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Research article

How teacher questioning can reduce the cognitive demand of mathematical tasks

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Abstract: This study investigates the impact of teacher questioning on the cognitive demand of mathematical tasks within the context of the Developmental Education in Mathematics (DEM) reform initiative in Norway. Using a case study design, researchers' video-recorded and analyzed twelve lessons by four primary teachers. The analysis focused on the function of teacher questions within classroom dialogues around challenging tasks. Findings reveal that while DEM emphasizes challenging tasks and conceptual understanding, teacher questioning often inadvertently simplifies problems, limiting students' opportunities for learning and development. This tendency is exacerbated by DEM's focus on rapid progression, which can conflict with the need for students to dwell on tasks that are challenging for them. The study underscores the need for teacher training to navigate the complexities of balancing rapid progression with student-led exploration and conceptual understanding.

Keywords: teacher questioning, challenging tasks, mathematical discussions, development

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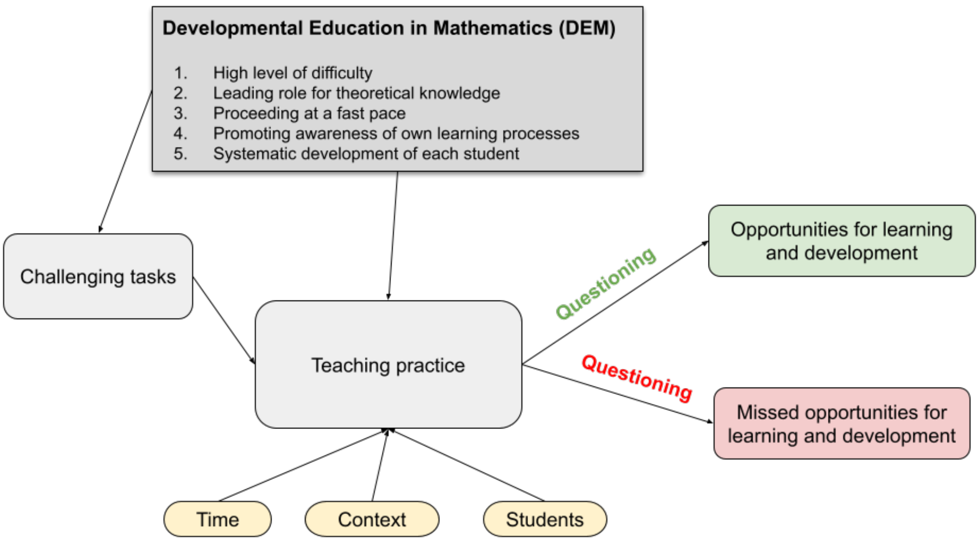

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1 Introduction

Many current reform initiatives concentrate on facilitating students' exploration of challenging mathematical tasks through productive discussions (e.g., Stein et al., 2008). One such reform initiative is Developmental Education in Mathematics (DEM). DEM is based on a system for primary education developed by Leonid V. Zankov, who was a student and later colleague of Lev S. Vygotsky. Zankov's system was built on Vygotsky's theories. Five pedagogical principles lie at the heart of Zankov's (1977) system, (1) teaching at a high level of difficulty (but within the students' zone of proximal development); (2) emphasis on theoretical knowledge; (3) proceeding at a fast pace; (4) promoting the students' awareness of their own learning processes; and (5) systematic development of each individual student. DEM builds on these principles and on a set of mathematics textbooks based on them. The textbooks for years 1–4 were originally written in Russian in the 1990s and have been translated and adapted to a Norwegian context by scholars at the University of Stavanger.

From Zankov's principles, it follows that challenging mathematics tasks play a central role in DEM, and "challenge" is here considered in relation to the zone of proximal development. The tasks often lend themselves to multiple strategies, and the textbook teacher guides (Melhus et al., 2023; Melhus, 2015) provide teachers with advice for how to conduct mathematical discussions based on the various tasks and solution strategies. Generally, DEM students do not read the tasks in the textbooks individually, but the teachers are advised to present the task on a screen, step by step, and then alternate between individual work and whole-class discussions. In line with Vygotsky's theories, classroom dialogue and discussions are prominent.

However, following DEM principles is challenging and teachers may face significant dilemmas when trying to balance the various principles (Gjære, 2023). The research literature in mathematics education generally indicates that the work of leading mathematical discussions centered around challenging tasks is demanding, which Stein et al. (2008) emphasized when presenting their five practices for leading productive mathematical discussions. Although studies have explored possible influences on the cognitive demand of tasks (e.g., Jackson et al., 2013), few studies have explored relationships between teacher questioning and discussions of challenging tasks. One exception is the study by Martin et al. (2015), which indicated that the level of the mathematical tasks and the teacher questioning influenced discussions, and they showed that teachers developed their questioning and enactment of tasks through professional development. Yet, few studies have explored how teacher questioning might reduce the demands of tasks when enacted in classroom discussions. Our study aims at contributing to fill this knowledge gap by investigating how teacher questioning might influence enactment of challenging tasks in the context of DEM.

2 Theoretical background

2.1 Defining challenging tasks

Tasks are integral to mathematics teaching. Some are mere exercises or routine tasks, whereas other tasks are more challenging. Challenging tasks are often emphasized in research, but researchers use different terms to describe such tasks. Some focus on the demands that tasks place on students, and they use terms like "cognitively demanding tasks" (e.g., Wilhelm, 2014). Others, like Russo and Hopkins (2017), use the term "challenging tasks" as synonymous of cognitively demanding tasks. Russo and Hopkins (2017) add that challenging tasks often have multiple solutions and are complex. Others refer to them as "high-level" tasks. For instance, Stein et al. (2008) consider "high-level cognitively-challenging tasks" as the prerequisite of productive mathematical discussions. Finally, some refer to such tasks as "meaningful" and "worthwhile". There is often more than one way of solving challenging tasks, they can be represented in different ways, and their solution requires communication and justification (Stein et al., 1996).

