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## COMPARATIVE ANALYSIS OF STEM EDUCATION PRACTICES IN TURKISH AND KAZAKH HIGHER EDUCATION

**Annotation.** The introduction of STEM (Science, Technology, Engineering, Mathematics) knowledge into the modern higher education system is one of the most pressing areas for the development of critical thinking, research skills, and functional literacy among students. The application of STEM-oriented approaches, especially in the teaching of geography, contributes to improving the quality of education through comprehensive analysis of natural processes, modeling, and the use of digital technologies. In this context, a comparative analysis of the experience of introducing STEM education in the Republic of Turkey and the Republic of Kazakhstan is of significant scientific and practical value. The aim of the study is to conduct a comparative analysis of the experience of introducing STEM knowledge into the higher education systems of Turkey and Kazakhstan in the context of developing students' critical thinking and research skills, as well as to identify current challenges and pedagogical opportunities in teaching geography. The study is based on qualitative methodology using documentary and comparative analysis methods. The sources used were official reports from the Department of Innovation and Educational Technologies of the Ministry of Education and Science of the Republic of Turkey, as well as academic and practical experience accumulated at the universities of Istanbul, Aydin, Hacettepe, and Ankara. In addition, the results of experimental studies conducted in Istanbul were analyzed. The results of the study showed that STEM education plays an important role in the development of functional literacy, critical thinking, modeling skills, and research skills in the teaching of geography. It was found that the international Scientix project implemented in Turkey, as well as initiatives to create STEM laboratories at universities, contributed to the systematic development of STEM education. In addition, cooperation between universities and general secondary education institutions was identified as a significant factor in the effective implementation of STEM approaches. It was found that STEM education practices are developing in both countries, but there are differences in the goals and methods of teaching. The results confirm that the rational use of modern digital devices, virtual interactive maps, and three-dimensional models in geography teaching contributes to increasing students' cognitive activity and the formation of subject-specific and meta-subject competencies. The findings of the study can be used to improve STEM education in the Republic of Kazakhstan, as well as to develop educational practices focused on the formation of critical thinking, research skills, and functional literacy among students.

**Keywords:** STEM education, critical thinking, research skills, geography education.

### *Introduction*

In the 21st century, modern digital technologies are developing day by day. In this regard, with optimal access to knowledge and information, there is an increasing number of stakeholders in obtaining new knowledge in the direction of research on the path of science. New innovative systems are emerging to continuously improve the professional qualifications of future educators according to the demands of life [1]. Among them, STEM-educational technology aimed at developing critical thinking skills, Research, modelling, mastering new digital technologies and implementing them in production based on discovering the links between science, technology, engineering and mathematics in future professionals [2].

The development of STEM education in Turkey and Kazakhstan is characterized by diverse institutional and pedagogical approaches. While STEM teaching practices in Turkey are gradually becoming more interdisciplinary and applied in nature, in Kazakhstan, STEM is most often manifested at the level of strategic documents and educational programs. An analysis of these differences allows us to identify ways to effectively implement STEM in higher education. A distinctive feature of this study is a comparative analysis of experimental



observations obtained on the basis of the author's research internship at Istanbul University, combined with scientific literature.

One of the urgent problems is to determine effective methods of its implementation in the educational process, since the increasing pace of digitalisation of all spheres of human society requires the application of the above technology at all levels of the education system, including science, research, digital technologies, modelling and practical use of the obtained results.

At the present stage, much attention is paid to the introduction of STEM-education in the educational process of secondary and secondary specialised and higher educational institutions, providing sustainable development and increasing the economic potential of the state, providing qualified specialists in the production and non-production spheres.

The analysis of data collected in the course of research conducted in the period from 2024 to 2025 has shown that STEM-education is one of the popular learning technologies widely used in the educational process of higher education institutions and general secondary schools of such countries as the USA, Germany, Japan, the Republic of Korea, China, Singapore, Turkey [3].

Therefore, the Concept of Development of Higher Education and Science of the Republic of Kazakhstan for 2023-2029 focuses on the introduction of STEM - educational technologies in the educational process [4].

In accordance with the requirements of the changing information society, as in other states, the Ministry of Education of the Republic of Kazakhstan continues to open STEM classrooms equipped with virtual laboratories functioning in a real-time system in accordance with the standard curriculum of secondary school, the curriculum of disciplines of 3D-graphics, robotics continues [5].

#### *Literature review*

Recent studies highlight the growing significance of STEM-based education in advancing UNESCO's Education for Sustainable Development and the UN Sustainable Development Goals. Integrating STEM principles into geography education supports students' understanding of sustainable development issues and promotes active engagement in solving real-world problems. The development of research skills, spatial thinking, and competitiveness among geography students is increasingly emphasized within modern educational systems.

In the context of the Fourth Industrial Revolution, Kazakhstan seeks to create a technological infrastructure aligned with Industry 4.0, where STEM-focused science education plays a key role [6]. International research demonstrates that STEM integration in natural science disciplines contributes to the formation of an innovative educational environment [7]. For this reason, many countries are incorporating STEM approaches into secondary and higher education curricula [8].

Geography education benefits significantly from STEM methods, which allow the analysis of urbanization, socio-economic inequality, migration, environmental change, natural hazards, and public health indicators. STEM-oriented teaching enhances students' spatial thinking and analytical competencies - skills essential for addressing contemporary challenges. National policy documents, including President K.K. Tokayev's Address and the State Program for Education and Science 2020-2025, emphasize the importance of strengthening scientific knowledge and expanding STEM infrastructure in educational institutions.

