Chapter 5
The Globalization of Science Education and Science Curricula: Discussion and Conclusions

Abstract In this exploration of the globalization of science curricula, a coding exercise, cluster analysis and discriminant analysis of twenty years of TIMSS data were used to answer three research questions: (1) Have there been changes in intended science curricula over the last 20 years? (2) If changes do exist, do they support the hypothesis that science curricula are becoming increasingly similar across countries? (3) Are there groups of countries where curricula are increasingly similar; can the basis of an international core curriculum be identified? The analysis provides strong evidence to suggest that there have been changes to countries' intended science curricula. The coding exercise found that all countries in the analysis had made changes to their intended curricula, although the extent of curricular changes varied considerably between countries. Cluster and discriminant analyses showed that over time there was a tendency for countries to cluster into one particular grouping based on responses to the TIMSS curriculum questionnaire. The number of TIMSS science topics that could be considered core to the curricula of the majority of participating countries increased over time, particularly at Grade 4, suggesting that science curricula are becoming increasingly similar across countries. Among the two groups of countries identified by the cluster and discriminant analyses, there was a clear tendency for one group to include a wider science curriculum encompassing a greater range of science topics than the other group. At Grade 8 the results strongly suggest that there has been convergence in science curricula over time. In terms of whether an international core curriculum can be identified, there are some TIMSS science topics which could be considered core to the curricula of most countries. Assessment is likely to play an important role, as high-stakes assessment is likely to influence science curricula and what is taught in schools.

Keywords Core science curriculum · Curriculum change · Curriculum convergence · Curriculum development · Globalization · Science curriculum Science education · Trends in Mathematics and Science Study (TIMSS)

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5.1 Have There Been Changes in Intended Science Curricula Over the Last 20 Years?

Unsurprisingly, the intended science curriculum in many countries has clearly changed over the last 20 years due to multiple factors, including advances in scientific theory, changes in educational and assessment practices, changes to governmental emphases in education, as well as the influence of international large-scale assessments such as TIMSS and other globalizing factors (as discussed in Sect. 2.2). Our investigation therefore prompted additional but related supplementary questions:

- What are the extent and scope of changes to science curricula?
- Are there recognizable patterns to these changes that enable inferences to be drawn about which factors are important for different countries in influencing the specific nature of the changes that are made to their science curricula?

Before considering these questions, when drawing conclusions and making inferences from our analyses, note that the reference dataset we used was the TIMSS curriculum questionnaire. This questionnaire records, for each participating country, whether their science curriculum covered the individual topics within the TIMSS framework during the specified year of study. We identified science topics that mapped across all TIMSS cycles considered in this study; 20 science topics were defined for Grade 4 and 21 for Grade 8. The TIMSS questionnaire does not, however, record the topics included in a country's curriculum that are outside the TIMSS science framework, nor does it record information on topics that are present in the TIMSS science framework but taught to a year group other than the one specified in the framework. As a consequence, this is not a measure of the total science curriculum for each country, but a measure of the similarity of their intended science curriculum to the TIMSS framework.

5.1.1 The Scope and Extent of Changes to Science Curricula as Measured by the TIMSS Curriculum Questionnaire Datasets

In Sect. 4.1, we presented the overall extent of the changes that countries have made to their curricula, based on comparisons that can be made between countries that have recorded curriculum questionnaires for the two TIMSS cycles in question (Tables 4.5 and 4.6). From this we conclude that:

- For most countries, the majority of TIMSS science topics remained stable (i.e. their inclusion or omission from the countries' intended curricula did not change) across each pairwise comparison.

- TIMSS science topics were more likely to be added to national curricula than removed. This may indicate a trend towards alignment of national curricula with the TIMSS science framework, suggesting that, when introducing new topics to their curricula, countries may favor the TIMSS framework topics over other priorities.
- There were a higher number of changes evident at Grade 4 as compared to Grade 8. A possible explanation for this is that a much greater proportion of the Grade 8 topics were already included in participant countries' Grade 8 curricula than the equivalent proportion of Grade 4 topics. This suggests that there was greater "capacity for change" in the Grade 4 curricula. In addition, Grade 4 is much earlier in the learning development of individuals and therefore more distant from the pressures of the end-of-school qualifications that prepare students for entry into the (globalized) jobs market. This might mean that there are fewer external pressures for a standardized curriculum at Grade 4 than at Grade 8, allowing greater experimentation and therefore a more fluid curriculum.
- A small number of topics show a changed emphasis between TIMSS cycles for each grade. This is where topics may be introduced to a restricted range of students (usually the more able) or extended from a restricted range to the entire cohort. The indication is that this type of change is much less prevalent than adding or removing topics for the entire cohort, perhaps because of the additional logistical complications of defining and resourcing the delivery of a specific curriculum to subgroups within a cohort.

