Discussing factors behind mathematics performance in Finnish comprehensive school education

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Abstract

The recent international and national assessment studies of mathematics have offered an opportunity to analyse our educational systems in a variety of ways. An examination of factors linked to students' mathematics performance enables us to identify strengths and weaknesses of the mathematics education we provide and, hopefully, also discover ways of improving it.

The lecture will introduce and discuss factors describing the elements of student backgrounds, mathematics instruction and the school environment related to mathematics performance in the Finnish educational context. First, a brief account of Finnish comprehensive-school education and of the search for background factors connected with students' mathematics performance is presented. The rest of the lecture takes a closer look at a number of significant factors and considers their importance for the development of mathematics education. Research on educational effectiveness is used as an underlying frame of reference in exploring these factors. The analysis is based mainly on the data of the TIMSS 1999 study, consisting of a large number of variables at student, classroom and school levels. The data are analysed using hierarchical linear modelling techniques. Information from the PISA 2000 study and the national assessments is also drawn upon.

The analyses reveal that student achievement is affected by a highly complex combination of factors. The findings show that 90 per cent of the variation in mathematics performance is attributable to variance between students, while only 10 per cent comes from between-schools variance. This result reflects the equal levels of mathematics performance across my country. The analysis highlights a number of interesting background variables affecting mathematics achievement. A student's self-concept in mathematics is the factor most strongly related to their performance. Their home backgrounds and regularity of homework are other factors with a positive effect on mathematics performance. Many of the findings pose new challenges to the development of mathematics education and teacher education.

Introduction

One of the key questions in all school systems is what kind of curricula and instructional practices would yield the best learning experiences and outcomes. The Finnish comprehensive school system and its outcomes have received wide international attention during the last few years (the so-called PISA effect). This great interest has produced a somewhat puzzling experience to all those responsible for and making decisions about mathematics education in Finland. Traditionally, we have been used to thinking that the models for educational reforms have to be borrowed from abroad. The sudden change in our role from a country following the examples of others to one serving as a model for others has prompted us to think seriously about the special characteristics and strengths of our education and school system. This concerns also our mathematics education. What kind of factors can be found behind mathematics performance? What is the significance of students' background factors? Is there a relationship between teacher's background or instructional factors and student performance? What about school factors? How could students' learning be promoted and the differences diminished by national education policies?

This presentation consists of three parts. First, I will briefly outline some main features of the Finnish comprehensive school. In the second part, I will describe how the factors relative to students' mathematics performance were explored and what the analysis revealed. In conclusion, I will then discuss the results in more detail from the perspective of the Finnish school and mathematics education system: How the results can be interpreted and what implications they might have for the development of mathematics education.

Features of the Finnish comprehensive-school education

Finland has nine years of compulsory schooling and children generally start school at the age of seven. Usually, for the first six years of comprehensive school, the children are taught by a class teacher, who generally teaches all or at least most subjects. Then, during the last three years, the different subjects are taught by specialised subject teachers. Almost all of the age group (99.7%) complete compulsory schooling.

The school network covers the whole country. Comprehensive schools are primarily run by local authorities, with the exception of a few private schools. The government contributes to the financing of all schools. For children, the teaching and educational equipment are free of charge. In addition, the pupils get a free warm meal at school. This tradition of free school meals goes back fifty years. As a rule, transportation is arranged by the education provider for distances of 5 km and above (for the lowest grades often for shorter distances, e.g. 2-3 km, as well). Presently, the smallest schools have fewer than ten pupils, and the largest ones about 900. There are some 4,300 comprehensive schools in Finland.

Statutes determine the core subjects which all pupils study, and the government determines the national objectives for education and the number of classroom hours allocated to each subject. At comprehensive schools, all pupils thus study the same core subjects with similar instructional contents. Besides this, learning usually takes place in heterogeneous groups. All this means that the core programme is almost identical to all students. Yet, of all classroom hours about 20 per cent are reserved for optional subjects freely chosen by the pupil and his or her parents. Furthermore, the schools can develop individual profiles by focusing on some area, such as languages, mathematics, sciences, sports, music or arts.

