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How and why facilitators adapt the core ideas of professional development activities on multiplying natural numbers

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The implementation of professional development (PD) programs not only requires a scientifically substantiated conception – it also needs a professional transfer. To ensure this, it is important to analyze facilitators' expertise and to understand, among other things, their adaptations of given PD material. Against this background, this paper presents a case study of a tandem of facilitators and their adaptations of selected PD activities for the PD content "conceptual understanding of multiplication". In doing so, we draw on existing research on facilitators' expertise and adaptations. We thereby aim at finding justifications for facilitators' adaptations and showing related consequences for teachers' learning and facilitators' preparation.

Keywords: PD Facilitators, PD activities, multiplication, conceptual understanding.

Introduction

Innovations in mathematics education can only reach the classroom through scaling-up professional development (PD) on crucial aspects for mathematics teachers. Within the German Center for Mathematics Teacher Education (DZLM), in which the context for this study originates, facilitators are prepared, among other things, for conducting PD sessions and thereby their expertise, which is central for the quality of PD programs (e.g., Borko et al., 2011), is promoted and investigated. With this paper, we contribute to the latter by investigating how facilitators deal with the demand of adapting given PD activities before conducting the PD on their own and by exploring their justifications. Thereby we focus on the PD program *Mastering Math* (Prediger et al., 2019), which aims at enhancing teachers' abilities to fostering at-risk students' conceptual understanding, and specifically here for multiplication. In the theory section, we start by specifying content-related facilitators' expertise and concretize it for the PD content in view. Then, we provide a brief literature review related to facilitators' adaptations, which forms the basis for the empirical part of our study. Therein we take a closer look at adaptations of a pair of facilitators – Tracy and Emily – carried out on the PD activities and investigate the consequences of the adaptations during the PD and the facilitators' justifications.

Theoretical framing

Specifying facilitators' expertise

Research concerning facilitators of PD for mathematics teachers, particularly for specific PD contents, is still an emerging field, with facilitators' expertise having been shown to be crucial for the quality of PD programs (e.g., Borko et al., 2011). Existing frameworks for investigating and conceptualizing facilitators' expertise often have been lifted from the teacher to the facilitator level (Prediger et al., 2019), for example, the ROG to the ROGI framework (Karsenty et al., 2023). This is also the

case for the framework for content-related facilitator expertise of Prediger et al. (2022b), which combines cognitive and situated perspectives (as suggested for example by Borko et al., 2014). It consists of jobs as typical and often complex situational demands of facilitating specific PD content, and practices as recurrent patterns of facilitators’ utterances and actions for managing the jobs. Facilitators’ practices can be specified by underlying categories, pedagogical tools, orientations, and situative goals. For this paper, the categories in terms of the knowledge that filters and focuses the categorial perception and the thinking of the facilitator play a crucial role. This includes, among other things, content knowledge on the PD-level (CK-PD), comprising the following knowledge areas on the classroom level: Generic pedagogical knowledge (GPK-C), pedagogical content knowledge (PCK-C, for example about students’ mathematics learning) and content knowledge (CK-C, sophisticated understanding of the relevant mathematical concepts).

To provide teachers with rich and content-related learning opportunities, the categories must be specified in content-related ways (Prediger et al., 2022b). In the next section this will be briefly done for the PD content concerning the conceptual understanding of multiplying natural numbers, in order to be able to analyze the facilitators’ practices for dealing with the job of adapting the PD activities with regard to underlying content-related categories.

Conceptual understanding for multiplication as PD content

The demand for the facilitators in the PD program *Mastering Math* is to promote teachers’ expertise in fostering at-risk students’ understanding of basic concepts, for example the conceptual understanding of multiplication, which is focused here (Prediger et al., 2022). It involves the core mathematical idea of “multiplicative thinking in bundled groups” (Goetze & Baiker, 2021). If this idea of unitizing is not addressed, it might inhibit meaning-making processes. For learning multiplicative thinking, repeated addition is indeed an important step, but is limited for understanding more complex topics like fractions or percentage calculation (ibid.). As the transition from additive to multiplicative thinking is an obstacle for many students, teachers need to learn how to foster students’ conceptual understanding of multiplication and to not focus on procedural skills alone (ibid.).