5.1.2 Patterns of Curricular Changes Made by Different Countries as Measured by the TIMSS Curriculum Questionnaire Datasets

As it is clear that there have been changes to the curricula of different countries across the TIMSS cycles, analyzing how these changes vary across different countries, and identifying any specific patterns in the changes that countries have introduced to their science curricula may provide important insights into the factors that may be driving such changes.

In order to investigate further, we focused our comparison of the curricula on countries that participated in the first available cycle of TIMSS (2003 for Grade 4 and 1999 for Grade 8) and the most recent cycle (2015 for both grades). We recorded all changes that had been made, including changes in the emphasis of a topic in the curriculum (namely changing a topic that had been specified as only for the most able students to a topic specified as appropriate for all students).

Accordingly, we grouped countries by the number of changes they made to their curricula with topics from the TIMSS framework (see Chap. 4, Tables 4.1 and 4.2). A greater proportion of countries made significant changes to their curriculum at Grade 4 than Grade 8, with 11 out of 20 countries at Grade 4 making changes to at least seven of the TIMSS framework topics (equivalent to a third of the framework topics). In contrast, only four of 24 countries at Grade 8 made a similar level of changes. This supports our earlier conclusion (Sect. 5.1.1) that changes are more common at Grade 4 than Grade 8.

Having identified the countries that made the greatest number of changes to their curricula between the specified time points, we investigated any apparent patterns that may explain why these changes were made. In our search for evidence of the influence of globalization effects, a particular focus was placed on whether the participation of countries in international large-scale assessments influenced the changes to their curricula, and specifically whether their participation and performance in TIMSS cycles had any influence on the changes they made. Robitaille et al. (2000) and Klieger (2015) both presented evidence that some countries do respond to their performance in international large-scale assessments with specific changes to their curricula.

The investigation focused on the countries that had made changes to at least a third of the relevant TIMSS science topics and compared their baseline performance in TIMSS, namely in 2003 (at Grade 4) or in 1999 (at Grade 8), to analyze the effect of changes at that grade. We used these baseline cycles as these provided the first internationally comparative data to governments of the performance of their students, and were therefore likely to have prompted discussion and review of the curriculum and how it may have been linked to performance in TIMSS. We also looked at the ranking of each of the countries in the TIMSS cycle to investigate whether performance in TIMSS could be related to the extent to which a country changed its science curriculum.

The IEA consistently emphasizes that the specific rankings in TIMSS are inaccurate, as a country's average scale score is presented as a range of values. The IEA also makes it clear that, when comparing performance, countries can only be judged as ranking separately if their scores are separated by at least the margin of error of measurement. However, within countries and in the international media, the nature of the ranking is often misunderstood and reported without such cautions, which may unduly influence policymakers into making changes to curricula.

Based on their TIMSS ranking, the 14 countries identified as having changed at least seven major topics of their curriculum divide into three distinct groups. These can be defined as:

- *Top-end competitors*: Countries that ranked between number two and number five in the rankings, but did not attain the top ranking, and so were perceived as competing for this in future cycles (Table 5.1).
- *Mid-ranking changers*: Countries that achieved scale scores above the international average but below the top five countries. These countries may be perceived as seeking to improve their position in the rankings (Table 5.2).
- *Below average responders*: Countries that achieved scores below the international average in the baseline cycle and have sought to respond with significant reform of their curriculum (Table 5.3).

