# Large-scale professional development and its impact on mathematics instruction: differences between primary and secondary grades

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Worldwide, substantial resources are spent on professional development [PD] for mathematics teachers. Still, the recommendations regarding effective PD are not specific enough to support practice and more research conducted on a larger scale and in multiple contexts is still needed. In this paper we report on a PD-program working together with over 10 000 students, 400 teachers, principals and municipality leaders. The results from surveys indicate that the teachers report having made changes in their mathematics instruction in line with those advocated in the PD. However, statistically significant differences can be seen between teachers from different grade levels. These differences are further discussed in relation to a set of core critical features of effective PD.

Over the past 25 years, the perceptions about what mathematics students should master and how they should learn it have changed. School leaders around the world are under growing pressure to reassure that students' results in mathematics improve (Even & Ball, 2009) and there is a tendency to move away from traditional to more inquiry-based approaches to teaching (Clewell, Cohen, Campbell & Perlman, 2005; Goldsmith, Doerr & Lewis, 2013). Professional development [PD] has been regarded as a key to improve the quality of education and in many countries substantial resources are spent on PD-programs for teachers (Desimone, 2009). In view of these wide investments, there is certainly a need for a strong base of research in order to guide policy and practice.

Within the research literature, there seems to be a consensus regarding some core critical features of effective PD, for example that it should be sustained, coherent with school and state policies and address both the subject specific content as well as how to teach it (e.g. Desimone, 2009; Marrongelle, Sztajn & Smith, 2013; Timperley, Wilson, Barrar & Fung, 2007; Wayne, Yoon, Zhu, Cronen & Garet, 2008). However, despite this general agreement, it is argued that the existing research on PD lacks sufficient specificity to support policy and practice (Cobb & Jackson, 2011; Wayne et al., 2008). Though the existing studies have contributed much to our understanding of effective PD, we still

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need more knowledge regarding PD conducted on a larger scale, with non-volunteers and in multiple contexts (Clewell et al., 2005; Goldsmith et al., 2013; Marrongelle et al., 2013; Wayne et al., 2008). For instance, research on PD for science teachers suggests that it may need to look different depending on the grade band (McNeill & Knight, 2013). Therefore, rather than focusing on the effectiveness of a PD-program as a global characteristic, future research should pay attention to how it works in particular settings and for different teachers (e.g. levels of experience, subject, grade level) (Chval, Abell, Pareja, Musikul & Ritzka, 2008; Goldsmith et al., 2013; Timperley et al., 2007).

In this paper, we examine a large-scale PD-program for mathematics teachers. The results from a previous study (Lindvall, 2016) indicate that this PD has affected the primary and secondary grade students' achievement in different ways. While the primary grade students (grade 1–5) show a small improvement, the students in the secondary grades (grade 6–9) demonstrate a declining trend. In order to gain a deeper understanding of these results, it becomes interesting to study how the program may have affected other issues related to mathematics teaching. Therefore, the aim with this paper is to examine and compare how the PD has affected the participating primary and secondary teachers' reported mathematics classroom instruction. The results are further discussed and used to elaborate on a set of core critical features of PD identified in the literature.

## What do we know about effective PD?

Even though scholars have discussed various characteristics of effective PD, recent research seems to point towards a larger agreement on some core critical features (Timperley et al., 2007; Wayne et al., 2008). In fact, Desimone (2009) argues that there exists a research consensus on five main critical features of PD primarily associated with changes in teacher knowledge and practice. Below, these features are described and will later be used to characterize the PD-program and to discuss the results. The reasons for this is because there seems to be a consensus about these features in the research literature and, as argued by both Desimone (2009) and Wayne et al. (2008), using a shared set of features allows for researchers to build on each other and thereby extend our knowledge. The features *content focus* and *coherence* are given more attention since these are the ones that differ primarily between the grade levels. Thereby, they are particularly supportive for discussing the results in relation to the purpose of the study.

