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Pre-service teachers' experiences in selecting and proposing challenging tasks in secondary classrooms

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This study aims to know if pre-service secondary school mathematics teachers are able to select, adapt or design appropriate challenging tasks and what are the main challenges that they face when working with challenging tasks in the classroom. The study is qualitative, based on observation and interviews. The participants are two preservice teachers at the 2nd (and final) year of their master of teaching degree. The results show that the preservice teachers, albeit facing several constrains, were able to find and adapt interesting tasks. They also identified several challenges in this activity, in the planning phase, during students' autonomous work and, most especially, during the whole class discussions.

Keywords: Challenging tasks, preservice teachers, planning, students' autonomous work; whole class discussions

Introduction

What students learn in mathematics mostly depends on the mathematical experiences offered to them in mathematics lessons (NCTM, 2014). Particularly powerful to promote the development of mathematical understanding are challenging tasks that require students to establish connections among different aspects of mathematics, formulate their own solution strategies and explore several pathways to solutions (Sullivan et al., 2015). These kind of intellectual activities requires new pedagogies in teaching mathematics and, consequently, raises new challenges to teachers, namely putting demands on teachers' knowledge (Sullivan & Mornane, 2014), on teachers' understanding of tasks, particularly their potential and demands (Foster & Inglis, 2017), and on teachers' classroom practice (Ponte & Quaresma, 2016). Most studies addressing this issue involve in-service teachers, but we what to understand which main issues are raise when pre-service teachers (PTs) are encouraged to propose challenging tasks in the classroom. This was the general issue that prompted us to develop a study with two pre-service secondary school mathematics teachers, aiming to answer the following research questions: (i What are the nature of the tasks selected, adapted or designed by the PTs? and (ii) What are the main challenges that PTs face when they propose and enact challenging tasks?

Theoretical framework

The centrality of tasks in mathematics classroom instruction has been recognized both by theoretical perspectives and empirical research (Shimizu et al., 2010). Several curricular documents around the world recommend the inclusion of "rich" or challenging tasks in mathematics teaching in order to promote students' high level thinking such as problem solving and reasoning (NCTM, 2014). However, different conceptualizations on the nature of such tasks have been proposed by distinct authors, and using different language, for instance "rich", "authentic" or "complex" tasks (Shimizu et al., 2010). The profusion of terms, and particularly the lack of explicitness concerning

their meaning, often does not contribute to develop a clear understanding in the educational settings about the core characteristics these tasks should have. As Foster and Inglis (2017) found in their study with a large number of mathematics teachers in the UK, teachers express contrasting perspectives about the nature of the tasks, namely having one task classified both as demanding and non-demanding or as engaging and non-engaging by different teachers.

One of the most well-known taxonomy for tasks is the one by Stein and colleagues which includes four levels of cognitive demand to characterize the mathematical tasks: two for lower-level and two for higher-level demands (Stein & Smith, 1998). According to the authors, the tasks that exhibit lower-level of cognitive demand may be targeted at *memorization* or to the use *procedures without connections,* that is without explicit attention to concepts and understanding; those rated as higher-level involve complex thinking and reasoning processes and are denominated as *procedures with connections* and *doing mathematics*. We have adopted the definition of cognitively demanding tasks proposed in this framework. Tasks may assume the form of problems, exploratory or inquiry tasks.

The practice of proposing and enacting challenging tasks that are set and maintain the intended level of cognitive demand has showed problematic for many teachers (Stein & Smith, 1998), and attention has been given to teacher education programs that might support teachers in developing new practices (Ponte et al., 2017). One of the main issues is the need to move to new lesson structures that supports a student-centred approach and values classroom discourse, namely through the promotion of whole-class discussion as an effective enactment of challenging tasks in the classroom (Russo & Hopkins, 2017; Sullivan & Mornane, 2014). As the study by Crespo (2003) shows when they are "left to their own devices preservice teachers' tendencies were to pose unproblematic problems to their pupils" (p. 264). It seems important that PTs are able to articulate their vision about teaching, namely the need to diversify the nature of the tasks that are usually proposed in the classroom, making possible for them to collaborate in the future with other teachers in developing new teaching practices (Towers, 2010) that may include challenging tasks.

Two important aspects of the teaching practice with challenging tasks are the questions the teacher poses to the class and how he/she sequences it (Mata-Pereira & Ponte, 2017) and providing appropriate enabling prompts for those students who experience difficulties in the task, such as, "reducing the number of steps, simplifying the complexity of the numbers or varying the forms of representation" (Sullivan et al., 2015, p. 126). In the case of PTs who lack the experience of teaching, these actions may even more challenging. Teacher education programs need to provide PTs with opportunities to learn within a "practice-based" experience that allows them to develop skills targeting specific practices (Forzani, 2014) such as selecting and supporting the enactment of challenging tasks in the classroom.

