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On improving the quality of natural science education in Kazakhstan

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Abstract. *Introduction.* Modern world globalisation process requires special technological development of states, which is based on natural science and engineering education. The *aim* of this article is to analyse existing programmes and methods of teaching natural science in Kazakhstan and to develop recommendations for making changes to the content of natural science education programmes in secondary schools. *Methodology and research methods*. A monitoring study was conducted on teachers' assessment of the content of school education in natural science subjects, utilising system-based, problem-based, and project-based approaches. This study included an analysis of international experiences in implementing STEM education within the teaching processes of natural sciences, as well as an evaluation of the effectiveness of the updated Model Curriculum for natural science education in general education schools in the Republic of Kazakhstan. *Results*. It was found that in the learning process, it is essential to enhance attention to the formation and development of scientific thinking skills and interdisciplinary integration. The findings confirm that practice-oriented training facilitates an understanding of how scientific knowledge evolves and helps to cultivate an appreciation for cross-cutting concepts and disciplinary ideas within science and technology. *Practical significance*. A series of recommendations has been formulated to enhance the curriculum of academic programmes in the natural sciences in the Republic of Kazakhstan.

Keywords: school education, natural science training, natural science education, mathematics, math education, school science, school mathematics, STEM

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Пути повышения качества естественнонаучного образования в Казахстане

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Аннотация. *Введение.* Современные мировые процессы глобализации предъявляют особые требования к технологическому развитию государств, которое базируется на естественно-научном и инженерном образовании. *Цель* статьи – анализ существующих программ и методик обучения естественным наукам в Казахстане и выработка рекомендаций по внесению изменений в содержание программ естественно-научного обучения для общеобразовательных школ. *Методология, методы и методики*. На основании системного, проблемного и проектного подходов проведено мониторинговое исследование оценки учителями содержания школьного образования по учебным предметам естественно-научного направления, в том числе анализ международного опыта внедрения STEM-образования в процессы обучения естественным наукам и эффективности влияния обновленной Типовой учебной программы обучения на состояние преподавания блока естественно-научных дисциплин в общеобразовательных школах Республики Казахстан. *Результаты.* Установлено, что в процессах обучения необходимо усилить внимание к формированию и развитию навыков научного мышления и междисциплинарную интеграцию. Подтверждено, что практико-ориентированное обучение помогает понять, как развиваются научные знания, сформировать понимание сквозных концепций и дисциплинарных идей науки и техники. *Практическая значимость*. Разработан ряд рекомендаций по внесению изменений в содержание программ по учебным предметам естественно-научного цикла в Республике Казахстан.

Ключевые слова: школьное образование, естественно-научная подготовка, естественно-научное образование, математика, математическое образование, школьная наука, школьная математика, STEM

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Introduction

In the modern world, there are active processes of globalisation. The challenges of the fourth industrial revolution, which predicts the introduction of artificial intelligence and cyber-physical systems into the life of mankind, set Kazakhstan the task of raising the education level. In particular, we are talking about teaching the natural sciences, which is one of the components of the country's competitiveness in the international arena in the field of natural science and technology.

The problem of formation of science literacy has attracted the attention of researchers all over the world since the 60s of the last century. During this period, reforms in science education have been carried out, many concepts and educational programmes have been created, political decisions have been made and implemented at governmental levels; scientific literacy has become a key topic all over the world.

In 1998, the OECD established the Programme for International Student Assessment (PISA) [1], the results of which prompted a number of countries to focus their efforts on developing students' functional literacy – the ability to use knowledge and skills to solve real-life problems and tasks in everyday life. Science curricula have been revised to reduce the knowledge component and emphasise the development of general skills and understanding of the nature of science, and strategies have been developed to develop skills in planning and conducting scientific investigations, scientific discussion, theoretical observation, and developing scientific models [2].

Nevertheless, analyses of long-term trends in educational attainment and equity show that in science, the average performance of OECD countries declined between 2009 and 2018 before reaching relative stability [3, 4]. This decline is a clear indication of the crisis of science education globally.