The first feature, *content focus*, may be the most influential factor of PD-programs' impact on teacher learning and student achievement (Desimone, 2009; Timperley et al., 2007). Still, we know very little about the actual content taught in various PD-programs and how this may influence teachers' instruction (Scher & O'Reilly, 2009). In the past years, a number of reviews and meta-analysis (e.g. Clewell et al., 2005; Scher & O'Reilly, 2009; Slavin &

Lake, 2008) have suggested that PD which put emphasis on both the subject knowledge and how to teach it are the most effective ones. This type of teacher knowledge, also referred to as pedagogical content knowledge [PCK], concerns the subject content in relation to knowledge of the students in class, the curriculum and teaching (Ball, Thames & Phelps, 2008). However, the concept of PCK is broad and can be divided into several subdomains (Ball et al., 2008). For example McNeill and Knight (2013) have shown that teachers participating in the same PD, but within different grades, experience unique challenges that need to be addressed for their particular contexts. Also, Chval et al. (2008) revealed that teachers themselves are asking for PD that is focused on the content and the grade level they teach.

In addition to content focus, Desimone (2009) argues that the teaching practices advocated in the PD should be *coherent* with teachers' knowledge and beliefs. Similar reasoning is brought up by Penuel, Fishman, Yamaguchi, and Gallagher (2007), who write that teachers are more likely to make changes in their instruction if the teaching practices advocated in the PD are aligned with the teacher's own goals of learning and their goals for students. Another important aspect of coherence is the PDs' consistency with the teaching practices endorsed in school and state policies (Desimone, 2009; Penuel et al., 2007).

Furthermore, effective PD should engage teachers in *active learning*, such as analyzing classroom videos or conducting mathematical lessons. Finally, it should include sufficient *duration* and *collective participation*, where teachers from the same school, grade or department all take part in the in-service education and meet regularly during an extended time-period. (Desimone, 2009)

## The PD-program

The project reported on in this study is a combined research and development program in cooperation with a university and a larger municipality in Sweden. The overarching goal is to establish an effective mathematics education within the municipality to ensure that all students receive the best possible conditions to develop mathematical skills and knowledge. The project includes several elements, such as PD for principals and establishment of new routines (e.g. annual formative tests in mathematics) and new positions (e.g. heads of mathematics at every school). In this paper, focus is put on the teacher PD-program. Within a five-year period, all teachers teaching mathematics at a public elementary school should have participated in the PD. Here we report on the results from teachers who participated during 2013/2014 and 2014/2015.

The PD-program's design can be described in relation to Desimone's (2009) five critical features of effective PD. Regarding *content focus*, the program is concentrated on teachers PCK specific to mathematics. Special attention is directed towards teaching for the mathematical competencies set out in the national curriculum (Skolverket, 2011). These five competencies are related to mathematical concepts, methods, reasoning, communication and problem-solving. In order to make progress towards this focus, two main tracks in the program are formative assessment (cf. Wiliam, 2011) and teaching mathematics through problem-solving (cf. Stein, Engle, Smith & Hughes, 2008).

Further, though we cannot determine a *coherence* between the PD and teachers' knowledge and beliefs, several actions have been taken in order to establish a coherence with school and state policies. Firstly, the program focuses on teaching practices in line with the national curriculum (Skolverket, 2011). Secondly, it involves a joint PD for principals and subject representatives. Thirdly, regular meetings devoted to discussions about the projects impact and future are held between politicians, principals, teachers and researchers.

Finally, the program's design stresses *duration*, as well as an *active learning* and *collective participation* among the participating teachers. All teachers teaching mathematics are expected to participate in the PD-program, which takes place locally at every school. During their year of participation, teachers meet for two hours every other week to engage in activities such as analyzing mathematical lessons and setting up annual plans for the mathematics instruction. These discussions are further supported by doctoral students in mathematics didactics, who also works as mathematics mentors within the municipality.

