What makes a modelling problem interesting? Sources of situational interest in modelling problems

O que torna um problema de modelação interessante? Fontes de interesse situacional em problemas de modelação

Mareike Schulze Elfringhoff
Department of Mathematics, University of Münster
Germany
m.schulze.elfringhoff@uni-muenster.de

Stanislaw Schukajlow
Department of Mathematics, University of Münster
Germany
schukajlow@uni-muenster.de

Abstract. Prior studies have shown that many students have poor modelling competencies. One reason for these results could be a lack of interest in solving modelling problems. Because not much is known about the sources of interest in modelling problems, we designed a qualitative study to investigate sources of students' situational interest in solving modelling problems. The research questions were: (1) What sources do students report for their interest in modelling problems? (2) Does task processing influence students' interest in modelling problems and the sources of situational interest? We presented four modelling problems with different real-world contexts to five ninth-graders. We asked the students to rank the problems with respect to their interest and to justify their rankings before and after solving the problems. Qualitative analysis showed two main sources of students' interest: emotions about the real-world context of the problem and efficacy beliefs. Our results support the importance of task-specific emotions and efficacy beliefs proposed in theories of interest and uncover the role of the real-world context in triggering interest in modelling problems.
Keywords: modelling; interest; real-world problems; efficacy beliefs; emotions; context.

Resumo. Estudos anteriores mostram que os alunos possuem poucas competências de modelação e um dos motivos para isso pode estar relacionado com o pouco interesse em resolver problemas de modelação. Por conhecermos ainda pouco relativamente a fontes de interesse em problemas de modelação, desenvolvemos um estudo qualitativo que procura conhecer as fontes de interesse dos alunos em problemas de modelação. Definiram-se as seguintes questões de investigação: (1) Quais

Quadrante: Revista de Investigação em Educação Matemática 30(1) 8-30
https://doi.org/10.48489/quadrante.23861
Received: March 2021 / Accepted: June 2021
In this article, the page numbers were corrected to 8-30.

as fontes de interesse que os alunos referem para problemas de modelação? (2) A realização das tarefas influencia o interesse dos alunos por problemas de modelação e pelos contextos situacionais? Com esse propósito, apresentámos quatro problemas de modelação a 5 alunos do 9.° ano e solicitámos que os alunos ordenassem os problemas de acordo com o seu interesse e que justificassem essa ordenação antes e depois de terem resolvido os problemas. A análise qualitativa mostra duas fontes principais de interesse dos alunos: emoções relacionadas com o contexto do mundo real apresentado no problema e as conceções dos alunos sobre a sua eficácia. Os resultados sustentam a importância das emoções especificamente relacionadas com as tarefas e conceções de eficácia que têm sido discutidas na teoria de interesse e mostram o papel dos contextos do mundo real na ativação do interesse em problemas de modelação.
Palavras-chave: modelação; interesse; problemas do mundo real; conceções de eficácia; emoções; contexto.

Introduction

Mathematical modelling competencies are important for students' present and future lives; consequently, modelling is part of curricula in many countries around the world. However, prior studies have shown that many students have only poor modelling competencies (Blum, 2015). What is the reason for this phenomenon? A quote from an interview demonstrates the dislike of real-world problems often seen in mathematics classes: "Well, all in all, I don't like real-world problems" (Laura – fictitious name, 9th grader). Indeed, as interest in mathematics is positively related to performance, achievement goals, and other achievement-related outcomes (Harackiewicz et al., 2008), poor interest can impede students' learning of mathematics. More specifically, interest in solving modelling problems and modelling performance were previously found to be positively related (Schukajlow & Krug, 2014a). Thus, promoting interest in modelling problems might help improve modelling competencies. But what do we know about interest development?

Emotions such as enjoyment or boredom and motivation-related outcomes such as interest are fundamental preconditions and aims of learning (Ainley et al., 2002; Harackiewicz et al., 2008; Pekrun et al., 2002; Schukajlow et al., 2017). Consequently, one aim of education researchers and mathematics educators is to enhance students' interest in mathematics. It is strongly believed that working on tasks that are considered meaningful increases interest (Cordova & Lepper, 1996; Mitchell, 1993; Rellensmann & Schukajlow, 2017). Modelling problems are presumed to enhance students' interest in mathematics by offering a connection to the real world and students' lives (Parhizgar & Liljedahl, 2019; Rellensmann & Schukajlow, 2017; Schukajlow & Krug, 2014b). However, some prior studies have demonstrated that students report the same or even less interest in problems with a connection to reality compared with intra-mathematical problems (Rellensmann & Schukajlow, 2017; Schukajlow et al., 2012). In other study, Parhizgar and Liljedahl (2019) reported students being more interested in word problems than in intra-mathematical problems or modelling problems. Researchers have speculated about the reasons for these unexpected and contradictory findings and have suggested as reasons the uninterestingness of real-world contexts and a feeling of low competence in solving modelling problems (Krug & Schukajlow, 2013; Parhizgar & Liljedahl, 2019; Rellensmann & Schukajlow, 2017). In this study, we analyzed sources of interest in modelling problems and the effect of task processing on interest to gain new theoretical insights into students' perceptions of interest and practical insights into how to make modelling problems more interesting. This study brings together findings from previous research on interest in different types of mathematical problems (Cordova & Lepper, 1996; Krug & Schukajlow, 2013; Rellensmann & Schukajlow, 2017; Schukajlow et al., 2012), the Four-Phase model of interest development as a process that moves from situational to individual interest (Hidi & Renninger, 2006), and a more detailed model of situational interest proposed by Mitchell (1993).

To investigate situational interest in modelling problems, we designed a qualitative study. We investigated (a) what sources students report for their interest in modelling problems and (b) whether task processing influences students' interest in modelling problems.

Theoretical background

Modelling problems

Mathematical problems can be categorized as intra-mathematical problems and problems with a connection to reality (real-world problems). Real-world problems include so-called dressed-up word problems and modelling problems (Niss et al., 2007).

Anchor

Last year, Markus got his sailing license, and now he is on the Möhnesee with his friends. They rented a sailing boat from the local yacht club. Because they are five people, they decided to spend more money to rent the biggest boat. The boat is able to anchor even at the deepest position of the lake and has an anchor chain that is 36 m in length.

As a water reservoir, the Möhnesee plays an important role in water supply, and the water level changes constantly.

Markus and his friends want to take a break and cast the anchor. On this day, the Möhnesee has a water depth of 29.5 m at their resting point. How far can the boat drift from their anchoring point?

