

Looking for Cultural and Geographical Factors in Patterns of Responses to TIMSS Items

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Abstract

The main goals of international assessment projects like TIMSS are to establish reliable and valid scores for achievement that can be compared between groups and related to various background and context variables. In addition, as we demonstrate here, the detailed item-by-item achievement results from TIMSS 1995 provide an opportunity for a closer investigation of the similarities and differences between groups of countries. Our procedure starts by a statistical clustering of countries according to similarities in response patterns across items. Countries in one group tend to have relative strengths and weaknesses for the same items. Our focus is on the following country clusters that constitute meaningful groups in a geographical, cultural or political context: English-speaking, German-speaking, East European, Nordic, and East Asian groups of countries. Remarkable similarities, but also interesting differences between mathematics and science have been revealed.

For each of the country groups we further set out to explore what characterise particularly “favoured” and “unfavoured” subject topics and test items (i.e. with particularly high or low percentage correct responses). In addition, these patterns are compared and analysed in a context of curricular similarities and differences. For this purpose we have reanalysed aspects of the TIMSS 1995 curriculum and textbook data from population 2, upper grade.

Introduction

Large-scale international surveys like TIMSS operate on an assumption that there is an equivalent way of defining knowledge in mathematics or science, a common agreement among a large number of countries concerning an operational definition of what constitutes abilities in mathematics or science. Research based on social constructivism, anthropological and ethno mathematics perspectives has pointed out the importance of cultural factors in mathematics and science education. Particularly in mathematics, which more

than most other subjects has been seen as universal and context free, we need to be aware of cultural factors (Sierpinska & Lerman, 1996; Gerdes, 1996, Barton, 1996).

Barton has pointed out that "... the benefit of cross-cultural studies in mathematics education is that cultural practice appear implicit to those who participate in them. Thus, recognition of certain aspects of our own mathematical education practice will only become apparent when seen in the light of those of other cultures." (Barton, 1996, p.1049). He further criticizes large-scale international comparative studies for not paying enough attention to cultural and social factors (ibid). However, there are convincing evidences (see Appendix B in Beaton et al, 1996a and b) that cultural factors play a minor role concerning over-all achievement in international tests. Nevertheless, there are strong reasons to investigate in some more detail which role cultural factors do play in international assessments.

The aim of the present paper is to investigate the significance and the patterns of cultural factors concerning how mathematics and science is taught and learned around the world. We will look for similarities and differences between countries both in achievement and curriculum data.

The TIMSS project represents a typical quantitative study where one of the main goals is to establish valid and reliable estimates on student achievement. Regardless of the measurement model (classical or IRT models) the main idea behind a test score is that responses to individual items are not interesting beyond its contribution to the over-all score. From a psychometrical point of view, the details about how students from different countries respond to individual items, often called "item-by-country interactions", is something that should be regarded as a sort of random noise, or "error variance". Seen from a different perspective, however, the details of this interaction represent something very interesting, namely a guide into strong and weak areas for each country. The item-by-item sets of percent correct responses ("p-values") establish highly interesting country-specific educational "fingerprints" which may bring rich information on traditions concerning how and for which purpose mathematics and science is taught in schools. Earlier analyses (Zabulionis, 2001; Kjærnsli & Lie, 2002) have shown that groups of countries can be established based on similarities in the patterns of responses. From these results it is clearly seen that the country grouping has to do with geographical factors, language and other cultural factors.

In the literature, we find a number of different terms, as Western mathematics, Asian mathematics, and Third World mathematics (Sierpinska & Lerman, 1996; Gerdes, 1996, Barton, 1996). We also find terms like a Nordic culture in science and mathematics education. Can we say that English-speaking countries have a more inquiry based approach to science education? In our analysis we want to see if TIMSS data can support and give sense to terms like this. We will

enlighten cultural differences and similarities between the countries that participated in the study, and try to understand and explain the differences and similarities we find. Are similarities between countries most likely based on a common language, on geographical factors, or on other cultural factors? Can we give meaning to the result by looking to the school curriculum in different countries? The first phase of TIMSS also contained investigations of curricular intentions by close analysis of curriculum guides and of samples of textbooks in mathematics (Schmidt et al, 1997a) and science (Schmidt et al, 1997b). For our purpose here we will focus our attention to the following set of data: For each subcategory in the TIMSS framework (Robitaille et al, 1993) it was recorded whether or not the topic was included in the national curriculum guide and/or the analyzed textbooks for grade 8.

