On the dualistic unity of natural science and the humanities

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Abstract. This paper is an analysis of the effectiveness of the Russian learners from the 2019 TIMSS International Monitoring Study report. While analyzing the document, the initial conclusion drawn by the author is that the mathematical and natural science literacy of Russian schoolchildren is quite high and that the educational system in Russia is stable. At the same time, the author suggests that rethinking the directions of educational development is impossible without taking into account the underlying processes occurring in the depths of basic general education. In the author's opinion, the lack of significant gains in the scores of Russian students over the last 2 phases of the TIMSS studies is an indicator of certain stagnation in primary mathematics and science education. The author is of the belief that a statement of this fact should contribute to the fundamentalism of education. Assessing the structural correlation between natural science and humanities knowledge by quantitative volume of academic load of mathematics and natural science disciplines, the author points to the dualistic unity of natural science and humanities knowledge in high school, which should contribute to the development of creative independent thinking of students. The author's understanding of the results of the context survey of Russian schoolchildren indicates the need to improve the professional expertise of the science teachers, which will improve the outcome of the educational process. The author suggests adopting the experience of other countries in implementing the interdisciplinary approach to the educational process. The author emphasizes that STEM education imposes special requirements on the teacher, who must have integrated knowledge of mathematics, science and technology, be fluent in computer programs, be motivated to work with children and be skilled in didactics.

1 Introduction

A distinctive feature of the modern world is the rapid development and, perhaps, the same rapid obsolescence of various technologies up to the change of the technological mode in the post-industrial digital society. This promotes, on the one hand, the integration of different fields of knowledge, as it creates complex tasks at the junction of different sciences and spheres of production, and on the other hand, it enables a differentiated approach, requiring a specific professional-applied training of workers and their narrow specialization. These realities of the modern production sphere are particularly responsible for the field of education, which determines "the formation of a new type of professionalism - transprofessionalism - readiness for interprofessional communication and transdisciplinary synthesis of knowledge" [1]. To train such specialists who can act in non-standard situations, solve innovative practical tasks, overcoming the stereotypes of the experience of previous generations, it is necessary to be based on key scientific and technical directions, covering breakthrough technologies from different professional fields. This means having a mastery of universal end-to-end technologies, covering major trends in the nano- and biospheres, information communications, and cognitive sciences [1]. The readiness for different types of communication also implies possessing the social-humanitarian technologies that ensure work in a special interprofessional environment [1, 2].

Thus, the main task of modern educational practice is to form a comprehensively developed personality with critical thinking, skilled in reflection and self-development, prepared for strong competition in the high-tech world and at the same time being a carrier of moral values, determined by the cultural codes of Russian spirituality. The way to solve this problem is "to meet the requirements of compliance of the content with the strategic goals of modern education and structural unity of educational content at different levels and at different stages" [3]. Characterizing the "content of education" as a holistic structural socio-cultural phenomenon with internal interconnection and interaction of the main elements, we can distinguish two main system-forming axes: natural science and humanitarian knowledge [3].

According to many experts [1, 3, 4], one of the main trends in the development of society is the fundamentalization of education, ensuring the presence of creativity in any human activity. The knowledge of fundamental knowledge gives an understanding of the scientific worldview as a holistic system of concepts and principles about the general properties and patterns of development of nature, society, and individuals. The natural sciences are the worldview basis for the formation of a scientific view of the world. It means that "the way to any modern science and technology, and simply to modern life,

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is by studying mathematics, computer science, physics, and other natural disciplines" [3]. In this regard, it should be assumed that the natural science knowledge is a high priority.

Other experts, on the contrary, consider the importance of the humanities to be a priority. Rethinking everything that has been accumulated by generations should involve not only organizational and technological, but also humanitarian, value and conceptual components, the fundamental bases of social and individual consciousness represented in the philosophical tradition and national culture [5]. However, considering that "the support in humanitarian spheres of activity (particularly, in education) on the classical categories of knowledge, developed exclusively within the limits of natural science knowledge, oriented on accuracy, countability and maximal rationalization, limits the possibilities for sense-making, preventing from understanding the individual nature of man, in relation to whom the laws of objectification, typification and unambiguous, purely rational interpretation do not work" [2]. In addition, some supporters of humanitarian education point out that it is "the stimulus for both the development of the education of the future and the emergence of new forms of teaching and the implementation of new ways to train educators". [6]. It is stated that "technicalization and digitalization are seen not only as a threat to the free individual, but also as a serious danger to the existence of society as a whole" [6].