Figure 1. "Anchor" modelling problem

Modelling problems are centered on a real situation and require a demanding transfer between the real world and mathematics. For example, in the Anchor problem (see Figure 1), a situation concerning a sailing trip is described. Modelling problems differ regarding the openness (open-endedness), the authenticity of the problem or the real-world situation (Maaß, 2010). Blum and Leiss (2007) described the process of solving a modelling problem as a cycle containing seven steps: To solve the problem, a student needs to (1) understand the given situation and form a situational model, which includes details that might be irrelevant for problem solving. By (2) simplifying, structuring, and making assumptions, the student then creates the real model, which can be transformed into a (3) mathematical model. The student can solve the problem using mathematics and receives a (4) mathematical result, which must be (5) interpreted and (6) validated with respect to the initial real-world situation. This process might require information from the text or the student's own experience. If the result is satisfactory, it is (7) presented. For example, in the Anchor problem, the student has to sort out unnecessary information (e.g., the number of passengers) and make an assumption about the height of the anchor to construct a real model. Different assumptions regarding the height of the anchor might lead to different results. The situation can be modelled as a right-angled triangle, and the missing side can then be calculated using the Pythagorean theorem. An exemplary solution to the Anchor problem is shown in Figure 2. To validate the result, the student might use a drawing of the situation or compare the result with personal experience.

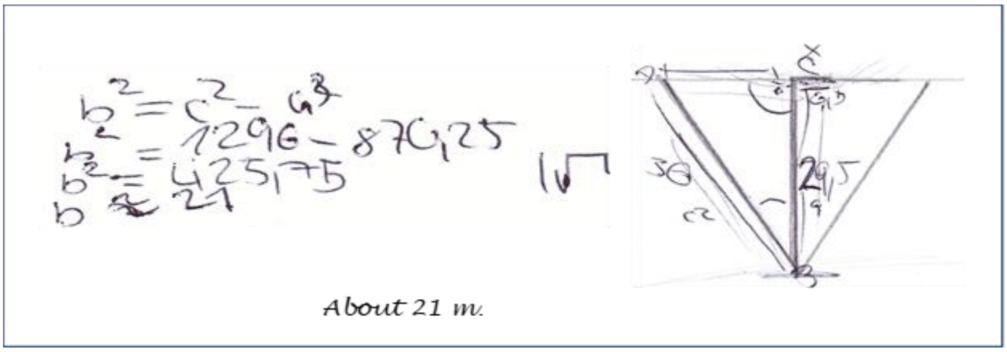

Figure 2. Exemplary solution to the Anchor problem

While all different types of problems play a relevant role in learning mathematics (Schukajlow et al., 2012), the importance of modelling competencies is undisputed (Maaß, 2010). In addition to transferring mathematical ideas to reality, modelling problems offer multiple solutions and the chance to feel autonomous (Schukajlow & Krug, 2014b) and can be perceived as meaningful by students (Kaiser-Meßmer, 1986; Niss et al., 2007; Rellensmann & Schukajlow, 2017).

Development of interest

Successful learning is influenced by cognitive dispositions, motivational factors, and personal interests (Schiefele et al., 1993). Even though research has yet to conclusively identify how interest and learning influence one another, the significance of interest has generally been acknowledged (Hidi & Renninger, 2006; Schiefele et al. 1993; Schukajlow & Krug, 2014a). Interest influences students' focus while working (Ainley et al., 2002), performance goals (Harackiewicz et al., 2008), use of deeper learning strategies (Schiefele & Schreyer, 1994), and persistence in the face of difficulties (Ainley et al., 2002; Rellensmann & Schukajlow, 2017).

From a theoretical standpoint, interest is a motivational factor that characterizes the relationship between a person and an object (Hidi & Renninger, 2006; Krapp, 2002; Schiefele, 1991). It is generated by positive affect toward the object (Ainley et al., 2002; Krapp, 2005; Rellensmann & Schukajlow, 2017). As a motivational factor, interest is unique. On the one hand, it has a stable trait character that serves as a predisposition for motivation. On the other hand, it is an immediate response to an object or a situation – the state character (Hidi, 2006; Schukajlow et al., 2017). Hidi and Renninger described this by distinguishing between individual and situational interest (2006). Individual interest is a stable attitude toward an object that is influenced by experience. Due to former positive experiences a student might come to a class already interested in mathematics (Mitchell, 1993). Situational interest can be described as an affective reaction stimulated by a person's environment. It is less stable and might last or fleet. A student's interest might be triggered by a specific problem which catches his attention. By engaging in interesting problems this interest might develop into individual interest (Hidi, 2006; Hidi & Renninger, 2006; Krapp, 2005; Mitchell, 1993; Rellensmann & Schukajlow, 2017).

Because situational interest can be influenced, teachers should focus on addressing situational interest by providing interesting and meaningful environments (Mitchell, 1993; Rellensmann & Schukajlow, 2017; Renninger & Hidi, 2016). Therefore, it is important to take a closer look at the development of situational interest. Hidi and Renninger (2006) presented a Four-Phase model that describes how interest develops. According to this model, interest develops from a triggered to a maintained situational interest which might then develop from an emerging into a well-developed individual interest (Ainley & Hidi, 2014; Hidi & Renninger, 2006). Mitchell subcategorized situational interest into catch and hold states (1993). For example, a student's interest in a problem might be triggered or caught by a picture of a lake next to the problem and the student's attention is focused on the problem. While engaging in the problem-solving process the interest can be maintained. Due to his or her experiences with solving problems the students might develop positive feelings and curiosity towards mathematics (emerging individual interest). High appraised value of mathematics and the pursuit to engage in mathematics even if faced with difficulties is typical for well-developed individual interest (Hidi & Renninger, 2006; Mitchell, 1993).

Interest differs from other forms of motivation, not only with respect to trait and state characteristics, but also in the fact that it combines affective (feeling-related) and cognitive (value-related) components (Ainley & Hidi, 2014; Hidi, 2006; Krapp, 2002; Schiefele, 1991).

Studies have shown that interest changes from being a rather emotion-related to a value-related concept during adolescence (Frenzel et al., 2012). Hidi stated that in the moment when interest is triggered, "interest may be appropriately considered as an emotion" (2006, p. 71), but, when maintained, both emotion and value play important roles (2006). Whereas the effect might include positive and negative emotions, negative emotions may become weaker as a person's interest increases (Hidi, 2006; Hidi & Renninger, 2006). The value-related side of interest describes the effect of personal significance (Krapp, 2002). The value a person attributes to an object is considered to have great influence on intrinsic motivation (Schukajlow et al., 2012). Designing conditions that will catch students' interest is considered to be easy (Mitchell, 1993). Stimulating factors (e.g., group work, the use of computers, elements of identification, or the presentation of inconsistencies) might be factors that help catch someone's interest (Cordova & Lepper, 1996; Hidi & Renninger, 2006; Malone & Lepper, 1987; Mitchell, 1993).

