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SURVEY PAPER

Evidence-based CPD: Scaling up sustainable interventions

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Abstract In this survey paper we approach the challenge of scaling CPD from four perspectives. First, we elaborate on crucial aspects of teacher learning and what taking the learning of these crucial aspects entails. Second, we focus on different CPD frameworks to showcase developments in CPD research and practice over the last 40 years and the influences of different views of CDP. Third, we elaborate what developing CPD in an evidence-based way means, before we finally discuss crucial issues of spreading CPD on a large scale. In this last perspective, we draw on Coburn's four dimensions characterizing the process of scaling CPD interventions, depth, sustainability, spread, and shift in reform ownership to discuss how the challenge of scaling high-quality CPD might be successfully addressed. Our literature review is based on findings from education research in general and mathematics education research in particular in order to pay attention to both overarching aspects of providing effective CPD and the domain-specific factors of mathematics teaching and learning. Against this background, we identify needs for further research and provide an overview how the papers in this Special Issue of ZDM might address these needs.

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1 Introduction

Manifold recent discussions about effective teacher education in mathematics are pointing to the need for continuous professional development (CPD) to be offered to practicing mathematics teachers. This need for CPD is evident in general, so that all teachers become used to being part of a professional learning community, but is particularly acute when a large-scale intervention is implemented by policy stakeholders with teachers need support to be able to develop according to the new expectations.

The increasing interest in CPD has led, not only to the development of various theoretical and methodological approaches in CPD research, but also to new models and designs of CPD in practice (cf. Sowder 2007). Some of these posit general models, while others are more specific and relate to the particular needs of mathematics teaching and learning (cf. Goodson and Hargreaves 2003; Zehetmeier and Krainer 2011). Variance is however considerable, even within the field of mathematics education, as Llinares and Krainer (2006) state in their review of PME (Psychology of Mathematics Education) research, where they identify the cultural diversity of CPD programmes arising from different national characteristics. Traditional approaches such as in-service education and training, provided by a range of agencies continue to exist, alongside models that embrace more collaborative practices to promote teachers' professional learning through for example study groups, teacher inquiry, learning studies or action research (cf. Bolam et al. 2005; Vescio et al. 2008; Goodchild 2014). These latter approaches serve different purposes that need to be distinguished in order better to understand their aims and challenges. For example, some provide support at the individual teacher level, others aim for change at the system level (Guskey 2000; Krainer

2008), while still others focus on an intermediate level, such as a region or school.

In this survey paper, we pay attention to the these aspects considering research findings from education research and from mathematics education. Given the manifold perspectives involved, we concentrate first on the persons addressed, namely the teachers and their learning, and the considerable challenges that have to be met in the design of CPD (chapter 2). Then we provide an overview of how CPD is defined and framed by covering different approaches to CPD that have resulted in various meanings and conceptual frameworks over the last 40 years (chapter 3). In a third step, we explain what developing CPD in an evidence-based way entails (chapter 4), and, finally, we explore essential aspects for scaling interventions and the requirements such efforts demand (chapter 5). Based on this literature review, we then outline future research perspectives and discuss how the papers and commentaries of this Special ZDM Issue shed light on crucial aspects and indicate in new directions (chapter 6).

2 Taking teacher learning seriously

Teachers' professional development takes place every day, inside as well as outside the classroom, through reflecting or talking about practice or students' work, preparing for the next day, being encouraged in school conferences or meetings with parents and so forth. Thus, we are confronted with a dualism of teaching and learning, as Guskey (2000) points out: "If we view professional development as an ongoing, job-embedded process, every day presents a variety of learning opportunities" (p. 19). And it is Schoenfeld (2006) who reminds us that "some of the most interesting approaches to professional development are those that take the notion of teacher learning seriously" (p. 485), where everyday activities are carefully documented and reflected.

What CPD in this view adds are systematic professional learning opportunities that build on daily experiences but provide theoretic and methodic frames to discuss and reflect upon teaching approaches and student learning (cf. Simon 2007; Timperley 2011). Shulman's (1999) verdict of "taking learning seriously" is thus applied to teacher learning. Balancing theory and practice, and considering the needs of the teachers is decisive within such CPD settings.

In contrast to this approach, most initiatives in the past were based upon the concept "to bringing knowledge from outside the person to inside" (Shulman 1999). In this respect, Cochran-Smith and Lytle (1999) provide an interesting analytical model by stating that "three different conceptions of teacher learning drive many of the most prominent and widespread initiatives intended to promote teacher learning" (p. 251):

- *Knowledge-for-practice* formal knowledge generated by research outside the school.
- *Knowledge-in-practice* knowledge generated by teachers studying their classroom and practices.
- *Knowledge-of-practice* practical knowledge by teachers generated by their own systematic inquiry.