Thus, in modern conditions of transition to the new digital technological mode in all spheres of human activity, including education, the problems of priority and opposition of "natural science" and "humanitarian" knowledge and ways of thinking acquire new fundamental significance.

In this respect, it can be considered an invariant phenomenon since the process of cognition is continuous and infinite. However, the natural-science knowledge about the scientific worldview, the properties of material objects of the micro- and macrocosm, the features and laws of their development, which change the value and semantic orientations of a person himself and, refracting through the prism of social demands of society, lead "to the peripetias of humanitarian knowledge", is variant and constantly renewed. [7]. In this context, the changes taking place in the humanities must be seen as a consequence of the changes in the natural sciences.

It should be emphasized that the deeper the human mind intrudes into the process of understanding the natural-science worldview, the clearer should be the realization of the essence and purpose of man himself in this world, his responsibility for it. This indicates not the need to prioritize the primary relevance of natural science or humanities knowledge. It "leads to the idea that for overcoming the problems in both spheres of knowledge, their integration is necessary, and not only at the methodological level, but also at the subject level" [8].

This conclusion demonstrates the mutual penetration of different ways of thinking and the unity of the seeming opposites of natural science and humanities knowledge. It should be assumed that a fundamental rethinking of the directions of educational development should be based on a return to the formation of a holistic dualistic way of thought among students, starting with the secondary school.

In this regard, the main issue and task of the conducted research is to study the latent variable of the educational system of Russia, which is the "status of mathematics and science education". The indicators of the emergence of this variable are quantitative indicators obtained in the International Monitoring Survey, in which Russian school students participated.

2 Materials and Methods

The purpose of this study is to analyze the Russian 4th and 8th grade students' success in mathematics and science subjects according to the International Mathematics and Science Study (The Trends in International Mathematics and Science Study, TIMSS) conducted by the IEA (International Association for the Evaluation of Educational Achievement) [9].

Therefore, the main microtargets of the study are:

- assessment of the current state of science education in Russia in the public school after the completion of the primary stage of education (4th grade) and the 8th grade, as well as a comparative analysis of their results;
- comparative analysis of the structure of educational programs in Russian schools and in schools of the leading countries participating in the TIMSS study in relation to the assessment of the quantitative volume of the teaching load of disciplines in mathematics and science subject areas;
- understanding the outcomes of contextual questioning of Russian schoolchildren, during which the emotional attitude of students to the study of mathematics and natural science, confidence in mastering a given subject area, as well as values in relation to science in a given subject area were revealed;
- establishing cause-and-effect relationships between the dynamics of quantitative changes in various indicators of the TIMSS study.
- The empirical basis of the study is the 2019 TIMSS statistical report [9], as well as the materials of the TIMSS summary report of the Federal Institute for Evaluation of Education Quality of the Russian Federation (FIEEQ) [9].

The main methods of the study are the processing and analysis of the information presented in these materials related to the quantitative indicators of learning achievements of Russian schoolchildren. The analysis of these documents enabled to systematize the information presented in them, as well as to formulate hypotheses on the factors influencing the learning achievements of 4th and 8th graders of secondary comprehensive schools in Russia in mathematics and natural sciences. A comparative analysis of the quantitative indicators given in the reports provided an opportunity to establish logical relationships between trends in their changes and formulate theoretical conclusions about the existence of cause-and-effect relationships between them.

A unified conceptual framework for the TIMSS study and a universal scale for presenting the evaluation results make it possible to compare the learning achievements of

students from different countries around the world with different educational systems.

The validity of the TIMSS study results is ensured by the representativeness of the sample of students on various stratification indicators.

3 Results and Discussion

Over the more than 20-year history of Russia's participation in this event, many changes have taken place in our country's educational system related to the content of education and the organizational forms of its implementation. Therefore, using the theoretical method of analysis, comparison, generalization, and subsequent interpretation, it is of interest to analyze the dynamics of the results demonstrated by Russian schoolchildren.

