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Towards an approach to teachers' professional development: Creating learning opportunities for teachers who teach mathematics

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This paper presents the first intervention cycle of a design-based research on teacher professional development carried out in Brazil. It aims to understand how the formative process helped teachers to understand what algebraic thinking means and how to work with it in the early years of elementary school. Data analysis was based on three principles of design concerning the Role and actions of the teacher educator, Professional learning tasks for teachers and Discursive interactions among participants. The results indicate that the design principles contributed to the teachers' understanding of the meaning of algebraic thinking and how to promote it in elementary students.

Keywords: Professional development, early algebra, teacher educator, professional learning tasks, discursive interactions.

Introduction

The development of teacher knowledge is a condition for improving the quality of education (Borko et al., 2008), and teacher education (initial or continuing) is a cornerstone of this process. Often, the professional education offered to teachers is superficial, disconnected from the ways in which they learn and far from the practice of teaching. This indicates the need to develop research that can contribute to a greater understanding and, consequently, a better organization of teacher education (McDonald et al., 2013). With a design-based research (DBR) approach (Cobb et al., 2016), a teacher education program was developed with the objective of promoting professional learning opportunities for teachers of the early years of elementary school, related to working with algebraic thinking. Thus, the present study seeks to answer the following question: “*How does the teacher educator's role in preparing professional learning tasks and conducting discursive interactions in a formative process, contribute to creating learning opportunities for teachers who teach mathematics in the early grades of elementary school?*” Although the teacher education process focuses on a specific mathematical theme, this study intends to contribute to the construction of general guiding principles for planning and carrying out teacher education processes, based on characteristics of effective professional development (Desimone, 2009) and from a model made to design and assess teacher education processes (Ribeiro & Ponte, 2020).

Theoretical framework

Over the last decades, the introduction of algebra in the school curriculum in the early years of elementary school has been a trend in Mathematics Education (Russel et al., 2011). This is because research has shown that, from an early age, children are already able to think algebraically (Blanton & Kaput, 2005) and that the development of this skill can favor the future learning of abstract algebra (Kieran et al., 2016). In this sense, teachers need to hold knowledge that enables them to work with algebraic thinking. Considering that elementary school teachers have little experience with classroom practice that can support work with algebraic thinking (Hunter et al, 2018), and how recent the

inclusion of this topic in the Brazilian national curriculum is (Ferreira, 2017), continuous development programs are critical to creating professional learning opportunities for teachers (Ribeiro & Ponte, 2020). Research points to the need for five characteristics to be present for a teacher education process to be of high quality and thus effective (Darling-Hammond et al., 2017; Desimone, 2009; Kennedy, 2016): (1) focus on knowledge of the subject and on how students learn this content; (2) active learning, in which teachers participate in the knowledge construction process; (3) coherent with the curriculum and school objectives, teachers' previous knowledge and beliefs; (4) duration of meetings with continuous and intensive opportunities; and (5) collective participation, in which groups of teachers participate and build an interactive learning community.

Kennedy (2016), in addition to pointing out the importance of the motivation of teachers to participate in these programs, also suggests that their effectiveness depends largely on the pedagogy adopted (how they are carried out). In this sense, the PLOT model (Ribeiro & Ponte, 2020) (Figure 1) highlights the Role and Actions of the Teacher Educator (RATE), the Professional Learning Tasks for Teachers (PLTT) and the Discursive Interactions Among Participants (DIAP), as domains which, in an integrated way, contribute to the creation of Professional Learning Opportunities for Teachers (PLOT), in a certain context.

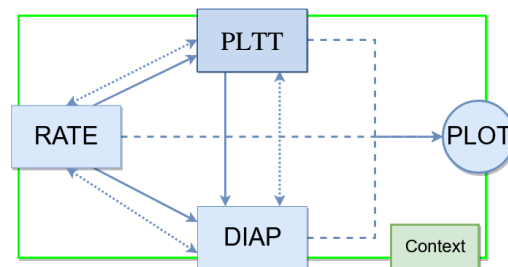


Figure 1: PLOT Model (adapted from Ribeiro & Ponte, 2020)

