HOW TO PROFESSIONALIZE TEACHERS TO USE TECHNOLOGY IN A MEANINGFUL WAY – DESIGN RESEARCH OF A CPD PROGRAM

Daniel Thurm, Marcel Klinger, and Bärbel Barzel

University of Duisburg-Essen, Germany;

daniel.thurm@uni-due.de

The German Centre for Mathematics Teacher Education (DZLM) together with the Ministry of Education is in charge of developing, delivering and evaluating a long-term continuing professional development program (CPD) with respect to graphics calculators (GC). In this paper we describe the design of the CPD program and two associated research studies. The studies aim at examining conditions which must be considered when designing a CPD program, and at investigating the effects caused by the CPD program on teachers' beliefs and classroom practices as well as on students' competencies. We developed a questionnaire to measure teachers' beliefs related to GC and a survey about the integration of the GC into classroom practice. Furthermore, an achievement test was constructed to measure students' competencies that focus on areas where the literature expects the GC to be relevant.

Keywords: continuing professional development, CPD, graphics calculator, efficacy

INTRODUCTION

Integrating the graphics calculator (GC) in classroom practice is a challenge for teachers (Clark-Wilson 2014) and agreement exists, that teachers need professional development and support (Barzel 2012) in order to make appropriate use of the GC. In this paper we describe a research project aimed at developing, delivering, and evaluating a long-term continuing professional development (CPD) program for integrating GCs in mathematics teaching.

The project is situated within the context that since the beginning of the 2014 school year the use of GCs in upper secondary school is compulsory in North Rhine-Westphalia, the biggest German federal state. Till this time most of the teacher did not use graphic technology in their teaching although it was requested from the curriculum. But as long as there have not been centralized final examinations lots of teachers did not follow this request. Nowadays North Rhine-Westphalia has established together with other German states centralized final examinations. The German Centre for Mathematics Teacher Education (DZLM) together with the ministry of education are collaborating to support teachers to master this new challenge by designing a long-term professional development program which directly aims at teachers in upper secondary classroom. The research project comprises three parts: the design of the program, investigating the conditions for this CPD program on teachers' and students' level and research on the efficacy of the program.

We first give a brief overview of the theoretical framework before elaborating in more detail on research questions, methods and design of the CPD program. Finally, we present first empirical results and end with a prospective view.

THEORETICAL FRAMEWORK

First of all our theoretical framework comprises the idea of design research for a CPD program (Gravemeijer & Cobb 2006; Swan 2014). On a second layer we focus as theoretical frame on criteria concerning effective CPD as well as on the state of the art in the field of a meaningful use of the GC in mathematics teaching of elementary calculus.

Criteria for effective professional development

A lot of research has been conducted to reveal possible effects of CPD programs for teachers (e.g. Timperley et al. 2007) and agreement exists that these effects occur on different levels (e.g. Kirkpatrick & Kirkpatrick 2006). Whilst there is a consensus in the research community that different levels of effects exist, their number varies: Whereas Guskey (2000) defines five levels of effects, Lipowsky & Rzejak (2012) distinguish four levels of effects: Level 1: *Participant's reactions*, level 2: *Participant's beliefs and professional knowledge*, level 3: *Participant's use of new knowledge and skills in the classroom*, and level 4: *Student learning outcomes*.

Guskey's (2000) additional level describes "Organization Support and Change" and is positioned between the second and third level in the hierarchy above. Guskey's extra level specifies whole school changes as a result of a CPD initiative. Since our study does not focus on whole schools but on individual teachers and their students we chose to orient on the four level model.