Profiles of performance item by item

Grouping of countries by cluster analysis

The starting point for our analyses was a matrix of p-values by item by country. We calculated the cell residuals by subtracting from each cell value the average over countries for the actual item and the average over items for the actual country. Thus we were left with a residual matrix, where each cell tells how much better or worse than expected that particular country scores on that particular item. The facts that some countries score higher than others and that some items are harder than others do not any longer show up in the data.

Cluster analysis allows us to find a pattern of clustering of countries based on how similar the sets of p-value residuals are. Figures 1 and 2 are so-called dendrograms that display the resulting clustering process for mathematics and science. These figures show how and at what “distance” countries link together into clusters or join already established clusters. The “distance” is here a measure of the magnitude of the correlation between p-value residuals. High positive correlations imply “closeness” and therefore small “distance”. In cases where correlations involve already established clusters of countries, mean p-value residuals have first been calculated for each cluster. In the two following sections the comments refer to what happens when we move from left to the right, i.e. to larger “distances” in mathematics and science. The “sooner” countries are linked together, the stronger these countries are forming groups based on similarities between patterns of performance from item to item.

Country clustering in mathematics

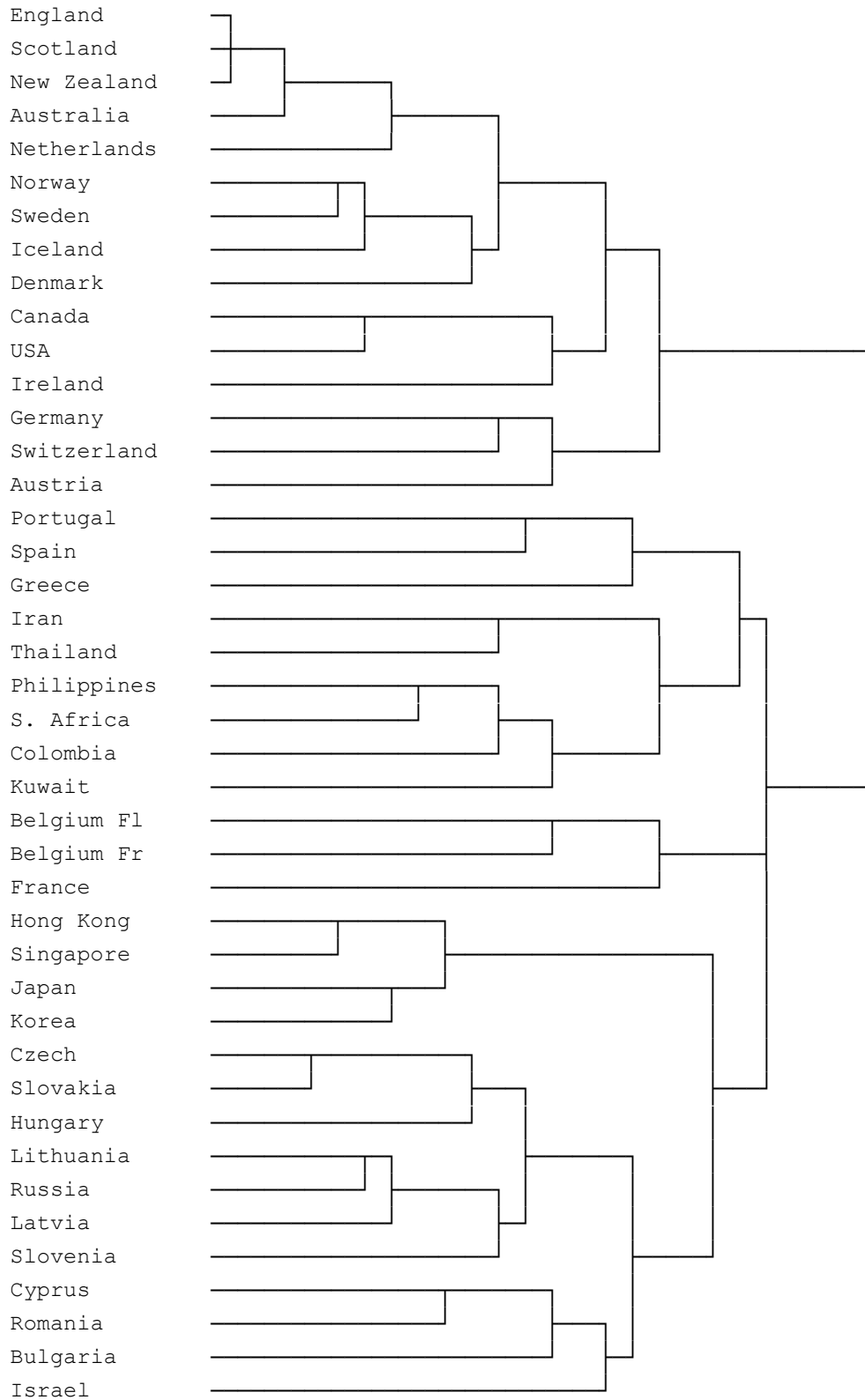
The result of the clustering process in mathematics is displayed in Figure 1. The dendrogram clearly displays that the English speaking countries are forming groups. The strongest group consists of England, Scotland, and New Zealand, with Australia linked to this group a little bit later. Canada and USA form their own rather strong North-American group, a group to which Ireland is linked later in the process.