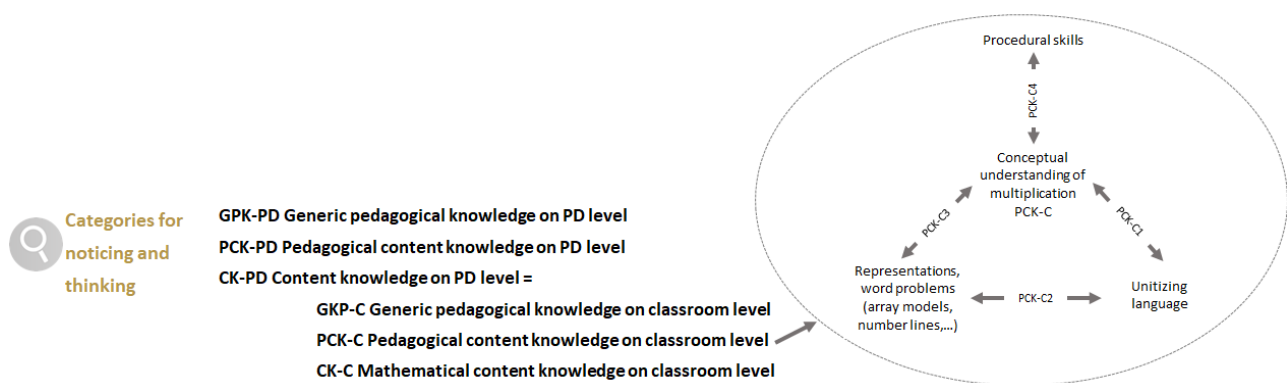


Figure 1: Relevant categories of facilitator expertise specified for CK-PD related to core ideas on multiplying natural numbers

Furthermore, the teachers should be made aware by the facilitators that the meaning-making processes of the students can be supported by relating different mathematical representations (e.g., concretely with dice or verbally with word problems) to each other, and by verbalizing the multiplicative

structures (Goetze & Baiker, 2021). Through the PD it should accordingly become clear to the teachers that conceptual understanding of multiplication is to be distinguished from procedural skills (PCK-C1). Furthermore, the use of the unitizing language (PCK-C1), the relation of different representations (PCK-C3) and their connections (PCK-C2) are fundamental for its development. These knowledge elements on the classroom level form the components PCK-C and CK-C of the CK-PD (see the specification of CK-PD in Fig. 1 above).

Facilitators' adaptations

In recent years, some studies provided information on essential aspects when preparing facilitators to use and adapt PD material. Specified PD programs (like *Mastering Math*) not only provide PD facilitators with slides that can be used in a PD session, but also offer information on, for instance, teachers' learning goals and learning pathways, and the role of the activities used during the PD for teachers (Karsenty et al., 2023). Nevertheless, PD for teachers is never one size fits all, but needs to take participating teachers' pre-requisites in terms of their knowledge, beliefs, and of course their needs into account. Keeping the necessity of adaptations in mind, Jacobs et al. (2017) stress that at least the core activities and learning goals of the original PD should be stated very clearly (for the facilitators) to allow for productive adaptations, maintaining the core of the PD. Otherwise facilitators' adaptations risk not supporting teachers to engage in rich discussions and to connect the PD activities to the targeted PD content (Roesken-Winter et al., 2021). For such modifications, Leufer et al. (2019) analyzed and revealed several categories for characterizing facilitators' adaptation practices for PD: FOLLOW, e.g., following one thematic block of the material as originally designed; OMIT, e.g., omitting a certain activity or thematic block; MODIFY, e.g., modifying a module, which always implies other adaptation actions on the material elements of which the module consists (one module can consist of several thematic blocks); SORT, e.g., modifying a module by resorting its thematic blocks into a new order; CREATE, i.e., developing a new activity within a thematic block. (p. 4). As categorizing PD facilitators' adaptations by the aforementioned FOMSC scheme allows for a better understanding of the quality of the adaptations made, we will investigate here, among other things, whether and how the identified adaptations can be assigned to the mentioned categories.

