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Enhancing Scientific Literacy Through STEM-Based Lessons

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Abstract: *Contemporary global trends in education are primarily focused on the forms, methods, and tools of teaching and learning, aiming to create a diverse, dynamic, engaging, and effective educational process. Scientific literacy is a modern trend in science education, oriented toward rethinking and updating the educational goals in the direction of developing knowledge, skills, and competences necessary for solving real-world problems. These goals are essential for every individual to achieve successful social integration and personal and professional realization. Over the past few years, STEM education has become the most successful model for the development of scientific literacy. A recent study reveals that STEM education substantially helps students in the comprehension of scientific notions, raises their interest and encouragement, and develops their higher-order thinking skills like critical analysis and problem-solving [1], [2]. Integrated STEM methods, in addition, had a positive impact on students' motivation and their ability to decide on socio-scientific issues based on the evidence that is the core of scientific literacy [3]. As educational systems will be changed, STEM integration is the key to support future generations with the skills required for informed citizenship and sustainable innovation.*
Keywords: *Interdisciplinary learning, scientific literacy, STEM education, student inquiry.*

1. INTRODUCTION

The development of scientific literacy should be one of the main goals in studying natural sciences. Cultivating it in the younger generation requires the application of various methods and approaches in line with contemporary educational trends. The methods and tools used for this purpose are diverse and applicable to all types of lessons and forms of learning. Nearly every teaching method can be adapted and used to foster scientific literacy.

Nevertheless, it can be assumed that knowledge alone is not the foundation of scientific literacy; rather, it is a unity of understanding the nature of science, personal qualities, and social development [4].

The term "scientific literacy" was first introduced by James Conant in his article General Education in Science [5]. It is widely accepted that Paul De Hurd was the first to define scientific literacy as the primary goal of science education [6], [7]. Hurd offers a clear perspective by describing scientific literacy as an understanding of science and its applications to individual experiences as a citizen.

According to Prenzel and Fisher, scientific literacy includes [8], [9], [10]:

• Understanding basic scientific concepts, phenomena, and theories;
• Knowing the stages and nature of scientific work and research (planning, conducting, and analyzing experiments, forming and testing hypotheses, presenting results);
• Having fundamental knowledge of the structure and essence of science (research topics, the history of science, etc.);
• Understanding the interrelations between science, technology, and society.

Miller views scientific literacy as a three-dimensional structure [11]:

• Mastery of a vocabulary of basic scientific terms and concepts (conceptual knowledge) sufficient to read and understand popular science articles;
• Understanding the processes and methods of science, i.e., the nature of scientific inquiry;
• Awareness of the impact of science and technology on individuals and society.

Holbrook and Rannikmae emphasize that scientific literacy is more than acquiring a system of scientific knowledge and methods of obtaining it [4]. It involves understanding fundamental principles, as well as concepts, history, and philosophy of science. This enables scientifically literate citizens to answer everyday questions, understand news content, form personal opinions on civic and cultural matters, and make economically productive decisions. Such individuals can describe, explain, and predict natural phenomena. The authors link scientific literacy with knowledge of the nature of science, personal development, and social values [12].

Hazen defines scientific literacy as a system of fundamental scientific knowledge, the process of acquiring it, and the ability to creatively apply it in daily life to solve problems that improve quality of life [13].
Tafrova-Grigorova highlights three key aspects of scientific literacy: understanding scientific concepts, principles, and processes; applying scientific knowledge and competencies; and evaluating the achievements and economic efficiency of science and technology, as well as their environmental and societal impact [14].
Other authors Kolarova analyze multiple definitions of scientific literacy and identify an "invariant" core [15]:
1. Understanding basic elements of factual and conceptual knowledge;
2. Understanding the nature of science;
3. Ability to apply scientific knowledge to explain phenomena (inquiry);
4. Ability to make informed decisions on socio-scientific issues in different contexts (personal, social, global);
5. Evaluating the mutual influence of science, technology, and society;
6. Demonstrating value-based attitudes and responsible environmental behavior;
7. Meta-knowledge: awareness of one's own understanding, cognitive actions, beliefs, and behaviors when investigating and solving scientific problems [15].