However, the implementation of STEM technologies in Kazakhstan's higher education remains limited, mainly due to insufficient laboratory facilities. Despite this, certain elements of STEM are already integrated into teaching practices. International experience shows that STEM laboratories significantly improve the quality of practical geography training by fostering independent research, innovative thinking, and interdisciplinary problem-solving [9]. As a multidisciplinary approach that combines science, technology, engineering, and mathematics, STEM continues to demonstrate substantial pedagogical and methodological value in geography education [1].

#### *Materials and methods*

From April 21 to May 21, 2025, during a research internship at Istanbul University in the Republic of Turkey, a comprehensive study was conducted on the experience of developing students' research activities based on the introduction of STEM educational technologies. The study examined the characteristics of students' critical thinking skills, research skills, modeling, scientific analysis, and forecasting of future developments in natural and socio-economic processes

The empirical basis of the study was formed by official reports of the Department of Innovation and Educational Technologies under the Ministry of Education and Science of the Republic of Turkey in the field of STEM education, as well as the experience of developing students' professional research activities accumulated at the universities of Istanbul, Aydin, and Hacettepe. These sources made it possible to identify the logic of implementation, pedagogical advantages, and institutional features of STEM education in the higher education system.

The study used methods of comparative analysis, generalization, and evaluation. The results of the analysis showed that laboratory work and experimental control tasks organized within the framework of STEM



education are implemented in an optimal structure and systematically, and are also aimed at developing students' scientific thinking.

Methodologically, the study was based on a qualitative comparative analysis approach. Document analysis was used as the main method, without conducting empirical surveys or experimental research. Document analysis allowed for a comparative assessment of the theoretical and methodological foundations of STEM education, implementation experience, and pedagogical models in the higher education system.

The study systematically analyzed the following sources:

- Scientific articles on STEM and FETEMM education in Turkey;
- Studies analyzing STEM competencies and educational programs in Kazakhstan;
- Scientific publications on STEM in the fields of geography, climatology, and ecology;
- Academic observations made by the author during a research internship at Istanbul University.

A comparative analysis was conducted based on the following main criteria:

STEM institutional place of education; pedagogical models used; level of staff training; proportion of teaching content and applied components; Potential for transferring STEM experience.

This methodological approach made it possible to scientifically substantiate the characteristics, level of development, and directions for further improvement of STEM education in the higher education systems of Turkey and Kazakhstan.

In order to supplement the results of the documentary analysis of the study and to reveal the practical aspects of implementing STEM knowledge in greater depth, expert interviews were used during the research internship. Expert interviews were conducted with academic staff directly involved in STEM-oriented teaching and research activities. In particular, professors and lecturers from the universities of Istanbul, Aydin, and Hacettepe who teach geography, physical geography, climatology, and ecology were involved in the research.

The main purpose of the expert interviews was to identify effective pedagogical practices, institutional conditions, and challenges in integrating STEM technologies into higher education curricula. Particular attention was paid to STEM-based teaching approaches that promote the development of critical thinking, research skills, modeling skills, and interdisciplinary competencies in students. The interviews were conducted in a semi-structured format, which allowed experts to freely describe their professional experience, teaching strategies, and the specifics of organizing laboratory and project work. The data obtained was qualitatively analyzed and systematized using thematic analysis. The results of the expert interviews made it possible to refine the conclusions obtained during the documentary and comparative analysis and to determine the relationship between institutional policy and actual teaching experience.

The use of expert interviews increased the reliability and validity of the research results and created conditions for the scientific justification of specific pedagogical mechanisms for the implementation of STEM knowledge in the higher education system.

The study involved teachers and researchers from higher education institutions in the Republic of Turkey who were directly involved in the implementation of STEM-oriented teaching in the field of geography education. The respondents were representatives of the universities of Istanbul, Aydin, and Hacettepe, who are engaged in teaching and research in the fields of physical geography, socio-economic geography, climatology, environmental engineering, as well as geographic information systems and remote sensing.

The selection of respondents was purposive and aimed at including specialists with practical experience in implementing STEM approaches in the educational process of higher education institutions. The study involved teachers who teach at the bachelor's, master's, and doctoral levels, which made it possible to cover different levels of student training and the specifics of applying STEM technologies in educational programs.

The professional experience of the respondents ranged from young teachers with up to 5 years of experience to professors with more than 20 years of academic experience. This ensured the representation of expert assessments and allowed for the consideration of various pedagogical and methodological approaches to the implementation of STEM education.

Data collection was conducted in accordance with the principles of anonymity and academic ethics. The article presents only summary results without indicating the personal data or specific job positions of the respondents. Participation in the study was voluntary, and the data obtained was used for scientific purposes only. The total sample size ( $n = 8-20$ ) meets the requirements for quality-oriented research based on expert interviews and thematic analysis.

### *Results*

At the present stage, within the framework of the introduction of STEM educational technologies, issues related to the development of functional literacy, critical thinking, modeling, and research skills among students



are becoming increasingly relevant. The results of research conducted in this context show that STEM education in the Republic of Turkey is being implemented systematically at the level of state strategic policy.

