Comparative studies in science and mathematics education: recent developments, risks and benefits

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Introduction

In his book *The World Is Flat: A Brief History of the Twenty-First Century* (2005)Thomas Friedman analyses globalization, primarily in the early 21st century. The title is used as a metaphor for viewing the world as a level playing field in terms of commerce where all competitors have equal opportunity. One may doubt if this is really the case but it is clear that more than ever before historical and geographical divisions are becoming increasingly less relevant.

In the field of education similar developments are on its way. The number of international schools is increasing in many countries as parents become more mobile and bilingual schools are becoming very popular, for instance in the Netherlands. In the latter type of schools not only language development is important but even more providing children for living in a world which is larger than the village, the city, the region, the country and the continent. In the field of higher education ministers of education from 29 European countries agreed in 1999 to adopt a system of easily readable and comparable degrees. The Bologna declaration[1] is the main guiding document of the Bologna process. It proposed a European Higher Education Area in which students and graduates could move freely between countries, using prior qualifications in one country as acceptable entry requirements for further study in another. In order to realise it was agreed to adopt a system essentially based on two main cycles, undergraduate and graduate. The degree awarded after the first cycle shall also be relevant to the European labour market as an appropriate level of qualification. The second cycle should lead to the master and/or doctorate degree as is common in many European countries.

It is not surprising that in such context comparative studies in education have become more prominent over the last years. In this paper, the basic elements of two large international studies (TIMSS and PISA) will be outlined and some results will be presented. In 2015, science will be the main field in the PISA-study and a new framework for science literacy is in its final stage of development, but not yet public. However, the main points of this framework can be highlighted .

Many publications in journals of science and mathematics education, both for teachers and researchers, have been devoted to TIMSS and PISA. Most articles take advantage of the results to analyse specific issues of science and mathematics education, such as gender, equity, culture, differences within countries and the impact on educational policy. Others

[1] http://www.ehea.info/

are critical, e.g. on the nature of the studies, the type of questions , the influence on assessment and the hypes to blindly follow countries with high results in these comparative studies. An overview of these benefits and risks will be presented.

TIMSS

In the field of science and mathematics education the International Association for the Evaluation of Educational Achievement (IEA) , a non-government organization, has been active since its inception in 1959 to conduct a series of international comparative studies designed to provide policy makers, educators, researchers and practitioners with information about educational achievement and learning contexts culmination in the periodic TIMSS-studies[2].

The TIMSS studies are aimed at measuring mathematics and science knowledge and skills aligned with curricula in the participating countries. The populations chosen are grades 4, 8 and 12. The studies in grades 4 and 8 focus on the full age group and take place every four years in many countries across the world. In grade 12 only those students that take advanced courses in mathematics and/or physics are included and these studies are less regular. Table 1 shows the number of countries participating for each age group.

Table 1 Number of countries participating in three types of TIMSS studies (1995-2008)

Year	Grade 4	Grade 8	Grade 12
1995	26	41	5
1999	--	38	--
2003	25	46	--
2007	36	48	10 (2008)

TIMSS grades 4 and 8

The TIMSS tests for grades 4 and 8 are based on frameworks[3] specifying the knowledge areas for grades 4 and 8, mathematics and science. For both subjects three cognitive domains are assessed: knowing, applying and reasoning. Questions are supposed to be close to what is common in the participating countries.

A selection of the results of the 2007 study [4]is reported in table 2, both for mathematics and science. The scale average is 500.