Research questions

Against the aforementioned theoretical background, we pursue the following research questions:

RQ1: What adaptation processes for PD activities regarding the mathematical core are visible for multiplying natural numbers and what consequences for addressed categories can be derived?

RQ2: What justifications are provided for the adaptations of the PD activities and which consequences for the preparation of facilitators are possible?

Methodology

PD project and PD activities

The study presented here is part of a research project, in which we investigate facilitators' conduction of PDs of the *Mastering Math* PD program (Prediger et al., 2022). This article focuses on the PD that deals with fostering the conceptual understanding of multiplication and division of natural numbers.

It is planned for three hours and consists of the presentation of input slides and the moderation of PD activities. Whereas facilitators' handling of the job of adapting the PD activities for the conceptual understanding of multiplication is considered here, a similar consideration for the division takes place in Shure et al. (submitted also for CERME13, TWG27).

The PD activities considered here are part of the PD material available for the facilitators and were introduced to them in a PD preparation program. Initially the activities were integrated in a targeted way for enabling the teachers to understand the core ideas of the PD. To be more precise, the PD activities aimed at different relevant categories (Figure 1) to be worked out by the teachers in accordance with the different sections of the PD. Thus, the PD is divided into an introduction (addressing especially CK-C), a section dealing with the PD content, namely the conceptual understanding of multiplication (addressing in particular PCK-C1-4), and a last section which focusses on the concrete realization of relevant aspects in student materials from *Mastering Math*. Within the sections, a total of nine PD activities are integrated. However, in this paper we only take three of them into account. They were selected, as they address different central PD categories and were adapted by the facilitators. The three focused PD activities are briefly presented below together with the intended goals.

- **Measuring tables** (PD activity 1): Teachers develop conceptual understanding for multiplication and recognize the aspect of unitizing as relevant element by measuring a table with rectangular cards (addressing CK-C). Thereby they have to recognize and distinguished multiplicative from non-multiplicative structures.
- **Analyzing word problems** (PD activity 2): Teachers analyze word problems formulated by students for the multiplication of $6 \cdot 5$ in terms of conceptual understanding for multiplication (PCK-C3) and differentiate it from mere procedural skills.
- **Analyzing a video clip of Belmin und Gülcan** (PD activity 7): Teachers analyze a video to consider students' possible misconceptions and to take up useful aspects for fostering their conceptual understanding for multiplication (PCK-C1-3). In the video the students must decide which graphical representations fit with the multiplication of $3 \cdot 4$. Gülcan thereby selects, on the one hand, a suitable picture with three dice with 4 points and chooses, on the other hand, representations that do not reveal multiplicative structures. Thus, her understanding of multiplication is not yet consistent and needs to be fostered. By analyzing and discussing the video clip and especially Gülcan's results, the teachers deepen essential aspects of considering conceptual understanding for multiplication and applying the way of verbalizing multiplicative structures.

Data collection

In total 14 facilitators participated in the focused research project. Before conducting the PDs in several rounds in tandems of two facilitators each with different groups of teachers, the prospective facilitators who are at the same time in-service-teachers were prepared over one year with regard to the existing PD program *Mastering Math*. The PDs of four tandems were partly video recorded and transcribed. Furthermore, the slides used by the focused tandems were collected. To capture facilitators' justifications for adaptations of the given PD material, each video-recorded PD session was also triangulated using a video-based and video-recorded and transcribed debriefing session in which both

facilitators discuss their PD with a researcher. Thus, not only the adapted materials were included in the analyses, but also the facilitation carried out and its reflections.

It should be noted that the original slides as part of the given PD material were adapted twice. First one of the seven facilitators' tandems adapted them and discussed it with their colleagues. The second adaptation was based on the first and was carried out by all tandems themselves. The data selected for the case study in this paper stems from Tracy and Emily. We focus on this tandem as they showed different adaptations, which they justified particularly by their own learning. The analysis of this data seems to have potential for deriving possible consequences for the preparation of future facilitators.