The three conceptions are derived from different conceptualizations of teaching, learning and the relation between them. Moreover, they serve to structure different approaches to providing CPD opportunities (Sowder 2007). Cochran-Smith and Lytle (1999) make an interesting point when concluding that "the salient differences among the three conceptions of teacher learning reside not in the methods used to foster teacher learning but […] in the assumptions that underlie these methods—in the images of knowledge, practice and teachers' role that animate them" (p. 252). That is, currently highly valued approaches like, for instance, inquiry groups and communities of practice may be designed very differently regarding their purposes and goals so that the methods themselves carry different views of teachers and their learning. As a consequence, Cochran-Smith and Lytle (1999) emphasize that one should be aware of the fact that a new method is not necessarily innovative in and of itself. Many CPD offers are still based on a *knowledge-for-practice* conceptualization (Cochran-Smith and Lytle 2001; Messner and Reusser 2000), evidencing that taking teacher learning seriously remains a major issue.

To understand teacher learning processes in more detail, Goldsmith, Doerr and Lewis (2014) undertook a meta-analysis on professional learning of practicing mathematics teachers, based on 106 articles written between 1985 and 2008. Besides providing a synthesis of this research, the authors aimed at understanding teacher learning in terms of an overarching conceptual framework. In particular, they wanted "to summarize the characteristics and findings of existing research in ways that will be useful to researchers, practitioners, and policy-makers as they design professional learning opportunities and research" (p. 6). Though a total of 219 articles were collected from refereed journals, only those explicitly reporting on "changes in knowledge, changes in practice, and changes in dispositions or beliefs that could plausibly influence knowledge or practice" (Goldsmith et al. 2014, p. 7) were taken into account. Thus, studies simply describing good teaching without providing data-based evidence of teacher learning were excluded.

Findings from these research studies were assigned to the different categories postulated in the Interconnected Model of Professional Growth by Clarke and Hollingsworth (2002): the personal domain (teacher knowledge, beliefs and attitudes), the domain of practice (professional experimentation), the domain of consequence (salient

outcomes), and the external domain (sources of information, stimulus or support). Based on their results, Goldsmith et al. (2014) draw the overall conclusion that teacher learning "is often incremental, nonlinear, and iterative, proceeding through repeated cycles of inquiry outside the classroom and experimentation inside the classroom […] (p. 20). This of course presents considerable challenges for the design of CPD. Also, they remind us to consider effectiveness of CPD programs, not only in broad terms, such as global characteristics, but also to reveal aspects of particular processes and settings that have proven to promote teacher learning:

> Typically, teachers' learning is treated as an indicator of the effectiveness of the program rather than as the primary object of inquiry. For this reason, many studies identified aspects of the Personal and Practice domains that professional development programs seek to affect, but few studies focused on the processes or mechanisms of teachers' learning; therefore, they have little to say about how teachers develop knowledge, beliefs, or instructional practices. (Goldsmith et al. 2014, p. 21)

Based on their review, Goldsmith et al. (2014) call for studies on CPD that have more to say about the processes and, what they declare "the mechanism" of teacher learning, instead of just discussing results of teacher learning. Thus, in the following, we focus on teachers' professional learning and related processes, while discussing different approaches to mathematics-specific CPD.

3 Different approaches to CPD

3.1 Developments in approaching CPD

Over the last 40 years, several shifts have occurred within the field of teacher professionalization such as the increasing significance assigned to the social dimension, changing the view of teachers working in isolation (Lortie 1975) to collegial collaboration (Krainer 2003). Another paradigmatic shift lies in conceptualizing teachers' CPD as distinct from in-service education and training (cf. Guskey 2004), changing the view of teacher learning only happening through formal and structured courses outside the classroom to continuous development embedded in teachers' everyday activities. Hargreaves (1994) gives an interesting metaphor for each of the concepts:

> The INSET [In-Service Education and Training] model during periods of reform treats teachers as needing occasional injections to pep them up, calm them down, or ease their pain. The professional development model requires a different metaphor: Unless teachers are offered through professional development a regular and balanced diet, they will not be effective practitioners. (p. 430)

There is however significant inertia in the system resulting in little change in the earlier views. Loucks-Horsley et al. (2003) describe some generic trends: "In the early 1970s, professional development was called in-service training" (p. 47), which comprised a "planned event, series of events or extended program of accredited or non-accredited learning" (Day 1997, p. 131). This model remains dominant in many countries as the most common conception of CPD (Guskey 2000). Even though the vision of teachers as lifelong learners has influenced research considerably, in-service education and training in the abovementioned conceptualization still appear "to be the most efficient and cost-effective way to reach the huge population of teachers" (Day and Sachs 2004, p. 8). Correspondingly Guskey (2000) stresses:

> Many teachers and school administrators regard professional development as special events that are restricted to 3 or 4 days during the school year. Seldom have they had input into the planning of these events, and only rarely are the ideas that are offered applicable to their situation. (p. 14)

Thus, interventions aiming at providing in-service training for teachers are regarded as a classical instrument for establishing reforms in teaching, serving the wider purpose of performativity (Sprinthall et al 1996; Sowder 2007). In many countries, training programs are for example mobilised as a means to manage a political crisis: an immediate reaction can be actioned, when, for example, educational excellence is challenged by students' performances in international comparisons. In European countries in particular, Day (1999) recognizes a historically rooted reluctance to adopt an idea of professional development that is systemic and life-long.

As a result, programs are often intentionally designed opportunities, but mainly conceived as bringing outside knowledge to the single teacher (cf. Cochran-Smith and Lytle 2001). Additionally, no particular relevance is accorded either to collegial work or to the system in which the teacher is working (Day 1999). This situation is particularly noticeable in mathematics, with the all too frequent challenges of recruitment of suitably qualified teachers and the widespread concern about teachers' mathematical content knowledge. The philosophy underpinning CPD settings is dominated by deficit compensation, rather than viewing CPD positively as supporting teachers in their professional growth, and, in the words of Wilson and Berne (1999), acknowledging that: "Professional teachers require professional development" (p. 173).

3.2 Frameworks and definitions of CPD

Clarke (1991) gives a concise definition of CPD as "any activity or process intended to change any combination of the following: teachers' beliefs and attitudes, teachers' knowledge and teachers' classroom practice" (p. 1). Similarly, Sowder (2007) identifies professional growth as "marked by change in teachers' knowledge, beliefs, and instructional strategies" (p. 161). From a slightly different perspective, Guskey (2000) defines professional development as "those processes and activities designed to enhance the professional knowledge, skills, and attitudes of educators so that they might in turn, improve the learning of students" (p. 16). These definitions focus on the individual teacher's characteristics in terms of knowledge and beliefs that guide their practices, while in contrast Sparks and Hirsh (1997) stress that a comprehensive understanding of CPD needs to take into account context factors such as the cultures and organizations in which teachers work. A comprehensive definition, considering such contextual aspects and specifically elaborating on the procedural character of lifelong learning, is given by Day (1999):

> Professional development consists of all natural learning experiences and those conscious and planned activities which are intended to be of direct or indirect benefit to the individual, group or school and which contribute, through these, to the quality of education in the classroom. It is the process by which, alone and with others, teachers review, renew and extend their commitment as change agents to the moral purposes of teaching; and by which they acquire and develop critically the knowledge, skills and emotional intelligence essential to good professional thinking, planning and practice with children, young people and colleagues through each phase of their teaching lives. (p. 4)

Such a concept of professional development "does not eschew INSET [In-service Education and Training], in the form of courses, but locates it in a wider learning context, as contributing to the repertoire of learning modes now used to promote growth of individuals and institutions, and taking place both on- and offside" (Day 1999, p. 131). Timperley (2011) adds another aspect to the discussion when stating that "learning is not a one-off event, but rather a process of learning and change over time" (p. 64). Some authors explicitly refer to such procedural aspects when applying the term *continuous* professional development "to describe all the activities in which teachers engage during the course of a career which are designed to enhance their work" (Day and Sachs 2004, p. 3).

Guskey (2000, p. 16) tries to systemize these different aspects of CPD by pointing to its three defining characteristics: It is an intentional process, an ongoing process and a systemic process. Thus, he stresses firstly that CPD is an intentional and purposeful process. Consequently, any events planned or designed should have a well-structured outline as well as clearly defined objectives as to what is intended to be accomplished. Establishing these objectives and keeping them in mind helps to explicitly distinguish these events from approaches that conceive CPD as "a set of random, unrelated activities having no clear direction or intent" (Guskey 2000, p. 17). Second, CPD is an ongoing process since our general knowledge is expanding every day. New results, for example in mathematics education research, may provide new insight into the mathematical content itself and potentially new effective teaching approaches.

Third, CPD should be much more than providing a single learning opportunity for a single teacher, rather: "true professional development is a systemic process that considers change over an extended period of time and takes into account all levels of organization" (Guskey 2000, p. 20). This corresponds to viewing CPD as a "bottom-up" process: putting change and responsibility into the hands of schools and teachers and viewing them as active, involved partners in the enterprise (Krainer 2002). Such a conception of CPD captures what Day (1999) posits: "Teachers cannot be developed (passively). They develop (actively)" (p. 2).