For Kazakhstan, the urgent need for a deep reconsideration of the root causes of science education problems becomes especially evident against the background of moderate results of 15-year-old schoolchildren in international comparative studies. Thus, in the PISA-2018 study, Kazakh students scored 423 points, behind the average of 485 points in OECD countries and ranked 49th among 81 countries. Despite the positive dynamics with an increase of 26 points compared to the previous studies, Kazakh pupils still lag significantly behind their peers from OECD countries: 45.2% did not reach the basic second level, while in OECD countries this indicator is 24.5%. This indicates pupils' inability to recognise correct explanations of familiar scientific phenomena and assess the validity of conclusions based on the proposed data. Fifth and sixth, the highest levels, where knowledge is applied creatively and independently in various, including unfamiliar, situations, were reached by only 0.8% of examinees, compared to 7.5% in OECD countries [5].

The content of science education in Kazakhstan demonstrates a noticeable lag from world standards in terms of teaching methodology and the level of competences and skills achieved. Curricula are still reproductive and knowledge-based, and disciplines of natural-mathematical direction have remained within the academic tradition. The introduction of the updated educational content is intended, among other things, to develop functional literacy, but, as noted by experts in the educational sphere, there is a problem of over-saturation of programmes with academic issues and a lack of practice-oriented tasks aimed at the development of competencies in the educational complexes of science subjects. The strong presence of cross-curricular links in primary education in cross-cutting themes is lost at the secondary level, reducing students' ability to solve complex problems requiring science literacy [6].

This approach does not take into account the potential of students to develop a scientific worldview. Therefore, improving the teaching of natural sciences, developing national tools and technologies that promote the application of knowledge to solve a variety of learning and practical problems is of key importance at the current stage of development of science education. The present article aims to analyse the existing programmes and methods of teaching natural sciences in Kazakhstan, as well as to develop recommendations for changes in the content of educational programmes for secondary schools.

Literature Review

Analyses of educational policies and practices of the most successful countries in international comparative studies have shown the main strategies for reforming science education, which can be taken into account when developing recommendations for Kazakhstani secondary education.

Finland. Finland has avoided the drive popular in Anglo-Saxon countries to harmonise educational standards and encourage frequent external testing, as well as reducing the curriculum to basic reading and mathematics. Over forty years of transformation, the country has moved away from a centralised system relying on external tests to a more localised model where curricula are created by teachers based on minimum national requirements. Finland focuses on teacher training, doing away with examinations to equalise educational opportunities for all students. The current National Core Curriculum is an elegant document of approximately 10 pages of guidelines for each subject, which inspires teachers to co-design local curricula and assessment methods. Science, technology and innovation are central to the reform, emphasising the development of creative thinking and self-directed learning. Under the wise guidance of teachers, students choose tasks that they complete according to individual weekly goals, working at their own pace. The focus of the educational process is on research, and teacher training in this area has become a key to improving teacher education in Finland. Thanks to innovative teaching and learning, Finland is now the leader among OECD countries in PISA results. Similar strategies have been successfully implemented in Australia, New Zealand and Canada, which are performing well, and in the Chinese provinces of Hong Kong and Macau, which are showing similar achievements[1].

Singapore. In the 2018 PISA results, Singapore ranked 1st in science literacy with 556 points. As early as the 1990s, the country saw a paradigm shift in education from a model based on knowledge transfer to one of creativity and independent learning. Curriculum and assessment were changed with emphasis on project work and creative thinking (OECD, 2016).

USA. The Commission on Excellence in Education's report, A Nation at Risk, in the early 1980s ushered in an era of standards-based reform. In 1985, the American Association for the Advancement of Science (AAAS) launched Project 2061[2], which explores and benchmarks science education. This project resulted in the creation of the Science for All Americans programme, which defines the goal of science education as the development of scientific literacy[3]. It was the basis for the first National Science Education Standards (NSES: National Science Education Standards) [7], the Next Generation Science Standards (NGSS: Next generation science standards) [8] and teaching materials, and further expanded the profile of science, technology, engineering and mathematics (STEM) education. The NGSS are an evolution of the NSES in American science education; the changes are reflected in the scope of science knowledge, the learning process and prioritisation, and there is an emphasis on engineering within science education [9].

England and Wales. In 1992, the system of objectives was significantly reduced as a result of a curriculum review [2]. The introduction of "Science Literacy for All" in England has included changes in the curriculum in recent years: the development of specific strategies for developing research skills, such as argumentation,

[1] https://edpolicy.stanford.edu/library/publications/543.html
[2] https://www.aaas.org/programs/project-2061
[3] http://www.project2061.org/publications/sfaa/online /

that promote the inclusion of different perspectives, and therefore pupils' voices, in discussions.