Another group is formed by Norway and Sweden, with Iceland and then Denmark linking to this group a little later. This Nordic group is then somewhat interwoven with the group of English-speaking countries. Other countries that are forming strong groups are Hong Kong and Singapore, a little later Japan and Korea before these four Asian countries form an East Asian group. This group seems to be distinguished from all the other countries, since it is rather late in the process that this group is linked to the East European group and then to the rest of the world.

The Czech Republic and Slovakia are closer than most other countries, with Hungary joining this group a little later in the process. Also Lithuania and Russia form a strong group, with Latvia and then Slovenia linking to this group a little later. Most of the East European countries are then linked together as one group. (It should be noted here that the label "East European" is used for simplicity reasons, even if strictly speaking it is not correct). Also Germany and Switzerland form a group, but later than most of the other countries we have commented on. Austria is linked to this group as a next step in the process. At about the same level, Portugal and Spain form a group together, but the process of forming groups among many of the Western European countries is rather complicated. The Philippines and South Africa form a group and later Colombia and Kuwait is linked to this group. The communality between these four countries is rather unclear, but may stem from the fact that they all are developing countries.

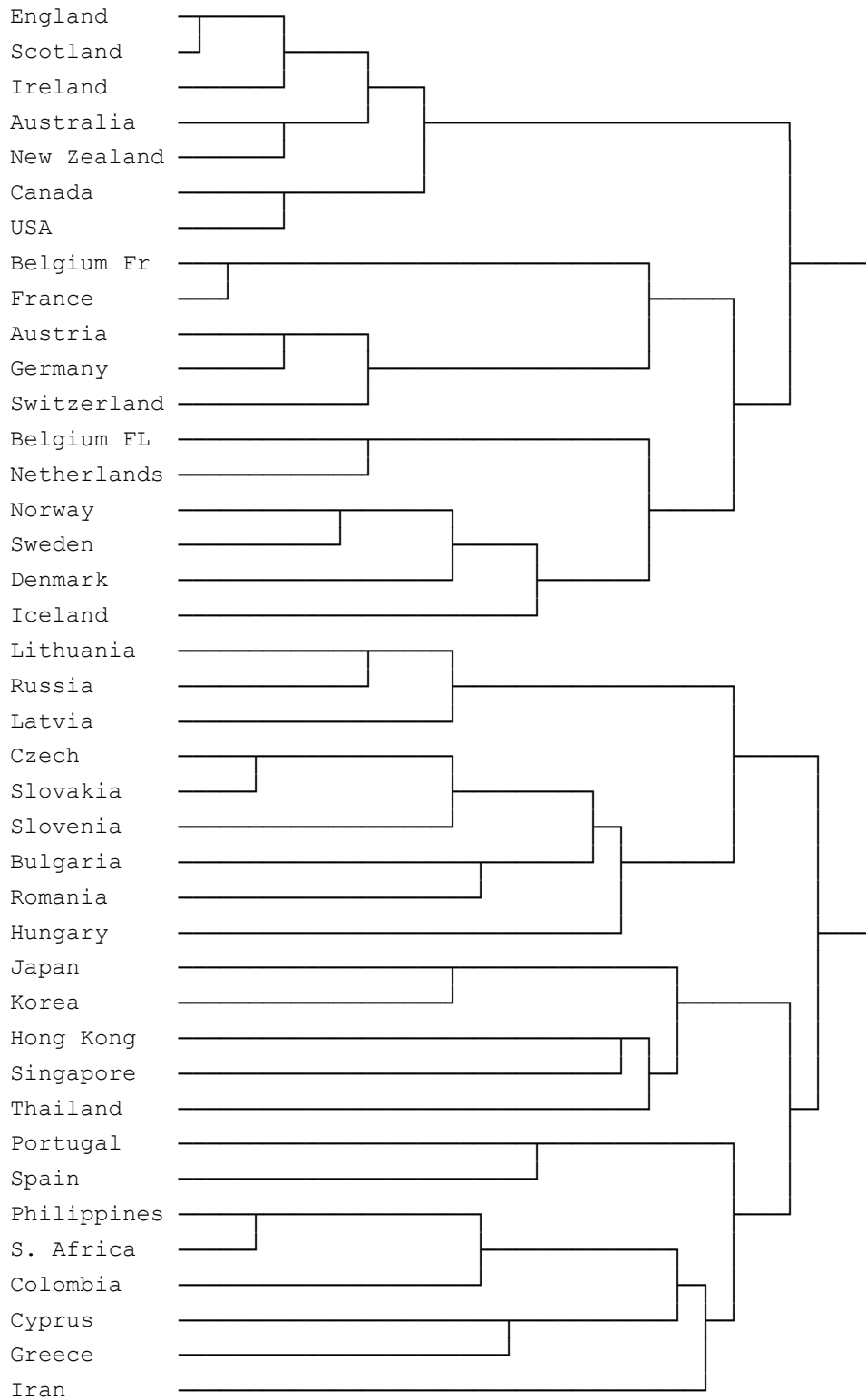
In the next paragraph we will comment on clustering of countries in science, before comparing similarities and differences in mathematics and science.

Figure 1. Dendrogram for clustering of countries according to similarities between countries in patterns across mathematics items



Country clustering in science