Table 5.1 Top-end competitors

Grade	Country	Rank in baseline TIMSS	Number of changes	Type of changes	Baseline average scale score	2015 average scale score
4	Chinese Taipei	2/25	10	Adder	551	555
4	Japan	3/25	7	Adder	543	569[a]
4	Hong Kong	4/25	9	Balancer	542	557
8	Singapore	2/38	8	Cutter	568	597[a]
8	Japan	4/38	4	Adder	550	571[a]
8	Republic of Korea	5/38	6	Balancer	549	556

Key
Adder = a country where curriculum changes resulted in more TIMSS science topics appearing in the country's intended science curriculum
Balancer = A country where curriculum changes resulted in roughly equal number of TIMSS science topics being added and removed from the intended science curriculum
Cutter = A country where curriculum changes resulted in fewer TIMSS science topics appearing in the country's intended science curriculum
[a]Average scale score improved by at least 20 points from baseline to 2015 TIMSS. 20 points represents one-fifth of a standard deviation in TIMSS. An improvement in scale score was selected as opposed to an improvement in ranking as this is directly comparable across cycles

Table 5.2 Mid-ranking changers

Grade	Country	Rank in baseline TIMSS	Number of changes	Type of changes	Baseline average scale score	2015 average scale score
4	Australia	11/25	12	Cutter	521	524
4	New Zealand	12/25	8	Balancer	520	506
4	Belgium (Flemish)	13/25	15	Adder	518	512

Key
Adder = a country where curriculum changes resulted in more TIMSS science topics appearing in the country's intended science curriculum
Balancer = A country where curriculum changes resulted in roughly equal number of TIMSS science topics being added and removed from the intended science curriculum
Cutter = A country where curriculum changes resulted in fewer TIMSS science topics appearing in the country's intended science curriculum

Unexpectedly, we identified a significant number of changes to the curricula of countries with top-end performance. It could be expected that high-achieving countries would have a curriculum enabling high performance in TIMSS and would therefore be less likely to require multiple curriculum changes. A clue to the force

Table 5.3 Below average responders

Grade	Country	Rank in baseline TIMSS	Number of changes	Number of topics added	Baseline average scale score	2015 average scale score
4	Cyprus	19/25	7	Adder	480	481
4	Norway	20/25	10	Cutter	466	538[a]
4	Armenia	21/25	7	Adder	437	–
4	Morocco	25/25	13	Adder	304	352[a]
8	Israel	26/38	11	Adder	468	507[a]
8	Morocco	37/38	10	Balancer	323	393[a]
8	South Africa	38/38	12	Adder	243	358[a]

Key
Adder = a country where curriculum changes resulted in more TIMSS science topics appearing in the country's intended science curriculum
Balancer = A country where curriculum changes resulted in roughly equal number of TIMSS science topics being added and removed from the intended science curriculum
Cutter = A country where curriculum changes resulted in fewer TIMSS science topics appearing in the country's intended science curriculum
[a]Average scale score improved by at least 20 points from baseline to 2015 TIMSS. 20 points represents one-fifth of a standard deviation in TIMSS. An improvement in scale score was selected as opposed to an improvement in ranking as this is directly comparable across cycles

for change is that the countries that achieved the top rankings, Singapore at Grade 4 and Chinese Taipei at Grade 8, instituted only minimal change following their high performance at that grade. It is therefore of interest that these same countries instituted significant changes in the alternate grades where they both achieved second place. One possible reason is that performing just below the top spot has prompted a review of the curriculum in order to be more competitive in future TIMSS cycles. All countries that fall into this group are also geographically close. This might reflect a competitive effect amongst neighbors, or may indicate specific regional cultural influences.

The response in terms of the nature of curriculum change varied. The majority response was to add TIMSS science topics to the curriculum. Singapore, however, removed or reduced the emphasis of eight TIMSS topics in its Grade 8 curriculum (which is in contrast to its treatment of the Grade 4 curriculum, as discussed). Hong Kong and the Republic of Korea rebalanced their curricula by adding and removing TIMSS topics. However, the changes made to the topics taught in each country are dependent on the nature of the "baseline" curriculum for that country, so conclusions about the preferred approach are difficult to make.

As we were also interested in whether any of the specific changes were connected to the performance of a country in future TIMSS cycles, we also recorded the average scaled score for these countries in the baseline and 2015 cycles. Although all of these countries maintained their high ranking in the 2015 cycle, only Singapore at Grade 8 and Japan at both Grade 4 and Grade 8 improved their scale score by a noteworthy amount (more than 20 points) over this period. It is not possible to say which specific factors contributed to improvement in these scores, but it is likely that curriculum effects played an important part.

