4.2. Formation of Environmental Competence of Senior Grade Students in the Process of STEM-Learning Using Project Technologies

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***Abstract**. The article explores the theoretical and practical foundations for developing environmental competence among senior-grade students through STEM-based education and project-based learning (PBL). The concepts of environmental competence, STEM education, and project-based learning are examined, and their interrelations within the modern educational paradigm are clarified. The study demonstrates that integrating interdisciplinary approaches, inquiry-oriented methods, and digital tools in STEM education enhances students' ability to apply environmental knowledge in real-life situations and cultivates a responsible attitude toward nature. Project-based learning is identified as an effective pedagogical strategy for fostering environmental awareness, critical thinking, teamwork, and research skills, which are essential for addressing contemporary ecological challenges. A model for implementing environmentally oriented STEM projects in secondary schools is proposed, emphasizing practical orientation, research activity, and collaboration between students, teachers, and local communities. The study highlights the Ukrainian experience in introducing ecological STEM initiatives and correlates it with international practices, demonstrating that this approach effectively combines theoretical knowledge with practical action, thereby contributing to the achievement of the Sustainable Development Goals.*

***Keywords**: environmental competence, senior-grade students, STEM education, project technologies, environmental education.*

Introduction

The modern education system is undergoing a profound transformation, driven by both internal social needs and global challenges. One of the most pressing tasks today is addressing the ecological crisis, which is manifested through climate change,

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environmental degradation, biodiversity loss, and a depletion of natural resources. In these conditions, the formation of environmental awareness and competence in the younger generation, capable not only of recognizing environmental problems but also of actively participating in their solution, acquires special importance. The education system is designed not only to inform, but also to cultivate a responsible attitude towards the environment, forming students' environmentally appropriate motivation, critical thinking, and skills for practical activities in the environmental sphere. In conditions of war, the problem of environmental protection becomes even more acute: large-scale pollution of air, water, and soil, destruction of ecosystems, accumulation of toxic substances, and an increase in technogenic and radiation risks pose new challenges to education. The formation of students' environmental competence is becoming not only an educational, but also a strategic national task. Accordingly, a modern school must provide conditions for the development of students' environmental awareness, understanding of the cause-and-effect relationships between human activity and the state of the environment, as well as the ability to act environmentally responsibly in both everyday life and emergency situations.

The urgency of finding new approaches to the educational process highlights the need to integrate a scientific base, interdisciplinarity, practical orientation, and active student participation. One of the promising areas for updating the content of high school education is the STEM approach (Science, Technology, Engineering, and Mathematics), which combines the natural sciences, technology, engineering, and mathematics to prepare students to solve real-life problems, develop innovative solutions, and foster critical thinking.

The STEM approach, combined with project-based technologies, contributes to the development of key competencies defined by the State Standard of General Secondary Education: the ability to learn throughout life, initiative, innovation, environmental literacy, and technological literacy. In the field of environmental education, STEM is focused not only on transforming knowledge about the environment but also on engaging students in active research, analysis, modeling,

forecasting, and the development of practical, solutions-oriented approaches.

Project-based learning, as one of the effective forms of implementing the STEM approach, orients students to achieve significant results – projects that have practical or social value. In the process of creating environmental STEM projects, senior-grade students not only acquire interdisciplinary knowledge and skills but also develop critical thinking, research competence, and the ability to work in a team. The combination of natural knowledge with technical thinking and awareness of environmental challenges forms students' holistic vision of human interaction with the environment. Environmental projects enable students not only to explore current issues but also to recognize themselves as agents of change, capable of influencing the state of the environment through targeted actions.

Scientific analysis suggests that project technologies in STEM education can enhance the development of environmental competence; however, the issues of their methodological support and optimization remain understudied. This is especially true for high school, where the formation of students' conscious environmental position and active civic position takes place. The relevance of developing environmental competence in senior-grade students through STEM education has led to the need for an in-depth analysis of this issue, which informed the topic of this scientific research.

The purpose of this study is to analyze the theoretical and practical aspects of developing environmental competence in senior-grade students through STEM education, utilizing project-based technologies.

To achieve this goal, the following tasks are *planned*:

1) to analyze the basic concepts: «ecological competence», «STEM education, «project technologies»;

2) to reveal the features of STEM education as an innovative direction for the formation of senior-grade students ' environmental competence;

3) to analyze modern approaches to the use of project technologies in the process of STEM education for the formation of environmental competence;

4) to develop a model for the implementation of STEM projects of an ecological orientation with the involvement of project technologies in secondary education institutions.

To achieve the set goal and defined tasks, the following methods were used: theoretical: theoretical analysis and generalization of literary sources – in order to analyze the problem of forming environmental competence of senior-grade students in the process of STEM-learning using project technologies; comparison, classification, generalization to clarify the content of the main concepts of the study; deductive, inductive methods – to determine the features of STEM education as an innovative direction of forming environmental competence of senior-grade students ; systemic method, formalization – to develop a model for implementing STEM-projects of an environmental direction with the involvement of project technologies in secondary education institutions; idealization and pedagogical modeling – in order to design a system of environmental competence of senior-grade students in the process of STEM-learning using project technologies; empirical: pedagogical observation, generalization of pedagogical experience – in order to generalize the state of use of project technologies in the process of STEM-learning for the formation of environmental competence.

Research Results

The formation of senior-grade students ’ environmental competence is one of the key goals of modern education focused on sustainable development. In the context of global environmental challenges, including climate change and degradation of natural resources, as well as the need to implement the principles of responsible consumption, school education should provide students with not only knowledge but also practical skills, motivation, and values for environmentally responsible behavior.