Context of the study and methods

This study was carried out with two PTs on the second year of the Master of Teaching degree at Universidade de Lisboa. During their field experience, PTs were invited to select challenging tasks to propose in two lessons that they were about to teach in their school placement, that would be observed by their respective university supervisor (the two first authors). By then, PTs had attended the teacher mentor classes for about one month and had the opportunity to interact with students, but this was the first time they were responsible for teaching a lesson by themselves. The request for

teaching with challenging tasks was not a surprise to PTs since, in alignment with current curriculum orientations for mathematics teaching, this masters' program provides extensive discussion on inquiry-based perspectives on mathematics teaching (Ponte et al., 2017).

Five PTs were attending the course. For this study, we select as cases two PTs that we regard as more contrasting considering the focus of our study: Marta and Magdalena, both fictitious names. Marta is 22 years old and graduated in Applied Mathematics and Computation. She developed her teaching practice in a private school, in an urban area of Lisbon. She taught a 12th grade class (age 17) with 13 students who are interested and motivated for studying, show good achievement in mathematics (only two have medium achievement, all the others have high). They are usually focused on the proposed mathematical work and try to help each other when working in pairs. Magdalena is 24 years old and graduated in Applied Mathematics. She teaches a 10th grade class (age 15) with 17 students in another private school near Lisbon. The students are heterogeneous regarding their school achievement, 35% had a negative grade in Mathematics at the end of the 1st school term and show many difficulties in the topics covered in previous years. Most of them show lack of study habits and are not very participative in class.

Following a qualitative research approach, data collection processes included the observation of two lessons with video recording, pre- and post-lesson reflections audio recorded with PTs, post-lesson written reflections, and their lesson plans. A first reflection (R1) occurs before each observed lesson. Immediately after, and preceding the post-lesson reflection (R2), there was a discussion about the lesson with the supervisor and mentor. Content analysis was used to analyse data, with pre-defined categories for the nature of the tasks (Stein & Smith, 1998). In the case of the challenges faced by the two PTs there were no predefined categories but we had as reference the review of literature presented in the theoretical framework.

The nature of tasks

In both observed lessons, PTs proposed one task to the class. The tasks sought to introduce or create the need for new knowledge, in particular to relate the signal of the second derivate with the direction of the concavity of the graph of a function (Task 1, Marta) or they were problems (Tasks 1a, 1b and 2, Magdalena). Task 2 by Marta was a problem of optimization, which sought to lead students to feel the need to know how to differentiate trigonometric functions. In both tasks, the students in Marta's class used the graphic calculator. All tasks included several questions and can be rated as *High Cognitive Demand* with different level of intellectual challenge (Table 1).

Table 1. Characterization of the tasks concerning the level of intellectual demand

Task 2 - Marta Tasks 1a and 2 - Magdalena	Procedures with connections	Requires "some degree of cognitive effort. Although general procedures may be followed, they cannot be followed mindlessly".
Task 1 - Marta Task 1b -Magdalena	Doing Mathematics	Requires "students to access relevant knowledge and experiences and make appropriate use of them in working through the task" and "considerable cognitive effort".

Magdalena's task 1a and 2 and Marta's task 2 are characterized in the group of *Procedures with connections,* because they demand to apply previous knowledge in new situations (to calculate measurements from a geometric object; to study a trigonometric function in a way similar to what they had done for other types of functions), requiring a transfer of knowledge. The other tasks present characteristics of *Doing mathematics*, since they require considerable cognitive effort, such as to apply to the second derivative of a function what they had learned about the first derivative (Task 1, Marta) or to establish diverse relationships between geometric objects, demanding a good visualization capacity, in particular, students need to use their knowledge about volumes of solids (cube and pyramid) (Task 1b, Magdalena).