Figure 2. Dendrogram for clustering of countries according to similarities between countries in patterns across science items



The dendrogram for science in figure 2 displays the clustering process in the same way as shown for mathematics. The following comments refer to what happens when we move to the right; to larger “distances”. The dendrogram clearly displays the strong clustering of the English-speaking countries, which in turn seem to be divided into meaningful subgroups (England - Scotland - Ireland, Australia - New Zealand, and Canada - USA, respectively).

Other countries that link strongly to each other are France and Belgium French, Czech Republic and Slovakia, Philippines and South Africa. There are also other clusters that seem to represent influences that would be expected, like a German-speaking group with Austria, Germany and Switzerland. The same do Belgium Flemish and Netherlands. The Nordic countries also make a group, but none of the Nordic countries are particularly close to each other. Norway and Sweden have the strongest link, and Denmark and Iceland join them a bit later. We can also see that the Nordic cluster link to Netherlands and Belgium Flemish.

The East European countries make one group, but not a strong one. Rather, one could say that they are divided into two groups with Lithuania, Russia and Latvia in one group and Czech republic, Slovakia, Slovenia, Bulgaria, Romania and Hungary in another (although Hungary links very late).

The East Asian countries also make a group, though not a particularly strong one. Portugal and Spain link to each other and the same do Cyprus and Greece. None of these links are particularly strong, probably weaker than what one would expect. And there is no strong evidence for a common South European cluster.

When looking at the dendrogram as a whole picture, one can see that all the countries are divided in two groups that link at the end. The first group consists of countries from England including Iceland while the other group includes all the countries from Lithuania to Iran.