One of the most promising approaches to achieving this goal is a combination of STEM education and project technologies.

STEM education – an interdisciplinary educational approach that combines knowledge from natural sciences, technology, engineering, and mathematics – opens up wide opportunities for understanding and solving environmental problems in practice. In turn, project-based technologies enable you to implement tasks that closely resemble real-life situations, which foster students' critical thinking skills, cooperation, and research activities, while also increasing their environmental awareness.

According to O. Matvienko and M. Fatich The acronym STEM is interpreted as: «science – the study of the natural world; technology – the definition of STEM technology includes any product created by people to meet needs, that is, a product that children create to solve a problem; engineering – the design process; mathematics – the language of numbers, shapes and quantities» (Matvienko et al., 2019, p. 123). According to the authors, STEM is not just a grouping of subject areas, but a movement to develop deep mathematical and scientific foundations that must be competitive in the 21st century.

In contemporary educational discourse, ecological STEM education is regarded as an effective tool for fostering students' competencies in sustainable development, critical thinking, and innovative activity (UNESCO, 2020). International experience demonstrates that integrating ecological components into STEM processes is achieved through various models and approaches that ensure interdisciplinarity, practical orientation, and project-based learning.

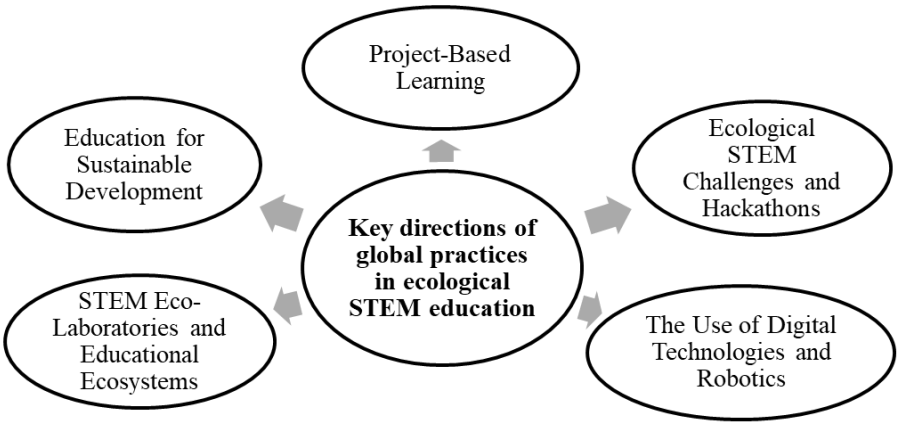

Figure 1. Key directions of global practices in ecological STEM education
Source: developed by the authors based on the reviewed literature

Project-Based Learning. In the United States and Canada, project-based learning is recognized as one of the leading approaches to organizing the educational process, particularly within ecological STEM education. Students are engaged in addressing local environmental issues, ranging from monitoring water quality in nearby bodies of water to designing models of «green» buildings that comply with the principles of energy efficiency and sustainable development (Krajcik & Blumenfeld, 2006). Such practices foster students' research skills, enhance critical thinking, and integrate knowledge from the natural sciences, technology, and engineering. In Ukraine, this approach is gradually gaining ground: in general, secondary education institutions are implementing ecologically oriented STEM projects that focus on environmental monitoring, energy efficiency, and waste management (Hurevych et al., 2021).

Ecological STEM Challenges and Hackathons. In many European countries and in Australia, school-based challenges and hackathons focused on addressing pressing environmental issues have gained significant popularity. Students work collaboratively on tasks related to developing innovative technologies aimed at reducing CO_2 emissions, improving waste sorting and recycling, or creating renewable energy sources (European Schoolnet, 2022). Such educational practices not only cultivate creativity and engineering thinking but also encourage students' social responsibility. In Ukraine, this approach has been reflected in a number of competitions, including *«MAN-Junior»* and the *«All-Ukrainian Contest of Ecological Projects»*, which motivate students to design their own eco-technologies and solutions in the field of environmental protection (Antonchenko & Pavlenko, 2024).

The Use of Digital Technologies and Robotics. Innovative digital tools are increasingly being integrated into the process of ecological STEM education. For instance, in Finland and Japan, geographic information systems (GIS), digital sensors, and robotics are actively applied to analyze environmental conditions, enabling students to obtain real-time data on climate change, air quality, or water conditions (Nishimura, 2019). In Ukrainian schools, the practice of using digital sensors, mobile applications, and Arduino microcontrollers to study natural processes is also expanding, bringing the educational process closer to European

STEM education standards (osvita.ua, 2024). This contributes to the development of students' ability to work with large datasets and implement practical engineering solutions.

STEM Eco-Laboratories and Educational Ecosystems. Singapore serves as an example of establishing innovative STEM eco-laboratories, where students work on real environmental challenges, particularly in the areas of vertical farming and the development of sustainable agro-technologies. In Germany, Green STEM Labs, organized under the auspices of the Fraunhofer Society, engage students in research activities in bioenergy and renewable technologies (Fraunhofer Society, 2021). In Ukraine, researchers propose the creation of holistic STEM ecosystems that integrate educational institutions, research institutes, and local communities, aiming to foster ecological competence and develop innovative thinking (Hurevych et al., 2021).

Education for Sustainable Development. According to UNESCO's recommendations, STEM education is regarded as one of the key instruments for implementing the concept of «education for sustainable development», as it combines scientific knowledge with practical actions aligned with the Sustainable Development Goals (UNESCO, 2020). In Ukraine, this idea is being implemented within the framework of the New Ukrainian School concept, which identifies ecological competence as one of the cross-cutting key competencies. At the same time, the STEM approach in the educational process is viewed as the foundation for fostering innovative thinking and students' ability to critically analyze contemporary environmental challenges (MON Ukrainy, 2020).