From the literature various characteristics can be derived as criteria of efficient in-service teacher training (e.g. Loucks-Horsley et al. 2009; Garet et al. 2001). On the basis of a review of the current research with a special focus on mathematics, six design principles of professional development have been generated by the DZLM (Barzel & Selter 2015; Rösken-Winter et al. 2015): (a) *Competence-orientation:* Focusing on the participants' competencies which one want to procure or improve. This means mathematics content knowledge and skills on the one hand as well as mathematics pedagogical content knowledge and skills on the other hand. Furthermore, these expectations have to be transparently communicated. (b) *participant-orientation:* Centering on the heterogeneous and individual prerequisites of participants. Moreover, participants get actively involved into the CPD instead of a simple input-orientation. (c) *stimulating cooperation:* Motivating participants to work cooperatively, especially between and after the face-to-face phases, e.g. in professional learning communities (e.g. Weißenrieder et al. 2015). (d) *Case-relatedness:* Using examples which are practically relevant and which participants can identify with. (e) *Various instruction formats*: Switching between phases of attendance, self-study and e-learning. (f) *fostering (self-)reflection:* Continuously encouraging participants to reflect on their conceptions, attitudes, and practices. When taking these six principles seriously, this yields to the necessity to realize CPD initiatives in long-term formats as well (Rösken-Winter et al. 2015).

The benefits of graphics calculators

Mathematics educators and authorities believe that classroom practice should shift from computation to an emphasis on conceptual understanding and problem solving (Simonsen & Dick 1997). Research indicates that technology like GCs can play an important role in achieving this goal. Studies have shown that the use of GCs can improve problem solving and conceptual understanding (Ellington 2006) which holds in particular for the calculus classroom where various representations such as *graphical*, *numerical* and *symbolic* play an important role. Switching between these representations is supported by technological tools (such as a GC) and can improve students' conceptual understanding of functions (Penglase & Arnold 1996). Furthermore, the GC can foster the ability to connect multiple representations of algebraic concepts (Graham & Thomas 2000) and can support an increased understanding of a dual approach to problem solving, using both symbolic and graphical solution methods (Harskamp et al. 2000). Moreover, a GC can be a beneficial tool when promoting discovery learning in the classroom (e.g. Barzel & Möller 2001).

However, Kissane (2003, p. 153) pointed out that "Availability of technology is not by itself adequate, of course, to effect changes in the mathematics curriculum. A crucial mediating factor is the teacher, and curriculum developers ignore the real needs of teachers at their peril. Mathematics teachers need professional development directly related to graphics calculators if they are to be the main agents of reform, and ultimately directly responsible for whatever happens in the classroom." Hence, it is important to apply the characteristics of effective CPD as outlined above to the special case of GC to design an effective CPD program.

RESEARCH QUESTIONS AND DESIGN OF THE STUDY

The whole project addresses the following three research questions:

1. How can an effective CPD program for GCs be designed?
2. Which conditions and criteria have to be considered for designing a CPD program with respect to GC with a focus on elementary calculus?
3. Is the designed CPD program effective?

The first research question leads to a theoretical-based design of the program which should be redeveloped in further cycles of designing and researching. The project started in spring 2014 with a first draft for a concept and material for the CPD program. The CPD program is offered at three sites across North Rhine-Westphalia with 30 teachers participating at each site. It is structured into four modules spread over a half year period. Every module consists of a face-to-face one-day course, elements of blended learning, exchange in professional learning communities and phases of classroom practice between the modules.

To answer the second and third question we chose a classical pre-test-treatment-post-test design with two nonequivalent groups: Teachers participating in our CPD initiative (EG: experimental group) and those who don't (CG: control group). Out of 90 participants of the initiative 40 volunteered to take part in our research. The control group consists of 147 teachers, who were enlisted by a circular letter and an associated website. All teachers taught tenth grade students. We collected data from the teachers (EG: 40, CG: 147) in the program, as well as from their students (EG: 554, CG: 2585).

Figure 1 provides an overview over the whole project. In this paper we only focus on research question 1 and 2 and elaborate in more detail on the design of the CPD program and the methods used to answer the research questions.

