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INFLUENCE OF TIMSS RESEARCH ON THE MATHEMATICS CURRICULUM IN SERBIA: EDUCATIONAL STANDARDS IN PRIMARY EDUCATION[1]

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Abstract. Since 1995, achievements in mathematics and science have been assessed worldwide every four years by TIMSS (Trends in International Mathematics and Science Study), whose outcomes have influenced the development and (re)design of mathematics and science education curricula in a number of countries. This paper examines how TIMSS has influenced changes in the mathematics curriculum in Serbia in primary education. The paper first briefly presents TIMSS results of Serbian students that call for curricular improvements. It then gives a summary of these changes regarding educational standards for the end of primary education. The paper ends with a critical examination of these standards and suggestions for their enhancement.

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1. Introduction

In response to internationalization in education, which may basically denote adapting educational products provided by international institutions to particular country needs (e.g., Cai & Howson, 2012), many countries have applied TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment) studies. These studies in Serbia have been carried out by the Institute for Educational Research and the Institute of Psychology, Faculty of Philosophy, University of Belgrade, respectively, financially supported by the Ministry of Education, Science, and Technological Development, Republic of Serbia, with limited or no support from other organizations and institutions (faculties/departments for teaching, professional societies, etc.). Despite the tendency of these studies to promote the acquisition of an internationally accepted core of mathematical knowledge and skills included in many countries worldwide, this inclusion in Serbia has been modest, escaping the trap (identified in Cai & Howson, 2012, for example) of developing a curriculum that is limited both mathematically (e.g., focusing on core knowledge and simple applications primarily) and

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societally (e.g., creating qualified and competitive workforce mainly). As Professor Milosav Marjanović underlined, mathematical abilities have to be developed through the learning of main topics (or main didactic themas, in his words), occasionally connected to real-world problems and free from an intensified formalism, and then we should not worry much if our students are not that successful with PISA test items whenever they are good at acquiring these main topics (see `http://www.vi.sanu.ac.rs/Odbor-obrazovanje/Prilozi/PISAtest.pdf`).

1.1 TIMSS and its impact

Since 1995, TIMSS has provided data on fourth and eighth grade students achievements in mathematics and science for more than fifty countries around the world, every four years (see https://timss.bc.edu/). Apart from such achievement data, TIMSS international databases contain the values of many contextual variables, used to explain differences in students' achievements within and among countries, resulting in a great number of secondary analyses (e.g., Bofah & Hannula, 2015; Kadijevich, 2008, 2013; O'Dwyer, Wang & Shields, 2015).

Many outcomes of primary and secondary TIMSS research have influenced the development and (re)design of mathematics and science education curricula in a number of countries. The first curricular changes, which started in the end of 1990s, were described in Robitaille, Beaton & Plomp (2000). Recent changes in the 21st century were documented in TIMSS encyclopedias (e.g., Mullis, Martin, Goh & Cotter, 2016). It can be said that in general, under the influence of TIMSS, a certain curricular convergence regarding topics to cover and skills to foster is taking place at a global, worldwide level (see Mullis, Martin & Loveless, 2016). Regarding particular TIMSS changes, one may, for example, examine the incorporation of TIMSS cognitive domains into mathematics curricula (e.g., Mohd Zain & Goloi, 2012, p. 583; Ndlovu & Mji, 2012).

1.2 TIMSS cognitive domains

Since the 2007 cycle, TIMSS research, for both grade 4 and 8, has considered three cognitive domains: Knowing, Applying, and Reasoning (Mullis et al., 2005). Stated briefly, the first domain refers to knowledge the student needs to know, the second focuses on the application of this knowledge in solving routine problems, whereas the third refers to his/her ability to deal with complex contexts, unfamiliar situations, and multi-step problems. In this document, each domain was described by an exemplified list of behaviors. These behaviors are listed in Table 1.