Pupils with learning difficulties are entitled to remedial education. Since 1997, educational authorities have been responsible for the education of all children, including those with profound developmental disabilities. The aim is to integrate special-needs education as far as possible into ordinary schools, but there are those who benefit more from separate special-needs education.

There is no actual graduation certificate or qualification to be gained upon completing the comprehensive school, but once a student’s compulsory education has been completed, it opens the way to all secondary education options, i.e. different types of vocational training or upper secondary school.

According to the National Framework Curriculum (National Board of Education 1994), all students get an opportunity to develop such basic mathematical knowledge and skills that create a necessary foundation in view of their further studies, employment and everyday life. The essential aim is to develop the student's ability to classify, organise and model situations that come up in the surrounding world, with terms she/he has learned. Along with this, the aim is to train students to engage in logical and exact thinking and to express their ideas verbally as well as in writing. Students should also have an understanding of the importance of mathematics in the past and present and its part in the development of our culture. In the new curriculum framework introduced at the beginning of 2004, the weighting of mathematics contents has been slightly changed.

Background factors related to mathematics performance

To move on to the second part of this presentation, the following question will be taken up: What are the factors describing student and teacher backgrounds, mathematics teaching and school environment to be related to students' mathematics achievement within the educational context described above? Taking part in the TIMSS 1999 study had a marked impact on mathematics education in Finland and the study offered us the extensive and versatile database to examine also this question.

We all know that numerous discussions have taken place and writings been published about the role, meaning and misuses of the recent international assessment studies. Comparative assessment serves a variety of goals. It can deepen our understanding of our own education system and society, it can be of assistance to policy-makers and administrators and it can be a valuable component of teacher education programmes. In addition to helping identify what is happening elsewhere, international assessment data offers an opportunity to estimate the relative effects of context variables on learning outcomes both within and between educational systems (Kaiser 1999). Within some segments of the scientific community there is a kind of consensus that comparative studies have a high pedagogical potential, but the limitations of such studies have to be considered as well. A lot of criticism has been presented towards different aspects of comparative studies in mathematics. This criticism has been directed at least to methodological questions, curricular issues and the usage of results in political and public debates (e.g. Clarke 2003, Howson 1999, Kaiser 1999). These themes have been and will be discussed in this congress as well.

In view of this present study it was important to know what are the relevant background factors concerning the school, mathematics instruction, and the student, and potentially explaining student performance in mathematics. In exploring these factors, research knowledge about educational effectiveness - especially the educational effectiveness model introduced by Creemers (1994) – and the IEA research framework of three curriculum levels (Travers and Westbury 1989) were used as the main underlying organisational frames.

The main assumption of the Creemers model is that student achievement is strongly influenced by student factors like social background, intelligence, and motivation, but also by what the students do during lessons and how they use their opportunities to learn. The purpose of the model is to give an overview of the classroom, school, and context factors that influence achievement. Quality, time, and opportunity are key concepts characterising all levels above the student level (Reezigt et al., 1999). Furthermore, when selecting the potential factors, we have also drawn on the very extensive empirical research available on the TIMSS 1995 and TIMSS 1999 data (Zabulionis, 1997; Bos and Kuiper, 1999; Köller et al., 1999; Fullarton 2004; Fullarton and Lamb, 2000; Lamb and Fullarton, 2000; Bos, 2002; Howie, 2002).

The set of background data collected in TIMSS 1999 by means of the student, teacher, and school questionnaires consisted of a very large number of variables concerning the students themselves and their activities, their mathematics instruction as well as their school environment (altogether more than 600 separate background variables). These data were explored to determine the potentially effective educational factors at student, classroom and school levels, and related indicators from the TIMSS 1999 questionnaires were selected for multi-level modelling analyses. At this final stage of variable selection we also made use of previous correlative findings on the TIMSS 1999 data (Gonzales and Miles, 2001) as well as the results of explorative path analyses (Kupari, 2001).