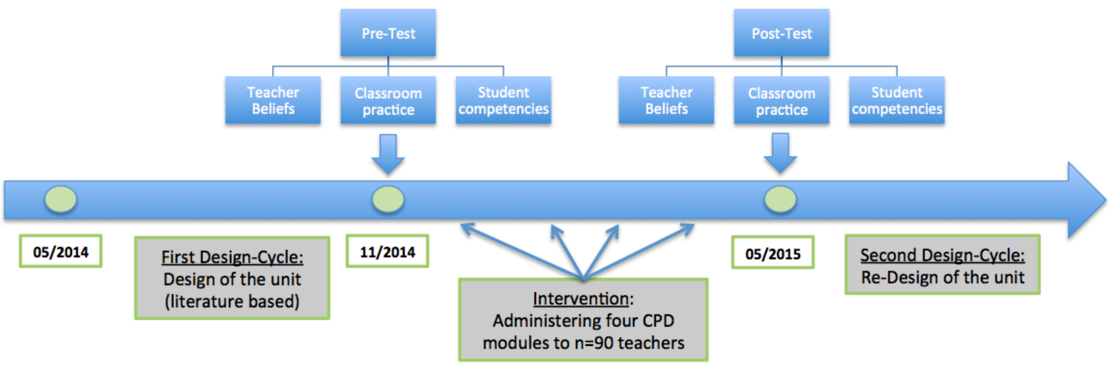

Figure 1. Project overview

Designing the CPD program

In the first design step the CPD program was developed by a group of researchers and experienced practitioners. The design was clearly driven by the design principles of effective CPD of the DZLM and by research results and experiences in the field of teaching calculus with technology (Zbiek et al. 2007; Barzel 2012). In the following we describe how the design principles were realised within the CPD program.

(a) *Competence-orientation:* The CPD course covers different dimensions of teachers' competencies, aiming at four main goals. The teachers should be able to use GCs in a flexible way, design tasks integrating GCs, organize the classroom in a technology based environment and develop appropriate formats and tasks for assessment with GC. The four modules were dedicated to these main aims: *Introduction into the work with GC – Designing tasks with an integrated use of GCs – Classroom organisation in a technology based environment – Assessment*. The design of these topics was based on research results. For example in the field of pedagogical content knowledge about functions, relevant concept images (vom Hofe 1995; Büchter 2008) and mathematical representations were presented to describe in detail the content. Systematic evidence is accessible on typical student errors, pre- and misconceptions, and ways of dealing with them effectively in mathematics lessons (Hadjidemetriou & Williams 2002; Barzel & Ganter 2010). All this was communicated and used for designing tasks and analysing students' solutions. The goals were made transparent for all participants, thus enabling teachers to clearly see the relation to their own teaching practice and increase their motivation while attending the program.
(b) *Participant-orientation:* First of all participant-orientation was ensured through a preliminary questionnaire regarding the teachers needs (with respect to content and didactical issues). All tasks used in the course are created in a way that they allow an immediate use in the classroom. Accompanying material and information about the task outline, possible solutions, typical errors and misconceptions, an idea how and where to integrate the task in the learning process and the relevant role of the technology. Furthermore, at the end of each course participants are actively involved in giving recommendations for content and methodology that should be included in the following meetings.
(c) *Stimulating cooperation*: Cooperation was especially stimulated by initiating professional learning communities with teachers from one school or neighboring schools. During the courses participants' work collaboratively within their professional learning communities on examples relevant for the classroom and discussing how to best implement them.
(d) *Case-relatedness:* All modules relate to practical aspects by discussing ideas based on the practical experiences of the teachers. Specific student results and examples are brought into the courses by the participants which form both a starting point for discussion and a context for application.
(e) *Various instruction formats:* Various instruction formats are used throughout all courses to ensure active participation. The CPD initiative includes phases of attendance, self-study and e-learning. Input, practical try-outs and reflection phases are alternating across the course.
(f) *Fostering (self-)reflection*: Participants are continuously encouraged to reflect on their conceptions, attitudes, and practices. Furthermore, participants are also encouraged to engage in self- and collaborative reflection on covered topics / material and possible transfer into their own classroom as well as on their own teaching or training practice.