China. In China, science has been included in the school curriculum from grade 1, and the standard of integrated science curriculum for students in grades 7–9 is implemented along with the curriculum standards for physics, chemistry, biology, and geography for both junior and senior high schools [10]. An STS (Science, Technology, and Society) curriculum component has also been developed and implemented. In 2017, STEM education was included for the first time in the "New Learning Standards" for primary schools in science [11].

However, there is also a view that challenges the validity of the concept of science learning in terms of PISA and the propositions that follow from it [12]. According to this view, striving to improve PISA results is detrimental to the quality of science learning. There are no studies to date that correlate PISA results with the science attainment of students at the end of secondary school.

Science education standards now place more emphasis on STEM, which does not focus on society and the environment, as opposed to STSE (Science, Technology, Society and Environment) which focuses on democracy and global citizenship. The low US performance in PISA seems to be due to the rise of STEM and the decline of STSE [12].

The research conducted by G. Nelson & C. Landel has shown that to be fully effective, reforms must begin in primary school [13]. For this level of education, the problem of teacher training is particularly acute worldwide. Four models of science teaching programme at primary level have been proposed to solve this problem [14, 15]:

1. Classroom teachers teach science subjects.
2. Science subject teachers with their own subject rooms provide resources and support to other class teachers.
3. Science subject teachers provide direct instruction at different grade levels.
4. On a district basis, science specialists serve as a source of information and support for classroom teachers in several schools.

Thus, international experience in reforming science education has shown the following main strategies:

- increasing the length of time spent in science education: emphasising basic learning in primary school;
- standardisation of the curriculum or decentralisation of the educational system;
- reducing the learning objectives in favour of the development of research practice;
- improving the content of science education;
- developing students' creative thinking and management of their own learning;
- integrated, problem-based learning, learning by enquiry;

– integration of engineering and technological content into science education; and
– teacher training.

Materials and Methods

During the monitoring study of the implementation of the updated educational content (March–July 2022) under the scientific project "Scientific Foundations for the Modernisation of the Education and Science System" (2021–2023), the research group set the following tasks:

- to check in practice the effectiveness of the Model Curriculum, EMC (educational and methodical complex) and the system of criteria-based assessment;

- to reveal:

a) the degree of compliance of the educational content and its implementation with national values and their focus on the formation of functional literacy;

b) the degree of compliance of the content of training programmes and teaching materials with the main provisions of the State Educational Standards;

c) the degree of use of the teaching and assessment methods recommended by the curriculum (understanding and application);

- to develop recommendations for finalising curricula, teaching materials of the updated educational content (if necessary); and

- to determine the strategy and prospects for improving the content of secondary education in the Republic of Kazakhstan and the learning process.

The results of field studies represent data sets that are difficult to process only by the "manual method". During the study software packages were used to optimise the analysis procedure: Vortex, SPSS (SPSS – Statistical Package for the Social Sciences).

The main sources of information were:

- interviews and surveys (questionnaires, focus groups, in-depth interviews); and
- observation (in the classroom).

Focus groups (face-to-face interviews) were formalised. A survey scheme was prepared (a questionnaire containing pre-prepared clear wording of questions and well-thought-out models of answers to them). In-depth interviews were a series of individual interviews on monitoring topics, conducted according to the Discussion Instructions. Four categories of respondents participated in the survey, focus groups:

1. Administration of educational organisations;
2. Teachers;
3. Students; and
4. Parents of students.

In total, 96 schools of the country took part in the focus groups, of which 39 were rural, 57 were taught in Kazakh, 33 were Russian, and 6 were Uzbek.

The total number of respondents, including subject teachers, administration and other pedagogical workers (social pedagogue, educational psychologist, teaching assistant, and medical worker), included 1438 people, 4th-grade students included 54 people, 5–9th-grade students included 493 people, 10–11th-grade students included 601 people.

For both young and experienced teachers to have the opportunity to be heard under the study, the authors observed the proportions of representation of different respondent categories in the focus group. Thus, in focus groups, 29% of teachers have more than 20 years of work experience. The proportion of respondents with 11–15 and 16–20 years of teaching experience is equivalent (14%), slightly less is the proportion of respondents with 6–10 years of experience (16%). The percentage of participation of young professionals is 12%, teachers with 3–5 years of experience – 9%. In the total population, 54% of the participants were teachers with experience up to 15 years and 46% with teaching experience of 16 years or more (Fig. 1).