By now a diversity of definitions characterizes the field of CPD. As Sowder (2007) points out "professional development is an umbrella term for many types of activities and settings" (p. 173). Similarly, Kelchtermans (2004) stresses that professional development "seems to have become a new 'container concept' in the educational research discourse" (p. 217). In the TALIS study (OECD 2009), types of CPD are compared with respect to the participation rate of teachers (in percentages) across 23 countries:

> After "Informal dialogue to improve teaching", the most frequently reported activities were attending "Courses and workshops" (81 %) and "Reading professional literature" (78 %). The least common types of professional development were "Qualification programmes" (25 %) and "Observation visits to other schools" (28 %) (Table 3.2). However, patterns vary widely, particularly for the more structured types of activities. (p. 57)

These findings point to a variety of CPD settings and clearly show the significance of "informal teacher learning", in contrast to formal qualification programs that offer a more systematic view on a topic. So what about the impact of these different types of CPD? Based on teachers' self-reports, findings from TALIS revealed that across countries "Individual and collaborative research", "Informal dialogue to improve teaching" and "Qualification

programs" were regarded as most effective forms of teacher learning. On average, almost 90 % of teachers estimated a moderate or large impact of these settings on their development (OECD, 2009). Even though such results should be read with caution as only an indicator of effectiveness, it is noteworthy that the findings show a stable trend towards embedded types of CPD which is shared across countries. They also suggest a tension between perceptions of the importance of informal learning and yet the judgement of effectiveness being linked to qualification programs.

There has been much progress in the field, and viewing in-service education as being job-embedded and part of CPD has also gradually begun to permeate the research agenda. It is to this shift that we now turn.

4 Developing CPD in an evidence-based way

4.1 State of research and institutionalization of CPD

More than 20 years ago, Hoyles (1992) reported a quantitative increase in research incorporating the teacher as an integral and crucial variable when studying the improvement of learning mathematics. At almost the same time, Cooney (1994) published his well-known paper *Research and Teacher Education: in Search of Common Ground*, where he claimed that "[…] the development of theoretical constructs are essential if we are to move the enterprise of teacher education out of the realms of being an activity and toward being a discipline worthy of study" (p. 631). 10 years later, Adler et al. (2005) provide a broad synopsis of teacher education research published in the years 1999–2003, based on a literature review of international mathematics education journals, international handbooks of mathematics education and international mathematics conference proceedings. Against this literature review, Adler et al. (2005) conclude that research in the field is dominated by small-scale qualitative studies giving the following explanation: "Having teachers as the focus of research leads to high complexity. This increases the tendency to keep the sample small in order to reduce complexity" (p. 369).

Meanwhile the research base has developed much even with respect to the field of practicing teachers and their CPD. Thus, in this Special ZDM Issue we explicitly draw on CPD that is developed in an evidence-based way, meaning that strengths of different approaches to CPD are evidenced by empirical findings whether by means of quantitative or qualitative research methods. In particular, we pay attention to how evidence-based CPD can be scaled by spreading initiatives and innovations which then maintain themselves for an extended time period. That this is an important issue was already identified by Slavin in 2008, when concluding:

> Evidence of effectiveness of educational programs is often cited to justify decisions already made or opinions already held, but educational program adoption more often follows the pendulum swing of fashion, in which practices become widespread despite limited evidentiary support and then fade away regardless of the findings of evaluation (p. 5)

The developments in mathematics education have been manifold. In many countries over the past 10 years, national standards for mathematics have been prescribed by Ministers of Education with resulting new demands on mathematics teachers. CPD that enables teachers to cope with such demands has thus become an important issue in many countries. In this context of change, balancing interventions to meet the needs of the system and the needs of individual teachers is one of the major challenges (Day 1997; Krainer 2001). Looking at CPD from a teacher's perspective, the starting point has here to be her daily practice and instruction (Cochran-Smith and Lytle 2001; Roesken, Hoechsmann and Toerner 2008). Looking at CPD from a systemic perspective, there is a need to scale interventions at large, while maintaining the original vision of building on teacher needs (see, e.g., the approaches of NCETM in England, DZLM in Germany, or NCM in Sweden).

In fact, the NCETM (National Centre for Excellence in the Teaching of Mathematics) was started with the specific aim to promote the professional development of teachers of mathematics throughout England, so CPD would be a responsibility and entitlement for all teachers. Prior to this point, professional development had existed but had tended to be rather ad hoc, short-term, geographically patchy, and comprising sets of courses as alluded to above. It was decided at a policy level that what was needed was an infrastructure that monitored and coordinated the provision nationwide. This was hugely ambitious, and the resource demands of time, funds and expertise of different types should not be underestimated (Hoyles 2010).