2. Motivation and Objective

The idea of STEM integration emerged in the last decade of the 20th century [16]. Today, STEM is recognized as an approach that integrates separate disciplines into a coherent educational field. Instead of studying the disciplines in isolation, STEM combines all four in an applied approach that better prepares learners to use their knowledge in real-world situations and pursue careers in science.
The acronym STEM stands for Science, Technology, Engineering, and Mathematics. White defines them as [17]:
Science: the study of nature through observation, experimentation, and measurement;
Technology: the creation and use of tools and devices;
Engineering: the practical application of scientific knowledge;
Mathematics: disciplines such as algebra and geometry focused on the study of numbers.
However, even White admits that it is difficult to provide a clear definition of STEM education, as these disciplines are constantly evolving [17].
STEM integration can be viewed from two perspectives: that of the students and that of the wider community (parents and teachers as learning facilitators). It allows students to choose subjects aligned with their interests, provides a sense of unity among the natural phenomena studied, and encourages interdisciplinary collaboration among teachers.
K. Garov and D. Peykova define STEM as "an educational approach based on the idea of teaching students in four specific disciplines - science, technology, engineering, and mathematics - through an interdisciplinary and applied methodology. This approach integrates the disciplines into a unified educational paradigm, based on real-world applications outside the classroom." [18].
Other experts identify seven key skills developed through STEM education: statistical thinking, problem-solving, creativity, argumentation, intellectual curiosity, data-based decision-making, and flexibility [19].
STEM laboratories offer numerous benefits: applying theory in practice, preparing for future careers, improving collaboration and communication, and offering innovative learning experiences. They play a vital role in modern education by promoting problem-based thinking and opportunities for exploration and discovery - essential for student success today.
Globally - and in Bulgaria - STEM education has grown in recent years as a curriculum aimed at presenting a cohesive learning platform grounded in real-world applications. The trend toward interdisciplinary education is strongly linked to constructivist ideas, where knowledge is actively constructed by learners through activities. Spontaneous activity should lead the learning process, not external motivations. Independence and group work are emphasized. Learning activities only have real educational value when students engage in solving their own problems and satisfying their interests.
In summary, the most frequently used terms to describe the nature of STEM education are "integrated approach" and "interdisciplinary approach".
According to new research, STEM subjects' combining results in students significantly increased interest, engagement, and academic performance in multiple educational settings. The focus on real learning

assignments and questioning-based STEM procedures develops critical 21st-century skills like imagination, collaboration, and evidence-driven decision-making [1]. Additionally, integrated STEM pathways cause a change from passive to active learning, allowing pupils to move their knowledge to new and unanticipated problems - a vital condition in the modern job market.

In a systematic review of teachers' perceptions and research into effective STEM education, Margot and Kettler concluded that the fusion of disciplines is not enough, but the real-world problem-solving tasks which promote both collaboration and independence must form the basis of its implementation. The results highlight that teachers are the learning process' facilitators who can design interdisciplinary scenarios connecting the content to societal issues [2].

Another powerful motivation factor is in the increased demand for a population that is scientifically literate and that can handle the world's problems such as climate change, public health issues, and technological disruptions. In their study, English, King, and Smeed, state that students' undertaking of engineering design activities situated in the STEM environment greatly deepens their grasp of science and considerably raises their engagement with the learning goals through hands-on inquiry [3].

Those project-driven outlines reach students' interests and thus make them more willing to learn. The integrated STEM education also corresponds well with the constructivist learning theories that concentrate on the learners' active participation in the process of knowledge construction.

