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Effects of Co-operative Learning and Embedded Multimedia on Mathematics Learning in Key Stage 2: Final Report

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Robert Slavin, Mary Sheard, Pam Hanley, Louise Elliott, Bette Chambers
Institute for Effective Education, University of York

Alan Cheung
The Chinese University of Hong Kong



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More information is available at www.nuffieldfoundation.org

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The mathematics performance of pupils in UK primary schools is similar to that in other developed countries, but there is enormous variation among pupils and among schools. In particular, schools in disadvantaged areas perform poorly in maths. A recent Rowntree report on poverty and exclusion found that 11-year-old pupils eligible for free school meals are half as likely to achieve basic standards in numeracy as more advantaged 11-year-olds (Joseph Rowntree Foundation, 2009). These schools are also most likely to have teachers without a strong background in teaching maths.

Comprehensive reviews of research evaluating mathematics interventions in primary schools (Slavin & Lake, 2008) and secondary schools (Slavin, Lake, & Groff, 2009) examined three categories of mathematics reforms: curricular reforms, ICT, and innovative teaching approaches. Both reviews found the strongest research support for the innovative teaching approaches, such as various forms of co-operative learning and teaching of metacognitive learning strategies. What these approaches have in common is that they provide extensive professional development to teachers on means of engaging and motivating pupils and helping them take an active role in their own learning. In particular, studies of co-operative learning have shown positive impacts in many studies, and can be readily disseminated.

The Institute for Effective Education (IEE) at the University of York adapted for the UK a co-operative learning approach to teaching primary maths designed to improve performance in all schools. This approach, called *PowerTeaching Maths*, is an adaptation of a co-operative learning strategy called *Student Teams-Achievement Divisions*, or STAD, which has been widely used and evaluated in the US (Slavin, 1995).

Co-operative learning

Co-operative learning is one of the most widely researched approaches to pedagogy in mathematics. In co-operative learning, children work in pairs or small groups to help each other master mathematics concepts and skills. Research on co-operative learning in mathematics has found strong impacts on mathematics learning if the methods incorporate two key elements: group goals and individual accountability. For example, co-operative learning improves mathematics learning when pupils work in small groups and may earn recognition based on the individual learning of all group members (see Davidson & Kroll, 1991; Slavin, 1995; 2009; Rohrbeck, Ginsburg-Block, Fantuzzo, & Miller, 2003; O'Donnell, 2000; Slavin & Karweit, 1984; Topping, Kearney, McGee, & Pugh, 2004; Howe, Tolmie, Greer, & Mackenzie, 1995; Johnson & Johnson, 1989).



Co-operative learning is widely supported by experts in mathematics instruction, and use of co-operative learning is a key recommendation of the National Primary Strategy. Groupwork and co-operative learning are specifically identified as being appropriate pedagogies to promote numeracy (Department for Children Schools & Families, 2009a). In Scotland, Education Scotland provides specific advice as to the effectiveness of co-operative learning strategies to promote numeracy as part of the development of the new curriculum, 'Curriculum for Excellence' (Learning & Teaching Scotland, 2009). Opportunities for co-operative group work are also identified in the mathematics national curriculum for Wales (Welsh Assembly Government, 2008). A large proportion of primary teachers report using co-operative learning frequently in teaching maths. However, studies find that the co-operative learning that is generally implemented in schools consists of unstructured group work, with little individual accountability and no group goals (Stein, Grover, & Henningsen, 1996; Hiebert & Wearne, 1993). Pupils sit together and are allowed to share ideas, but they often simply share answers rather than trying to explain ideas to each other (Antil et al., 1998; Emmer & Gerwels, 2002). Sharing answers without explanation has been found to inhibit, not aid, learning of mathematics in co-operative learning contexts (Webb & Palincsar, 2008). One of the main reasons why co-operative learning is expected to enhance maths development is its ability to structure experiences that promote metacognition, defined as knowledge of one's own cognition. It is the process of knowing why you know something and how you know it. Combining co-operative learning with metacognition training has been shown to be an effective pedagogical strategy (Meloth & Deering, 1994; Kramarski & Mevarech, 2003).