In a third perspective, we look as researchers at CPD from a scientific perspective, meaning that we insist on pursuing an evidence-based approach and on aligning research and policy as far as possible (Hoyles and Mundi 2013). Following the example of the NCETM but aligning it to different national objectives and needs, in Germany a centre was established to implement such an approach. The DZLM (Deutsches Zentrum für Lehrerbildung Mathematik—German Centre for Mathematics Teacher Education) intends to provide high-quality CPD for mathematics teachers while settling principles and quality criteria to define CPD standards. To ensure developing CPD in an evidence-based way, the centre follows a design-based

research paradigm (cf. Prediger and Link 2012; Tulodziecki et al. 2013; van den Akker et al. 2006). That is, all DZLM courses are developed and implemented in a research-based way as well as continuously evaluated and researched from different perspectives to guide the process of re-design and modification (DZLM 2014; Roesken and Kramer 2013). Both the NCTEM and the DZLM aim to provide a sustainable national infrastructure for subject-specific professional development for all mathematics teachers to meet their professional aspirations. Similarly, the NCM (National Centre for *Mathematics*) in Sweden is concerned with implementing large-scale CPD that will reach 40,000 teachers during 2012 and 2016 and is based on scientific evidence, research, theory as well as examples of best-practice.

4.2 Challenges and needs of research on CPD

Much is known about the professional knowledge of preservice and practicing mathematics teachers based on research in different countries and with different methods over the last decade. While the "Teacher Education and Development Study: Learning to Teach Mathematics (TEDS-M)" provided evidence as to how high-achieving countries train their mathematics teachers and how this results in stronger teacher knowledge (Blömeke and Delaney 2012; Tatto et al. 2012), a corresponding cross-country study examining both the quality and effectiveness of CPD is still missing (Lipowsky 2004; Sowder 2007; Roesken 2011). At least, these large-scale comparative studies have led to an elaboration of competencies characterizing effective teachers (Blömeke et al. 2011, 2012; Kunter et al. 2013) and of the processes that mediate the transformation of these competencies into classroom practice (Baumert et al. 2010; Blömeke et al 2015) which in turn influences research on CPD. In addition, classroom studies (e.g. Stigler and Hiebert 1999), also realized as quasi-experimental designs such as the Pythagoras study on instructional quality (Klieme et al. 2009), contributed to deeper understanding of the link between teaching practice and student achievement.

In an attempt to map the phases of research on teacher CPD, Borko (2004) points to the need to consider the following key elements as relevant in a CPD system: The CPD program, the teachers as learners, the facilitators or teacher educators, and the context of the CPD program. Based on these essentials, she differentiates three phases that build on each other to point to how research, aiming at providing high-quality CPD for all teachers, may progress. In phase one, the research reveals the effects of an individual CPD program at a single site on teachers' learning due to the CPD provided. In phase two, the research—while still addressing a single CPD program—investigates the effects as it is offered at more than one site and by more than one facilitator. Hence, variables under investigation now include context conditions and facilitators of CPD programs, in addition to the program itself and the teachers as learners. In phase three, the complexity increases as multiple CPD programmes, each enacted at multiple sites, are compared and contrasted. Thus, the generalizability of the results is extended and it becomes possible to study the relation between all four elements of the CPD system mentioned earlier.

Borko (2004) identifies the following as major activities of phase two: "refining a professional development program's tasks and materials for teachers (including the development of materials that are transportable across contexts), specifying the role of the facilitator, and developing resources and training for facilitators" (p. 10). By contrast, phase three CPD research takes a comprehensive view by comparing effects of components across different CPD initiatives. Requirements for phase three research are considerable as Borko (2004) points out:

> The complexity of the research design for a large-scale longitudinal field study of multiple professional development programs will undoubtedly require data collection and analysis tools that do not yet exist. Thus, in contrast to Phases 1 and 2, Phase 3 research projects will include substantial design work on research tools rather than professional development resources. (p. 12)

Despite these challenges, there has been progress, although research studies contributing within the frame of phase three are still few as are systematic empirical investigations of CPD effectiveness (Guskey 2000; Sowder 2007). One reason lies in the absence of instruments that would allow for researching in-depth developments of, for instance, teachers' competencies. However, what we can derive from some meta-studies that report CPD effects at different levels, are features that are shown substantially to support teacher learning and teacher instructional strategies (cf. Garet et al. 2001; Goldsmith et al. 2014; Lipowsky 2004, 2010, 2011; Timperley et al. 2007).