Conditions and efficacy

The evaluation and research on the program was split up in two parts – conditions and efficacy of the program – both on teachers' and students' level.

On teachers' level we investigate teacher beliefs about mathematics' nature and the teaching and learning of mathematics as a key dimension of teachers' epistemological beliefs which can have profound implications on their classroom practices as well as on student performance (Stipek et al. 2001; Staub & Stern 2002). To determine these beliefs we used a test at the beginning of the CPD program with a set of 14 items from the TEDS-M study (e.g. Blömeke et al. 2014). Besides these general epistemological beliefs about mathematics, it is clear that beliefs related to the use of the GC have a profound impact on classroom practice (Molenje 2012). Teacher beliefs regarding the GC were measured using a questionnaire (Rögler 2014), which consisted of 23 items with Likert-type forced responses on a five point scale with 1=Strongly Disagree and 5=Strongly Agree. The questionnaire covers beliefs about the advantages of GC usage as well as common beliefs about disadvantages of the GC. For the advantages of the GC the following scales were used: (a) *beliefs regarding the connection between GC usage and discovery learning*, (b) *beliefs about the support of multiple representations through GC*, (c) *beliefs that the GC supports shifting teaching away from computational focus*. The scales referring to the disadvantages of GC usage were: (d) *beliefs about a negative impact of GC on basic computational and pen & paper skills* and (e) *beliefs about the GC and time constraints*, as there is a general concern that there is not enough time to cover the technology and the required curriculum, (f) *beliefs that the GC supports press & pray strategies*, which means students rely heavily on technology use without conceptual understanding. The last category deals with (g) *beliefs about whether students must master concepts and procedures prior to calculator use*.

To measure changes in classroom practice a questionnaire was administered covering the following categories: (a) *use of the GC for modelling tasks*, (b) *use of the GC for discovery learning*, (c) *use of the GC for problem based learning*, (d) *use of the GC as a graphing device*, (d) *use of the GC for multiple representations in the context of functions*, (e) *use of the GC as a checking device*. Additionally, we included a category covering the discussion of limitations of the GC in the classroom. Each category was covered by several items specifying the particular category. Since it is known that survey data is well suited of describing quantity but not as suitable for describing quality (Mayer 1999), the survey focused merely on the frequency teachers used the GC in these situations.

On the students' level we constructed a pre-test and post-test to measure competencies of students. The pre-test consists of 14 items on linear functions, quadratic functions and quadratic equations as relevant preliminary knowledge for the new content covered in grade 10, the first year of the upper secondary school. The post-test focuses on differential calculus since this is the main content in grade 10. Both tests are connected via anchoring items, which are identical items which appear at both times of measurement. On a more general view on competencies, we tried to cover all concept images of functional thinking (e.g. Büchter 2008) and demanded the ability to switch between multiple representations of functional relations. Outcomes were measured by a simple raw score which was the number of items solved correctly by a student.

FIRST RESULTS

As the whole program is an ongoing process, we can only report few first results on professed beliefs and student performance in the pre-test. For the beliefs we focus on the scales (a), (d) and (g), covering beliefs about discovery learning and GC, computational skills and GC and beliefs whether students must master concepts and procedures prior to calculator use. Reliability of the scales were good with Cronbach's alpha .88, .86, and .92, respectively.