Table 2 Some TIMSS Results in Mathematics and Science 2007

Grade 4 N=36			Grade 8 N=48		
	Math	Science		Math	Science
Hong Kong	607 (1)	554 (3)	Chinese Taipei	598 (1)	561 (2)
Singapore	599 (2)	587 (1)	Korea	597 (2)	553 (4)
Chinese Taipei	576 (3)	557 (2	Singapore	593 (3)	567 (1)
Japan	568 (4)	548 (4)	Japan	570 (5)	554 (3)
Russian Feder.	544 (6)	546 (5)	England	513 (7)	542 (5)
England	541 (7)	542 (7)	Russian Feder.	512 (8)	530 (10)

[2]http://timss.bc.edu/

[3]http://timss.bc.edu/timss2007/frameworks.html

[4]http://timss.bc.edu/timss2007/intl_reports.html

Netherlands	535 (9)	523 (17)	USA	508 (9)	520 (11)
USA	529 (11)	539 (8)	Norway	469 (21)	487 (18)
Germany	525 (12)	528 (12)	Tunisia	420 (32)	445 (34)
Norway	473 (25)	477 (25)	Egypt	391 (38)	408 (41)
Algeria	378 (29)	354 (31)	Algeria	387 (39)	408 (42)
Morocco	341 (31)	297 (34)	Botswana	364 (43)	355 (46)
Tunisia	327 (33)	318 (33)	Ghana	309 (47)	303 (48)
Yemen	224 (36)	197 (36)	Qatar	307 (48)	319 (47)

In several countries the 2007 results have led to concerns about the international position. For instance in the USA, in the NCES report *Highlights From TIMSS 2007: Mathematics and Science Achievement of U.S. Fourth- and Eighth-Grade Students in an International Context*[5].

In 2011, 63 countries participated, although not all in both grades 4 and 8. In Africa only Botswana, Ghana, Morocco, Tunisia and South Africa participated. The 2011 results will published on December 11, 2012.

TIMSS Advanced

TIMSS Advanced[6] assesses final –year students with special preparation in Advanced Mathematics and Physics. Their courses last three to five years and prepare students for university programmes. The framework for Advanced Mathematics contains the topics algebra, calculus and geometry. The topics assessed in physics are mechanics, electricity & magnetism, heat & temperature and atomic & nuclear physics.

The grade 12 results in Advanced Mathematics and Physics are presented in figures 1 and 2.

Comparing the 2008 results with those of 1995 is difficult as the number of participating countries doubled. In interpreting the 2008 results one should take into account that the percentage of the age group participating in the study varies greatly between countries: in Mathematics between 0.7% (Philippines) to 40.5% (Slovenia); in Physics between 2.6% (Russian Federation) and Sweden (11%). Also the number of teaching hours varies between the countries: in Mathematics between 280 hours (Norway) and 760 hours (Netherlands); in Physics between 204 Russian Federation) and 560 (Netherlands). However, there seems to be no correlation between the results , the percentage of students and the number of teaching hours.