Russian 8th graders have been participating in the TIMSS study in Mathematics and Science since its beginning in 1995. The 4th grade pupils began to be tested a little later, beginning in 2003. Therefore, for the Russian education system, the participation in 2019 represents the seventh phase of the International Study. In particular, there were pupils from 49 subjects of the Russian Federation who participated in the TIMSS 2019 study. Each educational organization participating in the study evaluated the learning outcomes of either one 4th or 8th grade class. Thus, the total number of TIMSS 2019 participants representing Russia was 14,050 people, including 7,163 fourth-grade pupils and 6,887 eighth-grade pupils" [9].

Table 1 shows the dynamics of the results of Russia's participation in the TIMSS study in different years, showing the rating scores of Russian schoolchildren in the studied academic subjects.

Table 1. Outcomes of Russian schoolchildren in the TIMSS study.

Year of participation	1995	1999	2003	2007	2011	2015	2019
Research area	Average score based on the international scale						
Mathematics Grade 8	524	526	508	512	539	538	543
Natural Science Grade 8	523	529	514	530	542	544	543
Mathematics Grade 4	-	-	532	544	542	564	567
Natural Science Grade 4	-	-	526	546	552	567	567

The outcome dynamics presented in Table 1 shows that for the 8-grade secondary school Russian pupils, mathematical literacy turned out to be a failure in the 2000s, compared to the average scores of their peers in the 1990s. These experimental facts can probably be explained by the crucial processes in the Russian education system associated with modernization changes in the content of education, the implementation of new educational standards, etc., which started just in the early 2000s. It took more than 10 years for educators to adapt to new educational trends, and by 2011, having overcome the recession, the Russian 8th graders showed a significant increase in average scores on the international scale compared to similar indicators in the first phase of the study in 1995. For example, in 2011 for this category of pupils the quantitative increase in achievement was 13 points in mathematics and 19 points in natural sciences, and the mastery and demonstration of natural science knowledge appeared to have an earlier tendency to increment. Table 1 also shows that 8th grade science pupils had reached the level of their 1999 peers by 2007.

However, a comparative analysis of the average scores on the international scale for the Russian 8th grade pupils in 2011, 2015, and, further in 2019, can be interpreted ambiguously.

On the one hand, pupils still demonstrate a high level of mathematical and scientific literacy, but on the other hand, the lack of significant increases in the scores in the last three phases of the TIMSS study is an indicator of certain stagnation in mathematics and, especially, in science education in Russia.

A similar trend is also evident for the 4th grade pupils, characterized by a lack of meaningful increases in performance over the last 2 phases of the study in 2015 and in 2019, compared to steady increases in scores in 2003 and 2007 in math and especially in science, starting in 2003.

To analyze the current situation in the Russian Science and Mathematics education, a comparative analysis of the performance of Russian schoolchildren based on the materials of the last phase of the TIMSS study in 2019 was conducted (Table 2).

Table 2 shows that the results of Russian schoolchildren differ significantly from the top of all the rankings, the Singapore pupils. Thus, the ranking scores in Mathematics are less than the leaders by 58 points in 4th grade, by 73 points in 8th grade. A more positive result is in Natural Science, as 4th graders are 28 points less than the leaders and 8th graders are 65 points behind. As discrepancies exceed the statistical error limit of 5%, it is of interest to assess the content component in the educational programs of the Russian Federation and the top-ranking countries.

Many influences determine pupils' academic achievement. First of it is the internal motivation of pupils, determining the readiness to master the content of training at the conceptual level, as well as the quality of training associated with the objective criteria of the availability of facilities in the educational institution and subjective factors, in particular, such as the professional competence of teachers.

In the TIMSS technology, the universal objective criterion that determines the ability of pupils to learn is the teaching time of the educational program (EP) and the amount of teaching load dedicated to the teaching of Mathematics and Natural Sciences from the total number of its academic hours.

Table 2. Russian ranking and some countries participating in the TIMSS study 2019.