Project-based learning has proven effective in developing students' practical, interdisciplinary, and social competencies across various countries. In particular, in Ontario (Canada), the implementation of project-based learning in science and technology courses contributed to a 15–20% increase in students' average grades and improved their critical thinking and teamwork skills (Thomas, 2000). Importantly, this approach promoted not only academic progress but also the ability to make decisions in real-life situations. In the United States, research by the Buck Institute for Education indicates that students engaged in project-based learning demonstrated better outcomes in acquiring interdisciplinary STEM knowledge, particularly in the field of

ecology (Bell, 2010). Special emphasis was placed on developing practical skills for environmental research, which enhanced students' engagement and active participation.

In Sweden, the implementation of project-based learning in the course *«Ecology and Sustainable Resource Management»* enabled students to develop real eco-projects for local communities, which not only increased their motivation but also contributed to the development of research skills, activity planning, and teamwork abilities (Larsson & Holmberg, 2013). Similar experiences confirm the versatility of the method, which effectively combines educational objectives with socially beneficial activities. Comparable results are also observed internationally during hackathons and STEM challenges, where project-based activities stimulate the practical application of knowledge, foster leadership and communication competencies, and promote entrepreneurial thinking (Capraro et al., 2013).

In Ukrainian general secondary education institutions, elements of project-based learning are also being actively implemented. Within the framework of the New Ukrainian School and the activities of the Junior Academy of Sciences of Ukraine, students engage in interdisciplinary ecological STEM projects, which include monitoring the condition of water bodies, air quality assessment, the development of energy-saving models, and «green» architectural solutions (Hurevych et al., 2021). Educational competitions and initiatives, such as the *All-Ukrainian Contest of Ecological Projects*, are also widespread, where students present their own solutions for local communities, combining learning with a practical contribution to the development of a sustainable environment (Antonchenko & Pavlenko, 2024).

Thus, project-based learning in ecological and STEM education performs a dual function: on the one hand, it ensures the integration of theoretical knowledge with practical skills, and on the other hand, it prepares students to address current global and national challenges, including environmental issues and sustainable development objectives.

The effective functioning of a STEM educational environment is ensured by a set of key elements that contribute to the

development of the necessary competencies in students (Polihun et al., 2019). Let us consider it in more detail.

Table 1. Important components of a STEM educational environment

No	*Components of a STEM educational environment*	*Characteristic*
1.	Integrated curricula and elective courses	Based on a competency-based approach that involves the formation of practical skills and abilities. The development of creative educational content requires the cooperation of teachers, specialists in industry sciences, and representatives from industry and business, ensuring the relevance and practical orientation of training. This approach enables students to effectively apply their knowledge in real-world conditions and prepares them for the demands of the modern labor market.
2.	Adherence to interdisciplinary principles of learning	This approach enables students to tackle problems that transcend the boundaries of a single academic discipline, fostering their development of systemic thinking. Particular attention is paid to real-life and technological challenges that students face in conditions of incomplete or limited knowledge, which encourages them to find non-standard solutions, use available resources, experiment, and independently obtain information.
3.	Practical-oriented learning	It plays a crucial role in developing students' applied skills, enabling them to apply theoretical knowledge in real-world or simulated situations. This approach is implemented both within STEM disciplines and in extracurricular space – through projects, competitions, workshops, and club activities. This contributes to increased motivation, the development of creativity, and enhanced team interaction.

4.	Student project, team, and group activities	Among the leading forms of organizing the educational process, it is worth noting projects, integrated lessons, quests, case methods, excursions, theme days, competitions, scientific exhibitions, and engineering festivals. These forms are designed to develop critical thinking, teamwork, creativity, and the ability to independently solve practical problems. They contribute not only to the acquisition of knowledge but also to the development of key competencies necessary for successful self-realization in a modern digital society.
5.	Creating functional activity zones in the classroom	Zones for research, creative and communicative activities, as well as presentation platforms. Such an organization promotes the development of key competencies, fosters effective interaction, and encourages active student involvement in the educational process.
6.	Using modern teaching tools	Robotic sets (LEGO, LEGO Mindstorms, Cubelets, LittleBits, MakeBlock) that promote the development of skills in mechanics, electronics, programming, and engineering design. Additionally, digital measuring systems, microprocessor devices, programming tools, and network platforms are utilized to ensure that STEM education is inclusive and accessible to all students.
7.	Establishing cooperation between general secondary education institutions and external partners	Higher education institutions, scientific institutions, laboratories, museums, natural history centers, enterprises, and public organizations, among others. Such interaction contributes to the enrichment of the educational process, ensures the integration of theory with practice, and expands students' opportunities in gaining applied experience and involvement in scientific and technical projects. Thanks to joint initiatives, an open, innovative, and future-oriented educational environment is created, in which students are not only consumers of

		knowledge but also active participants in its creation.
8.	Active involvement of the parent community in STEM educational initiatives	It is an important condition for the effective functioning of the STEM environment. Parents not only support educational activities but also act as partners in implementing project activities, contributing to the organization of excursions, competitions, and meetings with specialists in the fields of science and technology. This fosters intergenerational cooperation and promotes a practical approach to learning.
9.	Systematic monitoring of learning outcomes	It involves not only assessing students' achievements but also analyzing the dynamics of their development, engagement in the learning process, and the effectiveness of the pedagogical strategies applied. Monitoring encompasses both quantitative and qualitative indicators, enabling you to identify strengths and areas for improvement, and adjust the educational trajectory accordingly to meet the needs of students and achieve program goals. This approach ensures flexibility in educational interaction and increases the effectiveness of STEM education.