## Data collection and analysis

In order to analyze and evaluate the project, multiple sources of data are collected on a regular basis. Here, results obtained from teacher surveys are reported. Almost all mathematics teachers at the respective schools, with the exception of a few percent that were given permission by their principals to abstain, participated in the PD-program. During the first (pre) and last (post) session they were asked to fill in a survey and the response rate was more than 99 %. In this paper, data from the primary ($n = 83$) and secondary grade teachers ($n = 26$) who attended both sessions are used when describing the projects impact on their reported instruction. Questions on teachers' perceptions about the PD were not included in the pre-surveys, whereby only data from the teachers attending the last session ($n_{\text{primary}} = 104$, $n_{\text{secondary}} = 31$) are included when reporting on these results.

The questions in the surveys concerned, among other things, teachers' perceptions on collegial cooperation, curriculum materials and their students. In this paper, emphasis is on questions regarding teachers' reported mathematics instruction occurring in the classrooms, as opposed to e.g. homework. On a four-point scale, they were asked to state how often they conduct certain activities in their mathematics classrooms. We also report on results from questions which only appeared in the post-surveys and that regard teachers' views of the PD and its implementation. The analyses of those questions showed large differences between teachers from the primary and secondary grades, whereby this data provides important information that supports the discussion of the study's results.

In order to assess if the PD-program had any impact on the mathematics instruction, paired sample *t*-tests were conducted for teachers in the primary and secondary grades respectively. Further, to assess the strength of the impact, as well as facilitating comparison between the two groups of teachers, the effect sizes were calculated in terms of Cohen's *d*. For interpreting the results the guidelines proposed by Cohen (1988) were used, with .2 representing small effect, .5 representing moderate effect and .8 representing large effect. Finally, independent sample *t*-tests were employed to compare the primary and secondary grade teachers' perceptions of the PD. Also here Cohen's *d* was used to assess the magnitude of the differences. However, one could argue that the Likert-scales should be seen as ordinal instead of continuous. Hence, also the non-parametric alternatives (Wilcoxon Signed Rank Test and Mann-Whitney U Test) were conducted, but they showed similar results as the *t*-tests.

## Results

The aim with this paper is to examine how the PD-program has affected the participating primary and secondary teachers' reported mathematics instruction. The results are summarized in table 1.

For the primary grades, the results show that the teachers, after the PD, report on taking a larger responsibility in leading the mathematics instruction compared to instruction before the PD. For example, statistical significant differences can be seen for statements on how common both lectures and whole-class discussions are during instruction. This is further supported by the fact that these teachers, after the PD, report that their students spend less time on speed-individualized work in their textbooks. However, the effect sizes are all considered to be small. The changes in instruction reported by the secondary grade teachers are in general larger, with the effect sizes varying between large, moderate and small. As the primary grade teachers, these teachers also report on leading more whole-class discussions and students spending less time on individual work in textbooks. However, in contrast to the primary grades, they also appear to have less lectures during instruction. Moreover, they report on students devoting more instructional time to memorizing formulas as well as less time on presenting their solutions to mathematical problems for the whole class.

Further, though not always significant, both groups of teachers report on putting more emphasis on all of the mathematical competencies. However, just as for the questions about instruction, larger changes can be seen for the secondary grades (see table 2). While the primary grade teachers only show small

Table 1. *The primary (P) and secondary (S) grade teachers' reported instruction before (Pre) and after (Post) participation in the PD*