PTs' perspectives about the tasks are similar to our analysis, but they not use the same terminology since this taxonomy was not explored with them. The aspects they mention are that their students were not used to solve this kind of tasks, they were called to develop mathematical ideas that had not yet been covered in class, and required processes of reasoning more complex than usual:

> The task is challenging for students because it addresses the second derivative and its geometric meaning without first introducing it "theoretically". (Marta, pre-lesson R1)
>
> They are challenging tasks because they confront the students with unexpected things, that they are not used to, and lead them to think and reflect on how they might get there. I think (...) this helps them to develop their mathematical reasoning. (Magdalena, pre-lesson R1)

For Marta, although the two tasks have in common being challenging, there are differences between them. While she considered task 1 as "a more oriented task" (that students have to answer a sequence of questions), she regards task 2 as "a problem" (Marta, post-lesson R 2). Task 1 is very structured, appealing mainly to calculations. Task 2 leads students to look at the proposed situation in a global way. For Magdalena, the proposed tasks are mainly problems, with the exception of a few questions from one of the tasks (task 1b) proposed in the first lesson which she considered to be exploration or investigation.

Pre-service teachers' challenges when working on challenging tasks

Regarding planning for these lessons, the two PTs did not hesitate to say that *to obtain challenging tasks* was quite a challenge for them: "The biggest challenge before the class was to build from scratch task 1 and to find a second task that would be challenging, suitable and relevant to this class" (Marta, post-lesson reflection 2). They searched in textbooks, but found no task with the sought features, so they also used other resources: Marta looked at materials of the Association of Mathematics Teachers brought especially by the teachers of her school. Magdalena made an extensive search in the internet and in several textbooks. For the second lesson she felt that it was difficult to find a suitable situation. When finally she found a situation that seemed promising to design the task, she still needed some guidance from her supervisor to guarantee it could be solved by different processes.

In their lesson plans, the two PTs expressed the intention to adopt an exploratory approach to teaching either by her own initiative in the case of Magdalena, or by the supervisor's suggestion, in the case of Marta. In both cases, PTs made plans that took into account the different phases of an exploratory teaching approach: introduction of the task, students' autonomous work and discussion with the whole class, accompanied by a synthesis of key ideas.

In all lessons, the introduction of the task was of short duration. Students were informed that they would work autonomously during a determined period of time and then there would be a whole-class discussion. At this stage of the lesson, no questions were raised by the students. It has not been observed, or referred by Marta or Magdalena, any challenge during this phase of the lessons.

During the students' autonomous work, the PTs circulated, accompanying the students' work, namely by answering some clarifying questions. Magdalena assumed that her role in these classes should be to support students through questioning, not telling them exactly what they should do. Nevertheless, she recognizes that this type of intervention sometimes has not the intended effect, in particular with students with greater difficulties. So, one of the challenges in these lessons is to know what *type of intervention* she should develop in line with the diversity of students in the class:

> I stand for not giving the answer and instead to guide students. But sometimes I'm afraid to say something that leads them to the answer and that they figure out [the answer]. (…) I think it's important that they think for themselves but when I am in front of students with more difficulties sometimes I don't know at which point should I just guide and guide... To me, that is most difficult. (Magdalena, post-lesson R2)

Associated with the phase of students' autonomous work, these PTs mention the challenge of time management in supporting different groups. Magdalena due the unexpected difficulties that came out in the first task, had to spend too much time with some students in order to understand what they were doing, to identify their errors and to think in questions or prompts that could help. Consequently, she has spent a lot of time with some students, limiting the possibility of supporting other students. Marta also mentions the challenge of "making a good management of the time I am spending with each group" (Marta, post-lesson R2), which she relates with the decision of when to leave the group and let those students working autonomously:

> Even if students in the group still remain with some doubts, I can give some guidance but I also need to know when to let them working and struggling by their own and come back to them later on (…) after supporting other groups (...) [But] to me, this decision is not always very easy: to give some guidance and to know when I should leave the group. (Marta, post-lesson R2)

The *time to devote to this stage* of autonomous work on the task and, consequently, the decision of when it is appropriate to close this phase and move to the whole-class discussion it is also an issue identified by these PTs:

> [I verified] that the students were not working as I had previously planned, which is not necessarily negative. The time that I had set was showing to be too short. It was a challenge that I had to face: to decide whether I should to move for discussion or not. (Marta, post-lesson R1)

The whole-class discussion presents also some problems to these PTs, such as *to take advantage* from this phase of the lesson, to explore it in a developed way. In the first lesson, Marta solved on the board the first questions of the task with the contributions of the students, and they did not raise any doubts, apart from some calculation problems. In fact, the real discussion began with question 1.5. when Marta questioned: "Who is able to explain to the class what is demanded in 1.5.?" A student began to answer, but Marta said: "Use your own words to explain what is asked here. It is a

question that raised a lot of confusion". Marta supported the discussion about the calculation of the limits, and simultaneously the graph of the given function and the tangent lines at given points were constructed in Geogebra. After the students' explanation, Marta also gives her own but there is no effective discussion. The discussion happens, in each moment, essentially between Marta and a certain student; there is no discussion among the students.