Documentary and comparative analysis data show that in the strategic development plan of the Republic of Turkey for 2015-2019, STEM education was considered one of the priority areas of the education system [10]. At this stage, a large-scale complex of scientific research, educational, methodological, and practical activities has been implemented with the aim of introducing STEM education. This work is coordinated by the Directorate of Innovation and Educational Technologies under the Ministry of Education and Science of the Republic of Turkey and covers the areas of supplementary education, pedagogical research, and the development of textbooks and teaching aids [11]. One of the projects that occupies a special place among these initiatives is the international Scientix project. This project has brought together more than 30 European countries since 2010 and aims to disseminate best practices in STEM education and support the professional development of teachers and higher education lecturers [12]. According to the results of a study, between 2010 and 2022, 42 scientific and methodological seminars and advanced training courses were organized in Turkey as part of this project [2]. This allows students to develop their ability to model, analyze, and predict natural and socio-economic processes. (Table 1).

Table 1. Measures of STE(A)M education realisation by Scientix project implemented in the Republic of Turkey [2].

<i>Main tasks of the Scientix project</i>	
1. Dissemination of best practice projects in STEM education fields across Europe;	4. Creation of a unified electronic platform for coverage of STEM projects in scientific publications of European countries
2. Market launch of products manufactured as a result of the project and their financing	5. To create a platform where teachers and researchers across Europe can share their experiences, exchange ideas and ideas
3. Holding national congresses, conferences, seminars	6. Professional development for teachers in STEM education areas through Online Learning and face-to-face training.

The introduction of STEM and STE(A)M education at the higher education level was first implemented through special laboratories opened at Hacettepe University in Ankara and Aydin University in Istanbul on the basis of natural and engineering faculties [13]. In these laboratories, undergraduate, master's, and doctoral students conduct research aimed at applying the results obtained in industrial practice.

In particular, the Department of Environmental Engineering at Hacettepe University, under the leadership of Professor Selim Latif Sanin, conducted a multi-stage study on the purification of drinking water and industrial wastewater using natural zeolite-based sorbents. In this study, all the main components of STEM - scientific analysis, the use of technological tools, engineering modeling, and mathematical processing - were implemented in a complex manner. The results of the study were put into practice in Turkey and Kazakhstan and demonstrated practical effectiveness [10]. In particular, Professor Selim Latif Sanin, PhD, Head of the Environmental Engineering Laboratory of Hacettepe University, together with students, masters, doctoral students of the educational programme of environmental engineering, works on the implementation of the results of research on the effectiveness of natural zeolite sorbent to create a filter for the treatment of drinking water and wastewater production in the production. At the first stage 'ecological engineering' studies the physical and chemical composition, sorbent properties, possibilities of absorption of harmful substances contained in water, using scanning electron microscope 'EVO 50 XVP' (Carl Zeiss) 'with system' INCA Energy-350 (Oxford Instruments)', conducting microanalysis by probing in the laboratory STE (A) M (Figure 1).

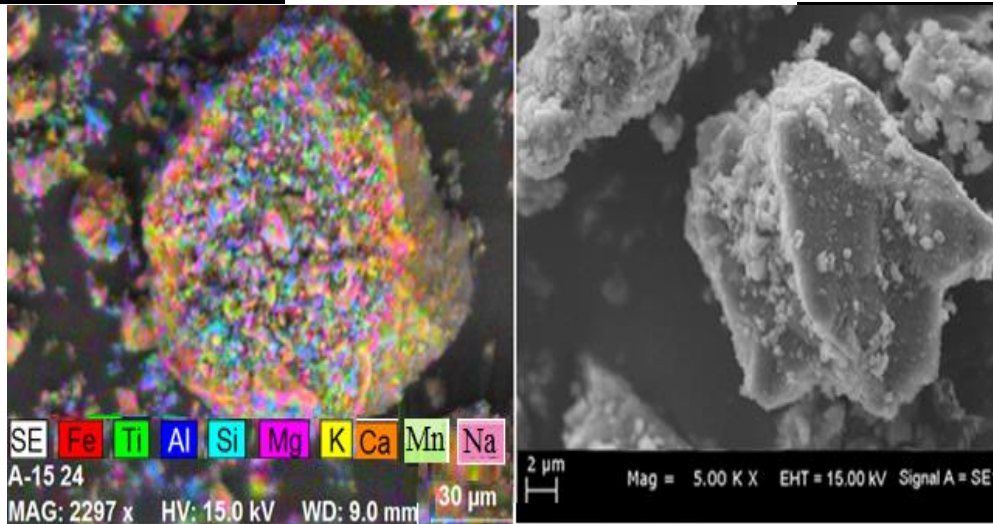


Figure 1: Results of the study using scanning electron microscope’ EVO 50 XVP “(Carl Zeiss)” with “INCA Energy - 350 (Oxford Instruments)” system

### Results of expert interviews on the implementation of STEM in Turkish universities

In addition to the results of documentary and comparative analysis, during the research internship, data was obtained from expert interviews with teachers and researchers at the universities of Istanbul, Aydin, and Hacettepe, who are directly involved in the implementation of STEM-oriented education. The experts represented the fields of geography, physical geography, climatology, and environmental engineering.

The interviews revealed that the implementation of STEM in the educational process of universities in the Republic of Turkey is systematic and relies on a combination of laboratory research, digital technologies, and student project and research activities. The experts noted that the use of digital maps, virtual laboratories, and simulation programs helps students develop independent analysis, critical thinking, and scientific forecasting skills.

It was also found that STEM-oriented courses allow for the integration of knowledge from various disciplines and help students develop strong interdisciplinary research skills. Teachers emphasized that a key factor in the effectiveness of STEM is regular work by students with real scientific data and practice-oriented tasks. The results of the expert interviews are summarized in Table 2.