Source: created by the authors

The features of STEM education as an innovative direction for developing senior-grade students ' environmental competence lie in its interdisciplinary approach and practical orientation. The integration of knowledge in science, technology, engineering, and mathematics provides a holistic understanding of environmental processes and phenomena, allowing students to see the connections between theory and real environmental challenges. The orientation towards project activities contributes to the involvement of schoolchildren in practice-oriented environmental initiatives, fosters a responsible attitude towards nature, develops research skills, and enhances the ability to solve both local and global problems related to sustainable development.

A crucial component is the development of critical and systemic thinking, which is necessary for analyzing complex environmental situations, assessing risks, and finding effective solutions through an interdisciplinary approach. The use of digital technologies, particularly data visualization, digital laboratories, and process modeling, enhances the research component and enables effective monitoring of the environment's state. STEM education also involves team interaction, which develops communication skills, the ability to work in a group, and the capacity to make collective decisions. Participation in socially significant eco-projects contributes to the formation of environmental awareness and a sense of responsibility to the community.

At the same time, STEM education motivates students to pursue scientific and professional self-realization in environmentally oriented areas, such as environmental protection, eco-engineering, and biotechnology. Ultimately, it is the approach that prepares students for the challenges of sustainable development, providing them with knowledge, skills, and tools to achieve the relevant Sustainable Development Goals - in particular in the areas of water resources protection, biodiversity conservation, combating climate change, and ensuring energy efficiency (Vasilashko et al., 2020).

Students' ecological competence, according to the State Standard of Basic Secondary Education, includes the ability to understand the ecological foundations of nature use, the need to protect nature, comply with the requirements of behavior in nature, use natural resources economically, understand the significance of the context and interdependence of economic activity and the need to preserve nature, which will contribute to ensuring the sustainable development of society (Tolochko et al., 2024, p. 51).

Ecological competence has a complex structure, which is formed through the integration of a number of key components:

– cognitive (awareness of the state of the environment, factors of its degradation, and ways of preservation);

– value (conscious attitude to nature and understanding of its value);

– activity (ability to environmentally appropriate behavior in everyday life);

– emotional and motivational (readiness to act for the benefit of the environment, motivation to participate in environmental protection activities).

One of the options for productive learning is project-based learning, the purpose of which is not to master a large amount of knowledge or complete educational programs, but to actually use, develop, and enrich students' own experiences and their understanding of the world. The essence of project-based learning is that, based on their interests, children, together with the teacher, design a solution to a practical task. The material of various educational subjects is grouped around project complexes. Educational design is primarily focused on students' independent activity, whether individual, group, or collective, which they perform over a specified period (Zalozna, 2022).

The main types of educational projects that are implemented in the educational process, taking into account the didactic goal, the method of organizing student activity, and the specifics of the final product, are shown in Figure 2.

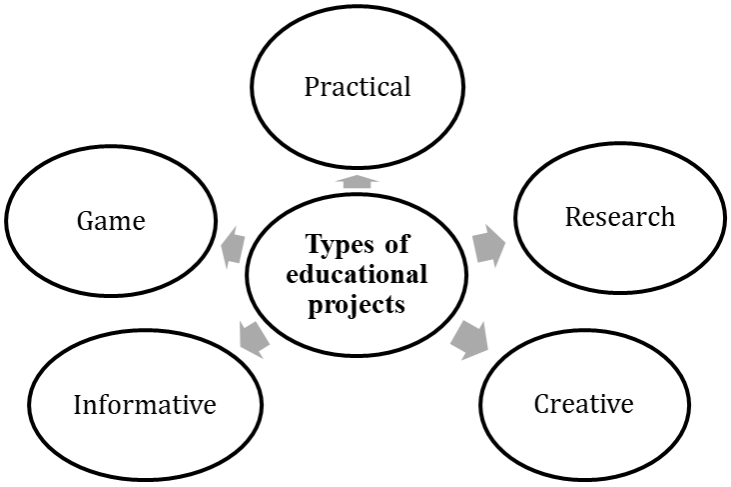

Figure 2. Main types of educational projects
Source: created by the authors

Creative projects involve the implementation of ideas that lack a rigidly structured framework. The organization of joint

activities among participants is based on a preliminary agreement regarding the expected result and the methods of its representation. Such projects focus on developing creative thinking, aesthetic taste, and the ability to express oneself. Examples of final products can be a handwritten journal, a collective collage, a video film, a thematic evening, or a creative holiday.

Game projects are characterized by the inclusion of elements of role-playing interaction. Participants assume roles determined by the project's content and purpose, allowing them to model interpersonal, social, or professional relationships. The role-playing component can be based on both fictional characters (such as literary or fairy-tale figures) and real historical or modern figures. This form helps develop communication skills, empathy, and a critical understanding of social information.

Information projects aim to obtain, process, and present information on a certain phenomenon, event, or problem. They involve independent search, selection, systematization, analysis, and generalization of factual material, with subsequent presentation of the results obtained in the form of a review, analytical report, presentation, or other similar formats. The primary emphasis is on developing students' information and analytical competence.

Practically oriented projects aim to create a real, socially significant product. Their result is clearly defined at the initial stage and is directly related to the needs of the student body or local community. These can be various documents, programs, recommendations, directories, models, and environmental initiatives (for example, a school garden project or landscaping of the territory). The implementation of such projects requires detailed planning, distribution of functions, a clear scenario of activities, regular coordination of work, and presentation of the achieved results.