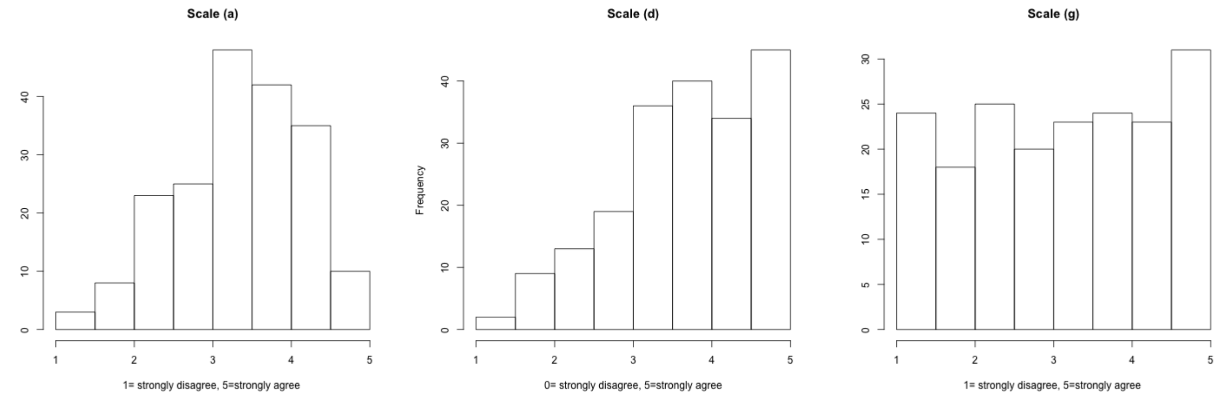

Figure 2. Histogram of the scales (a), (d), and (g), respectively from left to right

As it can be seen from the left histogram in figure 2, a large fraction of teachers belief that the GC can be a beneficial tool to support discovery learning. However, there are 18% of teachers with an average lower than 2.5 on this scale and hence do not share this belief. The middle histogram in Figure 2 reveals a clear concern of most of the teachers that pen & paper skills might be inhibited by the use of the GC. The right histogram in Figure 2 shows that teacher beliefs on (g) are quite heterogenous with a large number of teachers having quite extreme views to both sides.

The first student achievement test revealed some misconceptions and was able to quantify these. Figure 3 shows one item where option (b) represents an error Clement (1985) calls "treating the graph as a picture" which means "making a figurative correspondence between the shape of the graph and some visual characteristics of the problem scene". This option was chosen by 17.7% of the students. Furthermore, we also implemented items to diagnose a misconception called the "illusion of linearity" (De Bock et al. 2007) which is characterized by an improper linear reasoning in situations or processes which are nonproportional. We discovered that 9.5% up to 25.8% of the students (depending on the particular item) showed this misconception when graphing nonlinear processes. When a two-dimensional object is uniformly scaled and students should describe the behavior of the object's area, this amount was even higher: 75.2%.

OUTLOOK AND DISCUSSION

The preliminary results make clear that it is of crucial importance to take the preconditions with respect to teachers and students seriously. Results of the empirical study on prevalent beliefs should be included in the CPD course to initiate discussion about the different beliefs. When introducing concepts and content in the CPD program the teacher educators have to be aware of the beliefs towards the different aspects of GC and should choose methods to actively engage participants in reflecting on these beliefs. In addition, student competencies have to be considered when designing a CPD program in order to show teachers in detail where possible misconceptions are and how the integration of GCs can support to overcome these misconceptions. Further data analysis will focus on investigating connections between professed beliefs and classroom practice. After administering the post-test results on the efficacy of the CPD program can be obtained. This could give valuable insights whether teacher beliefs, classroom practice and student competencies have changed and which areas might be most affected. Based on these empirical data a redesign of the CPD program will take place with focus on integrating the empirical findings in content, methods and materials of the CPD program.