In the present study, we use the term "challenging tasks", and we follow Russo and Hopkins (2017) when we consider challenging tasks to be cognitively demanding. Furthermore, we consider challenge in terms of Vygotsky's theory of teaching-learning and development. Vygotsky (1998) described the zone of proximal development as the level that students could manage with the help of someone more knowledgeable. Similarly, we consider challenging tasks as tasks that go beyond the level that students can manage on their own (actual development level), and into the level that students can manage with the help of others (zone of proximal development). When explaining the principles of optimal difficulty and theoretical knowledge, Zankov criticized mechanical memorization and stated that the types of challenges students should encounter in school relate to generalizations and to understanding "various concepts, relationships, and dependencies" (Zankov, 1977, p. 57). We therefore connect mathematical challenges as seen from Zankov's perspective with the development of conceptual understanding (see Hiebert & Carpenter, 1992). This view also aligns with that of Doyle (1988) on the quality of students' mathematical work. When we discuss students' opportunities to learn, we refer to opportunities to grapple with mathematical challenges that are at a high level for the students, and that have the potential to support development of conceptual understanding.

Building on Doyle (1988), Stein et al. (1996) proposed the mathematics task framework. This framework has become influential in research on challenging tasks and specifies further what high-level mathematical work entails (Hsu & Yao, 2023). This framework considers the use of an instructional task from its representation in the textbook, via the teachers' presentation, to students' work done on the task in the classroom. This process determines the students' mathematical learning. Stein et al. (1996) considered learning outcomes; we consider learning opportunities.

Important to our study, the framework considers the level of cognitive demand of the students' mathematical work. The framework describes students' mathematical activity at six levels. Two of the levels (no mathematical activity and nonproductive exploration) are not considered here since all the discussions we analyzed were both mathematical and, to varying degrees, productive. The four remaining levels are as follows (Stein & Lane, 1996):

- *Memorization* (level 1) refers to students recalling facts, formulas, rules, or definitions, or the act of committing them to memory, with little or no conceptual or meaningful connections.
- *Procedures without connections* (level 2) refers to students using procedures without any awareness of how or why they work, or connections to underlying mathematical ideas. The goal is to get the correct answer, and the process is a routine operation with a well-rehearsed algorithm.
- *Procedures with connections* (level 3) refers to students using procedures—often suggested by the teacher or the textbook—in ways that connect with mathematical concepts and ideas, and which provides opportunities to gain a deeper mathematical understanding in the process of solving the task.
- *Doing mathematics* (level 4) refers to students solving mathematical problems for which they lack a clear and predictable solution method or strategy, and which require exploration and non-algorithmic thinking.

Levels 1 and 2, based on simple recall and reproduction of facts and procedures, generally describe mathematical activity at a low cognitive level. Levels 3 and 4, based on mathematical understanding and more complex thinking, generally describe mathematical activity at a high cognitive level. Level 4 refers to mathematical problem solving, which is a long-established field of mathematics education (e.g., Liljedahl & Cai, 2021). However, challenging tasks is a broader category that also includes in-depth work on tasks with procedures already known to the students (level 3).

Although this framework builds on Doyle (1988), we note here a connection with sociocultural theory. When solving challenging problems for which they lack a solution method (level 4 in the framework), students need to call on a knowledge base of mathematical facts and procedures (Schoenfeld, 1992). In this case, memory plays a role in a more complex solution process. Routine tasks, on the other hand, tend to ask students to recall only. Vygotsky (1978) posited that lower-level processes such as recalling a fact becomes integrated with higher-level processes requiring reasoning as the student develops, and that this development should be stimulated at school. This theoretical alignment forms an important part of our rationale for choosing the mathematics task framework for our study.

2.2 Research on challenging tasks

Research on challenging tasks is diverse. From our review of the literature on challenging tasks, we identify three broad groups of studies, focusing on 1) requirements for using challenging tasks, 2) the presentation or setting up of these tasks, and 3) the orchestration of discussions of challenging tasks.

First, research on requirements for using challenging tasks includes studying how teachers make sense of tasks (e.g., Monarrez & Tchoshanov, 2022), or investigating the knowledge needed to teach with challenging tasks. For instance, Charalambous (2010) studied the connections between mathematical knowledge for teaching and task unfolding. His study indicated that strong mathematical knowledge for teaching could support teachers' use of representations to help students make meaning of tasks, it could support teachers in providing explanations in task enactment, and it could help teachers respond to and build on students' responses in meaningful ways as they work on tasks. Research on knowledge requirements for teaching with challenging tasks also involves selection or development of tasks. Many studies focus on the tasks themselves, and they often draw on the classic works of Doyle (1988) and Stein and Lane (1996). In their efforts to classify tasks, those authors focused on the kinds of cognitive activity required to solve the tasks. Stein and Lane (1996) distinguished between two broad types of cognitive activities, where one emphasized the doing of mathematics (problem solving), and the other emphasized using well-rehearsed procedures. Many studies draw on Stein and Lane (1996) to make claims about the connections between the cognitive demand of mathematical tasks and students' learning.

A second group of studies explores what is involved in presenting students with challenging tasks, often called setup. For instance, Jackson et al. (2013) studied the relationship between the setup of challenging tasks and opportunities for learning. They found that opportunities for learning were higher when lessons helped students talk about task scenarios as well as the mathematical relationships in tasks. In addition, they found that the opportunities for learning were higher when the cognitive demands of the tasks were maintained. In more than half of the lessons studied, however, they observed that the cognitive demands of tasks were lowered in the setup phase, and they suggest that it is vital to further explore how cognitive demands of tasks can be maintained. Trocki et al. (2014) studied primary teachers' implementation of a setup practice called think-aloud, in which the teacher models her mathematical thinking of how to understand the problem for the students to hear. Some teachers reported uncertainty about where the line was between supporting the students in understanding the problem and solving the problem for them. Trocki et al. (2014) confirm that maintaining cognitive demands in the setup phase can constitute a pedagogical challenge for mathematics teachers. Brousseau (2002) describes this challenge in the "Topaze effect", where a teacher provides students with simplified questions that give the desired answer, without having the students really understand the problem.