Research projects are the most academically oriented. They require a scientifically sound structure, including the formulation of a clear goal and hypothesis, the selection of the study's object and subject, as well as the application of methods for data collection and analysis. Research projects involve a deep

immersion in the problem, including conducting observations, experiments, surveys, and other relevant activities. Special attention is paid to the processing and interpretation of results, which form scientific thinking skills and academic integrity in students.

In the process of project-based learning activities, students develop general educational skills and abilities that cover several key areas:

– reflective skills, which include the ability to consciously analyze the task, formulate questions such as: «Why do I need to learn this to solve the problem? »;

– search and research skills, which include the ability to independently generate ideas, search for and process missing information, offer alternative solutions to the problem, put forward hypotheses, and establish cause-and-effect relationships;

– teamwork skills, including the ability to plan collective activities, cooperate to achieve a common goal, communicate effectively, help each other, and analyze and correct the actions of team members;

– managerial competencies, which include the ability to design an activity or product, rationally plan time and resources, make decisions taking into account the forecast of possible consequences, and also conduct self-analysis of the process and intermediate results of work;

– communication skills, which include initiating learning interaction, conducting constructive discussions, arguing one’s own position, the ability to find compromises, mastering oral questioning and interviewing techniques;

– presentation skills, including the ability to confidently speak in front of an audience, possess elements of stage expressiveness, use visual materials to enhance the report, and answer unexpected questions (Zapopadna).

An educational project in teachers' activities is considered an integrated didactic tool that combines educational and instructional functions, focusing on the development of learners'

competencies. Its implementation involves the sequential processing of the following stages:

– analysis of the problem situation and definition of the key problem; setting tasks and forming goals;

– planning one's own activities;

– searching, selecting, and organizing the necessary information;

– choosing and applying the technology appropriate to the problem and determining the final product;

– conducting research activities (analysis, synthesis, formulating hypotheses, detailing, generalization);

– using the acquired knowledge and skills in various, including non-standard, situations;

– conducting self-analysis and reflection on the effectiveness of the actions performed;

– presenting the activity and its results, forming a positive image of one's own work (Vovk et al., 2021).

In the process of implementing project activities, the teacher plays several key roles (Fig. 3).

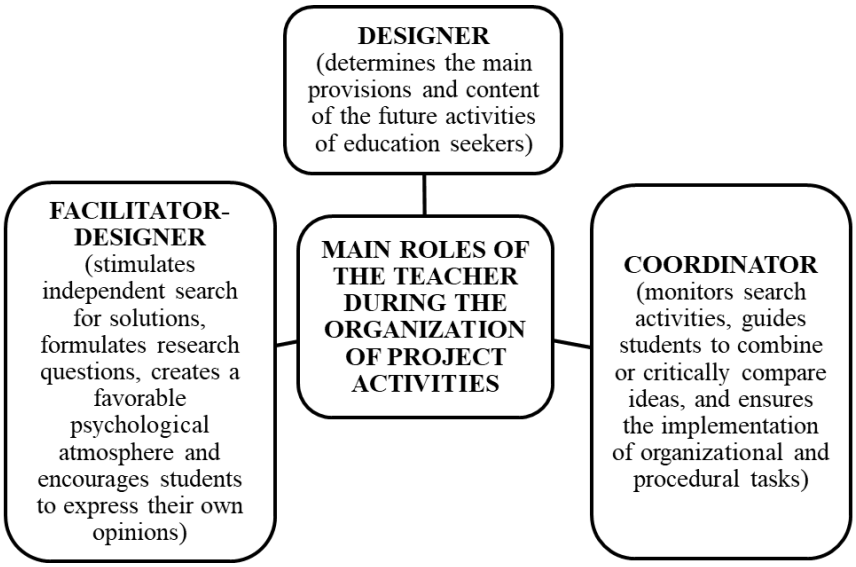

Figure 3. The main roles of the teacher during the organization of project activities *Source:* cited from O. Ilyina (2021).

The school's educational team can effectively implement STEM projects using the following forms of activity organization:

– problem-based learning, which stimulates students to actively think and search for solutions;

– research lessons, during which the teacher first formulates the problem, and students look for ways to solve it, based on the questions posed. Subsequently, students independently identify problems (with the support of the teacher), form hypotheses, independently select solutions, and summarize the results of the work together with the teacher;

– short-term observations-research with a description of the results under the guidance of the teacher;

– familiarizing students with theoretical concepts of research activities, in particular with research methods, working with primary sources, analysis, and formation of conclusions;

– conducting collective research, organized according to a predetermined plan and taking into account all key stages of scientific research, based on current topics (Vasilashko, 2020, p. 9).

Involving senior-grade students in environmental project activities contributes not only to deepening their knowledge and practical skills but also to the formation of a responsible attitude towards the environment and the development of creative thinking. Participation in such projects offers students the opportunity to actively contribute to the environment and make informed decisions about the sustainable future of the planet (Tolochko, 2024).

The structure of an environmental project includes a number of interrelated components, including: identifying a current need, conducting analytical research (analysis of existing analogues or solutions), formulating requirements for the design object, generating initial ideas, their critical analysis and a reasoned choice of the optimal option, planning actions, manufacturing or implementing the development, as well as evaluating the result and reflecting.

The implementation of environmental projects within the framework of STEM education is a crucial component in forming students' comprehensive knowledge, skills, and values that promote sustainable development and environmental preservation. This process involves the phased planning and implementation of activities that allow for systematic solutions to environmental problems, integrating interdisciplinary approaches from science, technology, engineering, and mathematics. The main stages of implementing such projects, which ensure the consistent and effective achievement of the set goals, are presented below (Fig. 4).