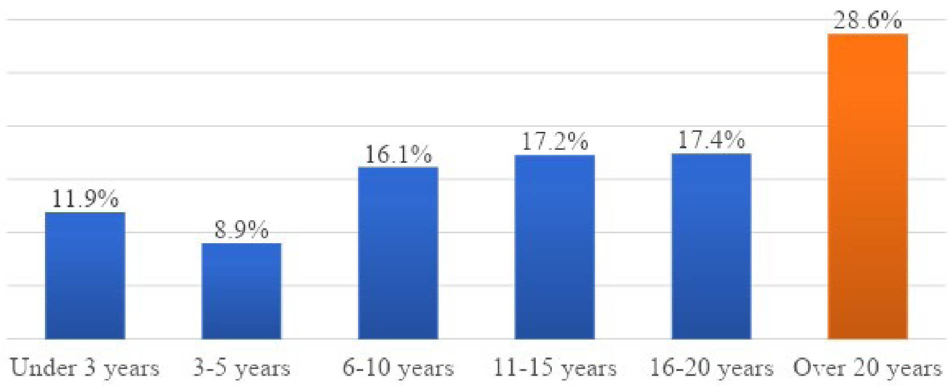

Fig. 1. Composition of focus groups of teachers by length of service, %

Source: Educator survey data in Google Forms

Processing of the results of the survey of teachers in Google Forms was performed in the SPSS program.

Results and Discussion

School teachers are the people most aware of the practical implementation of educational policy. Their participation in the study allowed us to identify the practical reasons for the low academic performance of students.

51.5% of teachers disagree and are neutral with the statement “The programme in my subject is not difficult for most students” (Fig. 2).

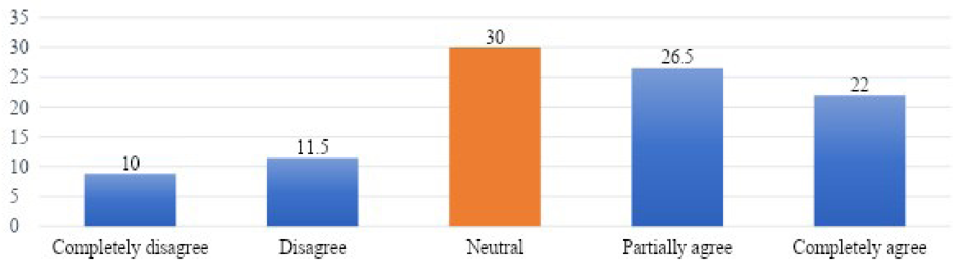

Fig. 2. The degree of teachers' agreement with the statement "The programme in my subject is not difficult for most students"

Evaluation by teachers of the school education content in subjects of the natural sciences is far from positive. With the statement "The programme in my subject is not difficult for most students", 35.8% of the interviewed teachers are "*neutral" in the subject "Biology", 35.9% in the subject "Physics", 40% in the subject "Chemistry".*

The proportion of respondents who *partially agree* with this statement is 33.3% in physics and 23.8% in chemistry (Table 1).

Table 1

The degree of agreement/disagreement of teachers with the statement "The programme in my subject is not difficult for most students", % of respondents in the context of the taught subjects

Response scale	1	2	3	4	5
Biology	11	15,6	35,8	19,3	18,3
Geography	17,9	15,4	26	25,2	14,6
Natural science	14,3	7,9	36,5	25,4	15,9
Computer science	8	10	34,8	27,4	18,4
Mathematics	10,5	15,6	35,4	27,9	10
Physics	9,4	7,7	35,9	33,3	12,8
Chemistry	11,4	13,3	40	23,8	10,5

Note. 1 – completely disagree, 2 – disagree, 3 – neutral, 4 – partially agree, 5 – completely agree.

Source: Educator survey data in Google Forms

The older the teachers' age, the more opinions among them that the programmes are not aimed at development students' practical skills. Thus, the proportion of young teachers who do not agree with the statement "The programme in the subject contributes to the development of students' practical skills" is 2 times less than teachers aged 51–60 and over 60 years. More than 60% of teachers under the age of 30 completely agree / partially agree with this statement (Table 2).