Data analysis

The two adaptations of PD activities were analyzed (with a qualitative focus) against the background of the two research questions. Thereby, the following two analytical steps were carried out:

(1) Analysis of the adapted PD activities (based on Leufer et al., 2019) in two versions in contrast to the original slides and regarding addressed core ideas (operationalized as categories, see figure 1) and thus possible learning opportunities for participating teachers (RQ1).

(2) Analysis of the video-recorded and transcribed PD and reflection sessions to derive justifications of the adaptations made by the facilitator tandems (here Tracy and Emily) (RQ2).

Results and discussion

Adaptation processes

Already in the first-round various adaptations according to Leufer et al. (2019) could be identified. Thus, some input slides or PD activities (see overview in Table 2) were changed or omitted.

Table 1: Adaption processes (orange arrows for changes, green for retentions) for Tracy and Emily

	Introduction		Content / pedagogical content background		Implementation in material	
	Adaption 1 – Multiplication	Adaption 2 – Multiplication	Adaption 1 – Multiplication	Adaption 2 – Multiplication	Adaption 1 – Multiplication	Adaption 2 – Multiplication
Activity used without change	Word problems		Video clip of Belmin and Gülcan		Example tasks from the project “mastering math”	
Activity changed		Word problems <i>Extended by own examples</i>				
Activity resorted		Video clip of Belmin and Gülcan				
Activity omitted / hidden	Measuring tables with rectangular cards	Measuring tables with rectangular cards				Example tasks from the project “mastering math”

However, only those changes that relate to the focused three PD activities and were initiated in the first adaptation or by Tracy and Emily will be discussed in more detail here:

- **Measuring tables** (PD activity 1): It was already omitted in the first adaptation and also by Tracy and Emily, who know it from their preparation. Thereby, the participants have fewer opportunities to explore the conceptual understanding of multiplication (i.e., CK-C) in more depth.
- **Formulating word problems** (PD activity 2): It is designed to initiate a diagnostic discussion about students' word problems, remained in both adaptations and thus enables the addressing of

PCK-C4. More precisely the teachers could recognize the differentiation between procedural skills and conceptual understanding for multiplication. Furthermore, Tracy and Emily extended the PD activity with further examples from their own students.

- **Video sequence of Belmin and Gülcan** (PD activity 7): It was used by Tracy and Emily during the introduction and thus at a much earlier point in the PD than planned. The unchanged task for the teachers was to identify students' conceptual understanding of multiplication based on their utterances in the video and to develop initial ideas for fostering students' understanding with these mathematical difficulties (addressing PCK-C & PCK-C3). As the teachers have not received any input on the conceptual understanding of multiplication at this stage, it is not very likely that Tracy and Emily explicitly address all possible categories (PCK-C1 & -C2).

In summary, by resorting the analysis of the video sequence of Belmin and Gülcan to the beginning of the PD, the PD section for elaborating the content/pedagogical content background no longer contains any activities. Thus, the teachers therefore no longer have to explicitly apply the contents presented in the input (especially PCK-C1 to -C3) to practical examples at this point in the PD.

Explanations for adaptations

For the above-described adaptations made by the facilitators we now present possible explanations. Thereby, we especially draw on Tracy and Emily's statements from the reflection sessions.

For the *omission of the activity "measuring tables,"* there seem to be different explanations: On the one hand, in mathematics education courses at German universities for prospective teachers there are often three different basic concepts of multiplication that are emphasized (Padberg & Benz, 2011). Furthermore, mathematics textbooks for primary school often address the idea of multiplication as repeated addition. In contrast, the internationally emphasized idea of multiplication as unitizing (described above), which forms a core idea of the focused PD here, is rarely made explicit. Thus, adherence to one's own prior PCK could lead to the omission of activities, particularly the 'measuring tables' activity, which requires dealing with one's own conceptual understanding of multiplication. On the other hand, the facilitators' own conceptual understanding of multiplication in terms of CK-C plays a role. This is emphasized in the Tracy's statement, mentioning challenges of her own learning process regarding the role of multiplication as repeated addition:

Tracy: I struggled during my preparation, when I read on a slide that you shouldn't emphasize this $4+4+4$ so much. I didn't really know that anymore, so I asked Emily: 'Tell me, why is that written there?'