Another cluster of countries grouped in the middle of the ranking table made multiple curricular changes at Grade 4 but not at Grade 8 (Table 5.2). The most striking aspects of this group are that two of the countries changed more than half of the TIMSS science topics in their curriculum, but that, despite these large-scale changes, there was minimal impact on the average scaled score. For example, only Australia achieved a slightly higher score in TIMSS 2015 than the baseline, with New Zealand and Belgium achieving a lower score in the later cycle.

The "below average responders" group is where we expected curriculum change to be most apparent (Table 5.3). We assumed that countries might be likely to reflect on poor performance in the baseline TIMSS survey and use this as an impetus to change policy, whilst using the TIMSS framework as a model for modifying their national curricula. This is the process that Klieger (2015) detailed for Israel. In line with this hypothesis, the majority of "below average responders" have made a significant number of changes to their curriculum and added TIMSS content. The exceptions to this case were Norway, where the curriculum changes resulted in the removal of nine TIMSS science topics from its curriculum, and Morocco, where the curriculum changes resulted in an equal number of TIMSS science topics being added and removed from its science curriculum at Grade 8.

In terms of the impact of these changes, the "below average responders" have shown significant improvement in their TIMSS average scale scores, with Norway improving by 72 points at Grade 4 and moving to a position well above the international average. Israel also moved to above the international average at Grade 8 in 2015. That said, both Norway and Israel achieved scores close to the international average in their baseline year. Morocco (Grade 4 and Grade 8) and South Africa (Grade 8) also saw significant improvements in average scale score, with South Africa improving by 115 points over the time period. That said, this improvement was based on a poor baseline score and ranking, and South Africa remained the lowest ranked country in the 2015 TIMSS cycle. Morocco similarly only gained one and two ranking places at Grade 4 and Grade 8, respectively.

Although these findings suggest that closer adherence to the science curriculum represented by the TIMSS framework has boosted performance for the poorest performing countries in the TIMSS international assessment, causality cannot be inferred. A wide range of other potential variables, which have not been examined in this investigation, could contribute to this improvement. That said, improvement would be expected as the curriculum and assessment became much better aligned with the TIMSS framework. The analysis also suggests that countries value the improvements that this alignment can provide and that they see the TIMSS framework as a suitable model on which to base their curriculum development.

5.2 If Changes Do Exist, Do They Support the Hypothesis That Science Curricula Are Becoming Increasingly Similar Across Countries?

Addressing this research question was contingent on countries' intended science curricula changing over the past 20 years. Our evidence (Sect. 5.1) revealed that this has been the case for many countries, so the next step was to determine whether these changes in intended science curricula supported the hypothesis that science curricula were becoming increasingly similar across countries. Our analyses provided mixed evidence to support this hypothesis.

5.2.1 Evidence That Science Curricula Are Becoming Increasingly Similar

Our analysis suggests that, in some respects, the science curricula of countries participating in TIMSS are becoming increasingly similar. Firstly, the coding of curriculum questionnaires indicates that over time, at both Grade 4 and Grade 8, the number of TIMSS science topics that were included in countries' intended science curricula was increasing, with countries on average adding more topics to their science curricula than they are removing (see Chap. 4, Tables 4.5 and 4.6).

One consequence of this was that a greater number of the TIMSS science topics were included in the majority (over 80%) of participating countries' science curricula in the 2015 TIMSS cycle than in earlier cycles. The finding is consistent for both Grade 4 and Grade 8. At Grade 4, seven of the 21 TIMSS science topics were covered by more than 80% of participating countries in 2015, compared to only two of the TIMSS science topics in 2003. The trend was less pronounced at Grade 8, with an increase from 12 to 14 of the 20 TIMSS science topics included in over 80% of participating countries' curricula. In Grade 4, in addition, there was also an associated drop in the number of TIMSS science topics that only appeared in the minority (less than 50%) of participating countries' curricula. This trend was not observed at Grade 8 as, in the baseline (1999) TIMSS survey, there were no TIMSS science topics that appeared in less than 50% of participating countries' curricula.