Mathematics in Years 3-8 has been one of the subjects most often studied in research on co-operative learning. Studies of effective co-operative learning approaches to mathematics include Al-Halal, 2001; Leikin & Zaslavsky, 1997; Johnson & Johnson, 1989; Ma, 1996; Sharan, 1980; Slavin, 1995; and Slavin & Karweit, 1984. Co-operative learning is especially well-suited to mathematics, as it helps pupils to understand their own misconceptions in the process of constructing meaning. Pupils in a group may all be learning material for the first time, and may be even more aware than their teacher of what other pupils do not understand. With appropriate guidance, pupils can give each other explanations that focus on their fellow pupils' misconceptions. Receiving such elaborated explanations can help pupils fill in gaps in their understanding, correct misconceptions, and strengthen connections between new information and previous learning (Webb, 2008). The techniques of structuring



classroom talk to maximise potential benefit is an important part of the structure of *PowerTeaching Maths*.

In essence, co-operative learning functions as a means of cognitive elaboration, helping pupils to both learn and understand (Webb, 2008; O'Donnell, 1996; Newbern et al, 1994). Modern conceptions of mathematics (DfE, 2009a) emphasise the importance of such mathematical reasoning as an integral part of doing mathematics. According to the Department for Education (DfE), mathematical reasoning requires the attainment of abilities to construct mathematical conjectures, develop and evaluate mathematical arguments, and select and use various types of representations. The DfE strongly recommends the use of mathematical discourse in the classroom, including pupils discussing their reasoning with other pupils and the teacher as well as explaining the basis for their mathematical reasoning. The National Primary Strategy recommendations on assessment make explicit reference to how co-operative learning can promote maths development, inclusion, and the aims of assessment for learning (DfE, 2009b). Similarly, mathematics discourse features prominently in the literature on assessing pupil performance (APP) provided by the DfE. Co-operative learning provides an ideal setting for such types of discourse, and indeed this has been investigated by a number of researchers (Johnson & Johnson, 1989; Webb & Farivar, 1994; Meloth & Deering, 1994).

Despite the strong and widely replicated experimental evidence supporting the use of co-operative learning in maths, little of this research has taken place in the UK. Most has been carried out in the US and Israel (Slavin & Lake, 2008; Slavin et al., 2009). The one large-scale evaluation, by Tracey, Madden, & Slavin (2010), failed to find any significant differences in maths learning between co-operative learning and control classes in Years 4 and 5. Implementation, however, was generally poor, and there was a need to do more to adapt the approach to the curriculum and culture of the UK. A key rationale for the present study was to create a high-quality version of co-operative learning better adapted to the UK and to seek to ensure good implementation, adding technology supports (described below) well as enhanced CPD for all implementing teachers.

Technology supports

In addition to co-operative learning, an important feature of the *PowerTeaching Maths* intervention is the use of embedded multimedia (Chambers et al., 2006, 2008), digital video content that is threaded throughout teachers' lessons to directly reinforce the learning



objectives. The theoretical rationale for using embedded multimedia is based on dual coding theory, which posits that information held both in verbal memory and in visual memory is retained better than information held in only one memory system (Baddeley, 2004; Mayer, 2005). Based on this and other research on instructional television programmes such as *Sesame Street* and *Between the Lions* (Linebarger, Kosanic, Greenwood, & Doku, 2004), the Success for All Foundation in the US developed a literacy intervention that made use of brief video segments integrated into teachers' daily lessons. Two large randomised clinical trials found that beginning readers who experienced the embedded multimedia content learned to read significantly better than those who received an identical curriculum lacking the multimedia content (Chambers et al., 2006, 2008). The Success for All Foundation developed and piloted a mathematics intervention that combines the STAD co-operative learning approach with embedded multimedia, and formative evaluations indicated substantial promise.