Comparing clustering of countries between mathematics and science

The dendrogram for science and mathematics displays some similarities as well as some differences. Similarities, however, seem more pronounced than differences. In both mathematics and science we see that the English-speaking, the German-speaking, the Nordic, the East European, and the East Asian countries form pretty strong groups. There are, however, some notable differences in the way the groups are formed for the English-speaking countries and the Nordic countries, and also how these two groups relate to each other. In science all the English-speaking countries do form a stronger group before the Nordic group is linked to it.

In both mathematics and science we see tendencies for some third world countries to form groups. Furthermore, the picture for West Europe is rather complex, making it very difficult to talk about one single group. The East European countries, however, seem to form a much closer relationship in both

mathematics and science. It appears that these countries seem to be much more characterized by one common tradition in mathematics and science education than are the western countries.

France form a specific group, especially so in mathematics. Even if it is linked to Belgium French, this is rather late in the process and for that reason we may talk about France as forming its own “group” with its own strong traditions, especially so in mathematics.

It should be noticed that the dendrograms cannot be used to compare the strength of the linkages for mathematics and science, simply because only relative “distances” are displayed in each diagram. However, in general the correlations within clusters are higher in mathematics than in science.

In our further analysis, we will take a closer look at some groups based on clustering of countries in these analyses. We will restrict this part of the analysis to the following groups of countries that have been established by the findings discussed so far:

- English-speaking group: Australia, Canada, England, Ireland, New Zealand, Scotland, USA
- German-speaking group: Austria, Germany, Switzerland
- Nordic group: Denmark, Iceland, Norway, Sweden
- East European group: Bulgaria, Czech rep., Hungary, Latvia, Lithuania, Romania, Russia, Slovakia, Slovenia
- East Asian group: Hong Kong, Japan, Korea, Singapore

Profiles of performance by content areas

Displaying profiles by content areas

In this chapter we will look more closely into what sorts of similarities or differences one can find among the groups of countries when it comes to student achievement across content areas, and how this relates to the international average across all countries for the content area. The results are based on the average percent of correct responses to items within each content area in Population 2, upper grade (Beaton et al, 1996a and b). Data are given for each domain for five groups of countries that have been selected based on the clustering of countries in the dendrograms in the previous sections: English-speaking, East European, East Asian, Nordic, and German-speaking countries. Figures 3 and 4 show the achievement in mathematics and science by content domain for each group of countries. Differences between p-values for each group and the international mean are displayed. Mean values are calculated for each group.

Profiles in mathematics

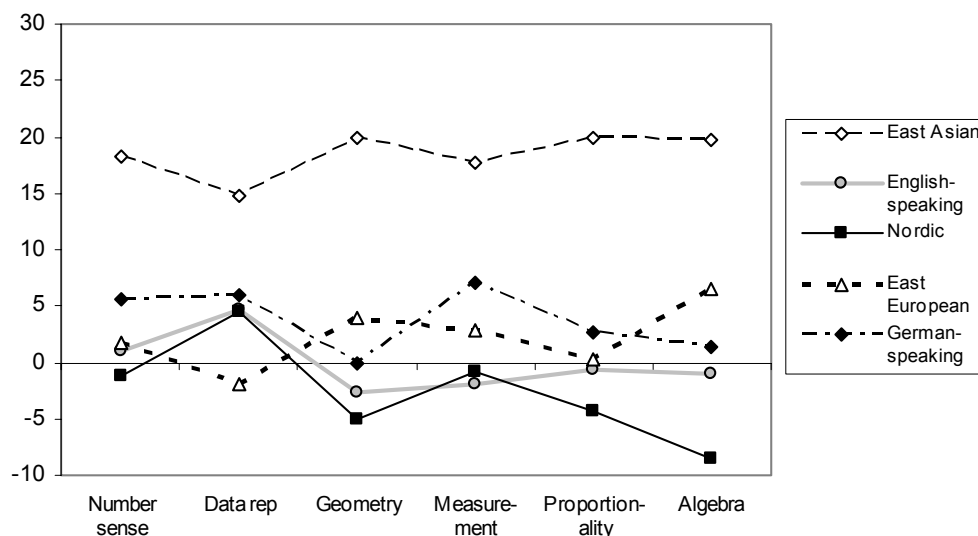
Figure 3 displays how the selected groups of countries perform in different content areas of mathematics. The content areas refer to the categories used in

the international achievement report for TIMSS 95 (Beaton et al, 1996a). For simplicity reasons we use a short form for two of the categories. “Fractions and number sense” is called only number sense even if it includes fractions. It should also be noticed that we commonly refer to the category “Data representation, analysis and probability” by using data representation or only data as a short form for this category.