Finally, a third group of studies focuses on teachers' orchestration of discussions around challenging tasks, and this is where our study fits in. Research on orchestrating mathematical discussions has often been conducted as qualitative studies that investigate how a small number of teachers conduct classroom discussions (e.g., Selling, 2016; Zolkower & Shreyar, 2007). Many studies focus on what teacher moves that can be used to facilitate discussions (e.g., Selling, 2016; Zolkower & Shreyar, 2007). Studies on mathematical classroom discussions often emphasize so-called "talk moves" (see e.g., Kazemi & Hintz, 2014), and several studies also include a focus on questioning (e.g., Selling, 2016). For instance, Lim et al. (2020) investigated the use of follow-up questions in discussions.

2.3 Teacher questioning and cognitive demand

To dig deeper into the use of questioning to facilitate discussions around challenging tasks, we also conducted a review of research on mathematics teacher questioning—focusing on the last two decades. This part of our literature review aimed at identifying trends in research on teacher questioning, and at investigating whether and how studies of mathematics teachers' questioning attended to relations between questioning and demands of tasks.

Discussions around challenging tasks depend on students' contributions, and teachers often rely on questioning to elicit students' thinking. Research on mathematics teacher questioning underline the importance of questions (e.g., DeJarnette et al., 2020), but multiple studies indicate that teachers find it challenging to ask good questions, and they do not receive enough training in effective or good questioning (e.g., Gal, 2022; Steyn & Adendorff, 2020). Several studies show that teachers can develop their questioning practice from lesson study (e.g., Cumhur & Guven, 2022), action research (e.g., Di Teodoro et al., 2011), or various types of professional development efforts (e.g., Gal, 2022; Roberts, 2021). Studies of developing questioning practice involve both pre-service and in-service teachers.

Although everyone seems to agree that questions should stimulate students' thinking and reflections, multiple studies show that teachers often use more conventional questioning that mainly prompts students to recall facts or procedures—even in reform classrooms (Boaler & Brodie, 2004). Previous research indicates that cultural context might influence questioning (e.g., Chikiwa & Schäfer, 2016; Ding et al., 2023; Kawanaka & Stigler, 1999; Peng & Cao, 2021; Warren & Young, 2008), and few studies have investigated mathematics teacher questioning in a Nordic context. An exception is Drageset (e.g., 2015), who studied teacher questioning in more conventional classroom contexts.

From a case study of teacher questioning in two Grade 8 classrooms in the U.S., McCarthy et al. (2016) suggest that it can be productive to analyze the questions teachers actually use in their classroom discourse. Such analysis, they contend, can raise teachers' awareness of questioning practice. Imm and Stylianou (2012) conducted this kind of analysis within the context of enacting cognitively demanding tasks. They analyzed the classroom discourse of five teachers, and teacher questioning was one of the variables studied. In "low discourse" settings (where teachers do most of the talking, and the discourse is mostly one-directional), teacher questioning was mostly procedural rather than conceptual. In contrast, in classrooms that involved more rich, inclusive and purposeful conversations, there was more of a balance between procedural and conceptual questions, and teacher questions invited student-to-student interaction.

In another study, which included 12 teachers (K–5), Martin et al. (2015) analyzed the connection between teacher questioning and the enactment of challenging tasks. Like many other studies (for a review, see DeJarnette et al., 2020), they found that high-level, open-ended questions encourage students to explain and justify, and thus lead to richer discussions. Martin et al. (2015) suggest that providing opportunities for engaging in justification and explanation is particularly important when enacting challenging tasks. Drawing on previous research, Martin et al. (2015) also suggest that teachers can reduce the challenge of tasks by being too directive, or by doing too much of the work for the students. This indicates that if teachers ask too many leading questions, or provide too much direction, they can reduce the challenge of the task and limit students' exploration.

Many studies of teacher questioning distinguish between questions of lower and higher order. Like Sanders (1966), many draw on Bloom's taxonomy and distinguish between taxonomies of questions ranging from lower order memory questions to higher order evaluation questions (e.g., Buchanan Hill, 2016). Studies often categorize questions in terms of Bloom's taxonomy without any explicit focus on the tasks and their cognitive demands (e.g., Diaz et al., 2013; Nathan & Kim, 2009; Zhu & Edwards, 2019). A few studies attend explicitly to the mathematical tasks—the studies by Imm and Stylianou (2012) and Martin et al. (2015) are among the most prominent examples—and González and DeJarnette (2012) include a task analysis, but many analyze discourse and questioning without mentioning the tasks discussed. Another example of a study of teacher questioning that also attends explicitly to the mathematical tasks, is the study by Ni et al. (2014). When studying the connection between the cognitive demands of tasks and teacher questioning, they found that although there was a connection between cognitively demanding tasks and higher order questions, teachers would often use low level questions with cognitively demanding tasks—typically in the process of clarifying the meaning of the task.

With this theoretical background, we aim to contribute to the field by approaching the following research questions:

1. What characterizes teacher questioning in discussions around challenging tasks within the context of DEM?
2. How might teacher questioning reduce the cognitive demand of tasks in the context of DEM?

3 Methods

3.1 Design and participants

To investigate what types of questions the teachers use in discussions of challenging tasks, and how different types of questions are used to scaffold such discussions, we conducted a case study of four Norwegian primary mathematics teachers. Two teachers, “Anne” and “Henry”, taught Grade 1 and the other two, “Mona” and “Siri”, were teaching Grade 4 at the time of the study. These four teachers had volunteered to participate, based on an open call for participants among teachers who had been using DEM materials for more than four years. We decided to focus on teachers with some experience in using the DEM materials, since we knew that many teachers found it challenging to use the materials in the beginning, and our focus was not on studying the learning of DEM. The students were selected since their mathematics teachers had volunteered for the study.

