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A quasi-experimental impact study of a professional development course for secondary mathematics teachers in South Africa

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We report on the impact of a mathematics professional development course on teachers' mathematical knowledge for teaching and their learners' attainment. Teachers' scores on a mathematics test improved significantly. Using a quasi-experimental design we examined the learning gains of Grade 9 learners (N=991) from nine secondary schools taught by teachers who had attended the course. We compared these results with those of learners (N=988) in the same schools taught by teachers who had not participated in the course. The intervention group learners made larger gains but these were not statistically significant. The teachers who had done the course had far fewer years of teaching mathematics at senior secondary level than their colleagues. This highlights the importance of a matched comparison teacher sample in impact studies.

Key words: Learning gains, mathematics teacher knowledge, impact of professional development.

Introduction

There are attempts across the world to improve teachers' mathematical knowledge in order to raise learner attainment. In South Africa, despite a wide variety of programmes costing many millions of Rand, there is little evidence that these interventions have had much impact on learners' performance in mathematics. The impact problem is frequently attributed to teachers' poor mathematical knowledge (Carnoy *et al.*, 2011; Taylor & Taylor, 2013).

In 2010 the Wits Maths Connect Secondary project (WMCS) set out to develop models of professional development for secondary mathematics teachers that would improve learner attainment in Mathematics. In 2012 the Transition Maths 1 (TM1) course was offered for the first time to a small group of teachers in one district in the broader Johannesburg area. In 2013 the Learning Gains I impact study showed that learners taught by teachers who had attended the course out-performed learners in the same schools taught by teachers who had not attended the course. The results were treated as "evidence of promise" since the sample was small, the gains were small and the variation within the treatment and comparison groups was large (Pournara, Hodgen, Adler, & Pillay, 2015). The notion of *learning gains* was employed as a measure of learner attainment where the gain is the change in test-score from pre- to post-test over one academic year. It is a useful notion in the context of impact studies because it enables us, to some extent, to attribute learning gains to the teaching received from a particular teacher in a given year. We are well aware of a range of interventions that are taking place in secondary schools and so we make all claims with caution, knowing that no individual intervention at the level of the teacher can account entirely for improvements in learner attainment.

The TM1 course has been revised and refined annually since 2014, and has now been offered to four more cohorts of teachers across the Gauteng province of South Africa, totaling approximately 150 teachers. A follow-on impact study, Learning Gains II, commenced in 2016 to extend the Learning Gains I study with a more robust instrument and a larger sample of teachers, learners and

schools. The key question the study seeks to answer is, “What is the effect of teachers’ participation in the TM1 course on their learners’ attainment in Mathematics?”

We begin with a brief review of the literature on teacher knowledge, mathematics professional development and the impact of these on learner attainment. Thereafter we provide a description of the TM1 course, giving the reader some insight into the mathematics and teaching components of the course by means of specific examples of tasks.

Teacher knowledge and learner attainment

Shulman’s (1986, 1987) distinctions between subject matter knowledge (SMK) and pedagogical content knowledge (PCK) have provided much impetus for a great deal of research on teacher knowledge. While it is widely agreed that the knowledge teachers need for teaching mathematics is more than sound content knowledge of mathematics itself, the elaboration of the detail takes different forms. Some refer to the additional knowledge as PCK (e.g., Krauss, Baumert, & Blum, 2008) while others (e.g., Ball, Thames, & Phelps, 2008) distinguish sub-categories of SMK as common, specialised and horizon content knowledge, and further sub-categories of PCK such as knowledge of content and students, curriculum and teaching. While we find the SMK-PCK distinction useful, the boundaries between them are too blurred to be useful as analytical constructs. We therefore choose to speak of “mathematics-for-teaching” (MfT) (Adler, 2005; Adler & Davis, 2006) as an amalgam of mathematical and teaching knowledge. MfT includes both subject content knowledge and mathematics-specific pedagogical knowledge.

Elsewhere (Pournara *et al.*, 2015) we have argued that in contexts where teachers’ mathematical knowledge bases are poor, proxy measures such as state certification, number of post-school maths/maths education courses taken and years of teaching experience may be relevant predictors of learner attainment in secondary mathematics. However, these proxy measures alone are insufficient as measures of teachers’ mathematical knowledge.