As a result of the pre-existing analyses, altogether 24 factors were selected in the modelling. The selected factors were divided into five groups (as suggested by Fullarton and Lamb (2000)). Three groups were composed of student-level factors, while the remaining two consisted of the combined classroom/school-level factors. The selected factors will be presented in the following slides. Because of the restricted time, only some of them will be elaborated a little more.

The first block included s*tudent background factors* and one factor (number of books in the home) is discussed more closely:

- *Number of books in the home.* This has proved to be a useful indicator of home literacy support (a proxy indicator). It reflects the social or cultural background of the student's home (Bos, 2002; Fullarton and Lamb, 2000). A wide range of reading material at home can be thought to foster academic interests and serve to encourage learning. There were also other questionnaire items available on home educational background, namely 'educational level of mother and father'. However, in Finland the percentage of missing values for these items was too high (more than 50%) to allow plausible computations to replace the missing values and that is why the variables could not be used.

The second block consisted of *student mediating factors* and two of these factors (self-concept in mathematics and positive attitudes towards mathematics) are described in more detail:

- *Self-concept in mathematics.* According the vast body of research, self-concept is understood as a hierarchical and multidimensional construct (e.g. Zanobini and Usai 2002, Shen and Pendulla 2000). Self-perceptions may contribute to students' activities in several ways: they determine the goals students set for themselves, how much effort they expend, how long they persevere in the face of difficulties and their endurance to failures. Girls, even if they are successful in mathematics, will often express 'fear of success' more than boys, being more wary of expressing their ability in mathematics. The index applied in this study was based on five questions.
- *Positive attitude towards mathematics.* Positive student attitudes towards mathematics are an important goal of most curricula, both as desirable outcomes in their own right and because students with positive attitudes are thought more likely to choose further studies in mathematics and to seek employment in related fields. Furthermore, a student's attitude can be regarded as a predictor for mathematics achievement. Also this index was based on five questions.

The third block included *student studying factors,* and teaching style is the factor to be looked more closely at here:

- *Teaching style.* This involved a dual approach with two initial factors constructed. The factor of student-oriented teaching style as well as the one for teacher-dominated teaching style was applied. The former includes teaching practices that focus on students' activity. With their teachers' incentive, students select, analyse and organise information in order to construct new knowledge. In this case neither the teacher nor the textbook constitutes authority in the classroom. The latter includes teaching practices which are strongly teacher dominated and favour transmitting knowledge and practices that are often organised in textbooks. It is important to note that these factors were based on students' perceptions of the frequency of teacher activities.

The last two groups included both teacher and instruction factors and school factors. In the pre-existing analyses, most of them had no significant correlation to student mathematics achievement but they were included in the modelling because of the previous research results. In the following, group size is described in greater detail:

- *Group size.* In the research literature, the direction of the relationship between group size and student achievement is disputed. Some studies show a negative relationship (small groups outperform bigger groups) and other studies a positive one. A common assumption to explain this contradiction is that other variables play an intermediate role in this relationship (Bos, 2002). In this study, the variable tells the number of students in the mathematics teaching group as reported by the teacher.

It is essential to assess the quality of the data from the Finnish perspective. How well did the mathematics items match with the Finnish mathematics curriculum and had the item contents already been dealt with at the 7th grade? Based on the TCMA-analysis, over 80 per cent of all items were assessed to be included in the mathematics curriculum of this grade level. However, roughly half of the geometry items were judged to lie outside the scope of the curriculum. These were contents typically related to congruence and similarity as well as to symmetry and geometric transformations. Furthermore, when the relationships between students' learning opportunities and test performance were analysed in the light of teacher questionnaires, it was found out that the contents of many geometric and algebraic items had been taught very unevenly across the country. Nonetheless, we can state that the TIMSS achievement test did measure our mathematics curriculum in a fairly relevant way.

A majority of the background factors included in multi-level modelling were student-level factors. Many of them were international indices or scales which had been constructed by combining several background questions. They present the advantage of being more stable and reliable measures, thus indicating the validity of the data.