Table 2

The degree of agreement/disagreement of teachers with the statement "The programme in the subject contributes to the development of students' practical skills" by age groups

Response scale	Teachers' age, number of people, %				
	20–30	31–40	41–50	51–60	61+
Completely disagree	4.2	5.7	7.4	7.6	6.4
Disagree	6.5	8.4	10.5	13.0	15.6
Neutral	24.2	27.6	32.3	30.3	33.0
Partially agree	31.6	31.2	25.7	26.6	24.8
Completely agree	32.4	26.4	25.7	21.9	18.3
Skipping answers	1.1	0.7	1.5	0.6	1.8
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Educator survey data in Google Forms

Table 3 demonstrates the proportion of teachers who "completely or partially agree" with the fact that the programme contributes to the development of students' practical skills prevails among the subjects "Physics" (54,7%), "Chemistry" (45,7%), "Biology" (38.5%).

Table 3

The degree of agreement/disagreement of teachers with the statement "The programme in the subject contributes to the development of students' practical skills" in the context of the taught subjects

Response scale	1	2	3	4	5
Biology	15,6	12,8	33	20,2	18,3
Geography	21,1	13,8	26,8	22,8	13,8
Natural science	14,3	11,1	39,7	17,5	17,5
Computer science	9	14,9	28,4	29,9	15,9
Mathematics	7,7	14,6	32,8	27,2	17,2
Physics	8,5	6	30,8	32,5	21,4
Chemistry	12,4	10,5	31,4	21	23,8

Note. 1 – completely disagree, 2 – disagree, 3 – neutral, 4 – partially agree, 5 – completely agree.

Source: Educator survey data in Google Forms

As the results of the study showed, in the learning process, not enough attention is paid to the independent and practical work of students in the lessons of the natural sciences, and the students themselves are not sufficiently motivated to acquire knowledge and apply it in life.

Thus, the monitoring study of the implementation of the updated content of education has shown that almost half of the surveyed teachers acknowledge the complexity of the programme of natural science subjects for students of Kazakhstani schools. The programmes are not aimed at developing students' practical skills, do not motivate them to acquire knowledge and apply it in life.

In order to analyse existing programmes and methods of teaching natural sciences in Kazakhstan, as well as to develop recommendations for making changes to the content of training programmes in the field of natural science education, the authors measured the number of learning outcomes in the curricula of secondary schools.

Table 4 shows the number of learning objectives provided by the Model Curriculum of the Republic of Kazakhstan in natural science subjects at the level of basic secondary education. Students have a choice of standard curricula and curricula with a reduced teaching load. In accordance with the order of the Ministry of Education and Science of the Republic of Kazakhstan dated October 30, 2018, No. 595 "On approval of the Model Rules for the Activities of Educational Organisations (Primary, Basic Secondary and General Secondary)", educational organisations, regardless of the type and form of ownership, independently choose Model Curricula, including those with an abbreviated training load, on which the learning process is performed[1].

Table 4

The number of learning objectives provided for by the Model Curriculum of the Republic of Kazakhstan in natural science subjects level of basic secondary education

Item	Sections	Subsections	Learning objectives	
			Main programme	Abridged programme
Biology	4 (17%)	18 (26%)	211 (25%)	140 (21%)
Chemistry	5(22%)	16 (23%)	230 (27%)	182 (29%)
Geography	6 (26%)	14 (20%)	182 (22%)	143(23%)
Physics	8 (35%)	21(30%)	223 (26%)	168 (27%)
Total in the country	23	69	846	633

The percentages in brackets show the percentage of specific subjects in the country's total results.

[1] https://adilet.zan.kz/kaz/docs/V1800017657

A review of foreign literature did not reveal an unequivocal opinion regarding the optimal number of learning goals that schoolchildren must reach within the secondary school.

P. Kácovský, T. Jedličková, R. Kuba et al. [16] compared the number of compulsory learning outcomes in natural science subjects included in national curricula in a number of European countries (Table 5).

Table 5

Number of required learning outcomes according to prescribed national curricula

Item	Czech	Estonia	Poland	Slovenia
Biology	31 (27%)	125 (34%)	109 (31%)	187 (30%)
Chemistry	27 (23%)	62 (17%)	84 (24%)	98 (16%)
Geography	29 (25%)	84 (23%)	69 (19%)	158 (26%)
Physics	29 (25%)	95 (26%)	95 (26%)	175 (28%)
Total in the country	116	366	357	618

The percentages in parentheses indicate the proportion of specific subjects within the country's overall results.