For instance, Garet et al. (2001) identified the following aspects as essential for high-quality CPD that fosters teacher and ultimately student learning: the degree to which the activity has a content focus, the extent to which the activity offers opportunities for active learning, the degree to which the activity promotes coherence in teachers' professional development, the form and the duration of the activity, and ultimately the degree to which the activity emphasizes the collective participation of groups of teachers from the same school, department or grade level. These findings were derived from a study of a federal program to support professional development of teachers mainly in mathematics and science. In view of their results, the

authors concluded that "to improve professional development, it is more important to focus on the duration, collective participation, and the core features (i.e., content, active learning, and coherence) than type" (p. 936).

Desimone (2011) drew on the these studies and suggested that the conceptualization and methodologies of studies concerned with measuring effects of CPD should be synchronized in order to improve validity of results. To provide a comprehensive conceptual frame, she regarded the following critical features necessary to describe and classify CPD programs: content focus, duration, coherence and collective participation. Accordingly, other studies confirmed that teacher learning is enhanced by teachers' collective participation, enabling them to co-plan and co-teach, and that effective CPD courses provide linkages to teachers' daily practice (Cochran-Smith 2001; Darling-Hammond and Richardson 2009; Wilson and Berne 1999; Yoon et al. 2007). As regards teachers' active learning, the focus of CPD on pedagogical content knowledge proved to be decisive, allowing teachers to examine their own students' work and to reflect their classroom activities against normative standards (Birman et al. 2000; Borko 2004).

5 Conceptualizing scaling CPD

It is a long way from high-quality CPD to scaling high-quality CPD. As generally with educational innovations, even if they are found to be effective in several instances and can be successfully adopted in new contexts, they face the risk of being dropped at an early stage or in favour of other innovations (Slavin 2008). It may be too difficult to communicate the content of a new program beyond the small number of dedicated early adopters or the program is insufficiently aligned with existing curricula or sustainable funding is missing. Research about how to support the longevity and scaling of a new program has pointed to several key aspects necessary to make educational innovations last: namely the existence of comprehensive teaching materials, local facilitators, local commitment, funding, support networks and continuous research and development (ibid.).

As yet, research on the maintenance of CPD has substantially contributed to defining high-quality CPD in terms of quality criteria. However, little is known about the processes of dissemination, particularly with regard to the nature and the quality of change processes that are to be enhanced. The research base is thin, and research on scaling is often restricted to investigating scaling interventions simply in terms of quantitative numbers, e.g., increasing the number of teachers or schools that profit from CPD (Coburn 2003). Hence research on the mechanisms of scaling up is definitely needed (Fullan 2000; Hargreaves and Fink 2000). In an attempt to conceptualize scaling, Coburn (2003) reminds us about the following:

> That is, scaling up not only requires spread to additional sites, but also consequential change in classrooms, endurance over time, and a shift such that knowledge and authority for the reform is transferred from external organization to teachers, schools, and districts. (p. 4)

Accordingly, Coburn (2003) identified four dimensions that characterize the process of scaling CPD interventions: *depth, sustainability, spread*, and *shift in reform ownership*. These dimensions significantly interact as she pointed out:

> That is, the more challenging a reform is to teachers' existing beliefs and practices, or the more aspects of classroom practice or levels of the system it engages, the more it may need well-elaborated materials and sustained, ongoing professional development to achieve depth. Similarly, reforms of this nature may require more effort on the part of reformers to work with multiple levels of the system to encourage normative coherence and sustainability. This suggests that the more ambitious a reform, the more challenging it may be to simultaneously achieve spread, sustainability, and depth. (p. 9)

Thus, establishing a centre to promote mathematics CPD that works in an evidence-based way, on a large scale and is at the same time sustainable is challenging. With regard to *depth*, individual knowledge and beliefs patterns of teachers as well as instructional strategies have to be aligned if CPD is to make an impact (Day 1999; Sowder 2007; Zehetmeier and Krainer 2011). The state of research on effective CPD already refers to this debate as categories like content, duration, collective participation, active learning, and coherence are brought into play and guide the conception of many CPD initiatives (cf. Desimone 2011).

In respect of *sustainability*, Henze et al. (2009) report that although studies may be aligned with research findings on CPD effectivity, they often do not adequately take into account the different school contexts. Then, sustainable impact is questionable. Zehetmeier (2010) clarifies the concept of *sustainability* in relation to effective CPD:

> The expected outcomes of professional development projects are not only focused on short-term effects that occur during or at the end of the project, but also on long-term effects that emerge (even some years) after the project's termination. Effects that are both short term and long term can be considered to be sustainable. (p. 1952)

That is, it is not sufficient to discuss sustainability in terms of outcomes, but time frame is an essential variable

as well, demanding follow-up support and research to pursue developments over time. What is not reflected in the definition is that in addition to expected outcomes, unexpected ones can influence innovations considerably (Rogers 2003).