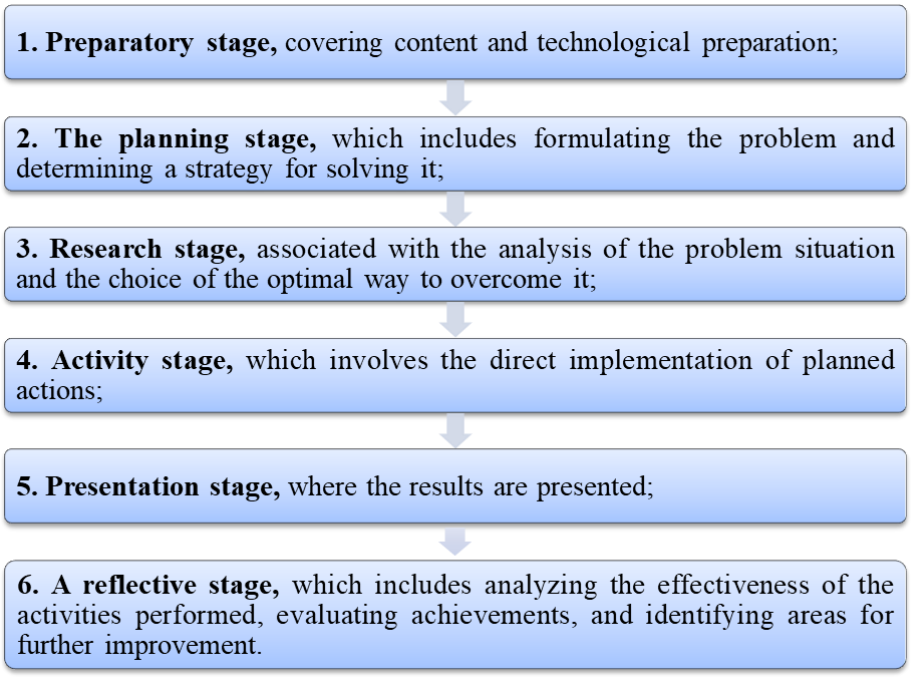

Figure 4. Stages of implementing environmental projects within STEM education
Source: created by the authors

The use of such stages ensures systematic, interdisciplinary, and practice-oriented learning, aligning with modern educational approaches and contributing to an increase in students' environmental awareness.

In this context, project activities within STEM education serve not only as a didactic tool but also as an effective means of developing students’ environmental competence. Its integrative

nature provides a combination of knowledge from natural sciences, technologies, engineering, and mathematics to solve current environmental problems. Thanks to this, students have the opportunity not only to deepen their subject knowledge but also to gain practical experience in applying it in real or nearly real-world conditions.

Project activities in the STEM direction stimulate the development of research skills, critical and systemic thinking, the ability to analyze environmental situations, and find ways to solve them based on scientific approaches. At the same time, such activities contribute to the formation of value orientations, a responsible attitude towards nature and the environment. Students recognize the importance of their own participation in environmental conservation, which enhances their personal interest in the educational process and the project's results. Thus, the STEM approach in project activities creates conditions for the holistic development of environmental competence as a key component of a sustainable educational process.

At the same time, implementing the STEM approach using project technologies presents several challenges. In particular, it requires increasing the level of teacher training, readiness for interdisciplinary teaching, the availability of educational and methodological support, and the appropriate material and technical base. In addition, it is essential to consider students’ individual characteristics, motivation, and the level of foundational knowledge in the natural sciences field.

Digital tools, online platforms for collaboration, data visualization services, means of remote communication, and technologies for monitoring environmental indicators all open up new opportunities for organizing effective project activities within the STEM education framework. The use of resources such as Google Workspace, Zoom, Padlet, Canva, ThingLink, ArcGIS, EcoSchools, EcoMonitoring, and others allows you to integrate elements of digital content into educational tasks, ensure an interdisciplinary approach, activate students' cognitive activity, and stimulate them to independently research environmental problems and find ways to solve them.

Digital technologies facilitate the visualization of complex environmental processes and phenomena, which is especially important in high school, where students are capable of analytical thinking and critical assessment. They also provide mobility, access to relevant scientific information, and open up numerous opportunities for international cooperation, the exchange of experiences, and participation in global environmental initiatives. In combination with project technologies, digitalization contributes to the creation of a modern educational environment, where the development of environmental competence becomes systematic, practical, and sustainable, leading to learning outcomes. Thus, digital tools act not only as a technical means, but also as a pedagogical factor that enhances the effectiveness of forming environmental awareness and students' readiness for environmentally responsible behavior in the real-world conditions of the modern world.

The integration of project technologies into STEM education enables students to participate in solving current environmental problems, work in teams, analyze results, and present their own ideas. To systematically organize such activities, a model for implementing STEM projects with an environmental focus using project-based technologies in secondary education institutions has been developed (Fig. 5). This model defines the key principles, components, stages of implementation, and expected results of integrated educational activities.

The model for implementing STEM projects with an ecological orientation, involving project technologies, involves creating an effective educational environment that fosters the development of students' environmental competence through interdisciplinary interaction and research activities. Its goal is to form students' environmental competence through the implementation of practice-oriented STEM projects.

The implementation of the model is based on the principles of integrativity, practical orientation, research approach, team interaction, and active community participation. Students, teachers, STEM specialists, and local community representatives are involved in the implementation of the projects.