Table 2. Competencies developed in students through STEM education at Turkish universities (based on expert interviews)

Competency group	Characteristics
Critical thinking	Analysis of complex natural and socio-economic processes, identification of cause-and-effect relationships
Research skills	Independent setting of research goals, formulation of hypotheses, interpretation of results
Modeling skills	Use of digital and mathematical models to analyze natural processes
Functional literacy	Application of theoretical knowledge to solve practical problems
Interdisciplinary competencies	Integration of knowledge of geography, physics, chemistry, and information technology

To summarize and visually present the results of the expert interviews, a diagram (Figure 2) was used to reflect the structure of STEM education outcomes at universities in the Republic of Turkey. The diagram shows the relative contribution of key competency groups developed in students through STEM-oriented education.

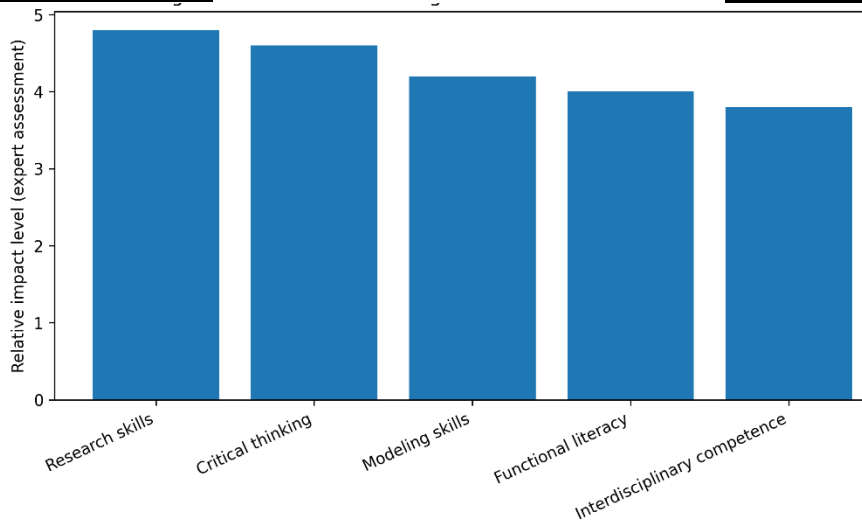


Figure 2. Structure of learning outcomes of STEM-based geography education (expert assessment)

According to expert estimates, the STEM approach has the greatest effect on the development of students' research skills and critical thinking. This is manifested in the ability of students to independently analyze natural and socio-economic processes, formulate research tasks, and interpret the data obtained. STEM education makes a slightly smaller but steady contribution to the formation of modeling and functional literacy skills, which ensure the application of theoretical knowledge in practical and professional activities. Interdisciplinary competencies reflect the integrative nature of the STEM approach and its focus on combining knowledge from different fields of science.

To assess the institutional conditions for the implementation of STEM - oriented geography education in universities in the Republic of Turkey, data from expert interviews and teacher surveys were analyzed.

The results obtained indicate a high level of institutional support for STEM education, reflecting the research-oriented nature of the university educational environment.

According to respondents, the most significant factor is the integration of scientific research and the educational process, which ensures the involvement of students in real research activities and the formation of sustainable professional competencies [14]. High scores were also obtained for the availability of technical infrastructure, including laboratory equipment, software, and digital educational resources. The level of institutional support for STEM initiatives from university management is rated slightly lower, but remains consistently positive (Table 3).

Table 3. Institutional factors supporting STEM integration

Institutional factor	Mean	SD
Availability of technical infrastructure	4.6	0.5
Institutional support for STEM	4.2	0.7
Integration of research and teaching	4.7	0.4

Expert interviews also revealed the main constraints hindering the wider and more sustainable implementation of STEM approaches in geography education at universities in the Republic of Turkey. Summary data on this aspect are presented in Figure 3.

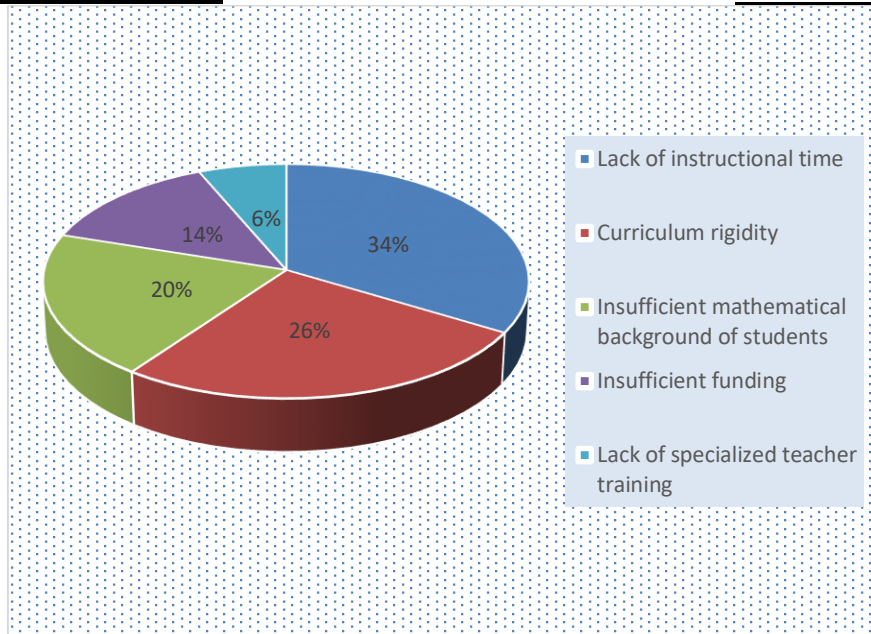


Figure 3. The main barriers to the introduction of STEM (based on the results of expert interviews)

Experts noted that the key barriers are mainly systemic in nature. The most frequently mentioned limitation is the lack of teaching time due to the high density of curricula and the need to comply with approved educational standards. Another significant factor is the rigidity of curricula, which limits the possibilities for flexible integration of interdisciplinary STEM modules.