Mitchell stated that holding interest has "a greater impact on students than conditions that simply catch or trigger interest" (1993, p. 426). Holding interest requires characteristics that empower students, such as involvement or meaningfulness (Harackiewicz et al., 2000; Hidi & Renninger, 2006; Mitchell, 1993). To ensure that students' basic needs for competence, autonomy, and social-relatedness are fulfilled, positive cognitive-rational and emotional feedback are required (Krapp, 2005). Competence is related to the feeling that one has an influence on the outcome of one's action (Deci, 1998; Krapp, 2005). Autonomy refers to the feeling of being independent and self-initiating, "to act with a sense of volition and agency" (Deci, 1998, p. 147). Both aspects are related to self-efficacy, the belief that one is able to obtain success with an action (Bandura, 1997). Self-efficacy is positively related to higher interest. Hidi (2006) states that higher self-efficacy might result in higher interest. An optimal level of perceived task difficulty is an important prerequisite for higher self-efficacy (Bandura, 2009) and feelings of competence and autonomy (Deci, 1998). High task difficulty might decrease the feeling of competence. Further, the experience of mastering obstacles might increase self-efficacy (Bandura, 2009). If task demands are too low, boredom and a loss of control might be experienced (Malone & Lepper, 1987; Parhizgar & Liljedahl, 2019; Pekrun, 2006; Rellensmann & Schukajlow, 2017).

Interest in modelling problems

As we noted in the prior section, interest refers to value-related and emotion-related components and is facilitated when a person perceives an object as meaningful (Renniger & Hidi, 2006). Intra-mathematical problems can facilitate the perception of meaningfulness when the mathematical problem is perceived as meaningful, whereas modelling problems can offer meaningfulness as students engage with the mathematical problem or the real-world context (Rellensmann & Schukajlow, 2017). By getting students to engage with everyday problems and establishing a connection with students' reality, modelling problems offer students a chance to develop higher utility value and higher interest (Blum & Niss, 1991; Krawitz & Schukajlow, 2018; Rellensmann & Schukajlow, 2017). Matching the real-world context with a student's personal individual interest has been suggested to promote students' perceptions of meaningfulness in modelling problems (López & Sullivan, 1992; Rellensmann & Schukajlow, 2017).

However, prior findings have presented a mixed picture. Cordova and Lepper (1996) showed higher intrinsic motivation for contextualized problems, and this motivation increased even more when the context was personalized. Contrary to these findings, Schukajlow et al. (2012) found no differences between student-reported interest in real-world problems and intra-mathematical problems administered to 224 ninth-graders. Krug and Schukajlow (2013) analyzed interest in modelling problems, dressed-up problems, and intra-mathematical problems and reported even lower interest in modelling problems than in dressed-up problems or intra-mathematical problems. One explanation offered by Krug and Schukajlow is that students might feel insecure about their solutions because they might not be used to solving modelling problems in school. Taking into account the task difficulty, Rellensmann and Schukajlow (2017) reanalyzed a subsample of this study and reported lower interest in real-world problems than in intra-mathematical problems. They suggested that, despite their findings, real-world problems should not be considered uninteresting in general because one of the reasons might be the choice of the real-world context. But this explanation builds on the assumption that the real-world context is crucial for task-specific interest (Rellensmann & Schukajlow, 2017). Whereas empirical results have shown the importance of the real-world context for strategy use (Albarracín et al., 2020), there is only limited knowledge about the importance of the context for task-specific interest. According to Parhizgar and Liljedahl (2019) students reported more positive feelings toward word problems than toward intra-mathematical problems or modelling problems. The researchers reported that modelling problems were seen as too difficult leading to frustration.

Høgheim and Reber (2017) designed a study to analyze how choice and personalizing the context to either individual or group interest influenced triggered and maintained interest. Contrary to their expectations, example choice had a significant influence on triggered but not on maintained situational interest, and their results showed no effect of the personalization of the real-world context on triggered interest. Further, one study showed that the extent to which students valued modelling problems was lower than for intra-mathematical problems (Krawitz & Schukajlow, 2018). The authors explained the low personal value of modelling problems with the lower relevance of modelling problems for passing exams or classroom practice and suggested that qualitative studies be conducted to gain deeper insights into students' perceptions of value.

The effects of task processing on students' interest have rarely been the focus of research so far. In a study on modelling problems, "dressed up" word problems, and intra-mathematical problems, the level of task-specific interest in all three types of problems targeted in this study decreased after task processing (Krug & Schukajlow, 2013). One explanation for this finding is that after task processing, students knew the solution and were no longer curious about the results or the problem-solving process. However, other factors might account for the decrease in interest. For example, changes in interest can depend on students' solution processes and may be different for students who solved the problem versus those who did not solve it.

The following study was built on results from the above-mentioned theories of interest and the reported differences in interest with respect to problems with and without a connection to reality, in order to collect more information about interest in modelling problems.

Research questions

The primary aim of this study was to obtain information about what features of a modelling problem or what students' experiences during problem solving served as sources of situational interest in modelling. Following Krug and Schukajlow's (2013) results, the other aim was to investigate possible changes in task-specific interest due to task processing. We studied the different sources of interest before and after task processing and their differences by focusing in particular on the real-world context. Our aim was to determine which characteristics of a modelling problem can capture students' situational interest and what a modelling problem needs to provide to hold their situational interest.

The research questions were:

1. What sources do students report for their interest in modelling problems?
2. Does task processing influence students' interest in modelling problems and the sources of situational interest?

Method

Selection of participants

The sample involved five ninth-graders (two boys and three girls between the ages of 14 and 15) from the high-achieving track of a German secondary school (German Gymnasium) who participated voluntarily. To select the participants and modelling problems, we administered a survey asking students from a mathematics class about their interest in mathematics and their interest in different real-world contexts. To assess interest in mathematics, we used a questionnaire from the Project for the Analysis of Learning and

Achievement in Mathematics (PALMA project; Frenzel et al., 2012). To assess interest in real-world contexts, we offered items such as "I am interested in [physics]". We included into the items contexts that we rated as interesting (or less interesting) using the Shell study on youth (Albert et al. 2015). Students rated the extent to which they agreed with the statements using a 5-point Likert scale (1 = not true at all, 5 = completely true). We also invited the students to note further real-life aspects they were interested in by presenting the item "I am interested in ….". By following the principle of maximum variation sampling (Miles & Hubermann, 1994), we chose to interview seven students who varied in gender and interest in different real-world contexts and in mathematics. All seven students had just completed a unit on the Pythagorean theorem and had some experience solving dressed-up word problems but only very limited experience solving modelling problems. On the basis of the selection of the students, we selected different real-world contexts as described next. After conducting the interviews, we selected five students who were able to verbalize the reasons for their interest in the interviews.

Data collection

Since interest is an individual concept and the sources of students' interest might be different, the students were interviewed individually. The interviews were conducted in a separate room in school on three days. After instructing the students how to solve problems by using the think-aloud method (Charters, 2003), we presented students with four different modelling problems and instructed them first to read but not to solve the problems and second to rank the problems with respect to their interest in the problems (see the overview in Figure 3). After that, we asked the students to explain their rankings. In the next step, the students were asked to solve the modelling problems using the think-aloud method. After solving all four modelling problems, the students were asked to explain their task processing and their efficacy beliefs.