In Table 1 some descriptive statistics on the student-level background factors have been presented. Based on this information most of the constructs seemed to be quite reliable. However, there were three constructs – for example perceived importance, success attribution and teaching style – with quite low reliability statistics, so one should be particularly cautious when interpreting the results concerning these factors.

Factor	N	M	SD	Range	α [1)]	r [6)]
Achievement score [2)]	2920	521.8	71.8	231-844	.86 [3)]	
Student's gender	2920	.50 [4)]		1 - 2		ns
Number of books	2886	3.42	1.08	1 - 5		.21
Educational aids	2890	1.70	.46	1 - 2		.18
Self-concept	2873	2.17	.64	1 - 3	.88	.51
Positive attitude	2851	2.02	.63	1 - 3	.83	.27
Perceived importance	2823	2.88	.43	1 - 4	.67	.17
Success attribution	2848	2.78	.30	1 - 4	.65	.06
Maternal expectations	2838	3.19	.47	1 - 4	.84	.04
Peer expectations	2819	2.66	.59	1 - 4	.88	-.05
Self expectations	2864	3.17	.56	1 - 4	.84	.08
Lesson climate	2781	2.55	.57	1 - 4	.71	ns
Teaching style [5)]	2747	2.04	.66	1 - 3	.52/.70	.12
Studying at home	2877	.57	.45	0 - 7		-.11
Extra lessons	2849	.14	.54	0 - 7		-.19
Out-of-school activities	2769	2.05	.94	0 - 7		-.28

Table 1. Descriptive statistics on the student level factors included in the multi-level model analysis. TIMSS 1999 / Grade 7.

Note: 1) No Cronbach α for single variables; 2) indices for achievement score computed on the basis of student's five plausible values; 3) the mean of reliabilities for eight test booklets; 4) the proportion of female students/teachers; 5) presenting α factors for both components; 6) Pearson correlation

Analysis of the data

During the last decade multilevel modelling techniques have become increasingly available to researchers for analysing hierarchically structured data (Bryk and Raudenbush, 1992; Goldstein, 1995; O'Dwyer, 2002). The strength of multilevel models in dealing with school data is based on the feature that they not only take account of the inherent structure of the data but also treat variables of different levels simultaneously within the same model. In recent years, hierarchical linear modelling (HLM, MLn) techniques have been taken into wide use (e.g. Fullarton and Lamb, 2000; Bos, 2002; Howie, 2002).

In this study the HLM technique was employed to specify a two-level country model (Bryk and Raudenbush, 1992). The sampling procedure of TIMSS 1999 required that the participating countries sample at least one classroom per target grade in each school. Most countries, also Finland, sampled only one classroom at Grade 7. However, this design limits the number of levels that can be modelled and thus in the Finnish context a two-level model could be formulated in order to explain the variation in mathematics scores between students (within schools) and between schools (classrooms).

The Finnish data comprised test answers and background questionnaire information from a total of 2920 students, 167 mathematics teachers and 159 school principals.

In considering the data the purpose is to explain the variation of students' mathematics performance (test score) by the background factors. The results of the analysis show the degree to which the variables of different levels account for that variation and which particular factors stand out as (statistically) significant predictors.

The HLM analysis involved consecutive testing of the model, so that after each stage another group of factors was added to the model. The initial model (so-called null model) helped us estimate first how the variation in students' scores was divided into between-students variance and between-schools variance, so that the model did not include any explanatory factors at this point. By examining the change occurring in the estimates of variance after adding each set of factors it was possible to analyse the effects of different – and different level - factors on students' mathematics performance.

Now, an important point for clarification: When discussing the factors contributing to student performance we often speak about "explaining" variance even though we realise that the cross-sectional studies can generate only correlations with, not causes of, student performance. In describing the results I will also use the word "explain" but I trust that you understand its limitations.