Cognitive domain	**Behaviors**
Knowing	Recall, recognize, compute, retrieve, measure, and classify/order
Applying	Select, represent, model, implement, and solve routine problems
Reasoning	Analyze, generalize, synthesize, justify, and solve non-routine problems

Table 1. TIMSS cognitive domains and their underlying behaviors

While almost the same behaviors were considered in the next, 2011 cycle (only generalize was replaced by generalize/specialize; Mullis, Martin, Ruddock, O'Sullivan & Preuschoff, 2009), the list of behaviors in TIMSS 2015 and 2019 was updated for Applying and Reasoning. The new lists were: Applying – Determine, represent/model, implement; Reasoning – Analyze, integrate/synthesize, evaluate, draw conclusions, generalize, justify (Mullis & Martin, 2013, 2017).

Although TIMSS official documents do not refer to Bloom's taxonomy of cognitive domain, the three cognitive domains Knowing, Applying, and Reasoning may be related to six cognitive categories comprising this taxonomy. Despite its revision (e.g., Anderson et al., 2001), the original categories knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom & Krathwohl, 1984) are still in use. By referring to them, it may be said that Knowing primarily calls for knowledge and comprehension, Applying basically involves comprehension and application, whereas Reasoning is mostly based upon analysis, synthesis, and evaluation. Accepting this position enables educators to view Bloom's cognitive categories as building blocks of TIMSS cognitive domains, as done in Gutvajn, Džinović & Pavlović (2011), for example.

1.3 Paper outline

This paper examines how TIMSS has influenced changes in the mathematics curriculum in Serbia in primary education. After a brief presentation of TIMSS results in the previous four assessment cycles that call for curricular improvements, the paper gives a summary of these changes regarding educational standards for the end of primary education. The paper ends with a critical examination of these standards and suggestions for their better elaboration.

2. TIMSS in Serbia

2.1 TIMSS results

Serbian students have participated in TIMSS since 2003. In 2003 and 2007, TIMSS tasks were solved by eights graders. Bearing in mind that Serbian students participated in PISA 2003 and 2006, authorities at the ministry of education decided that as PISA would continue to involve 15-year old students, future TIMSS assessments would involve younger students. Because of that, in the 2011 and 2015 TIMSS assessment cycles, the study involved fourth grade students. The same applies for TIMSS 2019 (in process). All TIMSS studies in Serbia have been carried out by the Institute for Educational Research (`https://en.ipisr.org.rs/`).

The results for these four assessment cycles are summarized in Table 2 (low scores that called for improvements are underlined). The main results (477, 486, 516, and 518) were much better for fourth graders.[2] The relatively unsatisfactory results of eighth graders in 2003 and 2007 (below 500 points) called for changes of the Serbian mathematics curriculum for compulsory education (grades 1–8), and the changes made around 2010 probably contributed to good TIMSS results in 2011

[2]Fourth graders were also better when the balance among the results for cognitive domains was examined. By applying a min/max measure of this balance (the minimum of the three scores divided by their maximum; Kadijevich, Zakelj & Gutvajn, 2015), the balance was 0.943 (467/495) in 2003, 0.948 in 2007, 0.983 in 2011, and 0.985 in 2015.

and 2015. Note that although Serbia was not among the top performing countries at fourth grade, it was definitely among them when countries with low Gross Domestic Product (GDP) were considered (e.g., TIMSS 2015 Grade 4 countries whose GDP per capita was less than 8,000 $ in 2014).

Year (grade)	**Aver. MA**	**Average MA by content domain**	**Average MA by cognitive domain**
2003 (8)	477	Number/Algebra/Measurement/Geometry/Data 477 / 488 / 475 / 471 / <u>456</u>	Knowing/Applying/Reasoning 495 / <u>467</u> / <u>468</u>
2007 (8)	486	Number/Algebra/Geometry/Data and Chance 478 / 500 / 486 / <u>458</u>	Knowing/Applying/Reasoning 500 / <u>478</u> / <u>474</u>
2011 (4)	516	Number/Geom. shapes & measures/Data display 529 / <u>497</u> / <u>503</u>	Knowing/Applying/Reasoning 520 / 511 / 514
2015 (4)	518	Number/Geom. shapes & measures/Data display 524 / <u>503</u> / 517	Knowing/Applying/Reasoning 513 / 521 / 517

Table 2. TIMSS mathematics achievement (MA) for Serbian students[3]

2.2 TIMSS influence

TIMSS results have influenced the educational system in Serbia in a number of ways (Gasic-Pavisic & Kartal, 2012, p. 796). For example, TIMSS data have been used in various analyses of the primary education system. Also, TIMSS methodology and some of its accomplished test items have been used in national testing. The most important influence of TIMSS in Serbia may be recognized in the development of educational standards for mathematics and science for the end of primary education in fourth grade.