In addition, some students were noted to have insufficient mathematical and statistical training, which makes it difficult to use quantitative methods of analysis and modeling in STEM-oriented courses. At the same time, factors such as lack of funding and lack of specialized training for teachers were assessed by experts as less significant, indicating the relative maturity of the institutional infrastructure for STEM education in Turkish universities. key thematic areas (Figure 4).

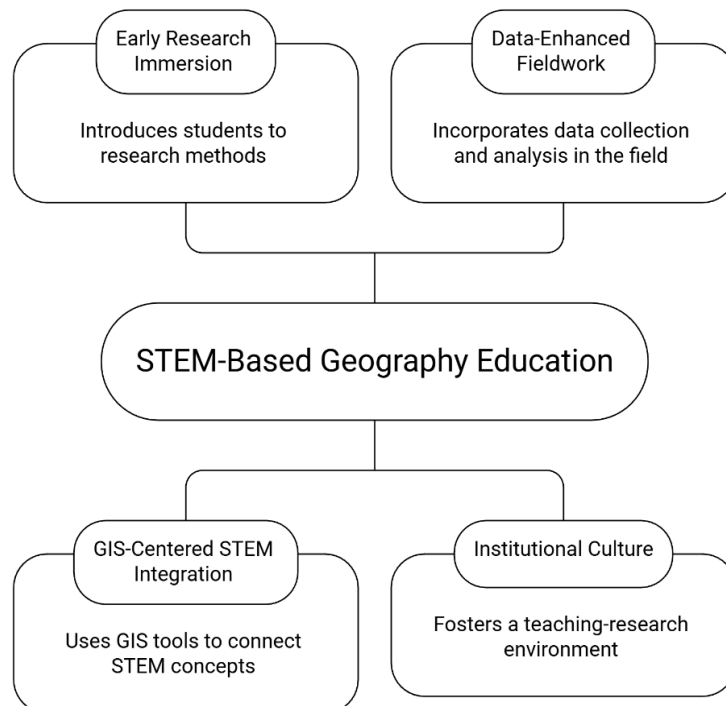


Figure 4. Conceptual framework of STEM-based geography education



Firstly, experts emphasized the importance of early involvement of students in research activities. It was noted that the STEM approach encourages students to work with real scientific data, digital maps, and monitoring results at the early stages of education, which forms sustainable research attitudes and independent analysis skills.

Second, special attention was paid to the role of geographic information systems and spatial analysis, which are considered a basic tool for implementing STEM in geography. According to teachers, it is GIS technologies that enable the transition from descriptive study of territories to analytical and modeling levels of knowledge.

Third, the experts noted that field research acquires the greatest educational and research value when integrated with subsequent data analysis, statistical processing, and modeling of results. This approach allows empirical observations to be linked to the theoretical and applied aspects of STEM education.

Fourth, a significant result of the qualitative analysis was the identification of the role of institutional academic culture. Experts pointed out that the effectiveness of STEM education is determined not only by the availability of modern technical infrastructure, but also by the level of integration of the educational process with scientific research, as well as the degree of student involvement in real scientific and applied projects [15].

Thus, the results of expert interviews complement the data from documentary and comparative analysis and confirm that STEM education in the universities of the Republic of Turkey is implemented as a holistic, research-oriented, and institutionally supported model. The results provide an empirical basis for a subsequent comparative analysis of the experiences of Turkey and Kazakhstan, which is presented in the following subsection.

#### **STEM education experience in the Republic of Kazakhstan**

The results of documentary and comparative analysis show that STEM education in the Republic of Kazakhstan is currently developing mainly at the level of strategic programs and state education policy. In official regulatory and program documents, STEM is most often considered in the context of the digitalization of education, technical modernization, and the development of innovative infrastructure in higher education institutions. This approach reflects the country's desire to integrate into the global educational and technological space.

In recent years, positive changes have been observed in Kazakhstan's higher education system, including the opening of robotics classrooms, the introduction of digital educational resources, and the upgrading of laboratory facilities for natural sciences and technical disciplines.

These measures contribute to the creation of material and technical conditions for the implementation of individual elements of STEM education and expand the possibilities for using digital tools in the educational process [16].

At the same time, the analysis showed that STEM has not yet been established as a comprehensive interdisciplinary pedagogical model at the level of higher education programs. In most cases, STEM elements are integrated into academic disciplines in a fragmented manner and are of an additional nature. The lack of a systematic approach limits the possibilities for interdisciplinary integration and reduces the potential of STEM education as a tool for developing students' research and analytical skills.

A significant limitation to the implementation of STEM approaches in Kazakhstani universities is the insufficient methodological training of teachers to implement research- and practice-oriented forms of education. This problem is exacerbated by the relatively low proportion of laboratory, project, and field work in the structure of curricula, which reduces the opportunities for students to develop modeling, data analysis, and independent research skills.