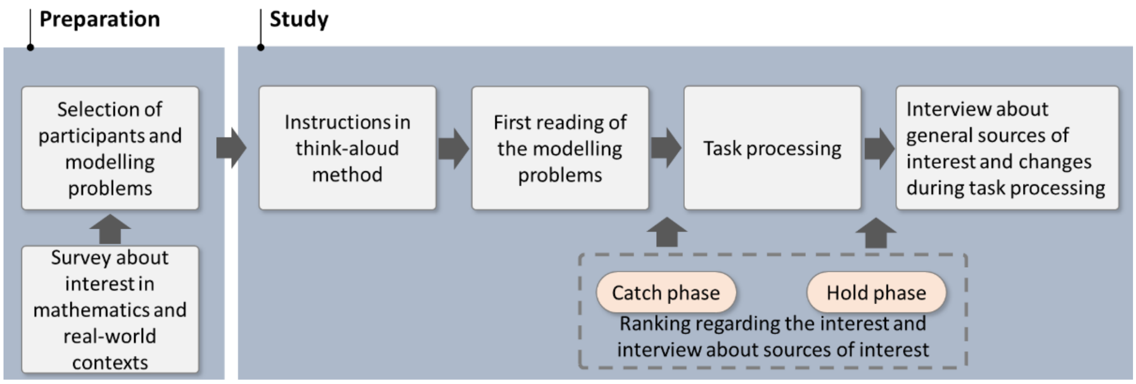

Figure 3. Overview of data collection

To investigate the impact of efficacy beliefs, we asked the students how certain they were about the correctness of their solutions. At the end, the students were asked to rank the modelling problems again. Students were interviewed in a semi-structured interview about the sources of their interest in these problems and in mathematical problems in general. If any of their rankings changed, they were asked to give reasons for these changes.

Modelling problems

We used four modelling problems in this study. To minimize the impact of mathematical content on interest-related measures as was found in a prior study (Krawitz & Schukajlow, 2018), we chose problems that targeted the length of one side of a right-angled triangle as a mathematical model and could be solved, for example, by using Pythagorean theorem. Two problems were adapted from prior studies (Rellensmann et al., 2020), and two new problems were developed for this study. To stimulate an intensive interaction with the problems, we decided to use problems that differed considerably in task difficulty and real-world context.

After selecting the students, we chose two real-world contexts that some students had identified as interesting (sailing and climbing) and one that we perceived to be uninteresting for most students (physics). A fourth context (reptiles) was chosen because one student reported this as an additional interest. We present two sample problems (for other two sample problems see appendix). The topic of sailing was chosen because some students reported interest in water sports (e.g., sailing) in the questionnaire ($M=3.55$, $SD=1.28$). Of our five participants, one reported very high interest in water sports, one reported rather high interest, two a medium level of interest, and one rather low interest. We adapted the content of the "Anchor" problem (see Figure 1) by using the "Möhnesee" as the location of the scene. This lake is located near the participants' school. As a second problem (see the "Physics" problem in Figure 4), we chose the topic of physics because of an average low level of interest in physics in the participating class ($M=2.84$, $SD=1.21$). Among the five participants, interest ranged from very low interest to rather high interest. We adapted this problem from previous studies to the context of a physics experiment (Baierl, 2018). Similar to the "Anchor" modelling problem, the problem contained irrelevant information, and problem solvers had to make assumptions to build a real model. The modelling process differed from the "Anchor" modelling problem with respect to the mathematical problem. Unlike in the other three problems, the mathematical model did not contain a right-angled triangle but instead an isosceles triangle with a known height. We assumed students would view this modelling problem as more demanding.

Physics

Mrs. Bohm and her students are investigating the interrelation of electrical voltage and the expansion of metal. For the experiment, an 82 cm long wire is fixed at a height of 15 cm, and a power source between 0 and 10 A is connected. A 20 g weight is hanging from the middle of the wire. When electricity is conducted through the wire, the wire expands, and the weight begins to sink. Jens increases the amperage to 3 A and measures the height of the weight, which is now 11.8 cm high. How much did the wire expand?

Figure 4. "Physics" modelling problem

Data analysis

The problem-solving process and the interviews were transcribed, and sequences regarding interest and efficacy beliefs were identified. The sequences were analyzed using qualitative content analysis (Mayring, 2010). Three category schemes were developed regarding the temporal reference, efficacy beliefs, and the sources reported for interest. More specifically, the sequences were coded with respect to the time before, during, or after task processing and statements about interest in modelling problems without a temporal reference. The efficacy beliefs were divided into high efficacy beliefs, medium efficacy beliefs, and low efficacy beliefs. The category scheme for the sources of interest in the problems was developed deductively. After coding two interviews, we adapted the category scheme and added the category of familiarity. The sources of interest were grouped into categories that referred to the real-world context, problem solving, the perceived level of task difficulty, efficacy beliefs, and other task features. Table 1 presents examples of each of these categories.

Table 1. Categories: sources of interest

Category	Description	Anchor example
Real-world context	Statements about the real-world context.	I like climbing. That’s why I find this appealing.
Problem solving	Statements about problem solving.	I had fun solving the first task and that’s why.
Perceived task difficulty	Statements about the perceived level of task difficulty.	Yes, because it was more demanding.
Efficacy beliefs	Statements about efficacy beliefs.	I think the least was the one with the gecko because spontaneously I had no idea how to calculate this.
Other task features	Statements about other task features, such as the openness of the task.	Well, I am happy about vague tasks because one is not so fixed to something, but [...]

The categories of the real-world context and the problem solving were subcategorized into statements that were emotion-related, value-related, or mentioned familiarity, as demonstrated in the following examples (Table 2).

Table 2. Real-world context subcategories

Category	Description	Anchor example
Emotion-related	Statements about emotions about the task that focused on the real-world context	I like climbing. That's why I find this appealing.
Value-related	Statements attributing a value to the real-world context	I think that it could be the most practical.
Familiarity	Statements about the familiarity of the real-world context	And when you know this from every-day life, I find it the most interesting.

To examine the objectivity of the category scheme, the stability of the scheme was tested by calculating the intercoder reliability for two of the five interviews. Satisfactory agreement was obtained (Cohen's Kappa was between .66 and .93; Fleiss & Cohen, 1973).

Results

In this section, we present general findings concerning the sources of interest that students reported and two exemplary interviews. Sequences referring to interest before task processing are accompanied by the student's name, the time, and the letter B; sequences referring to interest after task processing are identified by the letter A; and those without a specific reference to the time are marked with the letters NA.

Sources of interest

For the first research question, we first present general findings concerning the sources of interest that students reported in the interviews. The analysis revealed a variety of reasons for interest in modelling problems. The main sources of interest in modelling problems were emotions about the real-world context and efficacy beliefs.

For the processing of half of the 20 cases (five students who each worked on four problems) the learners offered either positive emotions or negative emotions about the context as the sources of interest:

Laura_B 08:37	As the most interesting, I pick the second because I like the Möhnesee.
Laura_B 08:26	Well, as the least interesting, I pick the last one because I don't like physics.

Value-based references toward the real-world context occurred only five times. Students also reported the familiarity of the context or problem solving as sources of interest. Further, students explained their interest by referring to their emotions about problem solving.