These results provide evidence that countries' curricula are becoming more similar over time, and that these changes appear to be increasing the likelihood of the same science topics being included in each country's curriculum. When interpreting the outcomes of this analysis, it is important to acknowledge that the number and composition of countries in each of the TIMSS cycles varies and that this has the potential to impact the results. It is also important to acknowledge that the finding that science curricula are becoming increasingly similar relates only to the curriculum as measured against the science topics included in the TIMSS curriculum questionnaire. Whilst the science topics included in the TIMSS framework are broad and balanced in terms of coverage of different aspects of science, they are not an exhaustive list of the potential science topics that could be included in a country's curriculum. Additionally, we have no information regarding the science curricula of countries that have not participated in TIMSS and so cannot make any claims about the extent to which non-participating countries' science curricula are becoming more similar over time.

The outcomes of the cluster analysis and discriminant analysis provide some evidence to support the conclusion that science curricula are becoming more similar across countries participating in TIMSS, with the evidence being stronger at Grade 8 than at Grade 4. The analyses provide strong evidence of convergence in the science curricula of countries participating at Grade 8 between 1999 and 2015, with the number of countries clustering into Group 2 growing at the expense of the number clustering into Group 1. In 1999, approximately half of countries clustered into Group 1 and half into Group 2. By contrast, in 2015, over 90% of countries clustered into Group 2 and less than 10% into Group 1 (see Chap. 4, Table 4.19). This suggests that, over time, at Grade 8, changes in intended science curricula are leading to an increasing number of countries with similar profiles in terms of the topics they do and do not include in their science curricula.

At Grade 4, however, the strength of evidence from the cluster analysis and discriminant analysis is less strong. The discriminant analysis suggests that changes in participating countries' science curricula have led to only mild convergence over time. In 2003, 55% of countries clustered into Group 1 and 45% into Group 2, whereas in 2015, 70% of countries clustered into Group 1 and 30% into Group 2 (see Chap. 4, Table 4.13). However, there was some movement of countries between the two groups across the TIMSS cycles considered, suggesting less convergence and more fluidity over time than at Grade 8 (see Chap. 4, Table 4.14). This may be because the science curriculum at primary level in some countries is less prescribed than at secondary level, where the subject usually has a higher status and profile and is often associated with high-stakes assessment.

One additional piece of evidence from the cluster and discriminant analysis, which supports the hypothesis that science curricula are becoming increasingly similar over time, comes from the science topics that were most important in predicting which group a country clustered into. For example, in 1999 at Grade 8 the science topic that was most important at determining which group a country clustered into was "chemical change (transformation of reactants, evidence of chemical change, conservation of matter, common oxidation reactions–combustion, rusting, tarnishing)". By contrast, in the 2015 TIMSS cycle, this was only the fifteenth most important topic in determining which group a country clustered in. Of the 21 countries participating in all three TIMSS cycles considered in this investigation, in 1999, this topic was included in 11 out of the 12 Group 2 countries' intended science curriculum. By contrast, it was only included in three of the nine Group 1 countries' curriculum (Chap. 4, Fig. 4.5). However, in 2015, the majority of countries in both groups (17 out of 21) included this topic in their intended curriculum for all students (Chap. 4, Fig. 4.6).

The findings from our coding exercise and cluster and discriminant analyses are consistent with findings from the literature review. Robitaille et al. (2000), for example, found that, in response to the 1995 TIMSS cycle, a number of countries, such as Iran and Kuwait, changed the content of their science curricula to incorporate new science topics on the environment. These changes, in turn, led to their science curricula becoming more aligned to the TIMSS framework. Similarly, revisions to the Israeli science curriculum have led to closer alignment between this and the TIMSS science framework (Klieger 2015). As countries' science curricula change and become more aligned to the TIMSS framework, one consequence is that the intended science curricula of different countries will converge.