Attempts to measure teachers’ mathematical knowledge have taken various forms across the world. In some instances, teachers have been given the same/similar test items to the learners they teach. Harbison and Hanushek (1992) and Mullens, Murnane, and Willett (1996) found that primary teachers’ scores on such tests were good predictors of learner performance. In South Africa, Taylor and Taylor (2013) reported the poor performance of Grade 6 teachers and learners on items in the SACMEQ III study, thus implying a link between (poor) teacher knowledge and (poor) learner performance. More sophisticated measures have been developed in Germany and the United States (Baumert *et al.*, 2010; Hill, Ball, & Schilling, 2008; Krauss *et al.*, 2008). These studies have both found associations between teacher knowledge and learner attainment.

While teacher knowledge is key in all contexts, it is particularly crucial in contexts of poverty and low achievement. Nye, Konstantopoulos, and Hedges (2004) and Krauss *et al.* (2008) have shown that variances in learning gains attributable to teaching are higher in low socio-economic status (SES) schooling contexts.

Professional development and learner attainment

The impact of professional development is a concern across the world. Based on a literature survey in English publications, Adler, Ball, Krainer, Lin, and Novotna (2005) reported a predominance of small-scale qualitative studies. The review of studies of professional development relating to school mathematics by Gersten, Taylor, Keys, Rolffhus, and Newman-Gonchar (2014) showed that very

few of the initiatives which met acceptable standards of rigour also led to positive effects on learner attainment. Sample-McMeeking, Orsi, and Cobb (2012) reported the effects of a middle school intervention in the US where teachers took university summer courses in mathematics lasting two to three weeks. They reported an effect size of 0.20 (Hedge's g) on learner attainment for teachers who had attended two courses but there was no discernible effect size for those who had attended only one course. Further work is clearly required to carry out rigorous studies on the impact of teacher professional development on learner attainment in mathematics, and this study makes a contribution in this regard.

The Transition Maths 1 course

The TM1 course is underpinned by the assumption that focusing on teachers' MfT will lead to better teaching which will in turn translate into improved learner attainment. It is targeted at teachers currently teaching in Grades 8 and 9 (first two years of secondary school in South Africa), and aims to address the transition from mathematics in the Senior Phase (Grades 7–9) to mathematics in the Further Education and Training (FET) phase (Grades 10–12). Teachers are typically nominated by their school or district to attend the course. They are then required to write a selection test before being accepted. The course was offered free of charge to teachers. While it is an officially recognized Short Course of the University, it does not carry accreditation towards a qualification but does carry Continuing Professional Development (CPD) points.

The course consists of eight two-day contact sessions over a ten-month period and focuses on mathematics content (75%) and aspects of mathematics teaching (25%) – a similar ratio to the course described in Sample-McMeeking *et al.* (2012) mentioned above. The mathematical content of the course includes algebra, number, functions, Euclidean geometry and trigonometry. Teachers submit seven assignments and write two tests which include mathematics content and tasks related to teaching.

We approach the learning of MfT through *revisiting* known mathematics (Pournara, 2013) and learning new mathematics. When working with familiar mathematics, a revisiting approach frequently draws on extreme cases and problematizes taken-for-granted aspects to deepen teachers' knowledge rather than merely redoing known mathematics to improve procedural fluency (Kilpatrick, Swafford, & Findell, 2001). For example, in working with linear functions we provide teachers with five representations (verbal, table, function machine, equation and graph) of the same function, say $y = 2x + 1$. We then invite them to consider questions about each representation, including some that are likely to be new and unusual, for example: “Where is *double* in the graph?”; “Where is *double* in the table?”; and “When the input is -1 , the output is also -1 . Is there another output-value that is the same as the input-value?”

We extend teachers' knowledge beyond the mathematics they currently teach so that they can teach Grade 10 (and possibly beyond) in the future. We therefore deal with Grade 11 curriculum content in algebra, functions and trigonometry, paying attention to common procedures in the senior secondary years such as completing the square, which we approach algebraically and geometrically. We reinforce connections between representations and between procedures by asking teachers to solve quadratic equations using three methods (factorizing, quadratic formula and completing the square) for typical examples such as $3x^2 - 5x - 2 = 0$ and unusual cases such as $k^2 = 5$.