Most of the participants referred to their efficacy beliefs before or after task processing as a reason for either high or low interest. Three times students reported a high level of perceived task difficulty as a reason for low interest and not once as a reason for high interest.

When asked what makes a problem interesting in general, similar results occurred. Most students (four out of five) referred to their efficacy beliefs and the real-world context as important sources of interest. Lukas reported the importance of being able to solve the problem:

> Lukas_NA 42:47 That's why I think one of the most important things is that you know how to proceed, at least in basic terms.

One student described the openness of a problem as a source of interest by referring to the autonomy the problem offered:

> Mike_NA 37:06 Well, I am happy about vague tasks because one is not so fixed to something, but [...]

Sources of interest before task processing

For the second research question, we compared the ranking of the problems before and after task processing and analyzed the sources of interest the students reported by differentiating between sources before and after task processing. Comparing the rankings, we saw a change in four of five interviews. Students referred to emotions about the real-world context nine times and to the familiarity of the context twice as sources of interest before task processing:

> Sarah_B 11:21 Well, that I found interesting, but I was unsure about the order between [task] two [the Anchor task] and [task] three because, with the Möhnesee, I know it, and sometimes I go there.

Before task processing, there were no value-related mentions of the context or any references to problem solving. Along with the real-world context, efficacy beliefs were the predominant source of situational interest.

Sources of interest after task processing

The sources of interest after task processing varied significantly. All students reported the real-world context as the reason for their interest and referred to their emotions, the value, or the familiarity of the context. Further, some students included problem solving in their explanations of their interest after task processing. They noted their emotions about problem solving four times and the familiarity of the problem once as sources of interest:

> Sarah_A 41:08 For task one, I somehow had fun solving the task all the time and that's why.

> Lukas_A 38:28 This matches the tasks we solved in class, that's why this was the most interesting task for me.

Further, we observed shifts in students' interest after task processing. One student reported that despite initially having negative emotions about the real-world context, she found the problem interesting because of positive emotions and a strong feeling of involvement while solving the problem:

> Sarah_A 39:28 Yes. Well, somehow, I had the drive to finish the task, even though physics is not my favorite subject (laughs), I must say, and not my strength. But, I don't know, it made me, that I got tied up over solving it. That's why, yes.

The main source of interest (or lack of interest) were efficacy beliefs. The following sequence shows that despite an initial triggering of interest, interest can dissolve after problem solving:

> Lukas_A 39:00 And then task two. Well, at first, I thought it would be more interesting [...] But then I didn't know how to calculate it.

In the following, we present two students, their interest in the different contexts and the two interviews. We selected these two students because their responses illustrated (a) the changes concerning the interest in the different modelling problems, (b) the process of solving the problems and the students' self-efficacy, and (c) how these factors emerged as sources of situational interest.

Sarah

The first student, Sarah, can be characterized as a higher achieving student with a medium level of interest in mathematics (M=3). According to her questionnaire, she is very interested in climbing and has a medium level of interest in physics and water sports. Before task processing, she rated the problems as displayed in Figure 5.

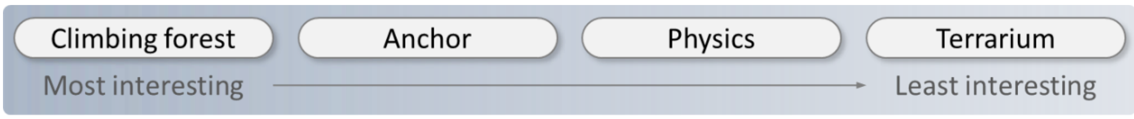

Figure 5. Ranking by interest, Sarah, pre-task processing

After task processing, her ratings changed (Figure 6).

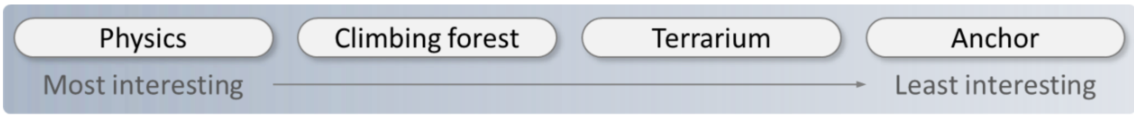

Figure 6. Ranking by interest, Sarah, post-task processing

Before solving the problem, Sarah rated the Climbing problem as the most interesting problem and reported her interest in climbing which we saw in the survey as a reason.

> Sarah_B 08:43 Well, task one. I like climbing. That's why I find this appealing.

After solving the problem incorrectly, she was still confident that her solution was correct and referred to the context and her emotions while solving the problem (Sarah_A 41:08). She mentioned having fun during problem solving. Sarah rated the Anchor problem as the second most interesting problem and justified this rating by referring to her positive emotions in this context. After not being able to solve the Anchor problem, she rated it as the least interesting. Her argument about the reasons for her interest shifted from the context to her efficacy beliefs:

> Sarah_A 40:08 Well, I think, as the least interesting, I would take task two because I was not able to work on it because I didn't know how.

Before task processing, Sarah rated the Terrarium problem as the least interesting because of her efficacy beliefs:

> Sarah_B 07:31 I believe the least interesting one is the one with the gecko because I had no idea how to solve it or how it should act.

Sarah struggled during problem solving. After task processing, she was confident that she found the solution to the problem and changed her rating from the least interesting problem to the third most interesting problem. In her response, she referred to her perception of difficulties during problem solving as the reason for her low level of interest:

> Sarah_A 40:56 I don't know, somehow with the third task, in the beginning, I had some problems figuring out how to solve it and this lowered my motivation.

Regarding the Physics problem, we could see a strong shift in her perceptions of interest after task processing. Before task processing, she rated the problem as the third most interesting and explained this by referring to her negative feelings about the context. Afterward, she rated the Physics problem as the most interesting problem because of her positive emotions and her strong involvement in problem solving (Sarah_A 39:28).

When she was asked about the differences between her rankings before and after solving the problems, she explained them with her efficacy beliefs:

Sarah_NA 41:47 I think that it is because, for some of the tasks, it was easier for me to solve them, and for others, it was more difficult. And I think that determined it.

When asked what makes a problem interesting in general, she replied:

Sarah_NA 45:21 Well, when it concerns something that doesn't interest me, as a hobby or so, then I find the task less interesting as well. And if the things that it's about appeal to me, if I like them, then I find it more interesting.

Laura

The second student, Laura, a student with a medium level of achievement, reported a low level of interest in mathematics (M=1.67). She reported greater interest in water sports, medium interest in climbing, and very low interest in physics. Before task processing, she ranked the modelling problems as depicted in Figure 7.