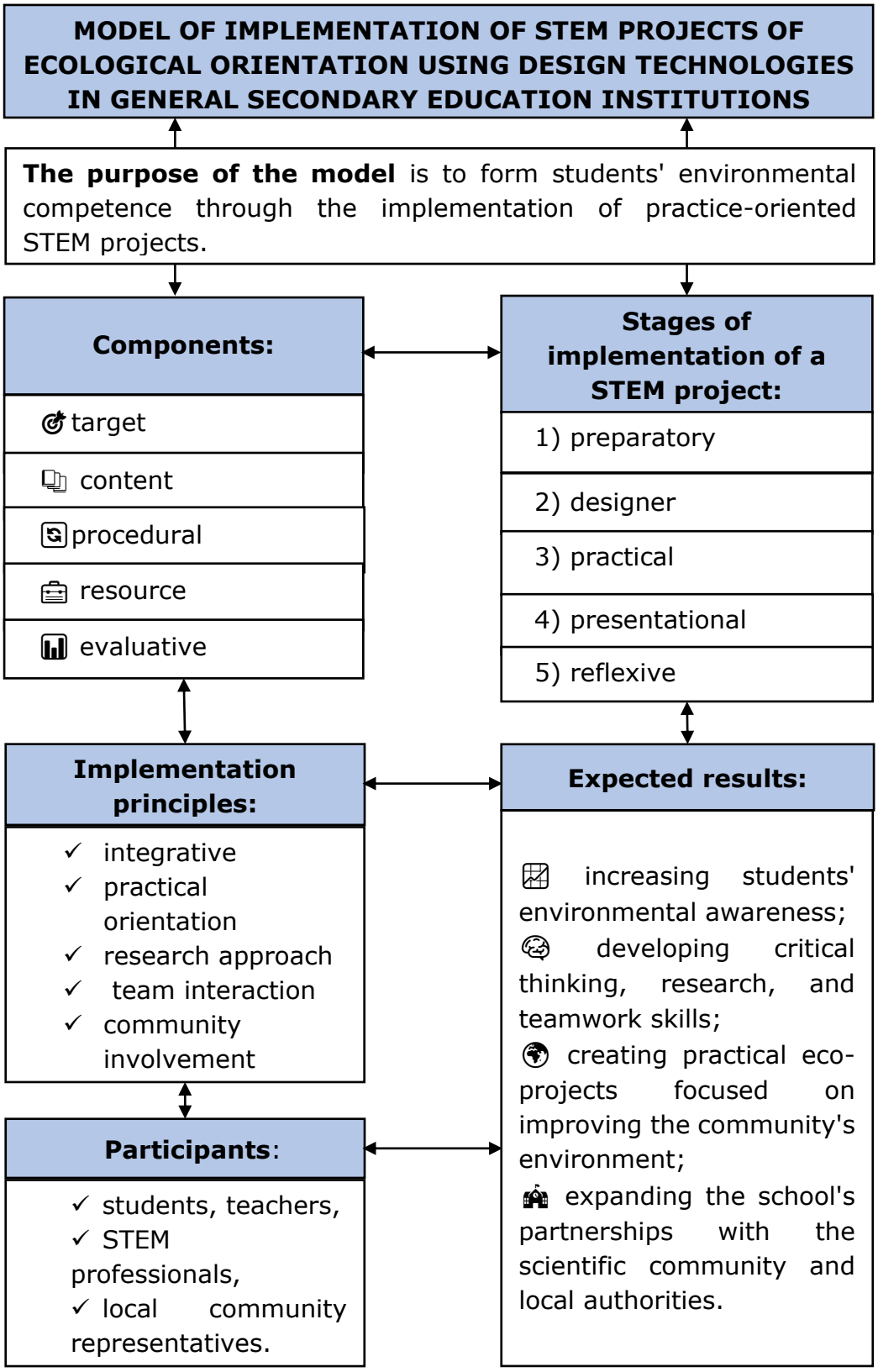

Figure 5. Model for implementing STEM projects of an ecological nature using project technologies in secondary education institutions
Source: created by the authors

Project activities are implemented in stages:

– at the preparatory stage, the problem is identified, teams are formed, and activities are planned;

– at the design stage, ideas, hypotheses are developed and methods are selected;

– the practical stage includes data collection, experiments, and product creation using digital tools;

– the presentation stage involves visualization of results and public defense;

– the reflective stage – assessing the effectiveness of the project and identifying opportunities for its scaling.

The expected results include an increase in students' environmental awareness, the development of critical thinking, research, and teamwork skills, the creation of practical eco-projects aimed at improving the community's environmental condition, and the expansion of the school's partnerships with the scientific community and local authorities.

Table 2 presents a selection of educational STEM projects of an ecological orientation for implementation in the educational process:

Table 2. Educational STEM projects with an ecological focus for implementation in the educational process

No	*Project topic*	*Project goal*	*STEM components*
1.	Clean Water – Healthy Community 	Investigate the quality of water in local sources and suggest ways to improve it.	**S (science):** analyze water samples (pH, hardness, contamination); **T (technology):** create a digital presentation of the results; **E (engineering):** design a filter or model of a purification system; **M (math):** calculate averages, build graphs.

2.	Green School: Energy Efficient 	Assess the level of energy consumption in the school and develop an energy-saving plan	**S:** study energy sources and their impact on the environment; **T:** use sensors or applications to collect data; **E:** create a model of an energy-efficient building; **M:** analyze energy consumption in kWh, economic calculation.
3.	Sorting is saving! 	To study the state of waste management in the community and popularize waste sorting.	**S:** classification of waste types, environmental impacts; **T:** creation of a mobile application/bot with instructions for sorting; **E:** development of containers for collecting recyclables; **M:** statistics of waste at school, reduction in volumes after the introduction of sorting.
4.	Monitoring the condition of the soil in our area 	Determine the fertility and level of soil pollution in various regions of the area.	**S:** study of acidity, presence of nitrates; **T:** use of GPS, Google Maps to plot data on the map; **E:** proposals for reclamation or greening of areas; **M:** analysis of changes by season, statistical processing of results.