Educational standards for mathematics, as with other school subjects in the Serbian compulsory education, have been defined by using three achievement levels, namely: basic, intermediate, and advanced. Mathematics in grade 4 was divided into several areas (e.g., Natural numbers and operations with them), and for each area, there were requirements concerning knowledge and skills required for these achievement levels (NEC, 2011). These requirements were carefully formulated after several rounds of discussion and empirical validation, so that these levels would be, respectively, reached by at least 80%, 50%, and 25% of students. Having in mind that the four TIMSS international benchmarks were respectively reached by about 90%, 70%, 40%, and 10% of Serbian fourth grade students (the exact figures were: 2011 – 90%, 70%, 36%, 9%; 2015 – 91%, 72%, 37%, 10%; Mullis, Martin, Foy & Arora, 2012; Mullis, Martin, Foy & Hooper, 2016), there is a correspondence between the three achievement levels and the three TIMSS benchmarks. In doing so, the basic level would correspond to the low benchmark ("have some basic mathematical knowledge"), the intermediate level to the intermediate benchmark ("can apply basic mathematical knowledge in simple situations"), and the advanced level to the high benchmark ("can apply knowledge and understanding

[3]Sources: Mullis, Martin, Gonzalez & Chrostowski (2004); Mullis et al. (2008); Mullis, Martin, Foy & Arora (2012); Mullis, Martin, Foy & Hooper (2016).

to solve problems"). As a result, the basic level would primarily call for the cognitive domain of Knowledge, the intermediate level for the domain of Applying, whereas the advanced level would do that for the domain of Reasoning (possibly with some behaviors of other cognitive domains activated to some extent). The content of Table 3, taken from a document regarding educational standards for mathematics in grade 4 (NEC, 2011), supports these domain calls.

Achievement level	**Requirement (cognitive behavior)**
Basic	1. know how to read and write the number given; know how to compare numbers; know how to locate the number on a number line (call for recognize/order/measure)*
	2. calculate the value of a numerical expression with a maximum of two operations of addition and subtraction within 1,000 (calculate)
	3. multiply and divide without remainder (three-digit numbers with one-digit numbers) within 1,000 (calculate)
	4. know how to set up an expression with one arithmetic operation on the basis od text (represent)
	5. know how to solve simple equations within 1,000 (recall/compute)
Intermediate	1. know how to apply the properties of natural numbers (odd, even, largest, smallest, preceding number, following number) and understand decimal number system (select/implement)
	2. know how to round the number given to the nearest ten, hundred, and thousand (select/implement)
	3. add and subtract, calculate the value of an expression with at most two operations (calculate)
	4. know how to solve equations (select/implement)
Advanced	1. know how to apply the properties of natural numbers to solve problem tasks (synthesize)
	2. know the properties of addition and subtraction and can apply them (select/implement)
	3. can calculate the numeric value of an expression with several operations, respecting their order (synthesize)
	4. can solve complex problem tasks given in textual form (analyze/resolve non-routine problems)
	5. can determine solutions of an inequality with one operation (analyze/generalize)

* Requirements translated into English by the author of this paper

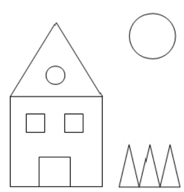
Table 3. Requirements (cognitive behaviors) for knowledge and skills by achievement level for area "Natural numbers and operations with them" in grade 4

The same domain calls apply for other content areas in grade 4 although cognitive behaviors are not that rich for some areas and some levels (e.g. Fractions – basic level). It can thus be said that TIMSS cognitive domains have been incorporated in educational standards. However, these domains are not mentioned in official documents describing the development of these standards. Instead, the application of Bloom's taxonomy is mentioned (Pejić, Kartal & Stanojević, 2013).