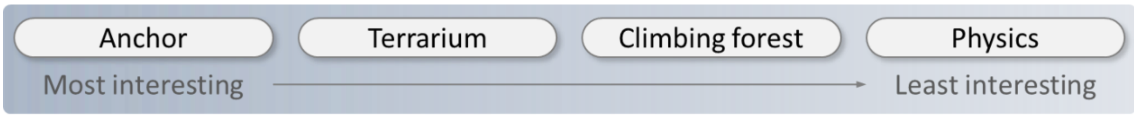

Figure 7. Ranking by interest, Laura, pre-task processing

She immediately ranked the Physics problem as the least interesting one, justifying this with her dislike of physics (Laura_B 08:26). She explained her rankings of the other problems by referring to her emotions about the real-world contexts (Laura_B 08:37):

Laura_B 09:18 Yes, because I like climbing, but not so much.

After task processing, her rankings differed only for two problems (Figure 8).

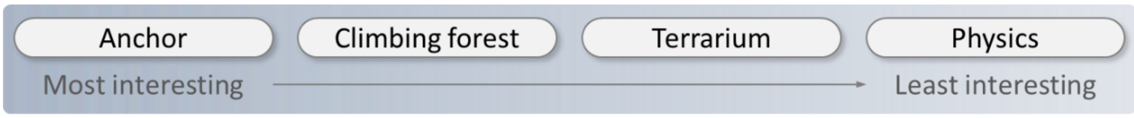

Figure 8. Ranking by interest, Laura, post-task processing

After task processing, her interest in the Physics problem remained the lowest, still based on her low interest in physics and the lack of familiarity and value of the context:

Laura_A 29:48 That was physics and that's something I don't calculate in reality.

Her interest ranking changed with respect to the Climbing problem and the Terrarium problem. She offered value-based explanations regarding the real-world context:

> Laura_A 30:31 This (points to the Climbing forest problem) I found more interesting than this (points to the Terrarium problem). Why I'm not sure, but somehow it would bring more than that.

While she reported only context-based sources as a reason for her interest in specific problems, she still referred to her efficacy beliefs when asked what makes a modelling problem interesting in general.

> Laura_NA 34:41 It matters if I can solve it or not.

Comparing the two cases, we can see that both students reported their emotions towards the real-world context as a source of interest before problem solving. After problem solving, Sarah – a student with medium interest in mathematics – focused on the process of solving the problems whereas Laura – a lower achieving student with low interest in mathematics – focused on the value of the real-world context.

Discussion

The importance of interest in the classroom is undisputed. Because solving problems is a main part of mathematical learning, providing learners with problems that are perceived as interesting should be a goal of mathematical education (Rellensmann & Schukajlow, 2017). The primary aim of our study was to analyze sources of situational interest in modelling problems. More specifically, we were interested in the relevance of the context and of the problem-solving process. On the basis of the assumption that situational interest varies significantly in a specific situation (Hidi & Renninger, 2006; Mitchell, 1993), we investigated changes in interest and sources of interest due to task processing by asking students to rank four modelling problems and to report their reasons for their rankings. The aim of this analysis was to identify which characteristics catch and which characteristics hold students' situational interest.

Our study revealed a variety of different sources of situational interest. As suggested in the theory of interest in solving real-world problems, our study revealed the importance of the real-world context for triggering interest (Rellensmann & Schukajlow, 2017). A new finding that is consistent with the theory of interest is that the emotions about the context played a predominant role. In the catch phase of situational interest, emotions about the real-world context and efficacy beliefs were in most cases the decisive aspects that were reported. These findings correspond with Hidi's (2006) assumption that, when interest is being triggered, it can be considered an emotion. Therefore, when constructing modelling problems, one focus should be the choice of real-world contexts that can trigger an emotional response. As indicated by our results, this can also be achieved by placing the situation in a familiar environment (Hidi & Renninger, 2006). However, contrary to theoretical considerations from modelling research (Blum & Niss, 1991; Krawitz & Schukajlow, 2018), the value of the context was not identified as an important source of students' interest for most students. One explanation might be that the problems were not clearly related to students' future lives. The responses to the Anchor problem may have been different if students had been on the boat and the drift from the anchor point was highly relevant to them. Only one student – a student with low interest in mathematics – mentioned the value of the real-world context several times. This finding suggests that for students with low interest in mathematics interest in solving problems can be increased by providing meaningful real-world contexts.

Our results suggest that a more differentiated view on interest is necessary as presented in Figure 9. During the hold phase of situational interest, after task processing, a wider variety of sources was reported by the learners. Although the real-world context still played a critical role in maintaining interest, the value of the context needed to be considered as well. One reason for this could be that the value of solving a problem might be visible only after intensive engagement with the problem.

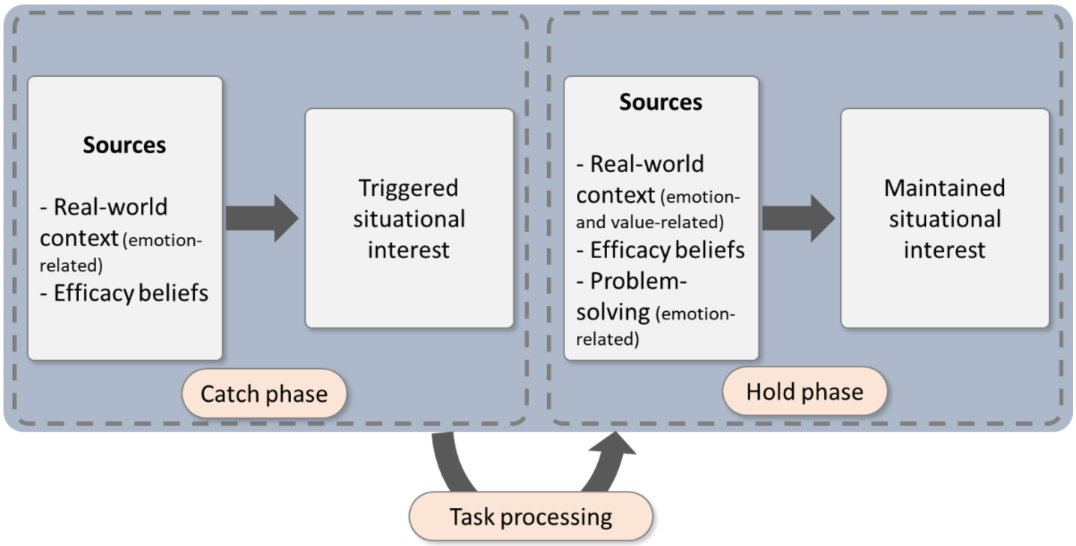

Figure 9. Overview of sources of situational interest in the catch and hold phases

High efficacy beliefs were often associated with high interest in the problem. After task processing, low efficacy beliefs were often mentioned as a reason for low interest after task processing. On the basis of these results, we propose that, even if interest had been triggered by the real-world context, low efficacy beliefs might result in low maintained interest. Contrary to theoretical considerations only a few students reported the perceived difficulty of the task as a reason for their interest. As perceived task difficulty and efficacy beliefs are strongly connected (Bandura, 2009), we still assume that task difficulty is one important part of maintaining situational interest. Students reported high interest when they perceived the problems as not too difficult and when they were confident they would be able to solve the problem. These findings suggest that an optimal level of task difficulty is fundamental for students' situational interest as suggested by Parhizgar and Liljedahl (2019). A new result that, to the best of our knowledge, has not been previously reported is that the openness of a problem seems to have a great deal of relevance. This result indicates that modelling problems can increase interest by enabling a feeling of autonomy. Consequently, positive effects of prompting students to find multiple solutions to modelling problems on interest that were found in a prior study (Schukajlow & Krug, 2014b) might hail from the openness of modelling problems.