A related is issue is how to aim at *spread.* Improvement at scale is concerned with reproducing teaching innovations that were successfully evaluated for use in a small number of classrooms within a broader frame (Cobb and Smith 2008). The authors suggest support structures like teacher networks, networks that include school leaders, and leaders of broader administrative jurisdictions to take into account that many countries have decentralized educational systems. Current research is rather narrowed to addressing change at the teacher level, when scaling to the overall system comprising school and district support structures need to be paid attention to. Thus scaling interventions involves stakeholders that have not been addressed in the first place, as teaching innovations were tested in individual classrooms (Cobb and Smith 2008).

In their meta-analysis on CPD for science teachers, van Driel et al. (2012) accordingly underline that spreading sustainable initiatives depends on the supportive role of facilitators. Other researchers focus on spill-over effects (cf. Sun et al. 2013) that do not stem from direct CPD impact, but are initiated by CPD in terms of implying collegial interactions. Their findings support that collegial collaboration, e.g., learning from CPD participants, thus contributes to spreading issues also to teachers who did not participate in the CPD course themselves.

Marrongelle et al. (2013) elaborated on providing CPD at scale and reported on the dissemination of teaching material related to the Common Core Standards for Mathematics from Kindergarten to grade 12. In sum 46 states and two territories agreed "to integrate research-based perspectives into a set of design recommendations for creating, sustaining, and assessing professional development systems for practicing mathematics teachers" (p. 306). To successfully achieve spread, this large initiative included support by many experts from mathematics education who provided the following set of recommendations to implement the standards nation-wide: *Emphasize Substance, Create and Adapt Professional Development Materials, Design Professional Development to Support Teacher Learning, Build Coherent Programs of Professional Development, Prepare and Use Knowledgeable Professional Development Facilitators, Provide Professional Development Tailored To Key Role Groups in Addition To Teachers, Educate All Stakeholders, Continuously Assess Professional Development,* and *Create Professional Development Consortia*. The list displays all too clearly the complexity of CPD when aiming at scale, the many and diverse people and expertise that needs to be involved and the many processes that must be addressed. In their review of four nation-wide initiatives in Austria, Australia, the United States and South Korea, Pegg and Krainer (2008) also identified as critical players teachers, education authorities and professional education organizations to move findings from research to scale. Besides identifying the specific strengths and weaknesses of the four initiatives, the authors conclude that collaboration, communication and partnerships are the essential features in achieving successful and lasting developments.

Last but not least, *shift in reform ownership* is particularly essential when we aim at effective scaling and the question how we can allow teachers to transfer new approaches into an "internal reform" that is relevant to their own school is crucial. However, it is controversial which strategies are useful to turn teachers into owners of a reform. In this respect Elmore's (1996) synopsis of the results dedicated to large-scale reforms is not promising: "The closer that an instructional innovation gets to the core of what takes place between teachers and students in classrooms, the less likely it is that it will be implemented and sustained on a large scale" (p. 4). At the same time, Alonso (2014) rejects a technical notion of ownership by pointing out: "Recent calls for 'evidence-based practice' or 'data-driven decisions making' expect teachers to apply 'best practices' (based upon others' research) or to do something about evidence (collected and interpreted by others)" (p. 7). Thus, much research is needed on scaling efforts and we need to ask ourselves how we can guarantee that scaling CDP at large reflects adequately the individual teachers' needs but at the same time the needs and goals of educational systems.

6 Scaling evidence-based CPD

6.1 Aim of this issue

The journal ZDM has undertaken strong efforts to publish high-quality CPD research over many years, e.g., by Confrey, Makar and Kazak (2004). Several special issues have also been dedicated to this research field, see "Approaches and Practices in Developing Teachers' Expertise in Mathematics Instruction" in (2011) or the forthcoming special issue 46(2) "Practices and strategies of promoting professional development of didacticians and teachers of mathematics: An international perspective" edited by Rongjin Huang and Barbara Jaworski. The intention of our special ZDM issue is to contribute to this evolving corpus of scholarly findings by specifically focusing on sustainability and large-scale efforts; whether they arise from national initiatives that need to be bedded down and adapted into the practice of teachers or they derive from more local design experiments that are seeking to scale out, or a mixture of the two.

The aim of this special ZDM issue is, thus, to examine in detail approaches that shed light on how teachers develop, following a three-folded benchmark:

1. The design of mathematics CPD in an evidence-based way,
2. The implementation of sustainable CPD interventions, and
3. Doing (1) and (2) on a large scale.

This special issue on mathematics teachers' CPD comprises theoretical papers on the nature of mathematics teaching that shed light on CPD challenges on a large scale and methodological approaches to measure the effectiveness of different types of CPD interventions in a sophisticated way as well as to capture the sustainability of interventions from design experiments to working at scale and reports of impact. New research results regarding CPD that take up the many issues mentioned above by means of new approaches to scaling CPD and measuring its impact from Austria, Germany, Sweden, England, USA, and Singapore are presented.