The first author observed and video-recorded three mathematics lessons from each of the four teachers—a total of twelve lessons. Two cameras were placed at different positions in each classroom to capture both teachers’ and students’ utterances and actions during whole-class discussions. The teachers were asked to plan and conduct these lessons as usual. Although we cannot completely rule out an observer effect on the participants’ behavior, the lessons seemed ordinary to us and neither teachers nor students attended to the cameras during recording.

The video recordings from the lessons were transcribed verbatim, and these transcripts provide a basis for the analysis. Excerpts included in this article were translated into English by the authors. We obtained informed and written consent from the teachers as well as parents or guardians of the students. In addition, the first author explained the purpose and design of the study to the students before data collection. The study was approved by the Norwegian Centre for Research Data (currently Sikt).

3.2 Analytic framework

In this study, we employed the analytic framework of Enright et al. (2016). Unlike frameworks that consider cognitive levels of teachers’ questions, following Bloom’s taxonomy, Enright et al. (2016) present a typology of teachers’ questions focusing on the functions of questions during mathematical instruction. Questions are not categorized based just on plausible inference about the teacher’s purpose with the question, but on the question’s observable function within the classroom dialogue. This means that not only the teachers’ questions but also the students’ responses and the context of the discussion are considered. There are two potential benefits of considering the function of questions as opposed to the purpose of questioning. First, the instructional function can be observed directly, whereas the teacher’s purpose when stating a question is not directly observable from videos and can only be guessed by the researcher. Second, even if the teacher asks a question with a clear purpose in mind, the students might interpret the question differently and answer according to their own interpretation of the question. Focusing on function instead of purpose thus reduces the amount of guessing and shifts the analysis from a high-inference to a low-inference process, resulting in a more stable construct (Enright et al., 2016). The framework makes a distinction between questions that help the teacher collect information about the status of students' work (IC questions) and questions that help the teacher access mathematical content (AMC questions). Within these two main categories, there are 11 distinct subtypes of questions, as described in Table 1.

Table 1. Framework for coding of teacher questions.

Question type	**Instructional function**	**Example from our data**
Question types focused on information collection (IC questions)		
Call for participation	Prompts students to participate by volunteering a mathematical contribution	Did you want to say anything else?
Check-in	Prompts students to report on the state of a task	Did you finish that one too?
Orienting	Prompts students to offer information (mathematical or not) that orients the teacher to what the student is working on	What can you see on the board right now?
Survey	Allows the teacher to gather information from multiple students simultaneously	Did anyone think like Student 1?
Question types focused on accessing mathematical content (AMC questions)		
Clarification	Prompts students to extend or clarify a mathematical idea	But it says six plus one there, and one plus six there, are they equal?
Confirmation	Prompts students to compare a voicing or representation of a mathematical idea with the student's intended meaning	Is that what you're thinking, Student 17?
Direct answer	Prompts students to give an answer to a problem	What's five times 16?
Eliciting mathematical explanation	Prompts students to explain or justify their mathematical reasoning	Can you explain your thinking?
Eliciting mathematical process	Prompts students to describe a process for solving a mathematical problem	What would you do first, Student 17?
Eliciting mathematical ideas/thinking/contributions	Prompts students to share their other ideas, not about explanation or process	What's special about these expressions?
Eliciting a stance on a mathematical claim	Prompts student(s) to share their thoughts about a specific mathematical claim; this could include taking a position on the claim or sharing their thinking about one or more possible positions or on the claim itself	Do you agree with Student 3's strategy?

Note: This table provides descriptions of question types and instructional function based on the framework by Enright et al. (2016, pp. 4–5) as well as examples from our own data material.

Although the framework generally worked well, we noticed that a lot of teacher questions remained unanswered. We therefore added a code for whether a question was answered by the students. Only the answered questions were coded according to the framework, since the function of a question that is not answered cannot easily be observed.

Some preliminary connections could be made with cognitive demands based on the descriptions of question types in Table 1. For instance, a question eliciting a mathematical explanation could likely result in student activity at a high level. However, our goal is not to make priori claims about whether the different question types are high- or low-level questions; rather, it is to empirically investigate the influence of teacher questioning on task enactment.

3.3 Analysis of data

The transcripts were analyzed in several steps. Initially, there was a need to clearly identify the analytical unit—what counts as a teacher question. Not all utterances by the teachers punctuated with a question mark in the transcripts were counted as questions. For example:

> Teacher: Can we say anything about how many digits the value must have?
> Student 18?
> S18: Um, two.

In the above quote from one of the transcripts, there are two question marks in the teacher's utterance. However, "Student 18?" was interpreted as indicating the student's turn to speak and was not coded as a separate question. The whole utterance of the teacher was coded as a single question in the category direct answer, since this fit both the question statement and the student's answer, and thus the function of the question in the dialogue. The data material from one of the four teachers (three lessons) was coded independently and then discussed in several iterations by both authors until a complete agreement was reached and a codebook established. Then, the first author coded the remaining material using the agreed-on code descriptions.

Next, we selected two episodes that shed light on our research question. The selection was done strategically to deepen the analysis of a questioning pattern highlighted by the coding process. For each episode, we present the teacher's setup of the task and a transcript of the mathematical discussion that followed. We applied the cognitive levels from the mathematics task framework (Stein & Lane, 1996) to explore how the teacher questioning influenced the cognitive demand of the tasks during the discussion phase. This deeper analysis forms the basis for the discussion that follows. Specifically, we attended to whether students got the opportunity to explain, discuss or reason about mathematical concepts and relationships pertinent to the task (indicating high cognitive demands) or whether they only reproduced mathematical facts or procedures to arrive at an answer (indicating low cognitive demands).

4 Results

Teachers ask a lot of questions in class, and this was also true in our data. Analyses of twelve lessons revealed an average of 88 questions per lesson, of which 70 aimed at accessing mathematical content (AMC). Table 2 provides an overview of the types of questions asked by each teacher, and in total.

