Thus, our results suggest that real-world contexts influence students' problem-solving performance from the earliest stages of mathematical modelling competency development.

Nevertheless, several limitations must be acknowledged. The sample size for the qualitative component was small, limiting the generalizability of the interview findings. The study focused on arithmetic modelling problems, which may not capture the full complexity of mathematical modelling across other domains. Additionally, the contexts chosen, while varied, may not represent the full spectrum of real-world situations relevant to primary students, especially considering the underrepresentation of vocational and societal contexts in primary curricula. Future research should expand the range of real-world contexts and problem types examined, include larger and more diverse samples, and investigate instructional interventions that explicitly target transfer skills. From a practical standpoint, our findings suggest that mathematics education at primary level should incorporate a wider variety of real-world contexts to better prepare students for diverse modelling challenges and to take the transfer issue into account. In conclusion, this study emphasizes the critical role of real-world contexts in influencing primary school students' performance on mathematical modelling problems and highlights the ongoing difficulties in transferring mathematical competencies across different real-world contexts.

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