Methods

The study used a cluster randomised trial in 42 schools in England to compare teachers using *PowerTeaching Maths* (PTM) to a control group of teachers using whatever methods and materials they ordinarily used.

Elements of *PowerTeaching Maths*

Co-operative learning

In *PowerTeaching Maths*, pupils are assigned to mixed-ability teams of four or five members. Each chooses a team name and is given the responsibility of ensuring that every team member learns the content presented in their maths lessons. In each lesson, after initially explaining a target concept, teachers pose on an interactive whiteboard a series of problems for pupils to solve in a "team huddle." They then call on a child at random from each team to represent the team with their answer and explanation. Because the pupils do not know which team mate will represent them, they must make sure that all team members understand each problem and solution.

Ultimately, all pupils are individually assessed, and teams are evaluated based on the average performance of all team members. In this way, pupils work with each other to help



ensure that everyone knows the material, a process known from extensive research to promote deep learning (Slavin, 1995, 2009, 2013; Webb, 2008; Rohrbeck et al., 2003).

Embedded multimedia

Using interactive whiteboards, *PowerTeaching Maths* contains frequent, brief video vignettes designed to do the following:

1. Illustrate concepts of mathematics, using graphic demonstrations, puppet sketches, humorous presentations, and other content.
2. Model problem-solving heuristics, using humorous puppet sketches, live action segments, and animations. Virtual pupils are shown in these clips struggling with difficult concepts or complex story problems and using proven metacognitive strategies, such as graphic organisers, breaking complex problems into smaller problems, and finding patterns.
3. Modelling effective co-operative learning processes, using humorous puppet sketches, live action segments, and animations. The clips show groups using effective methods for working in teams, such as active listening, explaining without telling, ensuring universal participation, and resolving disagreements amicably.

Curriculum

The curriculum was consistent with Key Stage 2 mathematics standards as they existed at the time of implementation. Teachers were provided with “flipcharts” for the interactive whiteboards, containing objectives, sample problems, embedded multimedia segments, and assessments. These were designed to be easy to modify so teachers could personalise the content to support their teaching goals, taking into account their pupils’ needs.

Training

Implementing a comprehensive, innovative programme such as *PowerTeaching Maths* requires intensive initial training and ongoing in-class support to obtain implementation fidelity. Each teacher participated in two days of training on both co-operative learning and the flipchart technology. In a few cases, when teachers could not attend the main training, shorter training was provided. Over the course of the year, each school then received about five coaching visits. The training and ongoing implementation support visits were conducted by the staff of the registered charity, Success for All-UK, a charity that works in schools throughout the UK. Resource developers at the IEE provided the flipchart training.



Research design

The evaluation of *PowerTeaching Maths* took place in 42 primary schools throughout England. Schools included relatively affluent as well as very disadvantaged intakes. In each school, all Year 4 and Year 5 teachers and children were invited to participate.

Schools were told that they would be assigned at random to receive *PowerTeaching Maths* in Autumn, 2011 or in Autumn, 2012. Those who were in the first group served as the experimental group, while the other served as a delayed-treatment control group. Schools were matched on Year 6 SATs, percent free school meals (FSM), percent English as an additional language (EAL), and percent special educational needs (SEN). They were then matched in pairs and assigned by coin flip to the experimental or control group.

Two experimental schools dropped out of the study, and one more failed to implement, but the pupils in these schools were tested and they remained in the sample in an intent-to-treat design. The final sample comprised 21 experimental and 21 control schools, 58 experimental and 60 control teachers, as well as 1,221 experimental and 1,303 control pupils.

Measures

Pupils were pre- and post-tested on Optional SATs in maths. These are assessments widely used in the UK to keep track of the learning of pupils in year levels other than Year 6, the official test year. Appropriate forms of Optional SATs were used to reflect the topics being taught throughout England and to avoid floor or ceiling effects. A key advantage of using Optional SATs is that these tests are already in use in most schools in England and that they cover the maths skills emphasised in the National Numeracy Strategy, still the de facto national maths curriculum in England in 2011-2012.