Surprisingly, our results propose that despite negative emotions regarding the problem during the catch phase, interest can arise in the hold phase during task processing (Hidi & Renninger, 2006; Hidi, 2006). We propose that a high level of involvement in the solving of modelling problems can maintain and sometimes even evoke students' interest, even in cases when modelling problems do not offer characteristics such as an emotionally appealing and familiar context that triggers interest in the catch phase before task processing.

Conclusions and limitations

In the present study, we investigated sources of interest by prompting students to rank different modelling problems by interest and to give reasons for their rankings. To analyze the influence of task processing on the sources of interest, we asked the students to rank the four modelling problems before and after task processing. We found that emotions about the real-world context along with efficacy beliefs played large roles in triggering interest, whereas a wider range of aspects were important for maintaining interest during task processing.

Before we discuss implications for teaching and research, we must acknowledge some limitations of the study. As usual for a qualitative study, one limitation is the size of the sample, which does not allow generalization across students. In particular, the generalization to different age groups is not possible because students' age might affect their interest (Frenzel et al., 2012). Another important limitation is that we deliberately selected modelling problems that could be solved with the same mathematical procedure. We did not vary the mathematical topics as prior studies have identified interactions between mathematical topics and interest-related measures (Krawitz & Schukajlow, 2018). By choosing problems concerning only one mathematical content area, the students may focus more on the real-world context as a source of interest. Focusing on only one mathematical topic may also have affected the emotions towards problem solving. Future studies should include different mathematical contents.

Our findings on sources of task-specific interest in modelling problems are relevant to education research and teaching practice. We suggest that the individualization of modelling problems is very important. By using topics that the students emotionally respond to, their interest can be captured. This might include everyday objects or simply a local reference. Surprisingly, the value of the problem did not trigger situational interest in our study. To hold students' interest, students must have high efficacy beliefs while and after they solve the problems. Teachers should try to increase students' efficacy beliefs by giving positive feedback and avoiding failure feedback (Pekrun, 2006). Encouraging students to validate their results can increase their efficacy beliefs as well and might help to hold their interest. Finally, we would like to point out the great insights that can be accessed by simply asking students about the sources of their interest. If teachers know more about students' interest, they can offer modelling problems that match students' interest. When students have a high level of initial interest before they solve a problem, their engagement in solving problems can increase, and via engagement, students can both maintain their interest and increase their modelling competencies in the long run.

Acknowledgments

Thanks go to Timo Wächter for his support in conducting the study reported here.

References

Ainley, M., & Hidi, S. (2014). Interest and enjoyment. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 205-227). New York: Routledge.

Ainley, M., Hidi, S., & Berndorff, D. (2002). Interest, learning, and the psychological processes that mediate their relationship. *Journal of Educational Psychology, 94*(3), 545-561. https://doi.org/10.1037/0022-0663.94.3.545

Albarracín, L., Ferrando, I., & Gorgorió, N. (2020). The role of context for characterising students' strategies when estimating large numbers of elements on a surface. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-020-10107-4

Albert, M., Hurrelmann, K., & Quenzel, G. (2015). *17. Shell Jugendstudie. Jugend 2015.* Frankfurt/Main: Fischer.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freemann.

Bandura, A. (2009). Cultivate self-efficacy for personal and organizational effectiveness. In E. A. Locke, (Ed.), *Handbook of principles of organization behavior* (Vol. 2, pp. 179-200). New York: Wiley. https://doi.org/10.1002/9781119206422.ch10

Baierl, O. (2018). *Hitzedrahtampermeter*. Retrieved from https://www.physikalische-schulexperi mente.de/physo/Hitzedrahtampermeter.

Blum, W. (2015). Quality teaching of mathematical modelling: What do we know, what can we do? In S. J. Cho (Ed.), *The Proceedings of the 12th International Congress on Mathematical Education* (pp. 73–96). Cham: Springer.

Blum, W., & Leiss, D. (2007). How do students and teachers deal with mathematical modelling problems? The example sugarloaf and the DISUM project. In C. Haines, P. L. Galbraith, W. Blum, & S. Khan (Eds.), *Mathematical modelling (ICTMA 12): Education, engineering and economics* (pp. 222–231). Chichester: Horwood.

Blum, W., & Niss, M. (1991). Applied mathematical problem solving, modelling, applications, and links to other subjects-state, trends and issues in mathematics instruction. *Educational Studies in Mathematics*, *22*, 37–68. https://doi.org/10.1007/BF00302716

Charters, E. (2003). The use of think-aloud methods in qualitative research. An introduction to think-aloud methods. *Brock Education Journal, 12*(2), 68-82. https://doi.org/10.26522/brocked.v12i2.38

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology, 88*(4), 715–730. https://doi.org/10.1037/0022-0663.88.4.715

Deci, E. L. (1998). The relation of interest to motivation and human needs – The self-determination theory viewpoint. In L. Hoffmann, A. Krapp, K. A. Renninger, & J. Baumert (Eds.) *Interest and learning. Proceedings of the Seeon-conference on interest and gender* (pp. 146-162). Kiel, Germany: IPN.

Fleiss, J. L., & Cohen, J. (1973). The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. *Educational and Psychological Measurement, 33*(3), 613-619. https://doi.org/10.1177/001316447303300309

Frenzel, A. C., Pekrun, R., Dicke, A. L., & Goetz, T. (2012). Beyond quantitative decline: Conceptual shifts in adolescents' development of interest in mathematics. *Developmental Psychology*, *48*(4), 1069-1082. https://doi.org/10.1037/a0026895

Harackiewicz, J. M., Barron, K. E., Tauer, J. M., Carter, S. M., & Elliot, A. J. (2000). Short-term and long-term consequences of achievement goals: *Predicting interest and performance over time. Journal of Educational Psychology, 92*(2), 316–330. https://doi.org/10.1037/0022-0663.92.2.316

Harackiewicz, J. M., Durik, A. M., Barron, K. E., Linnenbrink-Garcia, L., & Tauer, J. M. (2008). The role of achievement goals in the development of interest: Reciprocal relations between achievement goals, interest, and performance. *Journal of Educational Psychology, 100*(1), 105–122. https://doi.org/10.1037/0022-0663.100.1.105

Hidi, S. (2006). Interest: A unique motivational variable. *Educational Research Review*, *1*(2), 69-82. https://doi.org/10.1016/j.edurev.2006.09.001

Hidi, S., & Renninger, K. A. (2006). The four phase model of interest development. *Educational Psychologist, 41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Høgheim, S., & Reber, R. (2017). Eliciting mathematics interest: New directions for context personalization and example choice. *The Journal of Experimental Education, 85*(4), 597-613. https://doi.org/10.1080/00220973.2016.1268085

Kaiser-Meßmer, G. (1986). *Anwendungen im Mathematikunterricht.* Bad Salzdetfurth: Franzbecker.