Although they do not directly refer to high-quality teacher education processes, the domains of the PLOT model consider many of its characteristics. The Role and Actions of the Teacher Educator (RATE), when designing formative processes that consider the characteristics of the local context (characteristic no. 3 of high-quality teacher education programs), takes into account conduction and mediation actions (Stein et al., 2008) through exploratory teaching (Ponte, 2005) in order to create professional learning opportunities for teachers (Ribeiro & Ponte, 2020). The role of the teacher educator, in addition to proposing tasks and creating a collective work environment, has to do with providing adequate and relevant feedback for each situation, ensuring the active and collective participation of all involved (characteristics 2 and 5). The teacher educator's actions and questions should contribute to the reflection on the subject, seeking to establish a relationship between theory, experience and practice (Silver et al., 2007). The Professional Learning Tasks for Teachers (PLTT), which are strongly influenced by practice, focus inseparably on mathematical and didactical knowledge (Ribeiro & Ponte, 2020) (characteristic 1), and can be defined as tasks “that involve teachers in the teaching work, which can be developed in order to meet a specific objective for teacher learning and take into account the prior knowledge and experiences offered by the teachers” (Smith, 2001, p. 8). Smith (2001) points out that materials such as videos of classes (Borko et al., 2008), student work (Kazemi & Franke, 2004) and high cognitive level mathematical tasks (Ribeiro & Ponte,

2020) portray teaching practices and can create opportunities for teachers to analyze and evaluate real classroom scenarios (Silver et al., 2007).

Discursive Interactions Among Participants (DIAP) are directly associated with collective participation (characteristic 5). It assumes that professional learning opportunities can materialize from exchanges between peers, through dialogical communication (Craig & Morgan, 2015). One way to provide discursive interactions is through the exploratory teaching approach, as it presupposes the circulation of mathematical and didactical experiences and knowledge among teachers (Ribeiro & Ponte, 2020). Some authors suggest exploratory teaching should take place in four phases (Stein et al., 2008): introduction, realization in students' autonomous work, whole-class discussion and systematization.

Research Methodology

The present study was carried out in a qualitative-interpretive perspective with Design-Based Research (Cobb et al., 2016), in which data collection from the first design cycle was carried out in a continuing education program developed in the first half of 2019 in a São Paulo State education network, Brazil. Audio and video records of the meetings were collected, as well as written records from the teachers. The participants were 14 teachers from the early years of elementary school. The program lasted 32 hours, with 8 4-hour meetings, in an in-person format, and 32 hours of individual work. The entire teacher education process was video recorded with two cameras, one focused on the teacher educator and the other on the participants. The subgroup discussions were recorded in audio and written records of the teachers and the PLTT used were also collected. The teacher educator, with extensive professional experience at this level of education, is the first author of this paper.

Considering the central aspects of effective teacher education program and the domains of the PLOT model, we established the following factors as design principles (main characteristic of a DBR) (Cobb et al., 2016): (i) the Role and Actions of the Teacher Educator (RATE), which indicates the importance of considering the articulation between mathematics and didactics in and for teaching, the construction of an exploratory teaching-learning environment (Ponte, 2005) and the orchestration of discussions (Stein et al., 2008); (ii) the Professional Learning Tasks for Teachers (PLTT), which, by involving different practice records, promote the exploration of mathematical and didactical knowledge (Silver et al., 2007); and (iii) the Discursive Interactions Among Participants (DIAP), which, by affirming the importance of collective participation through dialogical communication (Craig & Morgan, 2015), involve teachers in an environment of reflection and discussion. Thus, the hypothesis of this research is that an intervention based on these principles contributes to promoting professional learning opportunities for teachers of the early years of elementary school regarding understanding the meaning and development of work with algebraic thinking. We used the three design principles as analytical lenses to consider the reflections brought by teachers and the ways in which the formative process provided teachers with opportunities for professional learning (Ribeiro & Ponte, 2020).