In addition to the maths achievement outcomes, teacher questionnaires were administered to obtain teachers' feedback on their implementation of PTM or control interventions. The content of the teacher questionnaire appears in Table 4.

Finally, observations of the degree of implementation of PTM were made in the experimental schools.



Analysis

The main analysis used hierarchical linear modelling (HLM), the state-of-the-art method for clustered designs (Raudenbush & Bryk, 2002). In this study, pupils and teachers were clustered within schools, making HLM the appropriate method. This is a conservative design, however, because it uses the school as the unit of analysis. The HLM analysis used the Optional SAT pre-tests as covariates. Data were combined across Year 4 and Year 5 pupils by transforming raw scores to z-scores (deviations from the Year level's mean).

Results

Table 1

Baseline Equivalence of Experimental and Control Schools

	Intervention	Control	Significance
Percent Achieving Level 4 and Above in KS2 Maths	79.3	78.4	ns
% Free School Meals	24.9	23.5	ns
% English as an Additional Language	36.8	37.6	ns
% Special Educational Needs	20.2	22.0	ns
Number on Roll	319.3	335.5	ns

Table 2

Pre- and Post-test Means in z-Scores

Optional SATs

	Pretest		Post-test		Adjusted Posttest Mean
	Mean	SD	Mean	SD	
Experimental (N=1221)	-0.13	0.98	-0.15	0.98	-0.04
Control (N=1303)	+0.12	1.0	+0.14	1.00	+0.04

Note: Combines Optional SATs across Years 4 and 5 after transforming to z-scores (mean=0, standard deviation=1.0).



Table 3
Hierarchical Linear Modeling of SATs Outcome

N=42 Schools (2524 students)

Level 1 model: $Y_{ij} = \beta_{0j} + \beta_{1j} (\text{Grade}) + r_{ij}$

Level 2 model: $\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{Mean Pretest})_j + \gamma_{02}(\text{Treatment})_j + u_{0j}$

$\beta_{1j} = \gamma_{10}$

<i>Fixed Effect</i>	Effect	SE	<i>t</i>
School mean achievement			
Intercept	0.01	0.05	0.21
Mean Pretest	0.78*	0.12	6.74
Treatment	-0.09	0.07	-1.19
Grade			
Intercept	0.59**	0.04	16.13
<i>Random Effect</i>	Estimate	χ^2	<i>df</i>
School mean achievement	0.18	146**	39
Within-school variation	0.89		

Note: * $p < .05$; ** $p < .01$.

Baseline equivalence

Table 1 shows that the experimental and control schools were well matched on KS2 maths scores, percent free school meals, percent English as an Additional Language, and percent Special Educational Needs, as well as school enrolment.

Achievement

The pre-test and post-test means for each group appear in Table 2, and the main HLM analysis appears in Table 3. Despite random assignment, there were substantial pre-test differences (effect size = -0.26, $p < .001$) favouring the control group. Statistically controlling for this initial difference, the overall impact of treatment was essentially zero, showing no difference between PTM and control groups. Both groups gained in maths achievement, but to the same degree.

Analyses for pupils in the low, middle, and high thirds of their Year levels at pre-test showed that all gained to about the same degree whether they were in PTM or control schools. There



were also no significant differences, according to schools' levels of free school meals or degree of implementation.

Table 4
Implementation of Key PTM Components

Team Set-Up	Percent Observed
Teams of 4 – 5	100
Team Names	94
Teams Seated Together	92
Team Recognition	86
Active Instruction	
Think-Pair-Share/Random Reporter	92
Model Think-Alouds	90
Extend Pupils' Understanding	92
Team Huddle/Mastery	
Monitor Teams, Facilitate Discussion	100
Ensure All Teams Engaged	92
Award Co-operation Points	86
Meaningful Conversations	92
Class Debriefing	
Pupils Chosen to Explain	67
Address Misconceptions	77
Pupils Do Team Check	73
Celebration	
Review Team Scores	81
Display Team Rankings Weekly	83
Celebrate Good Teams	35

N=52 teachers. Note that 8 additional teachers were in schools included in the evaluation but that ceased implementation during the year.