5.	Pollinator protection: biodiversity in action 	Investigate the role of pollinators (bees, butterflies) and develop initiatives for their conservation.	**S:** biological importance of pollinators, food chains; **T:** creation of an information website or interactive map of distribution areas; **E:** development of «houses» for insects, planting of honey plants; **M:** recording the number of pollinators in different areas.

Source: created by the authors

Let's consider the stages of implementing the educational STEM project «Clean Water – Healthy Community» for senior-grade students. The project aims to raise the environmental awareness of senior-grade students by researching the quality of water in their region and developing practical recommendations for its improvement. Within the framework of this project, students apply an interdisciplinary approach, integrating knowledge from natural sciences, technology, engineering, and mathematics, which is the basis of STEM education. Such practical experience not only helps master theoretical material but also develops the skills of research work, critical thinking, and teamwork, while fostering environmental competence and a responsible attitude towards the environment.

The purpose of the project: to investigate the quality of water in local sources and suggest ways to improve it.

Table 3 shows the stages of implementation of the project «Clean Water – Healthy Community», which reflects an integrated approach to the formation of environmental competence of senior-grade students within the framework of interdisciplinary research.

Table 3. Stages of implementation of the STEM project «Clean Water – Healthy Community» for senior-grade students

No	*Project stages*	*Description of actions*
1.	Problem definition and research planning	– Discuss the importance of clean water for community health and environmental threats. – Formulate the problem of water pollution. – Define the goals and objectives of the project. – Plan to collect samples from multiple sources (wells, rivers, boreholes).
2.	Data collection and analysis (Science)	– Collection of water samples at designated points. – Chemical analysis: pH, hardness, contaminants (metals, bacteria, etc.). – Recording of results in a table. – Primary analysis and comparison with safe water standards.
3.	Data processing and visualization (Mathematics, Technology)	– Calculation of average values of water quality indicators. – Creation of graphs and charts of pollution levels. – Preparation of digital presentation of results (PowerPoint, Canva, Google Slides).
4.	Development of a technical solution (Engineering)	– Proposal of options for filtration or water purification. – Creation of a filter layout or a model of a purification system (activated carbon, sand, gravel). – Modeling of the system operation and demonstration of efficiency.
5.	Project presentation and recommendations	– Presentation of results and developed models. – Discussion of recommendations for improving water quality. – Proposals for information campaigns to raise environmental awareness in the community.

6.	Reflection and evaluation	– Analysis of the results obtained and discussion of difficulties. – Determination of the formed competencies (ecological, mathematical, technological, engineering).

Source: created by the authors

Each stage of the project encompasses the key components of STEM education, including scientific analysis, technological data processing, engineering modeling, and mathematical information processing. The proposed structure fosters the development of practical skills, critical thinking, and a responsible attitude towards the environment, which are essential components in preparing modern youth to address current environmental challenges.

Thus, the mentioned STEM projects demonstrate the wide possibilities of integrating environmental topics into the high school educational process, ensuring an interdisciplinary approach and active student involvement in research activities. They contribute to the formation of key competencies, in particular, environmental awareness, critical thinking, data analysis and processing skills, as well as the ability to work with modern digital technologies. Thanks to the implementation of practically oriented projects, senior-grade students acquire not only theoretical knowledge but also important skills in design, modeling, and making responsible decisions in the field of environmental protection. Such an approach fosters environmentally responsible behavior, stimulates innovative thinking, and prepares students to contribute to solving pressing environmental problems at both local and global levels.

Conclusions

Thus, project technologies, in combination with STEM education, not only foster a high level of environmental awareness among senior-grade students but also equip them with the ability to make responsible environmental choices and take action in real life.

The study analyzed the basic concepts: «ecological competence», «STEM education», and «project technologies». The essence and content of each of these concepts were determined, as well as their relationship in the context of modern education.

The features of STEM education as an innovative direction were revealed, which consist of an interdisciplinary combination of knowledge in science, technology, engineering, and mathematics, practical orientation of learning, application of project and digital technologies, development of critical thinking, team interaction, participation in socially significant eco-projects, and orientation towards achieving the Sustainable Development Goals.

Modern approaches to the use of project technologies in STEM education, which serve as an effective tool for developing environmental competence, are analyzed. The study demonstrates that project activities enable students not only to integrate knowledge from various fields, including natural sciences, technology, engineering, and mathematics, but also to apply it in practice to solve real-world environmental problems. Project technologies contribute to the development of environmental competence by immersing senior-grade students in research activities, during which they independently identify problems, formulate questions, search for information, develop solutions, and evaluate results. This approach stimulates active cognitive engagement, fosters team interaction skills, promotes a responsible attitude towards the environment, and develops critical, systemic, and innovative thinking. An important component is also the development of practical skills, particularly in working with digital resources, conducting experiments, and creating environmentally oriented products or models.

A model for implementing STEM projects of an environmental focus with the involvement of project technologies in secondary education institutions has been developed, which takes into account the peculiarities of the educational process and is aimed at the consistent formation of students' environmental competence through the integration of interdisciplinary knowledge, which provides a systematic approach to solving modern environmental problems. The proposed model has significant implications and can be effectively integrated into the

educational process to enhance the quality of environmental education.

Prospects for further research aim to enhance the methodological support for implementing the STEM approach in environmental education and to develop digital educational resources that support environmentally oriented STEM projects.

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