Holbrook and Rannikmae are of the opinion that students become scientifically literate only when they are given the opportunity to learn how to think critically, come up with evidence-based arguments and reflect on the socio-scientific issues while at the same time they are acquiring content knowledge [12]. Besides, those abilities form the base of the informed citizenship and are also the basic requirements for lifelong learning - consequently, STEM, in this case, is not only a teaching method but also a strategic commitment for modern education systems.

3. METHODS

Didactic tests assess the mastery of specific curriculum content taught in an organized learning process. According to pedagogical literature, tests should be applied in school practice in combination with other diagnostic methods, even though they are based on solid scientific theory.

The test was conducted with two groups - an experimental and a control group, each consisting of 23 fifth-grade students. The goal was to determine the extent to which students had learnt about the carbon dioxide, according to the Bulgarian Ministry of Education curriculum.

One of the groups was given traditional teacher-led instruction, while the other group used a STEM-integrated approach - using computers and sensors for measurement, graphing results, gathering and interpreting data, creating tables of information, and also including biology (to investigate the greenhouse effect and its influence on living organisms) and physics (to learn about dry ice and its states of matter).

Experiment with Carbon Dioxide

A test was administered after the students participated in lessons from the subject "Man and nature". The purpose was to evaluate their understanding of the physical and chemical properties of carbon dioxide and the negative effects on nature.

The study was conducted in two groups of 5th-grade students from Blagoevgrad. The control group was instructed through conventional teaching methods, whereas the experimental group participated in a STEM-based integrated learning experience. The subject of the lesson was carbon dioxide (CO_2), which was in line with the local curriculum for the subject "Man and Nature."

The control group was instructed with routine classroom methods such as reading from the textbook, teachers' explanations, and notes on the blackboard. On the other hand, the experimental group was an interdisciplinary, practical-oriented learning setting that put inquiry and investigation in the first-place focus. Students relied on digital CO_2 sensors and tablets as tools for data collection to visualize their results in graphs and tables. They watched the sublimation of dry ice to gain a better insight into the gases' behavior, evaluated CO_2 concentrations in sealed and airy spaces, and conversed the importance of their discoveries in line with the global warming issue, photosynthesis, and the quality of indoor air. The STEM class combined the activities of Physics, Biology, and Mathematics while motivating students to investigate the interconnections between disciplines and recognize the real-world examples of scientific concepts.

In order to measure learning achievements and more specifically the growth of the scientific literacy, both groups had to perform the same post-lesson test. The test was made of 12 questions, which were grouped thematically into four main parts: the basic knowledge of carbon dioxide, the examples of the application of it in real-life, the scientific reasoning and inquiry, and the data interpretation and decent of choice.

The questions were separated into four groups:

Group 1: Basic Knowledge of Carbon Dioxide (Questions 1 - 3)
1. Give three physical characteristics of carbon dioxide.
2. Identify two natural and two human-made sources of carbon dioxide.
3. Explain one simple way the presence of carbon dioxide can be detected in a closed place.

Group 2: Application in Real-Life Contexts (Questions 4 - 6)
4. Describe the role of carbon dioxide in the greenhouse effect.
5. Give the reasons why it is necessary to ventilate classrooms regularly.
6. What would be the consequences for plants and animals if the atmosphere contained too much carbon dioxide?

Group 3: Scientific Reasoning and Inquiry (Questions 7 - 9)
7. Show the source of carbon dioxide in a simple way with the help of limewater.
8. Describe what will happen if dry ice is left at room temperature and also explain why it happens.
9. What methods would you utilize in order to measure carbon dioxide levels in various indoor locations and subsequently compare the results?

Group 4: Data Interpretation and Decision-Making (Questions 10 - 12)
10. Discuss the progress of carbon dioxide concentration in air sealed in a jar as shown in the graph example. What do you observe?
11. The table displays different CO_2 readings from various rooms in a school. Which room has the highest level, and why?
12. People can take various actions to reduce carbon dioxide emissions. Select one and then explain why it is important to do so.

4. RESULTS

The first set of questions (1-3) were designed to find out students' factual knowledge of carbon dioxide, which included its physical properties, sources, and role in everyday life. The results indicated that the experimental group had 80% accuracy, while the control group had 78%.