Table 2. Distribution of types of questions in the four teachers' lessons.

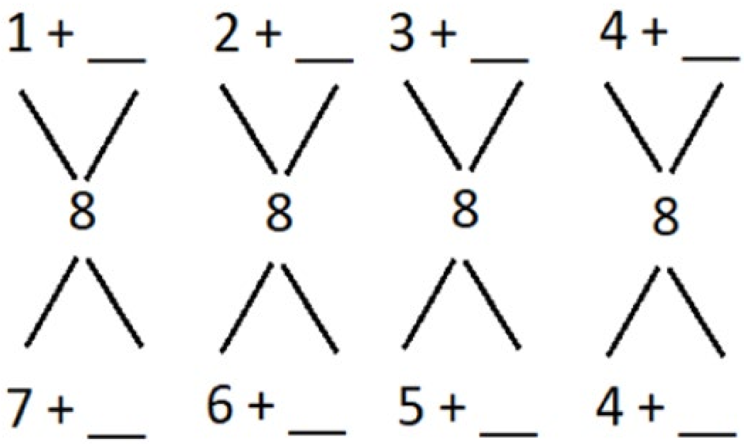
Question type	**Henry**	**Anne**	**Mona**	**Siri**	***Total***
Information collection questions (IC)					
Check-in	6	8	2	6	*22*
Orienting	1	5	3	2	*11*
Call for participation	92	10	22	34	*158*
Survey	6	5	1	16	*28*
Questions accessing mathematical content (AMC)					
Clarification	10	4	6	0	*20*
Confirmation	8	5	17	8	*38*
Direct answer	96	94	131	85	*406*
Eliciting a stance on a mathematical claim	31	24	29	51	*135*
Eliciting mathematical explanation	36	24	19	25	*104*
Eliciting mathematical ideas, thinking, contributions	19	16	19	8	*62*
Eliciting mathematical process	19	16	20	21	*76*
Sum	*324*	*211*	*269*	*256*	*1060*

Table 2 shows that there are some clear similarities between the teachers, but there are also nuances to the patterns of question use. For instance, Henry asked more *call for participation* questions than the other three combined, which might indicate that he had to work harder to encourage his grade 1 students to participate. As another example, Siri asked relatively more *survey* questions than the other three, and she also asked more questions to *elicit a stance on a mathematical idea*. Table 2 also shows that *direct-answer* questions were the by far most prevalent question type for all four teachers, and we therefore decided to look more carefully into this question type in our qualitative analyses. When examining how questioning was employed in discussions of challenging tasks, we found that direct-answer questions often reduced task demands, and this raises concerns about students' opportunities for learning in DEM. The next two sections present episodes that illustrate this.

4.1 Episode 1

The first episode is from one of Anne's Grade 1 lessons. The teacher had written the task on the board before beginning the lesson, showing four 8's with extensions showing sums to be completed (Figure 1).

Figure 1. Task on completing sums.



Note: This is the task that Anne wrote on the blackboard, reproduced by the authors from the video.

The task asked the students to complete the sums so that all of them became equal to 8. This task is meant to illustrate the leading role of theoretical knowledge (Zankov's second principle), and the teacher's guide (Melhus, 2015) indicates that the task provides opportunities for the students to learn the commutative property of addition. In DEM, students learn technical language like "the commutative property of addition"—even in Grade 1. When filling out the missing numbers, the students are supposed to discover that 1 + 7 equals 7 + 1 = 2 + 6 = 6 + 2, and so on. In Anne's class, she worked through this task in a teacher-led whole-class discussion, where she did all the writing on the board. During this discussion, Anne posed many questions coded as *direct answer*, as illustrated by the excerpt below. The class had finished the leftmost part (1 + 7 and 7 + 1) and were discussing that 8 is equal to both 2 + 6 and 6 + 2. Questions coded as *direct answer* are emphasized in bold:

> Teacher: Here, we have the same number in the middle, we are looking to get eight this time too. But now there is number two here (points at 2 in the top row). **What do we have to add here to get eight?** S1.
> S1: Six.
> T: Six. (Writes "6" in the empty place) Six plus two, is that eight? (Points at the numbers as she says them) Yes. But if it says six below here (points at the number 6 in the bottom row), **what do we have to add to six to get eight?** S2.
> S2: One.

T: Is it one? **If we have six and add one, how many do we get?** (Holds up six fingers, then lifts another)
S2: Seven.
T: We get seven! **So how much do we have to add to get eight?** S3?
S3: Um, two?
T: Two. (Writes “2” in the empty place) OK, and the next one, we are looking to get eight here too, there are a lot of things that add up to eight. We have three plus, **what do we have to add to three to make it eight?**
(…)

The discussion followed a similar pattern until all the numbers were filled out. We notice how all of Anne’s questions so far asked for missing addends: Knowing the sum and one of the addends, what is the other addend? This required the students to either recall number facts or to “count up to eight” as illustrated by the teacher’s finger use (the students had not yet been introduced to subtraction). According to the cognitive levels of Stein and Lane (1996), recall or (relatively) simple procedures are usually seen as indicating low cognitive demands. We were interested in the teacher’s questioning in the context of the whole discussion, and importantly, the mathematical goal that the teacher led the discussion toward. When the filling-out task was done, the teacher asked new questions, presumably to help the students focus their attention on the symmetry of the sums.

Teacher: But now I’m wondering, can you see what we have done here? **Can you see which number this is?** (Points at 1 in the top left) Let me hear it!
Students: One!
T: **What’s this number?** (Points at 7 in the top left)
S: Seven!
T: OK! **What’s this number?** (Points at 7 in the bottom left)
S: Seven!
T: **And what’s this number?** (Points at 1 in the bottom left)
S: One!
T: Huh. So, one plus seven is eight, and seven plus one is eight. Both of them. **What about here? Say the numbers.** (Points at the numbers in the second part of the task)
S: Two, six, six, two!
T: **Were they the same here too, the numbers?** Two plus six and six plus two?
S: Yes!