| How often do the following activities occur in your mathematics classes? | Grade | Mean (SD) Pre | Mean (SD) Post | Change in mean | t (df) | Effect Size |
|---|---|---|---|---|---|---|
| I lead whole-class discussions focused on mathematical concepts | *P* | 2.77 (.67) | 3.05 (.75) | .28 | 2.92 (74) | .39** |
| | *S* | 2.25 (.85) | 2.75 (.90) | .50 | 2.94 (23) | .57** |
| Students listen and / or take notes when I lecture | *P* | 1.44 (.84) | 1.90 (1.06) | .46 | 2.91 (76) | .48** |
| | *S* | 2.48 (1.05) | 2.08 (1.08) | -.40 | -2.31 (24) | -.38* |
| I lecture about new content through formal presentations | *P* | 2.42 (.86) | 2.68 (.86) | .26 | 2.43 (73) | .30* |
| | *S* | 2.72 (.79) | 2.60 (.76) | -.12 | -.77 (24) | -.15 |
| Students memorize formulas and calculation procedures | *P* | 1.82 (.87) | 1.97 (.91) | .15 | 1.26 (73) | .17 |
| | *S* | 2.13 (.76) | 2.65 (.94) | .52 | 2.79 (22) | .61* |
| I ask the students to motivate and explain how they have arrived at their answers | *P* | 3.64 (.56) | 3.66 (.53) | .02 | .39 (76) | .04 |
| | *S* | 3.35 (.75) | 3.58 (.58) | .23 | 2.00 (25) | .34 |
| I let several students present their solutions to math problems for the whole class | *P* | 2.66 (.70) | 2.58 (.70) | -.08 | -.90 (76) | -.11 |
| | *S* | 2.24 (.78) | 1.92 (.64) | -.32 | -2.32 (24) | -.45** |
| I let the students work at their own pace in the textbook | *P* | 2.77 (1.20) | 2.34 (1.27) | -.43 | -3.08 (72) | -.35** |
| | *S* | 3.20 (1.00) | 2.24 (1.23) | -.96 | -3.87 (24) | -.85** |

*Notes*. * $p < .05$; ** $p < .01$

significant changes related to competencies concerning mathematical concepts and communication, the teachers in the secondary grades report on moderate changes related to problem-solving and communication.

Finally, the analyses show that the two groups of teachers experienced varying degrees of difficulty in introducing changes in their mathematics instruction based on their experiences from the PD. Firstly, compared to the primary grade teachers ($M = 1.89$, $SD = .94$), the teachers in the secondary grades to a higher extent expressed that they had insufficient opportunities to practice on their new experiences ($M = 2.29$, $SD = 1.04$; $p < .05$, $d = .42$). Secondly, the teachers from the secondary grades ($M = 3.23$, $SD = .81$) perceived the available time for planning as a larger problem than those from the primary grades ($M = 2.77$, $SD = .97$; $p < .05$, $d = .50$). Thirdly, compared to the primary grade teachers

Table 2. *The teachers' reported instructional focus on mathematical competencies before (Pre) and after (Post) participation in the PD*

| Mathematical Competency | Grade | Mean (SD) Pre | Mean (SD) Post | Change in mean | t (df) | Effect Size |
|---|---|---|---|---|---|---|
| To use and analyze mathematical concepts and their interrelationships | *P* | 3.19 (.63) | 3.37 (.59) | .18 | 2.16 (74) | .30* |
| | *S* | 3.04 (.75) | 3.29 (.69) | .25 | 1.24 (23) | .35 |
| To formulate and solve problems using mathematics and also assess selected strategies and methods | *P* | 3.07 (.91) | 3.25 (.55) | .18 | 1.84 (75) | .31 |
| | *S* | 2.92 (.78) | 3.33 (.57) | .41 | 3.12 (23) | .60** |
| To use mathematical forms of expression to discuss, reason and give an account of questions, calculations and conclusions | *P* | 2.77 (.92) | 3.03 (.66) | .26 | 2.32 (74) | .32* |
| | *S* | 2.64 (1.00) | 3.24 (.78) | .60 | 2.60 (24) | .67* |

*Notes*. * $p < .05$; ** $p < .01$

($M = 2.15$, $SD = 1.04$), the teachers from the secondary grades ($M_1 = 2.61$, $SD_1 = .99$; $p < .05$, $d = .45$) also reported on the access to relevant classroom resources as a major issue in trying to change their instruction.

## Discussion

One aim of the reported project is to move away from the, in Sweden (Bergqvist et al., 2009), dominating traditional approach to teaching (c.f. Boaler, 2002) and thereby give students opportunities to develop *all* the mathematical competencies mentioned in national curriculum (Skolverket, 2011). The findings from this study indicate that this goal has been only partly fulfilled and particularly, that it differs between the grade levels. Compared to the primary grades, the secondary grade teachers report that they have made larger changes in their instruction. But at the same time, it is their students' results that have declined (Lindvall, 2016). The reasons for these differences can be understood from various perspectives. Here the variations are discussed in light of Desimone's (2009) critical features of effective PD. Since the design of the PD is the same for all teachers, the potential differences between the grade levels should be related to its coherence with teachers' knowledge and beliefs as well as school and state policies. However, to only discuss a PD-program's coherence is impossible without connecting it to its actual content. Therefore the critical features *content focus* and *coherence* will be emphasized in the discussion.