5.2.2 Evidence That Suggests Science Curricula Are Not Becoming Increasingly Similar

Although some aspects of the analyses and literature review supported the hypothesis that science curricula are becoming increasingly similar across countries, other aspects of the analysis suggested otherwise. Firstly, as already discussed, based on the outcomes of the cluster and discriminant analyses, the evidence for convergence in science curricula at Grade 4 was weaker than at Grade 8. This highlights the important point that it is too simplistic to make a broad generalization that science curricula are becoming increasingly similar across countries over time. The number of countries, phase of schooling (e.g. primary versus secondary) and time scale considered, all affect the conclusions that can be drawn with regard to this hypothesis.

Secondly, the majority of our analysis has focused on intended science curricula and, in other aspects of the curriculum, there is little evidence to support the notion that science curricula are becoming increasingly similar over time. For example, in terms of the amount of time spent teaching science, wide variations exist in the mean number of hours identified in each country, with no evidence of this converging over time. For example, in 2015 at Grade 4, the average time spent teaching science each year (as identified from the TIMSS teacher questionnaire) in Qatar was almost three times as much as in New Zealand. At Grade 8 a similar pattern emerged.

In addition, although the responses to the curriculum questionnaire indicated a tendency for more TIMSS science topics to be included in countries' intended science curricula in both grades over time, the teacher questionnaire responses painted a slightly different picture. For example, although we have not reported in detail on the results of our additional analysis of selected countries for the reasons cited in Sect. 4.4, we did find that the average percentage of students who had been taught the TIMSS science topics was slighter higher for both Grade 4 and Grade 8 in the baseline cycles (1999 for Grade 8, and 2003 for Grade 4) than in the most recent 2015 cycle. This suggests that, although there may be evidence to support the hypothesis of the *intended* science curriculum becoming increasingly similar over time, this is not necessarily reflected in the *implemented* science curriculum experienced by students. As research identified in the literature review suggested, although curricula can be centrally prescribed, the way in which they are interpreted and enacted can vary widely at the local level (Astiz et al. 2002; Cogan et al. 2001).

The literature review and outcomes of the discriminant analysis also suggest that, although science curricula may, in some respects, be becoming increasingly similar over time, the changes are not necessarily leading to uniformity, as countries still cluster into distinct groups. For both grades and in all cycles, our discriminant analysis produced two groupings. Other studies using a similar approach also identified multiple groupings, and this is true for both science (Kjaernsli and Lie 2008) and mathematics (Zanini and Benton 2015). These studies found a tendency for countries to group based on geographic and cultural lines, suggesting that these factors still play an important role in aspects of the curriculum for both science and mathematics.

5.3 Are There Groups of Countries Where Curricula Are Increasingly Similar; Can the Basis of an International Core Curriculum Be Identified?

We investigated whether there was any evidence that science curricula were becoming increasingly similar over time in certain groups of countries to establish whether the basis of an international core science curriculum could be identified.

5.3.1 Are There Groups of Countries Where Science Curricula Are Increasingly Similar?

We have already discussed the outcomes of the cluster and discriminant analyses (Sect. 5.2), which provide some evidence to suggest increased similarity of countries' science curricula over time.

Consideration of the science topics that most contribute to the country groupings enables the curricula of countries within each group to be categorized. Using the TIMSS 2015 data and the cluster and discriminant analysis for this year at both Grade 4 and Grade 8, it was possible to identify and characterize the curricula of the two groups of countries.

At Grade 4 in 2015, the main differences between the science curriculum profiles of Group 1 and Group 2 countries could be categorized by Group 1 countries tending to cover a greater number of science topics than Group 2 countries. The following topics, for example, were likely to be included in Group 1 countries' science curricula and unlikely to be present in Group 2 countries' science curricula:

- common sources of energy and uses of energy
- understanding that some characteristics are inherited and some are the result of the environment
- chemical changes in everyday life
- understanding what fossils are and what they can tell us.

Several of these topics come from the physical sciences area of the TIMSS science framework. This suggests that countries in Group 1 may have a more balanced and broad focus to their science curriculum. Countries in Group 2 appear to have less of a focus on physical science topics and instead focus on life sciences topics. It may be that physical science topics receive less attention as they can be more abstract and less concrete than some of the topics in life and Earth science, making them less likely to be taught at Grade 4. In addition, the life sciences topic "understanding that some characteristics are inherited and some are the result of the environment" is a relatively advanced concept for Grade 4 children and so it is perhaps unsurprising that it is not included in the curricula of many countries in Group 2.