The focus on mathematics teaching is built around the notion of teachers' *mathematical discourse in instruction* (Adler & Venkat, 2014) which is operationalised through what is known as the

Mathematics Teaching Framework (MTF). Here we focus on key elements common to all teaching practices: identifying and articulating a lesson goal; designing and selecting example sets; selecting representations; selecting and designing tasks; producing explanations and justifications; and, building opportunities for meaningful learner participation in lessons. Each of these aspects is sufficiently close to teachers' current practice and hence possible to implement and then to work on so as to become more skillful at each one. We illustrate the teaching focus through an example from a session on explanations where we deal with the pervasive error of conjoining in algebraic simplification. Teachers are asked to produce an explanation that will convince Grade 8 learners that $4p + 5 \neq 9p$. This typically leads to a range of responses from teachers such as those illustrated in figure 1.

- 1) *Numerical approach using a single case*: The letter stands for an unknown number. So, let's try $p = 2$. If $p = 2$, then what is $5p + 4$? Is it the same as $9p$?
- 2) *Appealing to everyday life using letter as object*: We can think of $5p$ as 5 pencils, but 4 is just a number. When we add, we won't get 9 pencils.
- 3) *Appealing to everyday life using letter as specific unknown*: We can think of p as a box with a number of sweets, but we don't know how many sweets are in the box. Is $5 \square + 4$ the same as $9\square$? i.e., Is 5 boxes of sweets plus 4 more sweets the same as 9 boxes of sweets?
- 4) *Comparing different algebraic expressions using principles of variation*: Let's compare different algebraic expressions. What is the same/different about the following expressions: a) $5p + 4p$
b) $5p + 4m$ c) $5p + 4$

Figure 1: Four possible responses to explain $4p + 5 \neq 9p$

We then ask teachers to study these responses and to evaluate each explanation in the light of its mathematical correctness, its generalizability and the extent to which it is appropriate for Grade 8 learners. While we have not yet researched teachers' responses to this kind of task, anecdotally we have noticed that they are not aware of the limitations of the *letter as object* (Küchemann, 1981) explanation. We therefore highlight the important yet subtle distinctions between explanations (2) and (3), showing why (3) is more productive for making sense of algebraic symbols later in algebra. We recognize that explanation (4) shows evidence of teachers' take-up of ideas of variation (Marton & Tsui, 2004; Watson & Mason, 2006), which we explicitly teach in the teaching sessions.

Research design and methods

We adopted a quasi-experimental design to assess the effect of the TM1 intervention on the participating teachers and on the attainment of their learners. We describe the sample of teachers taking part in the TM1 course in 2016 and the methods used to analyse their gains in MfT during the course. We then examine a sample of Grade 9 learners during the 2017 school year to assess the impact of the TM1 course in the first year after teachers' participation in the TM1 course.

Forty teachers completed the TM1 course in 2016. The gains in their MfT were assessed by means of tests, administered at the start and the end of the course. The test at the end of the course was more cognitively demanding than the test at the start and covered more topics. Both tests were developed by the project team.

Eleven teachers, in 9 schools, were invited to participate in the study because they were teaching Grade 9 Mathematics in 2017 and 15 of their colleagues, also teaching Grade 9 Mathematics, agreed to be part of the comparison group. In terms of analysis, a repeated measures t-test analysis was used to compare the mean test scores at the start and the end of the course. This was carried out only for the 11 teachers in the study.

At the same time, we tracked 991 Grade 9 learners taught by TM1 teachers over the 2017 school year. We refer to these as the TM1 learners. We also tracked 988 Grade 9 learners from the same schools but taught by teachers who had never participated in the TM1 course. These learners are referred to as the comparison group. A test was administered to both groups in February and September 2017.

The learner test, designed by the project team, tested key aspects of number, algebra and functions. Most items were typical curriculum items at Grade 8 and 9 levels. The test was designed to contain a spread of items across difficulty levels. It was piloted in 2016 with Grade 9 and 10 learners in schools similar to those participating in the study. A Rasch analysis showed that the test was fit for the purpose of testing learning gains at Grade 9 level although there were a few too many items that were difficult for many learners.

Each test response was marked as *correct*, *wrong* or *missing* with only 1 mark being allocated for a correct response. Therefore a learner's test mark simply indicated how many items s/he had answered correctly. There was no consideration of partially correct responses.

A repeated measures ANOVA analysis was carried out to see whether the interaction between pre/post gains in the learner assessment and the learners' group (control vs TM1 group) was statistically significant.

Results

We first present the quantitative results and analysis from the TM1 tests for teachers, and then the results of the learner test.