Results

Figure 1 describes the variance in mathematics performance at student and school levels as well as the changes occurring in that variance when different background factors are controlled for. In the first phase, a fully unconditional (null) model was tested. The results of the null model reveal, quite remarkably, that the overall variation in mathematics achievement derives predominantly (90 per cent) from between-students variance, while only about 10 per cent of the variation comes from between-schools variance.

The next step of the analysis involved adding *the student background factors* to the model. These factors (student's gender, number of books, educational aids) explained only a small share (3.4 per cent) of the between-students variance, but a clearly greater amount (15.4 per cent) of the variance between schools (which, as said, was small as such). Student's gender had no statistically significant effect; in other words, boys and girls performed at an equal level.

Student's mediating factors (e.g. self-concept, peer expectations) proved to clearly be the strongest predictors for the between-students variance and increased the percentage of explained variance by 21 percentage points. The mediating variables also helped to explain the variance between schools, but not as much as the factors concerning student's cultural and educational home background.

Students' studying factors (e.g. teaching style, extra lessons, out-of-school activities) brought only a slight increase (about 4 percentage points) to the proportion explained both for the between-students and the between-schools variance.

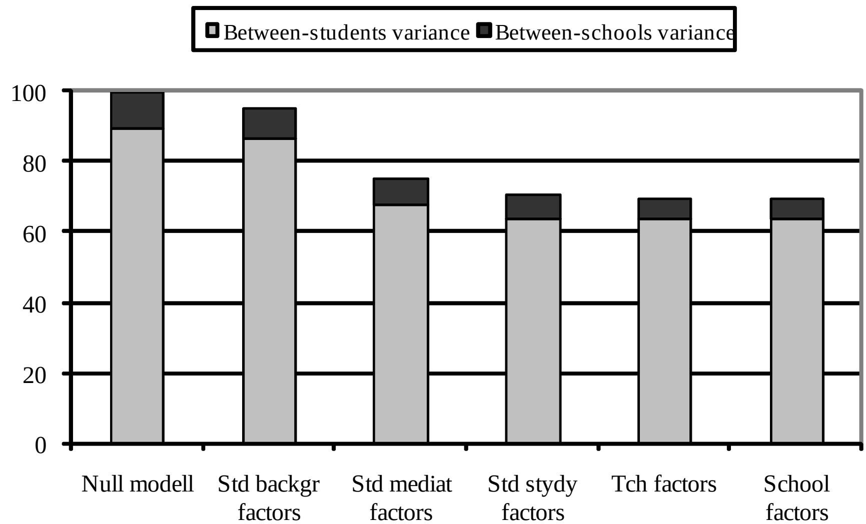

Figure 1. Division of variance and changes in variance after controlling different factors.

Adding *the teacher and instruction factors* (e.g. teaching experience, amount of homework) to the model increased to some extent (from 31.7 per cent to 43.5 percent) the proportion explained for between-schools variance, but made no difference in view of between-students variance. Bringing the three school factors into the model did not enlarge the proportion of explained variance any further at either level.

In this analysis the "final" model explained about one third of the overall variation of the 7th-graders' mathematics achievement, which can be considered rather usual in this kind of studies.

Figure 2 presents the factors which had a statistically significant effect on students' mathematics achievement. Only ten significant factors could be found. The strongest predictor for the 7th -graders' performance was *self-concept in mathematics* (i.e. how confident the student is about his/her own learning of mathematics). The difference between highly confident and weakly confident students' achievement scores was about 85 points, which was well above one standard deviation (72 in the Finnish data). Student's positive attitude toward mathematics had also a weak significant relationship to student performance.

Students' activities outside school time had some importance as well. As expected, the connection of two factors (i.e. out-of-school activities and extra lessons) was negative. The more the students needed additional instruction in mathematics outside school hours and the more time they spent for other activities after school - watching TV and videos, playing computer games, spending time with friends - the lower was their mathematics achievement.

The results revealed that both the educational aids and cultural background of the home (number of books in the home) were also associated with students' achievement: the stronger the support to schoolwork from home, the better the student's results.