Implementation fidelity

Teachers implementing PTM were observed an average of 3-5 times over the course of the year. Observers focussed on 18 essential elements of the PTM lesson cycle, especially the elements relating to co-operative learning. Observations were obtained from 52 PTM teachers. Most teachers were observed using all or almost all of the co-operative learning elements; the median number of elements observed was 16 out of 18. However, there were 7 teachers using as few as 3-10 of the elements, and it should be borne in mind that three schools with 8 teachers failed to implement entirely.



Table 4 shows the 18 elements and the percent of classes in which each was observed. The programme elements used most commonly had to do with forming teams, having them sit together and choose team names, using active instruction, and encouraging team members to engage in meaningful discussions. All of these were seen in at least 90% of classes.

Implementation of programme elements related to individual accountability and group recognition was much lower. Only about two-thirds of classes were seen awarding achievement points, celebrating team successes, and asking individuals to represent their teams. Similarly, the element of pupils working independently to demonstrate their mathematical understanding towards the end of the lesson was not always in place.

While the overall levels of implementation were quite good, the levels of lesson focus on group recognition and individual accountability were worrisome, as much previous research has indicated the importance of these elements in co-operative learning (see Slavin, 2013). Without them, there is a danger that pupils may simply give each other answers rather than prepare each other for assessments. Project staff observed a reluctance among teachers to formally assess pupils' learning of the maths content; even those teachers who did actively celebrate team accomplishments often based their celebrations on the teams' good behaviour or co-operation more than actual individual learning, so pupils did not have an incentive to try to ensure that their teammates would know the mathematics.

Table 5

Teacher Surveys (PTM Only)

1. How much has PTM helped pupils make progress in mathematical understanding? (percent)

Very much	7%
Quite a lot	61%
A little	32%
Not at all	0%

2. Has PTM contributed less than expected, expected, or more than expected levels of attainment? (percent)

More than expected	8%
Expected	81%
Less than expected	11%



3. Which groups of pupils made the most or least learning gains in PTM? (numbers)

	<u>Most</u>	<u>Least</u>
High Ability	7	18
Middle Ability	23	3
Low Ability	11	12
SEN	5	18
EAL	8	5
Boys	8	2
Girls	7	1

4. Which aspects of maths has PTM supported well? (numbers)

Explaining	28
Reasoning	19
Justifying	12
Problem Solving	7

5. How useful were the following? (percentages)

	Very/Quite Useful	A Bit/Not At All Useful	Don't Know/Not Used
Videos	93%	7%	--
Flipcharts	90%	10%	--
Recaps	79%	21%	--
Team Preparation Activities	59%	41%	3%

6. What has worked well in PTM? (Open question: number)

Working in groups/teams	13
Co-operative learning	7
Working in pairs	7
Flipcharts	10
Videos	10
Teacher modeling	4
Rewards systems	8
Explaining thinking	6
Increases enthusiasm	5

7. What has not worked well in PTM? (open question: number)

Lack of differentiation/mixed ability groups	19
Lack of challenge for high-ability pupils	9
Access and achievement for low-ability pupils	6
Pitching and levelling	7
Lack of variety	4



Survey Data

Table 5 shows outcome data for the PTM teacher surveys. These provide very useful feedback in explaining the disappointing achievement results.

Twenty-nine of the PTM teachers returned surveys. Of this number, 7% thought PTM helped pupils make progress in their mathematical understanding “very much,” 61% “quite a lot,” and 32% “a little” (Question 1). Question 2 finds most teachers saying that PTM enabled pupils to make expected progress. In Question 4, teachers say they thought PTM supported their pupils’ explaining and reasoning. Most liked the videos, flipcharts, team preparation activities, recaps, and other elements (Question 5), and most mentioned co-operative learning positively (Question 6). Examples of comments on co-operative learning included “it has been fantastic to see the children working so well together as a group”, “... we’ve adopted team working for other subjects now”, “working in teams has helped develop confidence in children who would normally be listeners”. In fact, none of the teachers mentioned co-operative learning as an overall negative factor.