Results

Design Principle: Discursive Interactions Among Participants (DIAP)

In its design, the PLTT *Generalization* asked teachers to discuss the students' productions, analyzing their justification regarding the veracity of the mathematical sentence (Figure 2). This part of the PLTT focused both on the mathematical knowledge demonstrated in generalizations and on the didactical knowledge, considering how students think, as teachers needed to interpret and give meaning to the different justifications made by students. Regarding the first mathematical sentence in Figure 2, which the students answered is false because “Calculations are not made, the result never has multiplications,” the teachers made some observations during the whole-class discussion:

T	V	F	Justificativa	Justification
$24 + 37 = 37 + 24$		X	<p>Costo não são letras, resultado nunca tem multiplicação Por tanto está errado!</p>	<p>Calculations are not made, the result never has multiplications.</p>
$0 \times 1 = 0$	X		<p>Porque toda vez um do o resultado que está no frente.</p>	<p>Because everything times one results in the prior number.</p>

Figure 2: Part of the practice record of the PLT Generalization

Moisés: There's no coherence...

Marina: Usually, they never see calculations with prior numbers. The teacher will give them the expression, not the result. They need to seek the results.

Adriana: Wow, I didn't think of that...

For both Adriana and Moisés, the student's answer made no sense, since the justification was unusual for them. On the other hand, Marina identified that students believed that after the equal sign there could be no other expression, only a result, considering the operational perspective of the equal sign. For Adriana, this discussion provoked a new way of looking at the situation:

Adriana: I didn't think of it like she [Marina] said... in my head she didn't understand [that] if I add 24 and 37, it's the same as adding 37 and 24. She didn't understand what was proposed there, that the result can't have expressions...

By sharing her interpretation with the teachers, Marina contributed so that everyone could look at the student's response from another point of view, motivating the emergence of a professional learning opportunity arising from discursive interactions between participants (DIAP), a situation planned by the teacher educator in the design of the professional development process, from an active and collaborative process, through dialogic communication.

Design Principle: Professional Learning Tasks for Teachers (PLTT)

In the first meeting, the teachers were asked to consider the work of a few students (Figure 3) and analyze the knowledge they demonstrated and what procedures they had adopted to solve the mathematical task: *Pedro was very happy because he finally managed to complete his fourth sticker album! Each album has 225 stickers. How many stickers does Pedro have in all?*

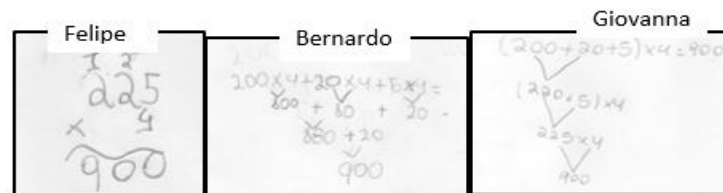


Figure 3: Records of the PLT “Analyzing a multiplication task”

After the analysis of this record of practice, carried out by the subgroups of teachers, the teacher educator asked, during the whole-class discussion, in which of these representations it was possible to perceive algebraic thinking. This questioning sought to survey the teachers’ knowledge about the main content addressed by the teacher education program. Teacher Débora selected the Bernardo’s representation and justified her choice by saying:

Débora: Because it demonstrates that it is a numerical expression, it has more than one operation, so it is generalizing, it left a specific calculation... See, there [in Bernardo’s representation] he used multiplication and he also used sum, so he is using more than one operation to get to the result.

In this excerpt, Débora associated generalization with the presence of more than one operation, in addition to linking it to numerical expressions, expressing your initial knowledge. After working with the PLTT *Generalization* (Figure 2), Débora expressed her concept of generalization, associating it with patterns and regularities:

TE: What is generalization in mathematics?

Débora: It’s when you have a situation... that serves not only a specific situation, but for more than one, there is a pattern, a regularity... for example, when they notice the regularity of the multiplication tables...

The PLTT *Generalization* prepared by the teacher educator, using records of practice, that were specially chosen to promote teachers' reflection, promoted the analysis of students’ productions and contributed to the emergence of professional learning opportunities, in which Débora redefined her concept of generalization.

Design Principle: Role and Actions of the Teacher Educator (RATE)

In another situation, faced with a difficulty presented by Eliana, the teacher educator, in addition to seeking to contribute to the reflection, offered feedback:

TE: What was easier, what was more difficult, what would you do differently?

Eliana: What I think would be more difficult in this task would be reaching all students.

TE: The groups were made up of how many children?

Eliana: Four.

TE: If you start in pairs, a task for two [students]. Because in groups of four, one does the work, another helps, another pretends to help, and the last one doesn’t even pay attention.