However, the effects of these factors were weak. Peer expectations appeared as an important predictor ($p<.05$) as well, so that the stronger these expectations were, the lower the student achieved.

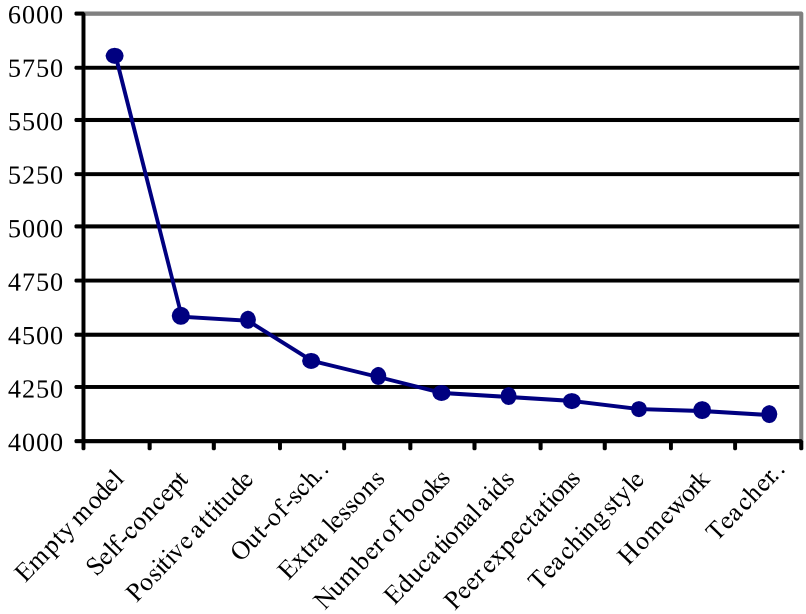

Figure 2. The model with student and classroom/school characteristics as explanatory factors: Reduction of variance.

As regards student's studying factors, teaching style was associated with student performance ($p<.05$). The results indicated that in terms of student performance the teacher-dominated approach was more effective than the student-centred one.

Among the teacher and instruction factors there were only two factors that statistically significantly explained student achievement, namely teacher's professional experience and amount of homework. Students whose teachers were more experienced and more often gave homework to their students performed better than the others.

Discussion

The analyses brought out many interesting findings that have relevance to the development of Finnish education policy and mathematics instruction. *Firstly*, the results showed that for the most part (90 per cent) the variation of 7th-graders' mathematics performance is attributable to the variance between students, while only 10 percent of the overall variation comes from between-schools variance. This means that internationally the differences between schools in Finland were small indeed. When these figures were compared to corresponding results from national mathematics assessments carried out in the 1990s, it was found out that the variance between schools had remained about the same (Kuusela, 2002). This finding confirms the equality aspect of Finnish mathematics education indicated also by the results of other recent international assessment studies: the variance in our student performance has been among the smallest across the participating countries; we have had a very small proportion of low achieving students, and gender differences in mathematics have been negligible.

The patterns of variance in mathematics achievement are quite different in different parts of the world. In some countries, the between-school variance ranges from one to six per cent, indicating highly equal mathematics performance among the schools within these countries. On the other hand, there are countries (e.g. Germany, the Netherlands) where the proportion of between-students variance ranges from 48 to 59 per cent and between-schools variance is as high as 38 to 52 per cent (Bos, 2002; Beaton & O'Dwyer, 2002).

A high percentage of between-students variance can be seen to be well in accordance with several earlier studies. For instance, the results of educational effectiveness studies (Reezigt et al., 1999) show that most of the variance occurs at the student level, while relatively small percentages of the variance are attributable to the classroom and the school levels. However, classrooms and schools have influence on mathematics performance and their influence can be very important for individual students. At the same time, we have to recognise that classroom level could not be included in our model.