Krapp, A. (2002). Structural and dynamic aspects of interest development: Theoretical considerations from an ontogenetic perspective. *Learning and Instruction*, *12*(4), 383-409. https://doi.org/10.1016/S0959-4752(01)00011-1

Krapp, A. (2005). Basic needs and the development of interest and intrinsic motivational orientations. *Learning and Instruction*, *15*(5), 381-395. https://doi.org/10.1016/j.learninstruc.2005.07.007

Krawitz, J., & Schukajlow, S. (2018). Do students value modelling problems, and are they confident they can solve such problems? Value and self-efficacy for modelling, word, and intra-mathematical problems. *ZDM Mathematics Education 50*, 143–157. https://doi.org/10.1007/s11858-017-0893-1

Krug, A., & Schukajlow, S. (2013). Problems with and without connection to reality and students' task-specific interest. In A. M. Lindmeier & A. Heinze (Eds.), *Proceedings of the 37th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 3, pp. 209–216). Kiel, Germany: PME.

López, C. L., & Sullivan, H. J. (1992). Effect of personalization of instructional context on the achievement and attitudes of Hispanic students. *Educational Technology Research and Development, 40*(4), 5–14. https://doi.org/10.1007/BF02296895

Maaß, K. (2010). Classification scheme for modelling tasks. *Journal für Mathematik-Didaktik*, *31*(2), 285-311. https://doi.org/10.1007/s13138-010-0010-2

Malone, T. W., & Lepper, M. L. (1987). Making learning fun: A taxonomy of intrinsic motivation for learning. In R. E. Snow, & M. J. Farr (Eds.), *Aptitudes, learning, and instruction: Vol. 3. Conative and affective process analysis* (pp. 223-254). Hillsday, New York: Erlbaum.

Mayring, P. (2010). *Qualitative inhaltsanalyse. Grundlagen und techniken.* Weinheim, Germany: Beltz.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis an expanded sourcebook* (2nd ed.). Thousand Oaks: Sage.

Mitchell, M. (1993). Situational interest: Its multifaceted structure in the secondary school mathematics classroom. *Journal of Educational Psychology, 85*(3), 424–436. https://doi.org/10.1037/0022-0663.85.3.424

Niss, M., Blum, W., & Galbraith, P. L. (2007). Introduction. In W. Blum, P. L. Galbraith, H.-W. Henn, & M. Niss (Eds.), *Modelling and applications in mathematics education: The 14th ICMI study* (pp. 1–32). New York: Springer.

Parhizgar, Z., & Liljedahl, P. (2019). Teaching modelling problems and its effects on students' engagement and attitude toward mathematics. In S. Chamberlin, & B. Sriraman (Eds.), *Affect in mathematical modeling* (pp. 235-256). Cham: Springer. https://doi.org/10.1007/978-3-030-04432-9_15

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*, 315-341. https://doi.org/10.1007/s10648-006-9029-9

Pekrun, R., Goetz, T., Titz, W., & Perry, R.P. (2002). Academic emotions in students' self-regulated learning and achievement: a program of qualitative and quantitative research. *Educational Psychologist, 37*(2), 91–105. https://doi.org/10.1207/S15326985EP3702_4

Rellensmann, J., & Schukajlow, S. (2017). Does students' interest in a mathematical problem depend on the problem's connection to reality? An analysis of students' interest and pre-service teachers' judgments of students' interest in problems with and without a connection to reality. *ZDM, 49*(3), 367-378. https://doi.org/10.1007/s11858-016-0819-3

Rellensmann, J., Schukajlow, S., & Leopold, C. (2020). Measuring and investigating strategic knowledge about drawing to solve geometry modelling problems. *ZDM*, *52*(1), 97-110. https://doi.org/10.1007/s11858-019-01085-1

Renninger, K. A., & Hidi, S. (2016). *The power of interest for motivation and engagement.* New York: Routledge.

Schiefele, U. (1991). Interest, learning, and motivation. *Educational Psychologist, 26*, 299-323. https://doi.org/10.1207/s15326985ep2603&4_5

Schiefele, U., Krapp, A., & Schreyer, I. (1993). Metaanalyse des Zusammenhangs von Interesse und schulischer Leistung. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie, 25*, 120-148.

Schiefele, U., & Schreyer, I. (1994). Intrinsische Lernmotivation und Lernen. Ein Überblick zu Ergebnissen der Forschung. *Zeitschrift für Pädagogische Psychologie, 8*, 1-13.

Schukajlow, S., & Krug, A. (2014a). Are interest and enjoyment important for students' performance? In C. Nicol, S. Oesterle, P. Liljedahl, & D. Allan (Eds.), *Proceedings of the Joint Meeting of PME 38 and PME-NA 36* (Vol. 5, pp. 129–136). PME.

Schukajlow, S., & Krug, A. (2014b). Do multiple solutions matter? Prompting multiple solutions, interest, competence, and autonomy. *Journal for Research in Mathematics Education, 45*(4), 497-533. https://doi.org/10.5951/jresematheduc.45.4.0497

Schukajlow, S., Leiss, D., Pekrun, R., Blum, W., Müller, M., & Messner, R. (2012). Teaching methods for modelling problems and students' task-specific enjoyment, value, interest and self-efficacy expectations. *Educational Studies in Mathematics*, *79*(2), 215-237. https://doi.org/10.1007/s10649-011-9341-2

Schukajlow, S., Rakoczy, K., & Pekrun, R. (2017). Emotions and motivation in mathematics education: theoretical considerations and empirical contributions. *ZDM Mathematics Education, 49*(3), 307-322. https://doi.org/10.1007/s11858-017-0864-6

Appendix

Modelling problems

Climbing forest

Mr. Meier is the owner of a climbing forest. 12 years ago, he opened the leisure attraction for both young and old. Now he has to renew the steel cables on which the safety ropes are affixed. To renew them, he needed more steel cable than he thought. Now he is left with only 22 m to connect the last two trees with a rope slide. To enable the visitors to slide from one tree to the next, the platform on the landing tree is lower than the one on the starting tree. On the starting tree, the rope is attached at a height of 10 m. The visitor lands 17 m away on another platform. There the rope is attached at a height of 8.5 m. To attach the rope to the tree, he needs 1.5 m on each side.

Does Mr. Meier need to buy more rope or is the amount of rope sufficient?

Terrarium

Geckos are amazing climbers. With specialized toe pads, they are able to climb vertical walls and even glass panes. Their main diet is insects and spiders. A gold dust day gecko and a fly have finished a tiring chase in a terrarium that is 2.3 m long, 0.9 m wide, and 1.5 m high. Now the fly is sitting in the top left rear corner, and the gecko is sitting in the bottom right front corner. The gecko has a chance, but it must be quick.

Which way should it go?