A similar pattern emerged at Grade 8 in 2015, where Group 2 countries tended to include a greater number of science topics in their curriculum than Group 1 countries. The following four topics for example were likely to be included in Group 2 countries' science curricula and unlikely to be present in that of Group 1 countries:

- interdependence of populations of organisms in an ecosystem
- major organs and organ systems in humans and other organisms
- Earth's processes, cycles, and history
- Earth in the solar system and the universe.

In contrast to the Grade 4 topics, none of these topics were in the physical sciences areas of the curriculum (chemistry and physics). It is not so obvious why these topics may differ so much between the two groups, particularly as the two biology topics cover quite different aspects of the subject, one ecological and one covering human biology. It may be that the two Earth science topics, particularly Earth's processes, cycles, and history, may be covered by Group 2 countries in subjects other than science, for example in geography. This may explain the importance of this topic in the clustering, although this cannot be said for certain.

This clustering pattern and the finding that there are distinct groups of countries with similar curricula is consistent with other research, such as that conducted by Kjaernsli and Lie (2008), who investigated the achieved curriculum in different countries using item responses to TIMSS science questions for TIMSS 2003 data. This study also identified a number of distinct groupings of countries that clustered together. Similar patterns have emerged on analysis of TIMSS mathematics data (Rutkowski and Rutkowski 2009; Zanini and Benton 2015).

Where our data differs from these studies, however, is that the cluster groupings in previous studies have tended to identify a larger number of country groupings, whereas this analysis has identified only two. Additionally, the cluster groupings in previous studies have typically grouped along geographic or linguistic lines, for example an Arabic grouping, an East Asian grouping, an Anglophone grouping etc. With only two groups identified in our study for each cycle, and therefore a larger number of countries present in each group, it is more difficult to make generalizations about the geographic, cultural and linguistic characteristics of countries. For example, at Grade 4 in 2015, Anglophone and Scandinavian countries are present in both groups.

At Grade 8 in 2015, the proportion of countries in Group 2 is greater than in Group 1, which makes characterization of this group easier. Group 1 did not tend to contain Anglophone countries and tended to have a higher number of North African and Middle Eastern countries, including Morocco, Lebanon, Dubai and Bahrain. In addition, no Western European countries were present, suggesting that at this grade there was some country clustering along geographic and cultural lines.

Although the cluster and discriminant analysis provides evidence to suggest that there are distinct cluster groupings and that there are defined curriculum characteristics of countries in each cluster, it is important to note that there is fluidity in these groupings. For example, at Grade 4 in particular, there is movement of countries between groups between each TIMSS cycle. This suggests that, while there is increasing similarity in countries' curricula, countries still have the potential to change and shift their curriculum profile and characteristics between groupings.

5.3.2 Can the Basis of an International Core Science Curriculum Be Identified?

In addition to identifying country groupings where there is convergence of science curricula, the second element of this research question pertains to whether the basis of an international core curriculum can be identified. This research provides evidence to suggest that the basis of a core international science curriculum can be identified. For example, the coding exercise has identified TIMSS science topics which could now be described as core (included in over 80% of participating countries' curricula) at both Grade 4 (Table 4.9) and Grade 8 (Table 4.10).

At Grade 4, the number of TIMSS science topics taught in the majority of participating countries increased over time from two in 2003 to seven in 2015, out of a total of 21 topics (Table 4.7). At Grade 8, there was a more modest increase, from 12 to 14, out of a total of 20 topics (Table 4.8). This growth in the number of topics taught in the majority of participating countries, particularly at Grade 4, suggests that a core science curriculum is emerging amongst countries. The seven "core" topics at Grade 4 in 2015 consisted of four life sciences topics, one physical science and two Earth science topics. This is consistent with findings from the cluster and discriminant analysis where Group 2 countries tended not to teach some of the physical sciences topics, i.e. it is unsurprising that fewer physical sciences topics are represented in the core science topics at Grade 4.