To begin with, while Desimone (2009) stresses that effective PD should be coherent with teachers' knowledge and beliefs, the question regarding coherence with teachers' actual practice is not mentioned. For example, the findings that the secondary grade teachers have made larger changes in their instruction may be due to the fact that the teachers in the primary grades started with instructional practices more in line with those advocated in the PD (e.g. more whole-class discussions). In other words, before participation in the project, the content focus of the PD was more familiar to the primary grade teachers. Even if the PD seems to have contributed to the instructional differences between the grade-levels now being smaller, this is not the case for students' results where the primary grades show a small improvement and the secondary grades a decline (Lindvall, 2016).

The coherence between the content of the PD and teachers' initial practice may help explain the rather contradicting results. If considering the results from the pre-surveys, as well as a previous study on mathematics instruction in Sweden (Bergqvist et al., 2009), it is clear that the PD-program places higher demands of instructional changes on the secondary grade teachers. Could it be that these requirements are too high? For instance, even though these teachers report on putting more emphasis on students' problem-solving competencies, the results also indicate that they less often let students present their solutions to mathematical problems for the whole class. These results may seem contradictory. However, as suggested by Schneider and Plasman (2011), specific features of inquiry based instruction are easier to learn whilst others, such as having students pose questions, are more challenging. Thus, the secondary grade teachers may have tried to put more focus on problem-solving, but have not yet reached so far that they use students' solutions as a basis for whole-class discussion. In fact, Stein et al. (2008) write that for teachers who are novices to teaching mathematics through problem-solving, the part including supporting students problem-solving skills during mathematical discussions based on students' solutions to the problem, is a particularly large challenge.

Nevertheless, if one wants to accomplish an instructional change, teachers likely have to be challenged. As seen in Timperley et al. (2007), the PD-programs showing the most positive effects were those who managed to strike a balance between being supportive and being challenging. Since the content focus of the PD in this study seems to be less coherent with the secondary grade teachers' initial practice, and thereby also more challenging, it may be even more important to consider how to support these teachers. Even so, the results indicate that, compared to the primary grades, the secondary grade teachers experience less support from their local context in carrying out changes in their instruction. First of all, the secondary grade teachers to a higher extent express that they experience barriers, such as available time for planning, in carrying out the instructional changes. Secondly, additional analyses of the teacher surveys suggest that the secondary grade teachers have experienced less support from their students, and the students' parents, in trying to make changes in their instruction. Thirdly, these analyses also indicate that the teachers in the primary grades perceive their mathematics curriculum materials as more supportive compared to those in the secondary grades. As argued by several scholars (Cobb & Jackson, 2011; Penuel et al., 2007), instructional improvement at scale is not just about teacher learning, but also regards questions on how schools and broader educational jurisdictions may support or constrain teachers in making the instructional changes. Thus, the results of this study suggest that not only the PD's coherence with school and state *policies* are of importance, but also if it is consistent with and supported by school and state *structures* (cf. Cobb & Jackson, 2012), such as organizational routines and positions.

To finish, even though the secondary grade teachers experienced more barriers in carrying out the teaching practices advocated in the PD, it is still those who report on having made the largest instructional changes. At the same time, it is the results of their students that have declined. Still, if one wants to determine the full effects of a PD-program it is not enough to do a single follow up after one year (Desimone, 2009; Wayne et al., 2008). For instance, Harris and Sass (2011) found that PD attainment in the current year has a negative effect on student results in high-school math, while it becomes positive after two to four years. Future research should therefore look at how teachers, instruction and students in both secondary and primary grades are affected by PD in longer terms.