These initiatives have in common that they all combine the fostering of CPD activities for mathematics teachers through different CPD interventions with systematic research on the effectiveness of the different types of CPD and with an eye on scaling interventions. In sum, nine papers report on studies that reveal particular aspects of how effective scaling requires multilevel changes, and three commentary papers discuss the contributions on a meta-level and the significance of the approaches. In the next section, we briefly explore some new directions the papers and commentaries of this special issue open up and how existing research gaps might be addressed.

6.2 Overview about the papers of this issue

A promising approach naturally meeting many of the criteria of effective CPD are programmes that support teachers in building professional learning communities. The paper by Kaur (2015) describes how a small-scale intervention was built up into a school-wide project through fostering communities of practice which in turn profited from the material developed throughout the CPD project. Essential aspects of scaling were two main processes: teachers' learning by teaching other teachers and teachers' learning by making their own work public to discuss and reflect upon it together with colleagues.

Weißenrieder et al. (2015) also focus on the significance of teachers' collaborative work within professional learning communities (PLCs), and explore how spill-over effects of CPD can be supported by CPD that enhances teachers' collaboration. That is, the authors explore how participants' development of self-efficacy measured with respect to collaboration could be positively influenced by CPD.

Likewise, Selter et al. (2015) focus in their study on comparing the effects of different versions of a multi-phase CPD programme that explicitly stimulated cooperation. Results of three different interventions are compared with respect to cognitive aspects such as competence development and affective-motivational measures such as, teachers' acceptance of the intervention. Thus, these three papers mainly explore *depth* and *spread* in terms of the abovementioned scaling framework.

The contribution by Zehetmeier (2015) deals with issues of CPD *sustainability* and *identify* factors that influence any scaling processes and affect the sustainability of CPD programs. The four papers are discussed in the commentary paper by Tirosh et al. (2015) who reveal fundamental issues concerning the sustainment and scaling-up of CPD programs and how these two dimensions are inter-related.

Three other papers of our Special Issue examine the role of multipliers in spreading and *sustaining* CPD. In these studies it is referred to what Maaß and Artigue (2013) labelled a "Cascade model" of CPD provision. Jackson et al. (2015), for instance, consider as a key aspect of supporting teacher learning on a large scale, the significant role of mathematics leaders' practices related to designing and leading high-quality CPD. The authors underline that scaling at large entails ambitious goals that mathematics leaders need to meet in order to substantially support their teachers' learning. In view of their results, they derive learning goals for mathematics leaders' learning and design principles that add to the existing body of critical CPD features as discussed in section two of this paper.

Roesken-Winter et al. (2015) conducted their study within the scope of the DZLM and investigated also the role of design principles for composing CPD for multipliers who in turn provide CPD for mathematics teachers on their own. Although all design principles conceptually developed by the DZLM were rated important, they underwent modifications on their way into multipliers' CPD practices. The paper by Busch et al. (2015) focuses on a specific theme, namely fostering teachers' diagnostic competences and how it relates to a state-wide CPD strategy pursued by ministry.

The three papers of this section share that they consider the role of multipliers as crucial to spread CPD at large and that developing multipliers follows its own rules which to date is a rather neglected area in research on CPD effectiveness. The commentary paper by Krainer (2015) reveals commonalities and differences of the three approaches to capture design principles for the professional development of multipliers, and points out the many challenges involved when spreading CPD is taking seriously. Goals and design

of the CPD for multipliers are compared, as are the research design and methods adopted.

The next two papers capture primarily the dimensions of *depth* and *ownership* and explore the specific design and impact of CPD programmes that embed digital technologies. Clarke-Wilson et al. (2015) reveal factors that indicate success of this type of spreading innovation by scaling from design experiments to implementation in hundreds of classrooms across England. In the study contributed by Kuzle et al. (2015) the focus is on deepening the professional knowledge on teaching statistics by using digital tools and how a CPD course for multipliers affects their own design and implementation of CPD courses for teachers. On the basis of this study it is outlined how CPD courses for multipliers need to be designed to consider different needs within a CPD system.

State-wide coordinated CPD is also discussed in the paper by Boesen et al. (2015). From 2012 to 2016 all Swedish mathematics teachers will participate in the Boost for mathematics CPD programme, reaching 40,000 teachers in nearly 6,000 schools and involving 20 different universities in the design of the programme. Finally the commentary by Schoenfeld (2015) provides additional thoughts on scale, to make sense of CPD at the system level while simultaneously holding on to finer grain sizes of implementation.

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