The biggest downside, which observers saw from the outset, involved differentiation. In the UK, maths teachers have long been expected to differentiate their lessons, which means to provide multiple versions of each lesson to give greater challenge to high achievers and additional help to struggling pupils, usually by grouping within classes. In contrast, co-operative learning puts high, average, and low-achieving pupils together in interactive groups, where peer tutoring is expected to help all pupils profit from demanding lessons. Teachers found this very hard to reconcile with differentiation. In Question 7, an open question asking “What has not worked well?”, the majority of teachers (19) mentioned lack of differentiation, mixed-ability groups, lack of challenge for higher ability pupils, access and achievement for low ability pupils, and “pitching and levelling”. That is, these teachers clearly struggled with the lack of differentiation that characterises co-operative learning (even though most liked co-operative learning itself). In Question 3, teachers expressed the opinion that it was middle-ability pupils who gained the most from PTM, not high or low ability, and they had particular concerns about pupils with SEN.

Examples of open-ended comments about differentiation were as follows: “No differentiation has caused problems. Least able find it hard and more able haven’t been challenged enough”; “Due to the children having such a range of abilities, it is difficult to teach a lesson



that is accessible to all”; “Higher ability (pupils) not challenged”; and “The lower ability (pupils) have struggled to access all of the work”.

Discussion

This large, randomised evaluation of a comprehensive approach to maths teaching in Years 4 and 5 found that teachers in England implemented most elements of co-operative learning with embedded multimedia, and most of them liked it. However, they often did not implement programme elements related to group goals and individual accountability for learning, which previous research has found to be essential to the effectiveness of co-operative learning. Perhaps as a result, the intervention did not make any difference in achievement in comparison to what was seen in the control group. Also, teachers expressed concern about the lack of differentiation in the *PowerTeaching Maths* intervention.

here are several ways to see these results. One could see them as a surprising disappointment in that co-operative learning has been so often evaluated and found to be effective, especially in the US. The limited implementation of team rewards based on the learning of all team members could be the main explanation for the findings. Also, it may take longer than a year for teachers to feel comfortable teaching maths without using formal differentiation, such as setting within classes, and instead building on co-operative learning to accommodate pupil differences. Differentiation (and within-class setting) appear to be far more prevalent in the UK than in the US, where co-operative learning has been successfully evaluated many times.

In future work on co-operative learning in mathematics in the UK, it could be important to incorporate differentiation strategies that do not use setting (which undermines the use of co-operative groupings). This could be done in many ways, including using modern technology to help low-achieving pupils fill in gaps and high-achieving pupils go ahead of the class if they are able to do so. For example, Sheard and Chambers (2011) recently carried out a randomised evaluation of 10 minutes of daily use of individualised handheld devices in Years 4 and 5 maths in England, and found strong positive effects. These devices provide pupils with questions at their own level, filling in gaps for low achievers and allowing high achievers to advance. It would be easy to combine this technology with the PTM intervention. Other individualised technologies are also being increasingly used in schools and at home, and could be adapted for this purpose.



The fact that this study could be done at all is important. Very few randomised studies of any kind have been done previously in the UK, and some have wondered if they were even possible. This study shows that they are possible and, in combination with methods such as surveys and observations, can produce very interesting and practical information for educators, policy makers, and researchers.

In light of the long series of studies that have found positive effects of co-operative learning in maths in other countries, it is worthwhile to consider how to adapt co-operative learning principles to better meet the needs of schools in the UK. Using technology both to improve implementation of key programme elements and to differentiate teaching to meet diverse needs may be a way to achieve enhanced maths outcomes for British children.

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