In the first moment of the discussion of task 2 (Figure 1), Marta begins by asking a group of students to explain what they did:

S: We tried to define a formula for the wire length.
Marta: Do you begin immediately to think in getting a formula?
S: Initially we tried a little by eye.
Marta: And what was your perception?
S: At the junction of the two triangles, if they joint at a midpoint (Marta, lesson 2)

1. Four villages are located on the four corners of a 1 km side square. When making a new cable installation linking the four villages, the company responsible for the project came to the conclusion that the most economical solution is the one of the following figure. It is known that this type of installation is considered for $x \in \left[0, \frac{\pi}{4}\right]$.

1.1. "As the angle x increases, the total length of cable required decreases". Do you agree with this statement? Justify.

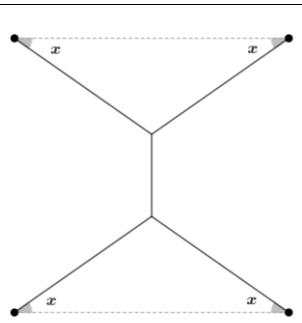


Figure 1. First question of task 2 in Marta's lessons

Marta decided not to use the material that she had prepared previously to support the discussion with the whole class and asked the students to go to the board to explain what they have done. She tries that each group presents his strategy, although the decision on *which should be the sequence* of students' work for presentation to the class was also a challenge for her:

> In the second discussion, as there were already so many groups knowing [how to solve the task] (…) knowing where to start [this was an issue]: [should I begin] by those who have not got there or [should I] give opportunity [to the others],.. I think this was also a challenge… (Marta, post-lesson R2)

Magdalena also had the intention to promote whole-class discussion after the students solved the tasks. In the first lesson, in face of students' struggling where they had many computations to complete, there was no time for the majority of students to solve the second part (Figure 2), which was the one that had more potential for discussion. In the second lesson, the students also took much more time than previewed to solve the task. In the face of lack of time, only one student presented his solving strategy and there was no interaction with other students apart from some questions for some clarification. So, the capacity to have a real *perception of the difficulty that the tasks may present to students* has been for Magdalena a restriction to develop a fruitful whole class discussion.

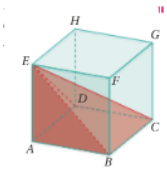
In the figure it is represented the cube [ABCDEFGH] and the pyramid [ABCDE]. It is known that $\overline{EC} = \sqrt{12}\ cm$. Determine the volume of the part of the cube that is not occupied by the pyramid.	

Figure 2. Task 1b in Magdalena's lessons

Conclusion

In this study, both PTs were able to find and adapt interesting tasks. However, they faced the constraint of finding or designing challenging tasks aligned with the specific mathematical topic they had to teach during their practice. They considered the tasks challenging since they were different from what is usually proposed to these students and appealed to mathematical ideas that students had not yet worked, being a means for new learning or to promote processes of reasoning that are more complex than usual (NCTM, 2014). This indicates that the teacher education environment provided the two PTs with the intellectual resources and dispositions necessary to identify and adapt challenging tasks to propose in their classes, contributing to their development of a shared idea of the nature of these tasks.

For an effective enactment of challenging tasks in the classroom, the two PTs adopted a new lesson structure (Russo & Hopkins, 2017; Sullivan & Mornane, 2014), identifying several challenges in this process. In planning, although always considered in the lesson plan, they see the *anticipation of students' difficulties in solving the task* as underdeveloped due to their lack of experience in teaching as they do have a deep knowledge of the students (Magdalena). During students' autonomous work, the *time and the support to give to students* were problematic for both PTs, namely in order to maintain the intended level of cognitive demand, as it has been found in other research with in-service teachers (Stein & Smith, 1998). During the whole class discussion, Marta faced challenges such as *selecting and sequencing the presentation of student's strategies*, knowing which ones to use, the most appropriate ways of doing it, namely when most groups had already solved the proposed questions correctly; *involving* all students in the discussion, even those who have more difficulties or are more reserved; *promoting a broad discussion among the students* which requires knowing how to break with the teacher-student-teacher circle; and *going deep in the exploration of what students say*, especially of what is mathematically important, but is difficult to understand for some students (Mata-Pereira & Ponte, 2017). From these results, we may say that the teacher education program support teachers in developing new practices (Ponte et al., 2017) specially in moments of planning. During the lessons, where it is necessary to take decisions in action, the pre-service teachers faced diverse challenges, most of them similar with those of in-service teachers.

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