No.	Country scores in the ranking							
	Mathematics Grade 4		Mathematics Grade 8		Natural Science Grade 4		Natural Science Grade 8	
1	Singapore	625	Singapore	616	Singapore	595	Singapore	608
2	Hong Kong	602	Taiwan	612	Korea, Rep.	588	Taiwan	574
3	Korea, Rep.	600	Korea, Rep.	607	Russian Federation	567	Japan	570
4	Taiwan	599	Japan	594			Korea, Rep.	561
5	Japan	593	Hong Kong	578			Russian Federation	543
6	Russian Federation	567	Russian Federation	543				
Average score of the TIMSS scale		500		500		500		500

Table 3 shows the TIMSS 2019 results based on principals' and teachers' reports of the total number of instructional hours per school year and the hours spent on teaching mathematics and science in the fourth and eighth grades, respectively.

From the data presented in Table 3, it is evident that for all the numerous discussions of the pedagogical community about overburdening of the Russian schoolchildren, the total annual volume of educational programs in primary and secondary comprehensive schools in Russia on average is one third less than the volume of educational programs for the corresponding age group in South-East Asia and the Pacific, which form the leading group.

Table 3. The volume of educational programs based on the results of the TIMSS study 2019.

Country	Total number of hours in the educational programs		Course load volume in Mathematics				Course load volume in Natural Sciences			
	Grade 4	Grade 8	Grade 4		Grade 8		Grade 4		Grade 8	
			Hours	%	Hours	%	Hours	%	Hours	%
Singapore	1009	1053	211	20.91	136	12.92	84	8.33	112	10.64
Hong Kong	1022	999	152	14.87	143	14.31	-	-	104	10.41
Republic of Korea	694	933	101	14.55	106	10.61	71	10.23	87	9.32
Taiwan	953	1137	147	15.42	157	13.81	86	9.02	136	11.97
Japan	904	1036	151	16.70	105	10.14	92	10.18	133	12.84
Russian Federation	663	868	102	15.38	142	16.36	48	7.24	220	25.35

Evaluating the total amount of teaching time for the study of Mathematics and Natural Sciences in the 8th grade of the Russian comprehensive school, it is concluded that both in absolute (362 hours) and relative (41.71%) equivalent it is significantly more than in any country whose pupils have a higher performance ranking. For example, in the educational programs of Singapore, the Republic of Korea, Hong Kong, Taiwan, and Japan, the total volume of Mathematics and Natural Sciences on average does not exceed a quarter of the total time of the EP in the academic year.

An assessment of the workload of Mathematics and all Science disciplines separately leads to the conclusion that the amount of mathematical knowledge in the curriculum of Russian 8th graders is approximately comparable with the corresponding volume of the curriculum in the other leading group countries. The scores of Russian 8th graders are almost 12% lower than the leader, which can probably be explained by a significant difference in the structure of the 8th grade Mathematics test from the Russian basic school curriculum (as assessed by FIEEQ). The almost equal implementation of Mathematics in Grade 8 in the absolute quantitative equivalent of teaching hours and the presence of differences in the content of mathematical knowledge, enable to assess positively the 6th place of pupils in this age category in the overall TIMSS rating and to conclude about the sufficient degree of effectiveness of teachers in this subject area.

Analyzing the Natural Science field of knowledge of this age group, it is worth mentioning that of all the leading countries participating in the TIMSS study, only Russia teaches Natural Science as a separate subject in the eighth grade of a secondary comprehensive school. The amount of academic hours in Biology and Chemistry is 54 hours per year, Physics - 60 hours, Geography – 52 hours, amounting to a maximum of 220 hours of science education in the academic year, which is about a quarter of the total amount of academic time. At the same time, the exceeding of the total volume of hours in Natural Sciences by almost 2 times in comparison with other leading countries provides 8th graders only 5th place in the overall ranking and 65 points behind the leader in its category, the Singapore pupils. This fact points to the need to assess the quality of science teachers and their professional competence. Mastering the subject didactic and methodological elements of competence should allow teachers to optimize the learning process and increase its results.

An analysis of the academic achievements of elementary school graduates suggests that 4th graders, master the content of Mathematics and Natural Sciences in a minimal amount, 1.5–2 times less than the countries of the leading group. In this situation, Russian schoolchildren do not exhibit worse results compared to their peers, demonstrating a sufficient degree of qualification of elementary school teachers.