Table 4. Key characteristics of STEM education implementation in higher education in the Republic of Kazakhstan

Indicator	Characteristic
Level of institutionalization	Primarily strategic and regulatory
Integration of STEM into curricula	Fragmentary, as an additional component
Material and technical base	Gradually being modernized
Practice-oriented training	Limited share
Methodological training of teachers	Insufficient
Interdisciplinary integration	Weakly expressed



Thus, the results of the analysis indicate that the Republic of Kazakhstan has established the basic institutional and infrastructural prerequisites for the development of STEM education. However, the lack of a systematic interdisciplinary approach, the limited practical focus of teaching, and insufficient methodological support for teachers are hindering the effective implementation of STEM in higher education. The results obtained provide a basis for further comparative discussion of the experience of introducing STEM education in Turkey and Kazakhstan in the Discussion section.

#### *Discussions*

The study conducted between April 21 and May 21, 2025, under the supervision of the Head of the Department, Professor Barbaros Genençgil, at the Faculty of Letters of Istanbul University, demonstrated that the educational program 0303200042 – Geography is widely used to develop students' subject-specific and universal interdisciplinary (meta-disciplinary) research skills through the application of STEM technologies. The findings confirm that STEM-based instruction within higher education programs in Turkey is not limited to declarative integration but is actively embedded in disciplinary content and teaching practice.

Within the course Meteorology and Climatology, the use of digital meteorological platforms such as Ventusky and Meteoblue enables students to independently analyze the spatial distribution of atmospheric pressure centers, air masses, seasonal patterns of air temperature and precipitation, prevailing winds, as well as the causes and sources of air pollution in the lower layers of the atmosphere across the world and the territory of the Republic of Turkey. The analysis of data collected during research activities is carried out within the framework of the educational program 0303200042 – Geography (CGRF1080) and is oriented toward collaborative learning, critical thinking development, and analytical reasoning. The application of active and interactive teaching methods allows students to independently identify regularities in natural and environmental processes and to establish cause-and-effect relationships between them.

During the scientific internship, Professor of Physical Geography Cihan Bayrakdar participated in a laboratory-based lecture session, during which students were introduced to a laboratory equipped with modern scientific instruments and shared their research experience. The professor emphasized that the analysis of the composition of rocks and soils as key elements in geomorphology courses fosters students' independent discovery of new ideas and enhances their research capabilities [17]. In addition, the teaching experience of Professor Kaan Kapan was examined during a course on the Middle East for fourth-year undergraduate geography students. The lecture included assignments aimed at developing analytical and critical thinking skills through problem-based and research-oriented tasks.

The comparative analysis of STEM education implementation in Turkey and Kazakhstan reveals fundamental differences in the institutionalization and pedagogical realization of STEM at the level of higher education (Table 5).

While both countries recognize the strategic importance of STEM education, the Turkish model demonstrates a more consistent alignment between policy intentions and practical implementation. In Turkey, STEM is increasingly embedded as an interdisciplinary and practice-oriented educational model supported by national initiatives, university-school collaboration, and continuous professional development of educators. This alignment contributes to the systematic development of students' critical thinking, research skills, and modeling competencies.

In contrast, in Kazakhstan, STEM education is predominantly positioned within strategic and modernization discourses, with limited transformation into a systemic interdisciplinary framework at the curricular and pedagogical levels (Table 5). The observed gap between conceptual recognition and practical implementation suggests that infrastructural development alone is insufficient for effective STEM integration. Instead, greater emphasis is required on curriculum redesign, methodological support for instructors, and sustained collaboration between universities and secondary schools.

From a theoretical point of view, the results confirm the findings of recent studies that view STEM education as an integrative pedagogical model rather than a set of separate methods and technologies. The experience of the Republic of Turkey demonstrates the compliance of the practical implementation of STEM with the key theoretical principles of interdisciplinary education, problem-oriented and research-based approaches. At the same time, the Kazakhstani model reflects a transitional stage in the development of STEM education, in which the strategic and conceptual recognition of STEM is ahead of its practical implementation in the educational process.



Table 5. Comparative analysis of STEM education implementation practices in higher education in Turkey and Kazakhstan

Criteria	Turkey	Kazakhstan
Strategic position	STEM education is regarded as an important direction of educational policy and is systematically promoted in the context of innovation, the labor market, and scientific development.	STEM education is clearly defined in national and institutional strategic programs.
Main context of development	STEM is closely linked to economic development, scientific research, and applied innovations.	STEM is often considered within the framework of digitalization, technical modernization, and the development of educational infrastructure.
Implementation at the level of higher education	STEM is gradually being formed as a systemic interdisciplinary and practice-oriented model.	The implementation of STEM as a systemic interdisciplinary model remains limited.
Place in curricula	STEM elements are included in curricula as core content, and links between disciplines are strengthened.	In most cases, STEM elements are included in subjects only as an additional component.
Pedagogical model	Project-based and research-oriented approaches prevail, with an emphasis on problem-based learning.	Traditional subject-based instruction predominates; project-based and research approaches are used partially.
Staff training	There are instructors who have undergone specialized STEM training; however, the need for continuous improvement of practical (hands-on) skills remains.	There is interest in the use of STEM technologies, but the methodological training of instructors is uneven.
Laboratory and digital infrastructure	STEM laboratories, research centers, and digital modeling tools are widely used at universities.	STEM infrastructure is developing, but not all universities are equally equipped.
University–school collaboration	Stable collaboration between universities and secondary schools is established through STEM projects.	The connection between universities and schools is episodic; a systematic model has not yet been fully formed.
Learning outcomes	STEM significantly contributes to the development of students’ critical thinking, research skills, and modeling skills.	Although the potential of STEM is recognized, outcomes have not been systematically measured and validated.
Main limitations	The need to update material resources and to provide continuous support for the practical training of instructors.	Weak interdisciplinary integration and insufficient methodological support.
Conceptual perception and practical implementation	There is a relative alignment between the conceptual level and practical implementation.	A clear gap is observed between conceptual perception and practical implementation.