Because, as already mentioned, Bloom's six cognitive categories may be viewed as building blocks of TIMSS cognitive domains, it can be said that, through Bloom's taxonomy, TIMSS cognitive domains have been implicitly incorporated in the educational standards for mathematics in fourth grade.

To improve mathematics education (following unsatisfactory achievements in TIMSS 2003 and 2007 among other reasons), a project was carried out in the end of the 2000s, concerned with the development of criterion tests for the end of the first cycle of compulsory education (IEQE, 2009). As a result, a set of one hundred TIMSS-like tasks was carefully developed to assess mathematical knowledge in the fourth grade, recorded on CD, and sent to all schools in Serbia in May 2009, coupled with detailed documentation including a computer program to enter and analyze achievement data. Schools were recommended to use this material to arrange assessments by the end of the 2008/2009 school year, and most schools did so, which contributed to teachers' and students' familiarity with TIMSS-like context and tasks. The one hundred mathematical tasks were developed for twenty-five learning outcomes (with four similar tasks per outcome), and respective Bloom's cognitive levels and achievement levels were assigned to each learning outcome, i.e.. task assessing it (Stanojević, 2010). Figure 1 presents a Level 1 task in geometry with knowledge as the assigned cognitive level, whereas Figure 2 displays a Level 2 measurement & measures task with application as the assigned cognitive level (IEQE,2009).

Count geometric shapes on the figure below and fill in the blanks.



There are ___ circles, ___ squares, and ___ trianges on this figure.

Figure 1. Counting geometric shapes

To find out whether there was some empirical evidence about this incorporation of TIMSS cognitive domains in educational standards in question, the three achievement levels were examined as Bloom-based TIMSS cognitive levels, i.e., Level 1 – Knowing: knowledge and comprehension; Level 2 – Applying: comprehension and application; Level 3 – Reasoning: analysis, synthesis, and evaluation. It was found that the cognitive level assigned to particular task (e.g., application) was present at the achievement level assigned to it (e.g., Level 2 – Applying: comprehension and application) for twenty learning outcomes. (The fact that some of Bloom's cognitive levels appeared at levels lower or higher than expected – e.g., analysis at Level 2 for fractions, or application at Level 3 for measurement & measures – showed that the overlapping of achievement levels cannot be avoided.)

Because seventeen of these twenty outcomes were later used as a foundation of educational standards for mathematics in the fourth grade, there is also empirical evidence of the incorporation of TIMSS cognitive domains in these standards. Note that such a contribution was particularly strong for five learning outcomes in the Measurement & measures area.

> The pupils departed from Novi Sad for a trip to Oplenac at 8:15 AM.
> They returned to Novi Sad on the same day at 5:30 PM.
>
> How many hours and minutes did the pupils spend on this trip?

Figure 2. Duration of one-day excursion

3. Closing remarks

National educational standards is a critical educational component (e.g., Klieme, 2004). Among other things, not only can they promote a better, more focused education nationwide, but also enable the assessment of its outcomes in a more objective way, finding directions for an elaboration of these standards, if needed.

The analysis of educational standards for mathematics in fourth grade in Serbia presented in this paper showed that the three achievement levels (basic, intermediate, and advanced) mirror the three TIMSS cognitive levels (Knowing, Applying, Reasoning) to a satisfactory extent. It is also realized that at each achievement level, some behavior(s) used at other level(s) may be activated to some extent, which evidences the overlapping nature of these standards. Although this nature cannot be avoided, it may be reduced.

To reduce the overlapping nature of achievement levels, educators should focus on 4–5 dominant cognitive behaviors that characterize each level (standards), and primarily these behaviors should be activated through the application of "what to know and do" requirements. (Compare with Long, Dunne & Kock, 2014, who proposed to combine levels of processing, as our standards, with dimensions of understanding, as our behaviors.) When the development of standards begins with those behaviors, educators can better specify these requirements and develop (possibly also novel) tasks to assess their attainment. With these dominant behaviors in mind, educators should also avoid having just two or three requirements for some content area(s) at particular achievement level(s) (e.g., Fractions – basic level), which would limit the diversity of assessment tasks applied. As educational standards need be continuously examined and improved (through professional/theoretical discussions and empirical validations), these suggestions may be used in an elaboration of these standards, especially the mathematics standards examined in this paper.

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