When comparing the data in Tables 4 and 5, one can state that the number of learning objectives in Kazakhstan significantly exceeds that of foreign countries: both in the Standard Curriculum and with a reduced teaching load.

The fact of the low level of results of natural science knowledge of Kazakhstani schoolchildren in international studies (PISA, TIMSS) does not speak in favour of programmes in Kazakhstan; in particular, they are overloaded with learning outcomes, which probably affects the quality of natural science education.

An analysis of international studies has shown the features of the basic curricula of the natural sciences in a number of countries (England, France, Czech Republic, Estonia, and Finland) that occupy high positions in the international PISA study [17]:

1. A high degree of integration of natural science subjects, strengthening the interdisciplinary nature of education.
2. Individualisation of work with the student.
3. Modern, problematic coverage of the content of education.
4. Strong emphasis on the use of ICT (Information and Communication Technologies) and the project method, as well as mathematical skills in the natural sciences.
5. Development of students' motivation and skills to manage their further education.

The concept of new standards for US state school science education is based on the idea of learning as a development process, from curiosity to what children see around them and their initial ideas about the world order to a more scientifically based and consistent view of the natural sciences [18]. The concept recommends **a limited** number of core learning objectives to prepare students with **sufficient**

background knowledge to participate in scientific research. The concept also recommends the following areas of science education:

– scientific and engineering practice;

– unification of the study of science and technology for the purpose of their common application in various fields;

– physics; life science; earth and space sciences; and engineering, technology and various science applications.

In the technologically advanced countries of the world, a completely new approach to learning has been developed, STEM education (Science, Technology, Engineering, Mathematics), which combines the natural sciences, mathematics and engineering. In the USA (United States of America), Great Britain, China, Australia, Korea, Taiwan, a curriculum called K-12 STEM (education from kindergarten to grade 12) has been developed, designed as a set of integrative interdisciplinary approaches to each of the STEM disciplines [19]. The leading countries popularise STEM education in the public consciousness on a national scale, carrying out coordination in various forms: a system of state and non-state organisations and associations (USA, China, Finland, Australia, Great Britain, Israel, Korea, Singapore), non-state organisations (STEMNET (Science, Technology, Engineering and Mathematics Network), Engineering UK, England) contributing to the implementation of national school programmes [19]. In the United States, these activities are carried out in accordance with the STEM Education Coordination Act.

In Kazakhstan, as part of the transition to the updated content of school education, active development of STEM education began: curricula contained elements related to the mastering of new technologies and mathematical modelling. Elective courses on the basics of robotics, programming, graphic design, engineering sciences, etc. were conducted in schools in Astana, Almaty and other regions of Kazakhstan [5]. In 2016, the number of schools with classrooms equipped for STEM education was 70% [20].

Nevertheless, the disappointing results of Kazakhstani schoolchildren in international monitoring studies indicate that our country still has much to do to ensure a sufficient level of science literacy to meet the personal, social, professional and intellectual needs of a person throughout life.

Conclusion

Based on the analysis of the research results and conclusions, we recommend changing the content of training programmes in the field of natural science education, including the following:

1. Formulating the general idea of teaching natural sciences, based on the formation and development of scientific thinking skills and the use of the scientific method.

2. Reducing knowledge-centricity in favour of increasing practice-oriented training programmes, increasing interdisciplinary integration in natural science education.

3. Changing the content of teaching natural sciences towards a problem-based and project-based approach.

4. Filling the programmes with content that motivates students to study natural sciences and develop the skills of students to manage their further education.

Regarding natural science education in general, it is necessary to:

1. Create a national concept of natural science and STEM education, which implies centralised coordination of state and non-state organisations engaged in scientific and educational activities.
2. Develop new national standards and school curricula considering STEM disciplines, providing them with assistance at the national level.
3. Develop innovative teaching methods.
4. Train qualified teachers and improve their skills in the field of STEM education.
5. Attract young people to research work with the participation of scientific organisations in the field of the latest innovative technologies.
6. Develop various forms and methods of cooperation between schools, universities and colleges in the field of natural science and STEM education.
7. Modernise the material and technical base of schools (updating equipment, using online platforms for learning, using the resources of universities in the activities of schools).
8. Improve natural science education in the field of additional education.

Subject to the development and effective implementation of natural science and STEM education programmes, considering international best practices, our younger generation will master all the skills necessary for successful self-realisation, competitiveness, and our state will receive qualified specialists for a scientific and technological breakthrough in the international arena in the future.

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