DEM emphasizes development of “theoretical knowledge,” and the goal of this task was to facilitate developing understanding of the commutative property of addition. The task invited students’ exploration of the commutative property of addition by highlighting how $1 + 7 = 7 + 1$, indicating that it is only necessary to learn “half” the addition table. Yet, analysis indicates that the teacher’s questioning might lead to lowered cognitive demand and prevent students’ exploration of the commutative property of addition.

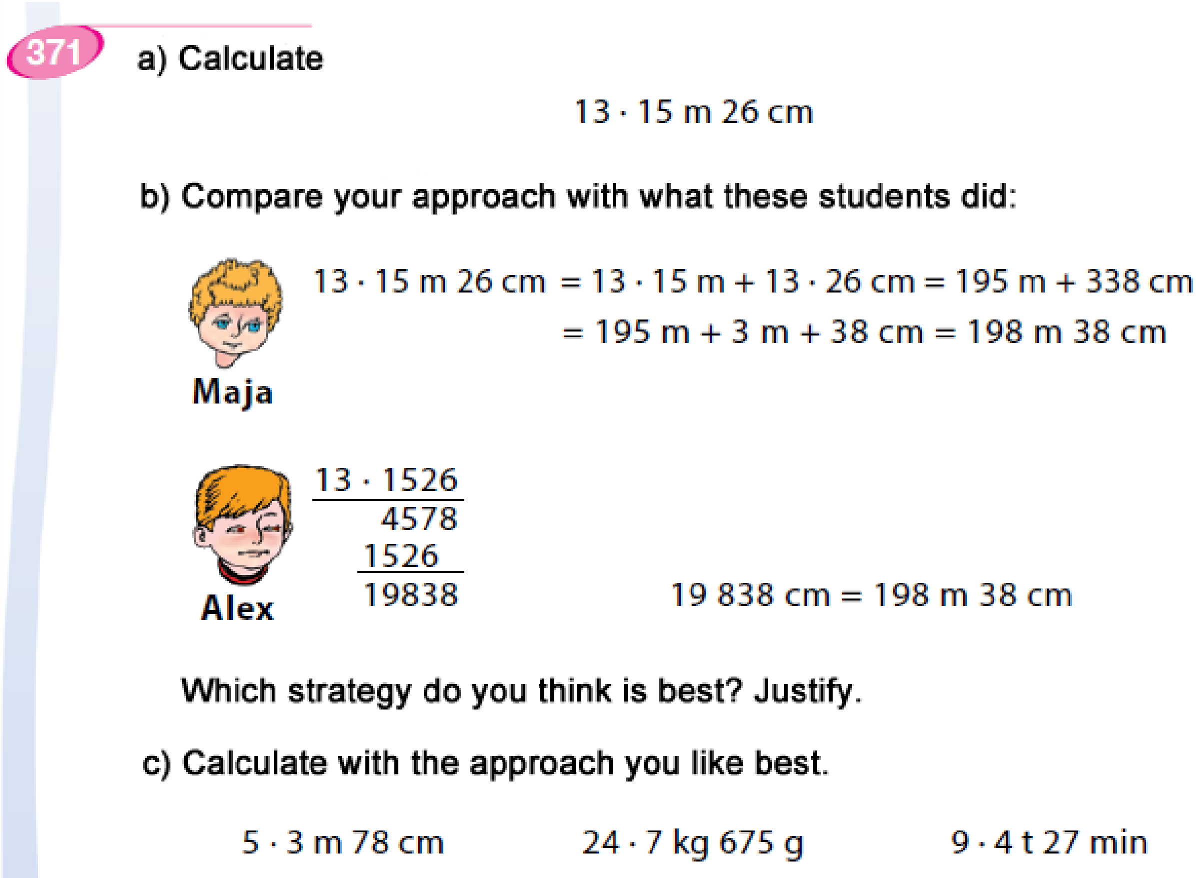
Each of the teacher's questions in this episode prompted the students to either recall facts, calculate simple sums (e.g., by using their fingers), or read the numbers aloud. A turn-by-turn analysis of the discussion and the teacher's questions indicates that this activity only puts low cognitive demands on the students. Throughout this episode, the teacher's questions only focused on individual sums and never explicitly connected them. For instance, when two was given, the teacher asked: "What do we have to add here to get eight?" A student then responded that six is the answer. Then, when six was given in the next sum, the teacher asked: "What do we have to add to six to get eight?" These are examples of strings of direct-answer questions, and they only invite students to recall simple addition facts, which indicates a low cognitive level. Although the aim was to highlight the commutative property of addition, the teacher kept asking questions about isolated sums, and she never asked the students if they saw any connection between them.

Although the teacher might have intended to lead the discussion toward the commutative property of addition, she never invited the students to express what connections they noticed, nor did she mention the term "commutative property". Orientation toward this important arithmetic principle could have given the students an opportunity to generalize and to notice a conceptual relationship, which could potentially put high cognitive demands on the student group, but the generalizations and identifications of relationships were only done by the teacher. Data provides little or no evidence that the students were considering the commutative property; they mostly responded by reading numbers out loud and carrying out simple addition. The answers given by some of the students indicate that they did not see any connection, like when S2 responds that one is the number that added by six gives eight, which was asked directly after having established that two plus six gives eight. Asking simple recall questions might be useful in the initial phase of discussing a task like this, for instance to clarify the meaning of the task, but the teacher could then have followed up by asking the students about what they observed, or if they see any connections between the sums. This might have maintained the cognitive demand and given the students an opportunity to learn about the commutative property of addition.

4.2 Episode 2

The second episode is from one of Mona's Grade 4 lessons, and it illustrates how Zankov's principle of rapid progression might lead to a type of questioning that delimits the cognitive demands of the task and the students' opportunities to learn. The topic was calculating with units of measurement. In this episode, the students first tried to solve task a) on their own before the teacher led a discussion about the two suggested strategies presented in b) (see Figure 2). Most students had used Maja's strategy at first, but the conclusion in the discussion of task b) was that they now preferred Alex' strategy. Next, the students tried the first two tasks in c).