On the other hand, many studies (e.g. Lamb and Fullarton, 2000; Hill & Rowe, 1996) suggest that certain parts of the variation in students' mathematics achievement can be explained by the differences between classrooms. For example, the results from the Flemish-speaking part of Belgium show that 28% of the total variance is due to differences between classes and that this proportion of the variance is greater than the proportion at the school level (student-level variance was 58%). Therefore, it can be suggested that when designing future studies, several classes per school be selected in order to ensure that also differences between classrooms could be examined.

Secondly, the analysis brought out a number of interesting background variables bearing significance to mathematics achievement. Student's self-concept in mathematics was by far the most significant predictor for their performance and was probably connected with their attitudes towards mathematics. Our previous analyses (Kupari, 2001) namely suggest that students' attitudes are strongly mediated through their mathematical self-concept. Another recent study, based on the TIMSS 1999 data, showed also very strong association between self-concept and student achievement (Fullarton 2004). Although the relationship between self-concept and achievement is well established in the research literature there is no agreement about the causal ordering of those constructs. Available longitudinal studies (Skaalvik and Valas 1999) have revealed that during the elementary school years academic achievement predominates over self-concept. On the other hand, there are researchers who propose that in the early years self-concept may undergo a process of shaping and reshaping dominated by the influence of academic experience. Once ability perceptions are more firmly established, the relation between achievement and self-concept is likely to become reciprocal. We can also find out interesting differences between countries in the self-concept relationship because of different cultural traditions or curricular standards.

However, self-concept and attitudes are factors that can be influenced and hence set challenges to mathematics teachers and teacher education. Students' self-concept and attitudes can be influenced by reinforcing each student's confidence in their capability to learn mathematics and by providing them with successful experiences. In view of learning it is also important to create a favourable atmosphere which makes students feel unthreatening and therefore willing to make a positive contribution to the lesson. In teacher preparation, the meaning of learners' self-concept and attitudes need to be duly addressed, as well as the topic of how teachers' own views and beliefs shape their teaching.

With regard to teacher’s teaching style, the finding that the teacher-dominated approach produced better scores than the student-oriented one was not as surprising as we first thought. In fact, we found other results which either produced similar association between teacher-dominated practices and student achievement or were otherwise in accordance with this finding. However, this issue requires some more elaboration. First, we should take into account that the variables used here reflect students' experiences from the teachers' way of teaching and the lower reliability indices of the scales may indicate this. We must also recognise that it is very problematic to capture the characteristics of the instruction given by teachers using questionnaire techniques. Second, teacher-dominated and student-oriented practices both can have effective qualities, and these approaches should not be seen as opposites or mutually exclusive. One explanation for the association described above might be that at this stage of schooling (7th grade) a teacher-dominated practice takes better care of the weaker learners, which then shows as a positive connection to student performance.

Finally, we could ask why the analysis brings out only a small number of variables as statistically significant predictors, although the TIMSS study involved extensive background questionnaires for students, teachers and headmasters, respectively, in order to find out explanatory factors for mathematics performance. There are many reasons for that. Firstly, when teachers and headmasters fill out questionnaires social expectations tends to come in play, which thus undermines the reliability of the responses. Secondly, some important background factors are sometimes measured by only a few items. To produce more reliable and valid factors and scales, a sufficient number of items should be used to measure the concepts. This is even more important in international studies to ensure the internal consistency and validity of the scales in all participating countries. It is also possible – even probable - that some other variables are more important for student achievement than the factors included in the study. Indeed, we would need various types of studies to investigate the complex network of explanatory factors underlying students' mathematics achievement. This calls for studies that build on a sound theory basis and focus on a reasonably limited set of 'culturally' similar countries.

In all, this study and its findings reveal that student achievement is affected by a complex combination of factors and that this combination has some national characteristics. We can learn from this study that effects on achievement cannot be easily determined nor easily explained. What works this time may not work another time, what works in one educational context may not work in another context. Therefore, more work is needed to get more relevant information about the interaction of teachers and individual students. But, although sorting out the relationships may be arduous and demanding, it is worth investing in. Through national and cross-national analyses nations can learn what benefits and weaknesses their educational systems have. On this basis they can then proceed to create the best possible conditions for their students’ learning.

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