Figure 1 Achievement in Advanced Mathematics in TIMSS Advanced 2008

[5] http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2009001

[6] http://www.iea.nl/timss_advanced_2008.html

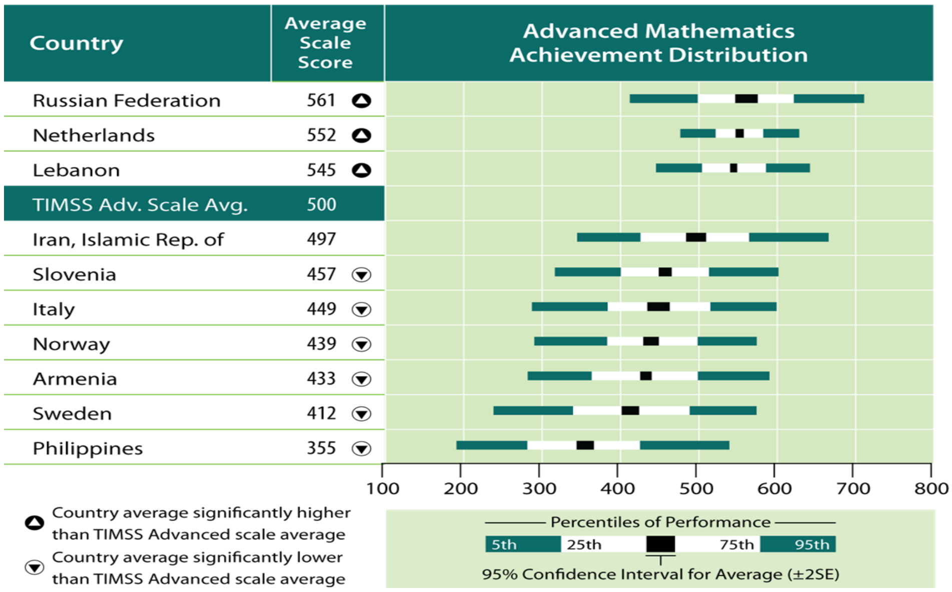
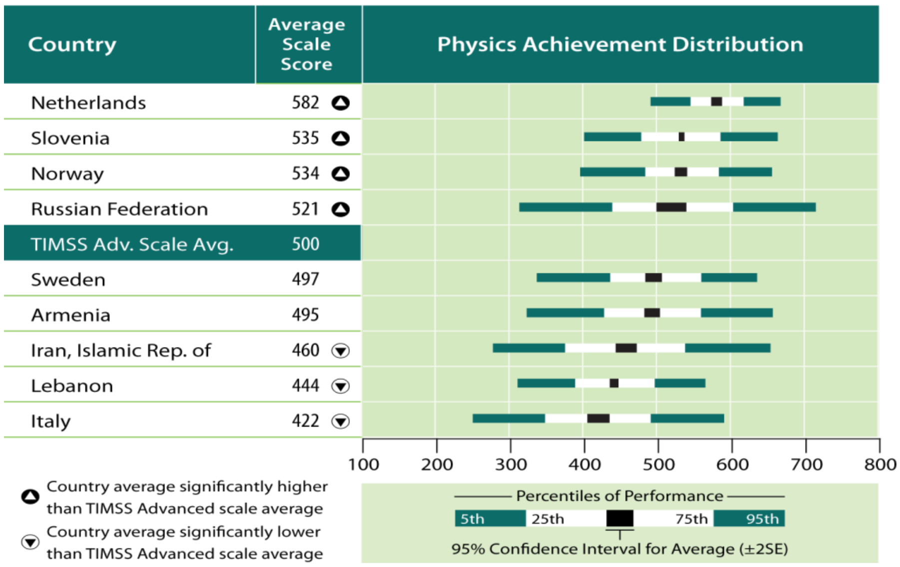


Figure 2Achievement in Physics in TIMSS Advanced 2008



TIMSS Video Study

TIMSS has also taken the initiative in 1999 to do a video study on hundreds of mathematics and science lessons (grade 8) in 7 countries (Australia, Czech, Hong Kong, Japan, Netherlands, Switzerland and USA). The lessons have been recorded and analysed according to purpose, classroom interaction and content activities. The signature of these lessons differs greatly between countries. Another interesting activity in this study was the judgment of educators of lessons in another country. A number of these lessons have been published on the TIMSS video website [7], which is accessible for anyone after registration.

PISA

[7] http://timssvideo.com

At the end of the previous century (1997) the OECD took the initiative to develop PISA, the Programme for International Student Assessment[8], which monitors the outcomes of education systems regularly within an internationally agreed framework and provides a basis for international collaboration in defining and implementing educational policies[9]. PISA focuses on students age 15 in the fields of reading, mathematics and science literacy and the tests are administered every three years since 2000, each time with emphasis on one field. The three frameworks are not based on common curriculum elements across the world (such as in TIMSS) but on skills and knowledge which students need in further life associated with commonly agreed 21st century priorities. This clear from the PISA-definitions of Mathematical and Scientific Literacy:

> Mathematics (2012 [10]): *"Mathematical literacy is an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts, and tools to describe, explain, and predict phenomena. It assists individuals to recognise the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens. "*
>
> Science (2009 [11]): *"An individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence based conclusions about science-related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen."*

Both definitions form the basis of the frameworks on which the assessment items are based. In 2012 Mathematics was the main topic, the results will be published in December 2013. Preparations are in progress for PISA 2015, when Science will be the main topic.