Looking firstly at the TM1 maths tests, the mean test scores for the teachers before and after the TM1 course were compared. The mean pre-course test mark was 57.3% and the mean final test mark was 72.1%. A repeated sample t-test analysis showed that this increase was statistically significant at the 5% level ($t = 3.67$, $df = 10$, $p < 0.05$). We therefore concluded that the course had a significant impact on the teachers' MfT. Given that the final test was more cognitively demanding and covered more topics, the statistics may under-report the impact of the course on teachers' MfT.

The results of the Grade 9 Learning Gains test scores were as follows: for the TM1 group the mean score increased from 13.2% to 19.5% from pre- to post-test. By contrast the comparison group's mean scores increased from 13.9% to 19.7%. The TM1 learners made greater gains, closing the gap between the two groups. However, using a repeated measures ANOVA analysis, the interaction between pre/post-test and learner group was not found to be significant (Wilks' Lambda = 1, $F(1, 1975) = 0.91$, $p = 0.34$). We therefore concluded that there was no statistically significant difference in the gains in the learner test scores pre to post between the comparison group and the TM1 group.

The teachers' levels of teaching experience provide a possible explanation for the apparent lack of impact of the intervention. We compared the TM1 teachers and the comparison group teachers on their number of years of teaching Mathematics (in general) and on their number of years teaching

Mathematics in each of Grades 8 to 12 (Table 1). We report on all 11 TM1 teachers but only on 12 comparison teachers because the biographical data for the remaining 3 teachers was incomplete.

	N	Years of Maths Teaching	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12
TM1 teachers	11	14.6	7.0	9.6	3.6	1.9	1.1
Comparison teachers	12	13.3	4.5	5.8	4.1	4.3	4.0

Table 1: Teachers’ average years of experience of Mathematics teaching per grade

The data shows that both groups had, on average, been teaching mathematics for a similar number of years although within each group there was a wide range of years of experience. While on average the TM1 group had more experience teaching at Grade 8 and 9 levels, the comparison group had considerably more experience teaching in Grades 11 and 12. This suggests that participation in the TM1 course does not make up for years of teaching experience at senior secondary level, particularly beyond Grade 10. However, based on the learner results, it could be argued that participation in TM1 enabled the teachers to do “as good a job” in teaching Grade 9 Mathematics as their colleagues who have more experience in teaching higher grades.

Given that the teachers in the comparison group are the “more senior” teachers with respect to mathematics, it is not surprising that the TM1 learners did not significantly outperform the comparison learners. If it can be assumed that teachers teaching higher grades have stronger mathematical knowledge for teaching, then the overall findings of this study fit with the underlying assumptions behind TM1 – that paying attention to teachers’ mathematical knowledge for teaching is a necessary condition for improving teaching.

Discussion and implications

As noted above, proxy measures of teachers’ knowledge may have some predictive power in contexts where teachers’ mathematical knowledge is generally poor. Based on the data presented, the proxy measure “number of years of mathematics teaching” needs to take into account the levels at which teachers are teaching within the secondary school. Secondly, as Clarke (1994) has argued, the impact of professional development programmes on teachers’ practice is delayed. Therefore, attempts to measure the impact of teachers’ participation in TM1 on their learners should not be undertaken in the first year after completing the course.

Impact studies, irrespective of whether or not they report statistically significant results, do not provide insights into the mechanisms which enable or constrain the desired change. Based on the data reported here, little can be said about why the gains were small for both the TM1 learners and the comparison group. Further research is necessary to unearth possible reasons for the continued low performance of learners in Grade 9 Mathematics. A related qualitative study is underway to investigate the nature of learners’ errors and the extent to which these errors may change between pre- and post-test. Such changes in the nature of learners’ errors cannot be picked up by a coding system that does not make allowance for partially correct responses. This points to the need for mixed methods impact studies where quantitative impact analyses are complemented by qualitative studies such as those that attend to learner error.

In terms of research design, particularly in the context of secondary mathematics in South Africa, the above finding on teacher background and learner attainment shows the importance of matched sampling in the teacher group. This will likely expand the size, cost and complexity of the study

since it is seldom possible to find comparison teachers, within the same schools, who have similar years of experience in Grades 8 and 9 but have not participated in TM1. Inevitably this means the inclusion of new comparison schools, which potentially strengthens the findings of the study. However, experience has shown that schools such as those participating in this study are not in a position to confirm which teachers are teaching in each grade until early-to-mid February by which stage data collection for a study such as this has already commenced. Consequently the matching of teachers is likely only possible after the pre-test learner data has been collected. This leaves some of the matching of teachers up to chance as the researchers have little control over these matters.

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