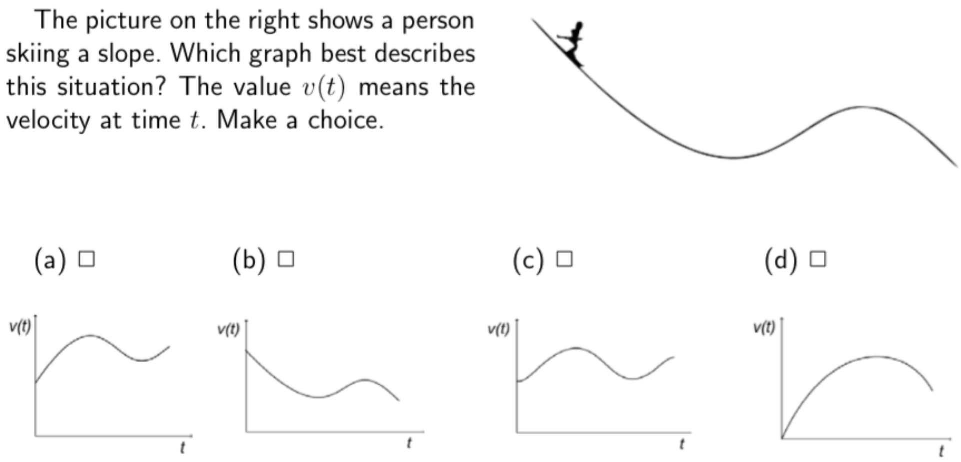

Figure 3. Example item for revealing the misconception "treating the graph as a picture" (translated, cf. Nitsch 2014)

NOTES

1. This research was partially funded by Deutsche Telekom Stiftung.

REFERENCES

Barzel, B., & Möller, R. (2001). About the use of the TI-92 for an open learning approach to power functions. *Zentralblatt für Didaktik der Mathematik 33*(1), 1–5.

Barzel, B., & Ganter, S. (2010). Experimentell zum Funktionsbegriff. *Praxis der Mathematik in der Schule 52*(31), 14–19.

Barzel, B. (2012). *Computeralgebra im Mathematikunterricht: Ein Mehrwert – aber wann?* Münster: Waxmann.

Barzel, B., & Selter, C. (2015, to appear). Die DZLM-Gestaltungsprinzipien für Fortbildungen. *Journal für Mathematik-Didaktik.*

Blömeke, S., Hsieh, F.-J., Kaiser, G., & Schmidt, W. H. (2014). *International perspectives on teacher knowledge, beliefs and opportunities to learn*. Dordrecht: Springer.

Büchter, A. (2008). Funktionale Zusammenhänge erkunden. *Mathematik lehren 148*, 4–10.

Clark-Wilson, A., Aldon, G., Cusi, A., Goos, M., Haspekian, M., Robutti, O., Thomas, M. (2014). The challenges of teaching mathematics with digital technologies – the evolving role of the teacher. In P. Liljedahl, C. Nicol, S. Oesterle, & D. Allan (Eds.), *Proceedings of the joint meeting of PME 38 and PME-NA 36* (Vol. 1, pp. 87–116). Vancouver: PME.

Clement, J. (1985). Misconceptions in graphing. In L. Streefland (Ed.), *Proceedings of the ninth international conference of the International Group for the Psychology of Mathematics Education* (Vol. 1, pp. 369–375). Utrecht: IGPME.

De Bock, D., Van Dooren, W., Janssens, D., & Verschaffel, L. (2007). *The illusion of linearity: from analysis to improvement*. New York: Springer.

Ellington, A. J. (2006). The effects of non-CAS graphing calculators on student achievement and attitude levels in mathematics: a meta-analysis. *School Science and Mathematics 106*(1), 16–26.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal 38*(4), 915–945.

Graham, A. T., & Thomas, M. O. J. (2000). Building a versatile understanding of algebraic variables with a graphic calculator. *Educational Studies in Mathematics 41*(3), 265–282.

Gravemeijer, K., & Cobb, P. (2006). Design research from a learning design perspective. In J. Van den Akker, K. Gravemeijer, S. McKenney, N. Nieveen (Eds.), *Educational design research* (pp. 17–51). New York: Routledge.