Summarizing these facts, we can conclude that the learning achievements of the Russian schoolchildren of different age categories are significantly influenced by factors associated with the motivation of pupils themselves and the professional competence of teachers, one aspect of which is the ability to stimulate pupils' interest in their subject area and to demonstrate its practical relevance.

This conclusion is supported by the results of a survey of Russian undergraduates, who, like all other participants in the TIMSS 2019 study, were offered contextual questionnaires that assessed:

- pupils' emotional attitudes toward learning Mathematics and Natural Science, where “I like it a lot”, “I like it a little”, and “I don't like it at all” indicators are used as evaluation criteria. [9];
- confidence in mastering a given subject area, where the indicators are the degree of the assessed characteristic “fully confident”, “doubtful”, “not confident” [9];
- value orientations, which are associated with the comprehension of the significance of the studied material and awareness of the practical value of studying the studied subject areas [9].

Table 4 presents an analysis of the results of the survey of Russian schoolchildren according to the given indicators, which leads to disappointing conclusions.

It has to be said that in the transition from the primary to the secondary level of comprehensive education, interest in learning Mathematics is declining. As a result, more than 2.5 times the number of schoolchildren who enjoy studying this subject area decreases. At the same time, the number of pupils for whom the subject remains only partially to their liking is practically unchanged as a percentage of the total number of pupils. It should also be admitted that the number of respondents who stop liking Mathematics altogether has more than doubled. These indicators fully correlate with changes in the number of pupils who are fully confident in their mathematical literacy and those who are not at all confident in it.

A similar trend can be observed in the Natural Sciences. Thus, the shift from studying an integral discipline in 4th grade, which 44% of learners highly enjoyed, to an average of 59% fewer learners retain a positive attitude toward the various subject areas of natural science at the end of comprehensive secondary school. By the same percentage of pupils, on average, the proportion of those who dislike science-related subjects increases.

The results of the study also indicate that the decline in cognitive interest and confidence in their knowledge that Russian 8th graders exhibit occurs against the background of the majority of them (about 80%) understanding to some degree the value of mathematical and natural science knowledge.

This fact means that using the values of personality, a professionally competent teacher can stimulate the cognitive interest of learners in their field of knowledge. However, analysis of the answers of the Russian respondents suggests a cause-and-effect relationship between the decline in cognitive interest among some learners and the formal teaching of many schoolteachers of Mathematics and Natural Sciences subjects in the general secondary school.

This fact is confirmed by a survey of pupils who were questioned about aspects of learning during Science classes. In particular, questions were asked about whether they knew what the teacher expected of them; whether the teacher understood them easily; whether the teacher gave clear answers to their questions; whether the teacher explained the science well; whether the teacher made it varied; whether the teacher helped the pupils to learn; whether the teacher connected new lessons with previous knowledge; whether the teacher explained the topic again if the pupils had not understood it. The responses were combined into a scale of learning clarity in Science lessons, on which 3 indicators were highlighted: “high clarity,” “moderate clarity,” and “low clarity.”

An analysis of the results [9] for the Russian 4th graders shows that about three-quarters of students (76%) reported “high clarity” in their Science lessons, 21% reported “moderate clarity,” and only 3% characterized their lessons as having “low clarity.” These answers are correlated with the presence of cognitive interest and confidence in their knowledge in many 4th graders on other assessment scales.

Eighth-grade learners were less positive about the clarity of science instruction compared to fourth-grade ones. And the change in clarity of the curriculum material and teacher requirements for 8th graders has almost identical quantitative results in each of the four subject areas. Only about 45% of learners reported “high” learning clarity, about the same number reported “moderate,” and about 11% admitted to “low” learning clarity. The decrease in the clarity of the requirements of science teachers, when comparing surveys of 4th and 8th graders, completely correlates with a decrease in cognitive interest in these subject areas (by 59%) and contributes to the appearance of uncertainty about their knowledge (by 50%) in 8th graders.

Table 4. Results of the TIMSS 2019 Contextual Questionnaire Survey of the Russian Schoolchildren.