## References

Ball, D. L., Thames, M. H. & Phelps, G. (2008). Content knowledge for teaching what makes it special? *Journal of Teacher Education*, 59 (5), 389–407.

Bergqvist, E., Bergqvist, T., Boesen, J., Helenius, O., Lithner, J. et al. (2009). *Matematikutbildningens mål och undervisningens ändamålsenlighet* [The goal of mathematical education and the purposefulness of teaching practices]. Gothenburg: National Centre for Mathematics Education.

Boaler, J. (2002). *Experiencing school mathematic: traditional and reform approaches to teaching and their impact on student learning*. Mahwah: Lawrence Erlbaum.

Chval, K., Abell, S., Pareja, E., Musikul, K. & Ritzka, G. (2008). Science and mathematics teachers' experiences, needs, and expectations regarding professional development. *Eurasia Journal of Mathematics, Science & Technology Education*, 4 (1), 31–43.

Clewell, B. C., Cohen, C. C. d., Campbell, P. B. & Perlman, L. (2005). *Review of evaluation studies of mathematics and science curricula and professional development models*. Washington: Urban Institute.

Cobb, P. & Jackson, K. (2011). Towards an empirically grounded theory of action for improving the quality of mathematics teaching at scale. *Mathematics Teacher Education and Development*, 13 (1), 6–33.

Cobb, P. & Jackson, K. (2012). Analyzing educational policies: a learning design perspective. *Journal of the Learning Sciences*, 21 (4), 487–521.

Cohen, J. W. (1988). *Statistical power analysis for the behavioral sciences* (2 ed.). Hillsdale: Lawrence Erlbaum.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: toward better conceptualizations and measures. *Educational Researcher*, 38 (3), 181–199.

Even, R. & Ball, D. L. (2009). *The professional education and development of teachers of mathematics*. New York: Springer.

Goldsmith, L. T., Doerr, H. M. & Lewis, C. C. (2013). Mathematics teachers' learning: a conceptual framework and synthesis of research. *Journal of Mathematics Teacher Education*, 17 (1), 5–36.

Harris, D. N. & Sass, T. R. (2011). Teacher training, teacher quality and student achievement. *Journal of Public Economics*, 95 (7), 798–812.

Lindvall, J. (2016). Two large-scale professional development programs for mathematics teachers and their impact on student achievement. *International Journal of Science and Mathematics Education*. Advance online publication. doi: 10.1007/s10763-016-9750-x

Marrongelle, K., Sztajn, P. & Smith, M. (2013). Scaling up professional development in an era of common state standards. *Journal of Teacher Education*, 64 (3), 202–211.

McNeill, K. L. & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: the impact of professional development on K–12 Teachers. *Science Education*, 97 (6), 936–972.

Penuel, W. R., Fishman, B. J., Yamaguchi, R. & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, 44 (4), 921–958.

Scher, L. & O'Reilly, F. (2009). Professional development for K–12 math and science teachers: What do we really know? *Journal of Research on Educational Effectiveness*, 2 (3), 209–249.

Schneider, R. M. & Plasman, K. (2011). Science teacher learning progressions: a review of science teachers' pedagogical content knowledge development. *Review of Educational Research*, 81 (4), 530–565.

Skolverket. (2011). *Curriculum for the compulsory school, preschool class and the recreation centre, 2011*. Stockholm: Skolverket.

Slavin, R. E. & Lake, C. (2008). Effective programs in elementary mathematics: a best-evidence synthesis. *Review of Educational Research*, 78 (3), 427–515.

Stein, M. K., Engle, R. A., Smith, M. S. & Hughes, E. K. (2008). Orchestrating productive mathematical discussions: five practices for helping teachers move beyond show and tell. *Mathematical Thinking and Learning*, 10 (4), 313–340.

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

Wayne, A. J., Yoon, K. S., Zhu, P., Cronen, S. & Garet, M. S. (2008). Experimenting with teacher professional development: motives and methods. *Educational Researcher*, 37 (8), 469–479.

Wiliam, D. (2011). *Embedded formative assessment*. Bloomington: Solution Tree Press.