The question posed by the teacher educator, promoted reflection because the teachers needed to think about what worked (or not) and what reformulations could be made. In addition, the teacher educator established a direct relationship with the teacher's position when considering her concern, suggesting that, if students were arranged in pairs, this could favor the understanding and performance of the mathematical task. This position of the teacher educator provided adequate feedback to the situation, based on her knowledge of didactic knowledge, establishing a direct relationship with practice.

From the perspective of orchestration of the discussions, the teacher educator proposed reflections when the teachers discussed the division algorithm in a task done by the students:

- Débora: [The students thought] of the multiplication tables of the numbers that were in the brackets [divisors], that any number multiplied by number 1 will always result in the dividend.
- TE: But... only by number 1? [...]
- TE: I would put this on the board and ask the group. Look, this group found this, do you agree, does everyone agree? But just for number 1? Because, for example, when I divided, I had this number [in the quotient], if I multiply it [by the divisor] I have this number [dividend]. This goes for any division.
- Débora: I didn't notice that.

In this excerpt, the teacher educator assumes the role of guiding problematizations and calls attention to a rule, which although valid for number 1 would also be valid for other numbers, and that Débora said that she hadn't noticed. The teacher educator's action, articulating mathematical and didactical knowledge, drew attention to a mathematical regularity, causing the teacher to look at the division operation differently.

Discussion

The results show that the professional development process designed and carried out, considering the three design principles, supported the creation of professional learning opportunities in which teachers reflected on the meaning of algebraic thinking and didactics in mathematics classes, advancing in their perspectives. The PLTT *Generalization*, by presenting records of students' work on a mathematical task (Ribeiro & Ponte, 2020), focusing on knowledge of students' reasoning (Desimone, 2009), encouraged the teachers to discuss collectively (Darling-Hammond et al., 2017) the presence of generalizations in the students' justifications (Figure 2). In this case, together with the aforementioned PLTT, the other two domains of the PLOT model, the Role and Actions of Teacher Educator (RATE) when designing the PLTT and promoting the analysis of the students' records, and the promotion of Discursive Interactions Among Participants (DIAP), contributed, as stated by Débora, to reframe her understanding of the meaning of generalizations. The results show us that the design of the PLTTs and, especially, how the teacher educator led them through questions and actions (Stein et al., 2008) created opportunities for teachers' professional learning as they provoked reflections in Débora, who realized that there was a regularity in the division algorithm and how this could be worked with students. In addition, by giving a suggestion on how to proceed to reach all students, the teacher educator provided pertinent feedback (Darling-Hammond et al., 2017) on the situation posed by Eliana establishing a bridge between teachers' theory and practice (Silver et al., 2007).

In addition, during the discursive interactions, Marina presented her interpretation that for the student there can be no other expression after the equal sign. This position by Marina may have contributed

to the creation of an opportunity for professional learning, by leading Adriana to make a new interpretation, showing that situations of professional learning can arise from the exchange between peers through dialogic communication (as in Craig & Morgan, 2015).

Conclusion

In addition to the design principles adopted by this study (Role and Actions of the Teacher Educator (RATE), Professional Learning Tasks for Teachers (PLTT), and the Discursive Interactions Among Participants (DIAP) pointing to the creation of learning opportunities, there is a strong interdependence between them, as both PLTTs design and its conduction are the teacher educator's tasks. The teacher educator thus gains a prominent role considering that the professional development process can be more in-depth and interconnected with practice depending on his/her actions. It is up to the teacher educator to carefully plan the teacher education learning processes (Kennedy, 2016), defining objectives, content and strategies organized in PLTTs (Ribeiro & Ponte, 2020), and to orchestrate (Stein et al., 2008) discursive interactions (DIAP), provoking reflections and providing appropriate feedback for each situation (Darling-Hammond et al., 2017). To create professional learning opportunities, it is not enough to place teachers in discussion groups (Kazemi & Franke, 2004); there is a need to carefully plan what to discuss. Thus, the teacher educator's knowledge is emphasized, both with regard to the knowledge of the content discussed in the teacher education program and to how it is led (Desimone, 2009). Although the present study has a mathematical focus on working with algebraic thinking in the early years, we suggest that the design principles that we use can be generalized to other mathematical themes or even other disciplines, which could give rise to further research.

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