Each group form a unique profile and thus the figure indicates differences between groups of countries in how much attention or how important a content areas are judged in these countries. In that perspective, it is the profile which is to be emphasized, not how high or low a group of countries are achieving.

The figure reveals that we have two very different types of profiles, one consisting of East Asia and East Europe, the other consisting of the English-speaking, the German-speaking, and the Nordic countries. Even if there are clear similarities between the groups in the two types of profiles, we also see distinct differences within each type, which give sense to talk about five different cultures in relation to mathematics education.

Figure 3: Profiles of performance (compared to the international means) in mathematics for the country groups



The profiles for the East Asian group and East European groups are very much the same, despite the East Asian has much higher over-all performance. In both groups, they perform relatively better in traditionally mathematical content areas as geometry and algebra, than in more daily life related mathematics as data representation and probability. When it comes to proportionality, there is a clear difference between these two groups, the Asian group performing relatively much better than the East European group. This result is in accordance with what we saw in the dendrogram: Two distinct groups, one in East Asia and one in East

Europe, which are linked together in a way that indicates a closer relationship between these two mathematical cultures than with other groups.

The English-speaking, the German-speaking, and the Nordic countries reveal similarities as well as some distinct differences. All these groups perform relatively better on data representation and probability than the East Asian group and the East European group. They also perform relatively better in number sense than in geometry. All three groups performed relatively low in algebra compared to number sense and data representation, but this is most pronounced for the group of Nordic countries. In measurement, the German speaking countries performed relatively better than the other two groups. The Nordic group performed both relatively and absolutely lowest in algebra, geometry and proportionality. The patterns revealed in figure 3 again support what was revealed in the dendrogram (figure 1) about which countries that first formed a group and which groups or countries that are joined together later in the process.

We have also used the residuals used for constructing the dendrograms to calculate the mean residuals within each group of countries. This allowed us to have a closer look at on which items a particular group achieves particularly well or bad. The items with the lowest or highest residuals in a group revealed that it was typical for the East Asian and East European group that they scored relatively low on items were the students were asked to read information given in diagrams or tables, and high on items dealing with fractions. The East European group scored particularly well on algebra items, the East Asian in the topic of calculating areas. Typical for all these items seem to be that they deal with more pure classical and abstract mathematics.

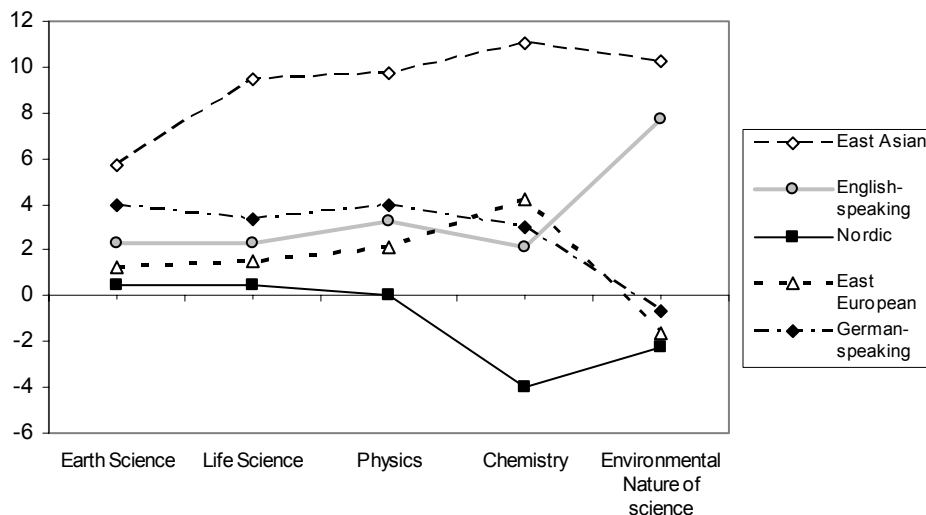
Contrary to this finding, the English-speaking group, the German-speaking group and the Nordic group all performed relatively best on items more related to daily life as estimation and rounding of numbers. All these groups scored relatively low on items dealing with more classical abstract mathematics as fractions and algebra. There were also differences between each of these groups, as the German-speaking group scored relatively lower on geometry items dealing with congruent figures than the other.