	Mathematics		Natural Science				
	Grade 4	Grade 8	Grade 4	Grade 8			
				Biology	Chemistry	Physics	Geography
Enjoying the study of science	Portion, %	Portion, %	Portion, %	Portion, %	Portion, %	Portion, %	Portion, %
Enjoy it very much	42	17	44	26	27	29	22

Enjoy to some extent	41	46	42	52	47	50	52
Dislike it at all	17	37	14	21	26	21	26
Confident in their knowledge							
Fully	24	12	29	21	17	17	23
Doubtful	46	44	46	51	36	45	51
Not sure	30	45	24	28	48	38	26
Appreciate the subject							
Highly esteemed		26		32			
Appreciate to some extent		53		50			
Do not appreciate		21		18			

4 Discussion

A comprehensive assessment of the current stage of scientific education in secondary education in Russia leads to the primary conclusion that Russian schoolchildren have a sufficiently high mathematical and natural science literacy, which is confirmed by the TIMSS study.

The high scores in the TIMSS rankings for all years of our country's participation in the study indicate, in our opinion, the stability of the Russian educational system regarding fundamental mathematical and natural science education.

However, it must be assumed that rethinking the directions of educational development is impossible without considering the underlying processes taking place in the depths of basic secondary education. At the same time, the quantitative results of the TIMSS study, rating scores and assessments of Russian schoolchildren enable some conclusions to be drawn, which may be useful for the further strategic development of the Russian education system.

In particular, the lack of significant increments in the scores of Russian schoolchildren is an indicator of the lack of positive dynamics of growth in the quality of basic math and science education. Establishing the fact of certain stagnation in these subject areas should help to comprehend the main trends associated with the need to ensure the fundamentalization of education as the main condition for innovative socio-economic development of Russia.

Establishing the fact of unacceptability “in modern conditions of loss of fundamentality of secondary education and recognizing the need to return to fundamental, timeless knowledge” [3], it is possible to confirm that it is the fundamentality of education that is one of the main trends in educational practice [4], which will ensure the formation of competences demanded in the modern high-tech world of end-to-end technologies, digital twins, convergence of different fields of knowledge. It should be noted, however, that the scientific worldview and its inherent rationality are not synonymous with the “functional” human being [10], who is incapable of evaluating, from a humanistic standpoint, the goals of societal development [10], who is unable to assess from a humanistic standpoint the goals of society's development and the ways to achieve these goals. In the “cretinism of narrow professionalization” and the “displacement of worldview reference points” [10], it is not natural science knowledge that is to blame, but its specific carrier.

An assessment of the quantitative volume of the mathematics and science subject areas in high school indicates a structural relationship between science and humanities knowledge, the latter being in favor. In primary schools in particular, the total amount of fundamental subjects does not exceed 25% of the educational program. In the transition to high school the portion of such disciplines increases, but does not exceed 45% of educational programs. This circumstance reflects the dualistic unity of both natural science and humanities knowledge, which should be the basis for the development of creative independent thinking of pupils, who in the future will become transprofessionals in modern society.

The comprehension of the results of the questionnaire of Russian schoolchildren enables to establish the need to improve the professional competence of teachers of natural science disciplines in secondary schools in the field of its subject, didactic, educational, methodological, and psychological and pedagogical components. In particular, the implementation of the interdisciplinary nature of the educational process, which is practiced in various educational systems around the world, makes sense. So-called STEM learning places special demands on the teacher, who must have integrated knowledge of Mathematics, Natural Sciences, and Technology [11], be fluent in computer programs, be motivated to work with children, and be skilled in didactics. The implementation of such a training profile in master's degree programs of teacher education in Russia has already begun, but this trend should have legislative support at the state level, ensuring the need to improve the qualifications of teachers working with students of this age category.

In conclusion, it is worth noting that in different scientific discussions about the priorities of natural science or the humanities, their opposites exist only in the minds of certain individuals. Natural-scientific thinking doesn't prevent in any way the “search for culturally conditioned meanings in the humanities (in particular in education)” [5]. It is clear that “a reasonable combination of technical and humanitarian components of education is needed” [10] with the aim of shaping not only high professional competencies of today's students, as well as general cultural moral values and strong moral principles that enable them to reach not only professional heights and career growth, but to become highly developed in the spiritual sense.

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