Figure 2. DEM tasks on calculating with measurement (Arginskaya et al., 2017, p. 54).



371 a) Calculate

$13 \cdot 15$ m 26 cm

b) Compare your approach with what these students did:

Maja

$13 \cdot 15$ m 26 cm $= 13 \cdot 15$ m $+ 13 \cdot 26$ cm $= 195$ m $+ 338$ cm

$= 195$ m $+ 3$ m $+ 38$ cm $= 198$ m 38 cm

Alex

$$\begin{array}{r} 13 \cdot 1526 \\ \hline 4578 \\ 1526 \\ \hline 19838 \end{array}$$

19 838 cm = 198 m 38 cm

Which strategy do you think is best? Justify.

c) Calculate with the approach you like best.

$5 \cdot 3$ m 78 cm $\qquad 24 \cdot 7$ kg 675 g $\qquad 9 \cdot 4$ t 27 min

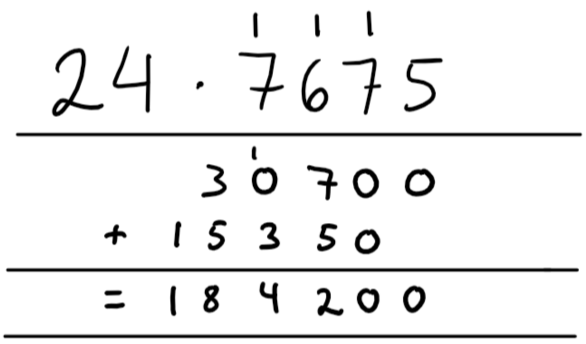
Note: The middle dot sign is the standard sign for multiplication in Norway. The multiplication algorithm shown next to Alex' strategy is commonly used in Norwegian primary schools. The task is translated by the authors.

In the discussion preceding the analyzed excerpt, the students discussed two different strategies for multiplying with measurements. One student presented his solution to task a), and another was able to rephrase the first student's work in his own words. When the teacher presented "Maja's" strategy (which she had observed that several students had used) from the textbook, other students could correctly explain this solution as well. The teacher did not pose many questions; those she posed were either eliciting mathematical explanations or eliciting a stance on a mathematical claim.

The excerpt below concerns the task 24 × 7 kg 675 g. The students had worked individually, and gave four different answers to the task: 47 250 g, 184 200 g, 1 696 300 g (the student suggesting this answer said it seemed unrealistic and that he thought it was wrong), and 46 200 g. The students' answers, given in grams, indicate that they had used Alex' strategy (see Figure 2) and not converted back to kilograms. Since the students had suggested several different answers, the teacher faced the decision of how to deal with this uncertainty. In this case, she decided to go through the calculation on the board together with the students. A reproduction of the algorithm as she wrote it on the board is included in Figure 3. Again, direct-answer questions are in bold.

Teacher: OK! I think we must do that one. 24 times 7 675. I'll begin with multiplying the ones. **Four times five, people?**
Students: 20
T: **Four times seven?**
S: 28
T: **Plus two?**
S: 30
T: **Four times six?**
S: 24
T: I want more people with me. **Four times six?**
S: 24!
T: **Plus three?**
S: 27
T: **Four times seven?**
S: 28
T: **Plus two?**
S: 30
(...)
(The discussion followed this pattern until the calculation was completed, see Figure 3)
(...)
T: And then I got- **which number is this?**
S: 184 200!
T: OK! Student 21 got it right! Yes, let's move on.

Figure 3. The completed multiplication, as written by the teacher on the board.



Note: The figure was reproduced from the video by the authors.

The background for this episode was that the students had discussed the two methods and agreed that Alex' method was superior to Maja's. The teacher seemed to be happy about this, and she had asked the students to solve a multiplication task using this method, but they had made several mistakes and reached different solutions. Instead of engaging the students in a discussion to elicit their thinking and use the students' thinking to solve the task, the teacher decided to engage the students in the rapid-fire exchange above. During this exchange, the teacher posed 19 questions, all of which were coded as *direct answer*, and all of which concerned single-digit multiplication as steps in the multiplication algorithm. The exchange concluded when the correct answer was reached, and the teacher did not make any connections with the previous discussion about advantages and disadvantages of the two strategies, and she did not provide any opportunities for reflection or critical thinking. With exception of the first turn in the excerpt ("I'll begin by multiplying the ones"), the teacher did not use language referring to place value (tens, hundreds, etc.). We interpret this as reinforcing a mechanical approach to the algorithm, which indicates low cognitive demands.

Our point here is not to suggest that all exchanges were like this. Indeed, in the discussion that preceded the analyzed excerpt, the teacher posed fewer and more high-level questions, eliciting her students' mathematical thinking and explanations. Then it appears that the teacher ran out of time and decided to guide the students on the right track. This illustrates how the principle of rapid progression in DEM might collide with other DEM principles—as well as common progressive ideas—of letting the students explore, and having the teacher elicit and use students' thinking to move the discussion forward. To ensure a more rapid progression, the teacher here ended up posing a sequence of direct-answer questions, which resulted in a lowering of the cognitive demands of the task and possibly also limiting the students' opportunities to learn.

5 Discussion and conclusions

Multiple studies have explored what questions teachers ask (e.g., Boaler & Brodie, 2004), how teacher questioning corresponds with the demands of the tasks (e.g., Imm & Stylianou, 2012), and how teacher questioning might influence the cognitive demands of the tasks (e.g., Martin et al., 2015), but few studies have explored how teacher questioning might reduce the cognitive demands of challenging tasks. Our study contributes to the field by focusing directly on this, and our analysis illustrates that there are situations where the use of teacher questioning in classroom discussions might collide with the principles of a reform initiative like DEM. Based on our analysis of these two episodes, we argue that teacher questioning might constrain efforts to facilitate development of conceptual understanding in reform efforts like DEM, and that the principle of rapid development or progress in reform efforts like DEM might collide with the underlying aims of eliciting and using students' thinking in mathematical discussions based on challenging tasks.