The analyses so far reveal that what is seen as mathematical competence at one level in school differs distinctly from one cultural group to another. The complexity revealed also underline the need to analyses data in a number of ways when looking for similarities and differences between cultural groups. In the next section we will do a similar analysis of science data, before comparing the results in mathematics and science to see if it makes sense to talk about the same cultural groups in both subjects. Thereafter we will conduct an analysis based on data from the TIMSS 95 curriculum study to seek further insight into the factors behind the cultural groups we have focused on.

Profiles in science

Figure 4 presents the profile by sciences content for the selected groups of countries. Some interesting features can be seen in the figure. Each country group can be separated from the others, as no two of the profiles follow each other all the way. The differences are largest in specially two areas, “Chemistry” and “Environmental Issues and the Nature of Science”. In chemistry, Asian and East European countries perform relatively better while the Nordic countries perform remarkably low in this content area. In the content area called “Environmental Issues and the Nature of Science”, the English-speaking countries perform relatively particularly well. The Nordic countries also perform relatively well while the East European and German-speaking groups perform distinctly lower in this area. This domain consists of different type of items, both items from Environmental Issues and from Nature of Science. From the beginning of the TIMSS Study it was meant to be two separate domains, but later it has been made decision to collapse them.

Figure 4: Profiles of performance (compared to the international means) in science for the country groups



The profile for the East Asian countries stands out from the profiles in all the other groups in Earth Science; they perform relatively low in this area.

Next we will analyze p-value residuals item by item to see if we can find some support or explanations to the profiles for science in figure 4. We have, as in mathematics, looked at the items with lowest or highest residuals within each group. The item with highest positive residual for the East European countries deals with what is formed when a neutral atom loses an electron. This is an item that requires pure factual school knowledge and is a typical example on an extremely curriculum-dependent item, i.e. which will distinguish strongly between students that have had the opportunity to learn this in school or not. The result

seems to confirm this, since this item has been one of the most difficult items in the English-speaking and Nordic groups.

The item with highest positive residuals in the East Asian countries, where the students have to know what is made of bacteria or not, is another example of an item that require factual knowledge. As an opposite example, in an item with particularly high score in the Nordic countries students are asked to write down one way a person could have caught influenza. This is an open-ended item where the students to a greater extent can use their daily knowledge and language. The same can be said about the item with highest relative performance in the English-speaking countries, where the students have to write down one example of how computers help people do their work.

When looking closer at the items with the lowest residuals (i.e. with relatively lowest performance), this group of items in the East European countries are dominated by items in the categories Environmental Issues and Life science. In the East Asian and English-speaking countries biology items dominated among the particularly difficult items. Not surprisingly (see the profiles in figure 4), items with the highest relative difficulty in the Nordic group are from the content areas Chemistry and Earth Science and are further characterized by their dependency on concrete factual knowledge.

Comparing with curriculum and textbook data

Now we will present an analysis based on data from the curriculum study in TIMSS 95, thus trying to make further sense to the grouping of countries we found in our statistical approach. In TIMSS 95, analyses of population 2, upper grade curriculum guides and textbooks were carried out in all the participating countries for both mathematics (Schmidt et al, 1997a) and science (Schmidt et al, 1997b). Different types of analyses was included, one based on an a priori grouping of countries based on geographical regions “Neighboring or nearby countries often share traditions, cultural similarities, and historical interactions” (Schmidt et al, 1997a, p. 147). By an a priori grouping topic coverage data were compared between eight regions, Latin America, Australia and New Zealand, East Asia, Western Europe, East and Central Europe, The United States and Canada, North Africa with the Middle East, and South Africa. They also created groups of countries statistically, strictly based on similarities and differences revealed in the textbook coverage data. A comparison of the results of that grouping with the a priori grouping lead to the following conclusion for mathematics “The traditional a priori grouping tried here did not uncover key topic variance of magnitude in distinguished groups. Statistical approaches did not reify a priori groupings – traditional factors simply were not effective in revealing distinctions in this case.” (ibid, p.160). A similar conclusion was given for science (Schmidt et al, 1997b, p. 166), even if notable differences between the statistically created groups could be identified.