Also, within the PD, the facilitators had reacted cautiously to a teacher's question regarding the relevance of the core idea of multiplication. To what extent unitizing as core idea could be made explicit does not seem to be clear to Tracy and Emily. Both explanations – differences between their own prior PCK regarding the focused topic and the intended PCK, or the perceived uncertainty with the core ideas addressed in the PD (especially that of unitizing and its distinction from repeated addition) – could be adequate for the non-explicit thematization of this content knowledge aspect (CK-C).

Tracy and Emily justified the *enrichment of the given word problems* with own examples (see table 2) by their own previous disbelief in students' gaps in conceptual understanding. For example, they

explained that they could not believe students' fundamental difficulties in formulating word problems for multiplication tasks like $6 \cdot 5$, which they were confronted with in their PD preparation:

Emily: No one who has not consciously looked at their teaching from this perspective believes it. We didn't believe it either [...]. Every time we went out of that PD preparation we thought: 'Well, she's been telling us something again...'

According to Tracy and Emily, it was only by trying out this task with their own students that they realized that many of them had not fully developed a conceptual understanding of multiplication:

Emily: I tried it and laughed my head off. They did it just like the students in the examples.

To prevent a similar disbelief of the teachers participating in their PD, they brought in their own students' written products in addition to the given word problems.

The *justification* Tracy and Emily gave for resorting to the PD activity on the video sequence to the introduction of the PD is that they wanted to convince the teachers about the relevance of fostering at-risk students' understanding of basic concepts through the authenticity of the video sequence:

Tracy: Well, if you haven't seen the video, I don't think the awareness of the problem is there. That students have the idea that the angle $\overset{\cdot\cdot\cdot}{\cdot}$ represents $3 \cdot 4$. I remember in my first PD session of *Mastering Math* I didn't believe it either, but that was totally productive for me. I think you must see this before you develop problem awareness, otherwise you think: Yes, I know it, it's no problem, I always do it like this.

In the original PD, this activity offers the facilitators an opportunity to find out which aspects (like the categories PCK-C1-3) of previous PD sequences the teachers recognize and apply. The analysis of the video sequence should show that Gülcan has (rudimentary) conceptual understanding of multiplication, that cannot be used consistently for an adequate interpretation of different representations. An important support for fostering their students' understanding that the teachers could work out by this PD activity is to apply the unitizing language (PCK-C2-3) and thus to establish the connection of CK with PCK-C1. Due to the understandable intention of Tracy and Emily to sensitize the teachers at an early stage of the PD through an authentic situation, the focused activity receives a different character. The extent to which the teachers may recognize the connections between relevant categories (CK-C and PCK-C1-4) remains unclear here, as it depends on teachers' prior knowledge.

Conclusion and consequences

In summary, the analyses reveal that the identified adaptations of PD activities can be assigned to the categories of Leufer et al. (2019) and show that they can be based on subjectively highly plausible explanations. Regarding the tandem of facilitators focused here, the adaptations were justified for example, by their own learning adaptation processes during the PD preparation, their experiences gained from their own teaching or their own learning resources and can influence the design of the PD they conduct, and thus the learning of the participating teachers. However, it must be considered that the intended core ideas of the PD program may be less explicit or produce different connotations due to the adaptations made, and thus could be understood differently by participating teachers. In the case described here, the adaptations made by Tracy and Emily, or in advance by another tandem, certainly caused the intended categories (CK-C and PCK-C1-3) to be less emphasized than originally intended. It is planned that the analyzed aspects and the insights gained here will be considered in our future PD preparation sessions, especially with regard to the justifications made for the undertaken

adaptations. Even though our analyses only refer to one specific PD content and one pair of facilitators, the revealed adaptations, consequences and provided justifications can substantially inform the re-design of the PD preparation course. For example, the content, the purposes, and the aims of different PD activities should be discussed with the prospective facilitators more in detail, so that the teachers in their PD courses have enough possibilities to deal with PD core ideas (see categories in Figure 1).

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