The results of the study show that the effectiveness of STEM education implementation is largely determined by the professional position of teachers and institutional academic culture. Turkish universities, particularly Istanbul and Hacettepe Universities, have seen the steady integration of scientific research and the educational process, creating conditions for the implementation of research-oriented learning. Teachers who are actively involved in scientific activities are key agents of STEM transformation, providing a link between theoretical knowledge, practical research, and student learning outcomes.

For geography education, the STEM approach is an effective tool for transforming the learning process from a predominantly descriptive model to an analytical and problem-oriented one. The use of geographic information systems, digital climate data, and modeling of natural and socio-economic processes allows students to develop skills in spatial analysis, critical thinking, and scientific forecasting. Thus, STEM education contributes to increasing the scientific and applied significance of geography in the higher education system.



A comparative analysis shows that Turkey has a more coordinated interaction between educational policy, institutional support, and pedagogical practice.

In Kazakhstan, however, there remains a gap between the conceptual understanding of STEM and its practical implementation at the level of curricula and teaching methods. This indicates that the development of material and technical resources alone does not guarantee the effectiveness of STEM education without systematic methodological support and interdisciplinary integration.

It should be noted that this study has a number of limitations. First, the analysis is based primarily on documentary sources, expert interviews, and a limited sample of respondents, which reduces the statistical generalizability of the results. Second, the study covers the experience of individual universities and does not claim to provide a complete picture of all models of STEM education implementation in Turkey and Kazakhstan. Nevertheless, the depth of the qualitative analysis allows us to identify key trends and patterns in the implementation of STEM in higher geographical education.

In the future, it would be advisable to expand the study by conducting large-scale empirical research, including quantitative surveys and longitudinal observations aimed at assessing the long-term impact of STEM education on students' educational and professional outcomes. Of additional interest is a comparative analysis of the experience of implementing STEM in other countries, which will allow for a more accurate assessment of the transfer potential of various educational models.

#### *Conclusion*

This study, conducted as part of a research internship at Istanbul University, provided a comprehensive overview of the institutional, pedagogical, and methodological foundations for the implementation of STEM education in the higher education system of the Republic of Turkey. The results show that the Turkish model of STEM education development is characterized by the consistency of state educational policy, institutional support, and actual pedagogical practice, which ensures the sustainability of STEM initiatives and their transition beyond the declarative or experimental level. An important outcome of the study was the identification of STEM transfer as an effective mechanism for integrating research-oriented learning, digital technologies, and interdisciplinary content into university educational programs. The analysis showed that STEM transfer in Turkey functions not only as a set of pedagogical technologies, but also as a tool for shaping a research-oriented educational environment in which students are actively involved in data analysis, modeling, and solving practice-oriented problems. This confirms the role of STEM education as a factor in the transformation of higher education towards a research and practice-oriented model of learning.

The comparative nature of the study made it possible to establish that the differences between Turkey and Kazakhstan are due not only to the level of material and technical support, but also to the peculiarities of curriculum design, pedagogical traditions, and institutional academic culture. The experience of the Republic of Turkey demonstrates that the effectiveness of STEM education is largely determined by the integration of scientific research and the educational process, the continuous professional development of teachers, and the sustainable interaction of universities with general secondary education institutions. All these factors together help students develop critical thinking, research skills, and readiness to tackle complex socio-economic and environmental challenges. The experience gained during the research internship, including academic observations and professional interaction with the faculty of Istanbul and Hacettepe Universities, confirmed that STEM-oriented geography education is most effective when integrated into real research contexts. The systematic use of digital platforms, geospatial data, laboratory analysis methods, and project-based research assignments allows students to go beyond theoretical mastery of the material and develop the universal analytical and modeling skills that are in demand in today's scientific and professional environments. In a broader scientific context, the results of this study contribute to the development of STEM education theory and practice, confirming that the successful implementation of STEM approaches requires not only strategic recognition and infrastructure investment, but also a transition to interdisciplinary integration of curricula and research-oriented pedagogy. The conclusions allow us to assert that the adaptive implementation of individual elements of the Turkish STEM education model, particularly those related to academic culture, educational program design, and practice-oriented teacher training, can significantly increase the effectiveness of STEM education development in the higher education system of the Republic of Kazakhstan. In conclusion, it should be noted that the results of the study confirm that STEM education, implemented as a holistic and research-oriented model, is an effective tool for improving the quality of higher education and preparing students for the demands of the modern information society. The study provides a solid scientific basis for further research in the field of STEM transfer and is of practical importance for educational policy makers, administrators of higher education institutions, and teachers focused on the development of STEM education.