Based on the above experiences we looked at other sources of data from all countries to combine coverage in textbooks and curriculum guidelines. Table 7.1 (in both Schmidt et al 1997, a and b) gave coverage (yes or no) for each single subtopic in the framework for each country. By giving weights from 2 (covered in textbooks AND curriculum guideline) via 1 (covered in textbook OR guideline) to 0 (not covered) we established a “coverage by country” matrix to be analyzed further. Our procedure consisted of comparing the average correlations of these weights within country groups compared to average correlations between all pairs of the involved countries. We could then test whether patterns of topic coverage could explain some of the clustering of countries based on performance data described earlier. Any indication of within-group correlations exceeding mean correlations would suggest similarities in topic coverage as significant explanation for the clusters.

Table 1 includes mean correlations between countries both within groups and for the total of countries (included in any of the groups). Some distinct features are revealed by the table. Firstly, in almost all cases the within-group mean correlations are higher than elsewhere, thus indicating that even this rather vague indication of topic coverage can contribute to an explanation of the country clusters. Secondly, correlations are generally much higher in mathematics than in science. This finding clearly relates to the fact that while it may be said that “mathematics is mathematics”, school science vary considerably more from country to country. In particular, some countries teach integrated science courses at this grade level, while others instead present one or two of separate physics, biology, chemistry etc courses.

Table 1: Mean correlations between countries within groups and for the total of countries (included in any group)

Countries	Mathematics	Science
English speaking	0.40*	0.28*
German-speaking	0.38	0.21
Nordic	0.50	0.18**
East Europe	0.45***	0.23***
East Asia	0.23	0.26
ALL	0.33	0.19

* No data for England was available

** Denmark was deleted due to very restricted data available

*** No data for Bulgaria was available

Admittedly, the support from the curriculum and textbook data for our clustering of countries is not strong. However, this must be seen in the light of two important points. Firstly, the yes-no scale for the topic coverage data is a very restricted one, not allowing for important differences in emphasis put on each topic. And secondly, since the data concerns the particular grade, what is learned in previous grades will not show up in the data. Hence we regard the evidence

for curriculum factors as influential for the country clustering as convincing. Elsewhere we have taken another step in exploring differences and similarities between countries' achievement in TIMSS, this time by comparing with data on teacher emphasis (Angell et al, 2004).

Conclusions

Our additional analyses of TIMSS data support the view pointed out by anthropologists, researchers in ethno mathematics and others that cultural factors are influential factors that we need to take into account in mathematics and science education. Even if studies like TIMSS has as a main goal to measure and compare a national levels of achievement in mathematics and science, these data can just as well be analyzed from the perspective of enlightening cultural differences between the participating countries. The cultural similarities and differences we have found, support the view that it makes some sense to talk about different distinct traditions in mathematics and science: a Nordic, an English-speaking, a German-speaking, an East Asian, an East European tradition etc. Admittedly, there seems to be some differences between mathematics and science, as to what extent the above-mentioned countries share a common tradition and form robust clusters. Nevertheless, similarities seem more obvious than differences.

Similarities may well be based partly on similarities in language, but also factors like geography and political history seem to play important roles. And all these influential factors are interwoven when curricula are set up and textbooks written. As Purves (1987, p.104) put it: "In order to understand why students in a particular system of education perform as they do, one must often reach deep into the cultural and educational history of that system and education." In this paper we have taken up some of these challenges by analyzing a combination of achievement and curriculum TIMSS 1995 data. Even if we have not penetrated very "deep" into this cultural and educational abyss, we have revealed some patterns that seem to contribute to what constitute cultural similarities and differences in mathematics and science education around the world.

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