The core of the science literacy frameworks has been based so far on three scientific competencies: (1) identify scientific issues, (2) explain phenomena scientifically, and (3) use scientific evidence. These competences are based on both scientific knowledge and attitudes towards science, and should be applied to personal, social and global contexts. Scientific knowledge is split into knowledge of science and knowledge about science. The former contains the usual concepts in the fields of life, physical and earth science. The latter could be characterized as insight into the nature of science. Table 3 shows some cognitive results of PISA 2009 [12].

Table 3Some Cognitive results of PISA 2009 in the fields of Science, Mathematics and Reading

	Brazil	**Germ.**	**Indon.**	**Italy**	**Japan**	**Mex.**	**NL**	**Sing.**	**Turk.**	**USA**

[8] www.pisa.oecd.org
[9] http://www.youtube.com/watch?v=q1I9tuScLUA

[10] http://www.oecd.org/pisa/pisaproducts/46961598.pdf
[11] http://www.oecd.org/pisa/pisaproducts/44455820.pdf
[12] http://www.oecd.org/pisa/pisa2009keyfindings.htm

Science	405 (53)	520 (13)	383 (54)	489 (35)	539 (5)	416 (50)	522 (11)	542 (4)	454 (43)	502 (23)
Math.	386 (57)	513 (16)	371 (61)	483 (35)	529 (9)	419 (51)	526 (11)	562 (2)	445 (43)	487 (31)
Reading	412 (53)	497 (20)	402 (57)	486 (29)	520 (8)	425 (48)	508 (10)	464 (5)	464 (41)	500 (17)

Discussion

The PISA-results have been explained by many factors in a large number of articles (see a selection of the literature in the appendix) . The PISA-results have also been subjected to a great deal of criticism. Some authors claim that the questions favour specific countries and cultures, although all questions have been subjected to rigorous reviews. Others claim that the questions are not according to current national curricula, but that was not the purpose of PISA. Other points of discussion are what should we learn from the PISA results (benefits), what should we do with it in practice and how can we avoid politicians to easily embrace teaching characteristics elsewhere (such as in Finland and Singapore) which might not simply be transferred to another educational context.

In the Netherlands the PISA results initially led to satisfaction at the policy level. Recently some concern was raised about a slightly lower position of the Netherlands in the international rankings. The Ministry of Education has recently ordered that schools should take care that in every PISA-survey the national results should be several points higher. In the meantime the PISA frameworks are used to adapt the current Dutch curricula in junior high school, not so much in knowledge of science, but more in knowledge about science (procedures, epistemics). In the USA a similar trend is visible in the new *Framework for K-12 Science Education. Practices, Crosscutting Concepts, and Core Ideas*(NRC, 2012)[13] which better fits with the draft PISA 2015 Framework for Scientific Literacy.

Would this lead to one international curriculum for science and mathematics education? In my view that is unlikely as the economic, social and cultural situation is too different across the world. But I do expect that interaction between curriculum developers in various countries will increase by exchanging experiences and studying best practices. When implementation is done in a thoughtful way it will be beneficial to the quality of science and mathematics education worldwide. I hope this conference will have a function in this process.

Appendix: A selection of the literature about PISA

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[13]http://www.nap.edu/openbook.php?record_id=13165&page=1

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Basl, J. (2011). Effect of school on interest in natural sciences: A comparison of the Czech Republic, Germany, Finland, and Norway based on PISA 2006. *International Journal of Science Education*, *33*, 1, 145-157.

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Hatzinikita, V., Dimopoulos, K., & Christidou, V. (2008). PISA test items and school textbooks related to science: a textual comparison. *Science Education*, *92*, 664-687.

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Knipprath, H. (2010). What PISA tells us about quality and inequality of Japanese education in mathematics and science. *International Journal of Science and Mathematics Education*, *9*, 389-408.

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