Guskey, T. R. (2000). *Evaluating professional development*. Thousand Oaks: Corwin Press.

Hadjidemetriou, C., & Williams, J. (2002). Children's graphical conceptions. *Research in Mathematics Education 4*(1), 69–87.

Harskamp, E., Suhre, C., & Van Streun, A. (2000). The graphics calculator and students' solution strategies. *Mathematics Education Research Journal 12*(1), 37–52.

Kirkpatrick, D. D., & Kirkpatrick, J. D. (2006). *Evaluating training programs: the four levels*. San Francisco: Berrett-Koehler.

Kissane, B. (2003). A model for professional development for graphics calculator use. In A. Rogerson (Ed.), *The Mathematics Education into the 21st Century Project, 19–25 September 2003, Brno, Czech Republic* (pp. 153–157).

Lipowsky, F., & Rzejak, D. (2012). Lehrerinnen und Lehrer als Lerner – Wann gelingt der Rollentausch? Merkmale und Wirkungen effektiver Lehrerfortbildungen. *Schulpädagogik heute 5*(3), 1–17.

Loucks-Horsley, S., Stiles, K. E., Mundry, S., Love, N., & Hewson, P. W. (2009). *Designing professional development for teachers of science and mathematics*. Thousand Oaks: SAGE.

Mayer, D. P. (1999). Measuring instructional practice: can policymakers trust survey data? *Educational Evaluation and Policy Analysis 21*(1), 29–45.

Molenje, L. (2012). *High school teachers' use of graphing calculators when teaching linear and quadratic functions: professed beliefs and observed practice*. Doctoral thesis. Syracuse University, Syracuse.

Nitsch, R. (2014). Schülerfehler verstehen: Typische Fehlermuster im funktionalen Denken. *Mathematik lehren 187*, 8–11.

Penglase, M. & Arnold, S. (1996). The graphics calculator in mathematics education: a critical review of recent research. *Mathematics Education Research Journal 8*(1), 58–90.

Rögler, P. (2014). Überzeugungen von Mathematiklehrkräften als Basis zur Entwicklung von Lehrerfortbildung zu Technologien im Unterricht. In J. Roth, & J. Ames (Eds.): *Beiträge zum Mathematikunterricht 2014* (Vol. 2, pp. 983–986). Münster: WTM.

Rösken-Winter, B., Schüler, S., Stahnke, R., Blömeke, S. (2015). Effective CPD on a large scale: examining the development of multipliers. *ZDM Mathematics Education 47*(1), 13–25.

Simonsen, L. M., & Dick, T. P. (1997). Teachers' perceptions of the impact of graphing calculators in the mathematics classroom. *Journal of Computers in Mathematics and Science Teaching 16*(2/3), 239–268.

Staub, F., & Stern, E. (2002). The nature of teacher's pedagogical content beliefs matters for students' achievement gains: quasi-experimental evidence from elementary mathematics. *Journal of Educational Psychology 94*(2), 344–355.

Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and Teacher Education 17*(2), 213–226.

Swan, M. (2014). Design research in mathematics education. In S. Lerman (Ed.), *Encyclopedia of mathematics education* (pp. 148–152). Dordrecht: Springer.

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2007). *Teacher professional learning and development: best evidence synthesis iteration [BES]*. Wellington: Ministry of Education.

vom Hofe, R. (1995). *Grundvorstellungen mathematischer Inhalte*. Heidelberg: Spektrum.

Weißenrieder, J., Rösken-Winter, B., Schüler, S., Binner, E., & Blömeke, S. (2015). Scaling CPD through professional learning communities: development of teachers' self-efficacy in relation to collaboration. *ZDM Mathematics Education 47*(1), 27–38.

Zbiek, R. M., Heid, M. K., Blume, G. W., & Dick, T. P. (2007). Research on technology in mathematics education – a perspective of constructs. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 1169–1207). Charlotte: Information Age.