We claim that teacher questioning can reduce the cognitive demand of tasks and thereby constrain students' development of conceptual understanding. DEM and other reform initiatives emphasize development of conceptual understanding, and challenging tasks provide opportunities for students to think critically, make connections between mathematical concepts, and develop a deeper understanding of the mathematical ideas (e.g., Jackson et al., 2013; Stein et al., 1996). Yet, our study showed that the teachers often ended up using questions that prompted students to only recall facts or procedures. For instance, in the first episode, the task aimed at inviting students to make connections and engage in deeper thinking about the commutative property of addition, but the teacher's use of direct-answer questions appeared to prevent this. This finding suggests that this question type could be connected with low cognitive demands, which corresponds with observations from other studies indicating that too many low-order questions might have a negative effect (e.g., Ni et al., 2014). In addition, the teachers in our study used direct-answer questions to break down the task into small units, and this appeared to simplify the task, as documented by previous studies (e.g., Jackson et al., 2013; Ni et al., 2014; Wilhelm, 2014). This use of teacher questions also resulted in neglecting the mathematical relationships that the task potentially could invite the students to consider. Jackson et al. (2013) suggest that teachers should use questioning to explicitly connect features in the task with the mathematical concepts being explored, but this was missing in our study. For instance, although the task in the first episode invited students to make connections and develop conceptual understanding about the commutative property of addition, the teacher's questioning simplified the problem and resulted in the students being primarily engaged in answering a string of simple questions without considering the underlying conceptual properties. This corresponds with the Topaze effect (Brousseau, 2002), where the teacher's questioning does lead to the desired answer, but without helping the students understand.

Using low-order questions to simplify challenging tasks can be tempting for teachers. After all, "helping" students reach the correct answer feels like the right thing to do. Yet, this kind of "helping" students can have negative effects and leave students in a state where they have reached the right answer without understanding, as Brousseau (2002) emphasized. This can be particularly challenging in a context where teachers often do not receive sufficient training in productive questioning strategies in their education (e.g., Gal, 2022; Steyn & Adendorff, 2020). We argue that DEM with its emphasis on rapid progression might be particularly prone to this, and our second episode illustrates this. In this episode, we see how efforts to elicit students' thinking might lead to situations that involve confusion or errors, and an underlying principle of rapid progression might prompt teachers to guide the students in the right direction. This could be done by using strings of low-level questions to progress more quickly, instead of spending time facilitating discussions where students get the opportunity to sort out their own mistakes and develop a more solid understanding. The preliminary discussion of Alex' and Maja's methods involved higher-order questioning that invited students to explain why one method was superior to the other, similar to what is suggested in the literature (e.g., Ni et al., 2014). In the exchange in the second episode, however, the teacher ended up breaking it down into small pieces, and her questioning lead to a simplification of the task. Studies indicate that teachers often end up reducing the cognitive demands when enacting challenging tasks (e.g., Ni et al., 2014; Stein et al., 1996), and our analysis of the second episode shows how teacher questioning can have this effect.

Ni et al. (2014) emphasize how teacher questioning can lead to sharing the authority in the mathematics classroom by inviting students to consider other students' thinking, but the episodes we have presented illustrate a teacher-centered approach where the teachers' questioning does not invite students to joint authority. The teachers were also doing most of the thinking in the way they used direct-answer questions in these episodes. Again, resorting to this kind of teacher questioning can be tempting in many contexts, but we suggest that it is particularly pressing in a context like DEM, where there is an emphasis on rapid progression.

We do not intend to criticize individual teachers with our analysis and discussion, but our study has highlighted some potential challenges that teachers might be faced with. These challenges are particularly pressing in a context like DEM, in which there is a strong emphasis on theoretical knowledge and rapid progression, which may be conflicting principles. Gjære (2023) showed how such tensions could lead to teaching dilemmas. We connect the findings of our study with the dilemma of telling, in which teachers must choose between promoting conceptual explorations when students are stuck and moving the lesson forward. This dilemma can affect teachers' questioning patterns, prompting them to hand-hold the students—for example, by asking direct-answer questions. According to Zankov (1977), primary education should support students' development through challenging tasks that promote reasoning. Over time, overly directive questioning may undermine this goal.

We want to highlight four challenges that teachers need to be particularly attentive to. First, in facilitating discussions, teachers may unconsciously simplify challenging problems and thereby limit student thinking. Second, teachers may often guide students with questions instead of allowing them to attend to concepts. Third, a string of simplistic questions can lead to teacher-led solutions instead of student understanding. Finally, solving challenging problems often involves errors and dead ends, which can conflict with rapid-progression initiatives like DEM. When such challenges are visible even among teachers who are experienced with DEM materials, and are enthusiastic about the approach, it is likely that teachers who are new to such a reform initiative, or who are less enthusiastic about it, might also face such challenges. A dilemma of teaching is to balance rapid progression with student exploration and critical thinking. It is not easy to overcome this dilemma and avoid these challenges, and we suggest that it requires deliberate and specific training.

Research ethics

Author contributions

Å.L.G.: conceptualization, data curation, investigation, methodology, project administration, formal analysis, visualization, writing—original draft preparation, writing—review and editing
R.M.: conceptualization, methodology, formal analysis, visualization, writing—original draft preparation, writing—review and editing

Both authors have read and agreed to the published version of the manuscript.

Artificial intelligence

No artificial intelligence has been used in the research or writing of this article.

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Institutional review board statement

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Informed consent statement

Informed, written consent was obtained from all research participants. Parents or guardians provided consent for underage students.

Data availability statement

The video data is unavailable due to privacy restrictions. Anonymized transcripts (in Norwegian) are available from the corresponding author, Å.L.G., upon request.

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Conflicts of Interest

The authors declare no conflicts of interest.

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