Two of the topics which increased most in terms of the proportion of countries including them in their science curricula at Grade 4 were “human health” (which had an increase of 29 percentage points between 2003 and 2015), and “understanding that weather can change from day to day, from season to season, and by geographic location” (which had an increase of 27 percentage points). These topics reflect major global issues facing the world today. For example, the importance of a healthy diet and exercise can be viewed in light of rising levels of obesity which are affecting many developed countries across the world. Additionally, an understanding of weather patterns and variations is crucial to an appreciation of climate change.

At Grade 8 the core science topics were spread more evenly across the different science subjects. In TIMSS 2015, four biology topics, three chemistry topics, three physics topics and four Earth science topics could be considered core. This may reflect the fact that, at secondary level, as students are introduced to topics such as the particle model and the structure of atoms, more aspects of chemistry and physics become accessible to students and can be more readily included in science curricula.

The presence of an international core science curriculum and the evidence from this study which suggests that this core curriculum appears to be growing over time is consistent with research highlighted in the literature review identifying that international large-scale assessments are leading to the standardization of education systems (Spring 2008), and the suggestion that these assessments are facilitating policy borrowing and the homogenization of education over time (Rutkowski and Rutkowski 2009). There is the potential, in future, that as more countries participate in surveys such as TIMSS and compare their outcomes on these assessments with those of other countries, curriculum reform will drive further convergence of curricula, leading to a stronger core international science curriculum. There is also the potential that new core science topics will emerge, based on global issues and challenges, or to better reflect advances in science or in areas of science with more economic potential, such as genetics and genomics.

Although this research suggests that it is possible to identify the basis of an international core science curriculum, there are a number of caveats which it is important to acknowledge. Firstly, the core curriculum identified here is defined on the basis of countries that have taken part in at least one of the TIMSS cycles considered in this report. Whilst the number of participating countries is high, the sample cannot be considered representative of all countries, with a higher number of economically developed countries participating in TIMSS and a relatively small number of countries from Africa and South America for example. As a result, we can only state that there is evidence of a core curriculum amongst countries that participate in TIMSS.

Secondly our analysis only considers science content as opposed to other aspects of the science curriculum such as the emphasis placed on science investigation, or the skills emphasized within the curriculum, such as scientific reasoning or problem-solving. Although we attempted to collect information on these aspects of the curriculum, due to inconsistencies between TIMSS cycles in the way this information was collected, it was not possible to make such comparisons. These features of the science curriculum are very important, but it is not possible within the limitations of this analysis to establish whether there are any international core standards with regard to the curriculum emphasis placed on science investigation or on scientific reasoning or problem-solving skills.

A further challenge and caveat is that our judgement of whether there is evidence to support the basis of an international core curriculum uses the TIMSS curriculum questionnaire responses. It has already been noted that the accuracy of these questionnaires and how well they reflect school curricula will vary between countries for several reasons. Firstly, in all countries there will be variation in the way the curriculum is interpreted and enacted in schools. Additionally, in some countries, particularly those with a federal structure, different curricula are likely to be in place in different states or provinces. As a result, a single curriculum questionnaire response for these countries is unlikely to accurately reflect the curriculum content of each state or province within the country.

The curriculum questionnaire provides information on whether a country includes a particular topic in its science curriculum at Grade 4 and Grade 8. Whilst this provides a useful summary of what is included in the curriculum, it is high-level information, and does not provide information about the level of scientific detail included for the topic. For example, the exact content of the Grade 8 topic on cell structure and function could vary considerably between countries. In some countries, the curriculum could simply specify the basic structure and function of animal and plant cells, whilst in others, the curriculum may require more detailed knowledge of cell organelles and the specialization of cells for different roles. Therefore, whilst we have identified common core topics taught in the majority of participating TIMSS countries, there could still be wide variation in particular topics between countries.

Finally, whilst we have identified topics that could be considered part of an international core science curriculum at Grades 4 and 8, this analysis has not taken into account how countries assess their science curriculum. Assessment is likely to play an important role as high-stakes assessment is likely to influence the science curriculum and what is taught in schools. Again, due to inconsistencies in the way the assessment questions in the TIMSS teacher and curriculum questionnaires have been phrased over multiple cycles, it has not been possible to compare assessment arrangements for science at Grades 4 and 8. Obtaining this information would be illuminating as it would identify whether there are common or core approaches to assessing the science curriculum at Grades 4 and 8, in addition to the core topics included within assessment.

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