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**Семинар Е., Лайсханов Ш.У., Уқушева Т.К., Атабаева А.М.  
ТҮРІК ЖӘНЕ ҚАЗАҚ ЖОҒАРЫ БІЛІМІНДЕГІ STEM БІЛІМ БЕРУ ТӘЖІРИБЕСІНЕ  
САЛЫСТЫРМАЛЫ ТАЛДАУ**

**Аңдатпа.** Бұл мақалада студенттердің сыни тұрғыдан ойлауын және зерттеушілік дағдыларын дамыту контекстінде Түркия Республикасы мен Қазақстан Республикасында STEM білімін енгізу тәжірибелері мен өзекті сын-қатерлері қарастырылады. Зерттеу Түркия Республикасының Білім және ғылым министрлігі жанындағы Инновациялар және білім беру технологиялары департаментінің ресми есептеріне, сондай-ақ Стамбул, Айдын, Хаджеттепе және Анкара университеттерінде жинақталған



практикалық тәжірибелерге негізделген. География пәнін оқытуда STEM-ге бағдарланған білім беруді қолдану осы тәсілдің педагогикалық артықшылықтарын ескере отырып және Стамбул қаласында жүргізілген эксперименттік зерттеулердің нәтижелеріне сүйене отырып талданады. Зерттеу барысында STEM білімінің функционалдық сауаттылықты, сыни ойлауды, модельдеу қабілеттерін және зерттеу дағдыларын қалыптастырудағы рөлі айқындалады. Түркияда жүзеге асырылып жатқан Scientix халықаралық жобасы, сондай-ақ университеттер жанынан STEM зертханаларын құру бастамалары STEM білімін жүйелі түрде ілгерілетуге ықпал еткені көрсетіледі. Сонымен қатар, мақалада университеттер мен орта мектептер арасындағы ынтымақтастықтың STEM білімін тиімді енгізудегі маңызы талданып, студенттердің табиғи үдерістерді талдау, проблемаларды шешу және цифрлық құралдарды қолдану құзыреттіліктерін дамытуға ерекше назар аударылады. STEM тәжірибесі Түркия да, Қазақстанда да әлі де дамып келе жатқанын және екі ел арасында әртүрлі мақсаттар мен оқыту әдістері бар екенін көрсетеді. Осы мәселелерді талдай отырып, бұл зерттеу Қазақстандағы STEM білімін жетілдіруге үлес қосуға бағытталған. Зерттеу нәтижелері географияны оқытуда заманауи цифрлық құрылғыларды, виртуалды интерактивті карталарды және үш өлшемді модельдерді ұтымды пайдалану студенттердің танымдық белсенділігін арттырып, пәндік және әмбебап метапәндік құзыреттіліктерді қалыптастыруға ықпал ететінін дәлелдейді. Алынған тұжырымдар Түркия мен Қазақстан студенттерінің сыни ойлауын, зерттеушілік дағдыларын және функционалдық сауаттылығын дамытудағы STEM білімінің маңыздылығын көрсетеді.

**Кілт сөздер:** STEM білімі, сыни тұрғыдан ойлау, зерттеу дағдылары, географиялық білім.

**Семинар Е., Лайсханов Ш.У., Уқушева Т.К., Атабаева А.М.**  
**СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПРАКТИКИ STEM-ОБРАЗОВАНИЯ В ТУРЕЦКИХ И  
КАЗАХСТАНСКИХ ВЫСШИХ УЧЕБНЫХ ЗАВЕДЕНИЯХ**

**Аннотация.** Внедрение знаний STEM (Science, Technology, Engineering, Mathematics) в современной системе высшего образования является одним из актуальных направлений развития критического мышления, исследовательских навыков и функциональной грамотности студентов. Применение STEM-ориентированных подходов, особенно в преподавании географии, способствует повышению качества образования за счёт комплексного анализа природных процессов, моделирования и использования цифровых технологий. В данном контексте сравнительный анализ опыта внедрения STEM-образования в Турецкой Республике и Республике Казахстан обладает значимой научной и практической ценностью. Целью исследования является сравнительный анализ опыта внедрения STEM-знаний в системе высшего образования Турции и Казахстана в контексте развития критического мышления и исследовательских навыков студентов, а также выявление актуальных вызовов и педагогических возможностей в преподавании географии. Исследование основано на качественной методологии с использованием методов документального и сравнительного анализа. В качестве источников были использованы официальные отчёты Департамента инноваций и образовательных технологий при Министерстве образования и науки Турецкой Республики, а также академический и практический опыт, накопленный в университетах Стамбула, Айдына, Хаджеттепе и Анкары. Дополнительно были проанализированы результаты экспериментальных исследований, проведённых в Стамбуле. Результаты исследования показали, что STEM-образование играет важную роль в формировании функциональной грамотности, критического мышления, навыков моделирования и исследовательских умений в процессе преподавания географии. Установлено, что международный проект Scientix, реализуемый в Турции, а также инициативы по созданию STEM-лабораторий при университетах способствовали систематическому развитию STEM-образования. Кроме того, сотрудничество между университетами и организациями общего среднего образования определено как значимый фактор эффективного внедрения STEM-подходов. Выявлено, что практика STEM-образования развивается в обеих странах, однако существуют различия в целях и методах обучения. Полученные результаты подтверждают, что рациональное использование современных цифровых устройств, виртуальных интерактивных карт и трёхмерных моделей в преподавании географии способствует повышению познавательной активности студентов и формированию предметных и метапредметных компетенций. Выводы исследования могут быть использованы для совершенствования STEM-образования в Республике Казахстан, а также для развития образовательной практики, ориентированной на формирование критического мышления, исследовательских навыков и функциональной грамотности студентов.

**Ключевые слова:** STEM-образование, критическое мышление, исследовательские навыки, географическое образование.