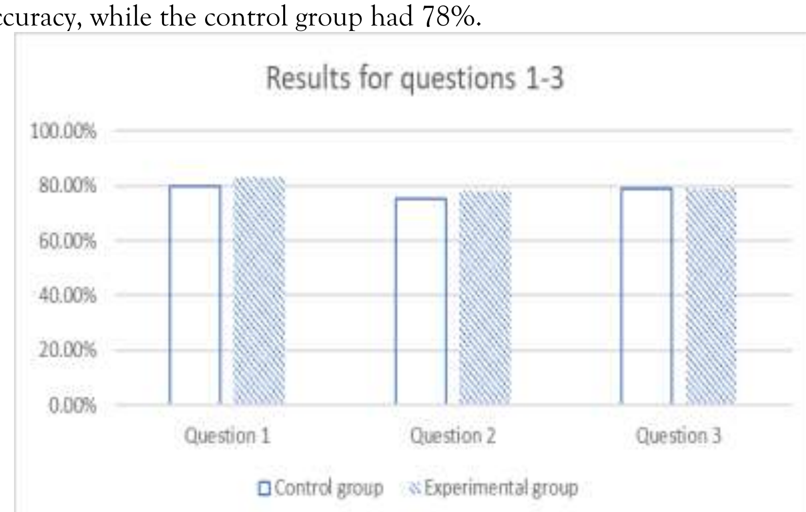

Fig. 1. Results for Questions 1-3: Basic Knowledge of Carbon Dioxide

The second group of questions (4-6) were about real-life applications, like understanding the greenhouse effect, evaluating indoor air quality, and identifying the role of carbon dioxide in ecosystems. Here, the experimental group scored 90% here, while the control group managed to get 81%.

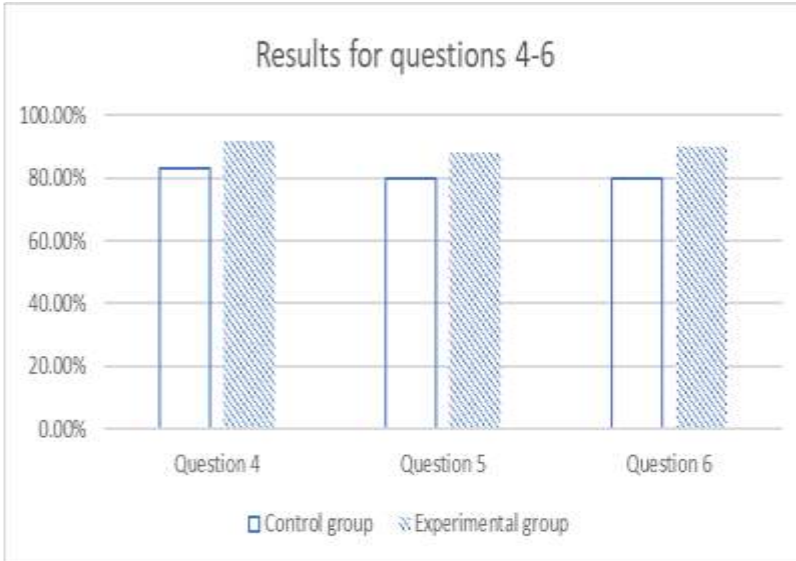

Fig. 2. Results for Questions 4-6: Application in Real-Life Contexts

The third group of questions (7-9) aimed at evaluating students' scientific reasoning and inquiry skills. Learners were to come up with a short experiment, to explain the results decisively and to show the understanding of the phenomena such as sublimation and gas dynamics. The experimental group prevailed again by scoring an average of 82% correct answers, while the control group got just 71%.

The significant difference here highlights the power of practical, interdisciplinary education in enabling students to comprehend abstract theory through everyday events. The implementation of sensors and instant response in experiments allowed a more profound conceptual grasp.

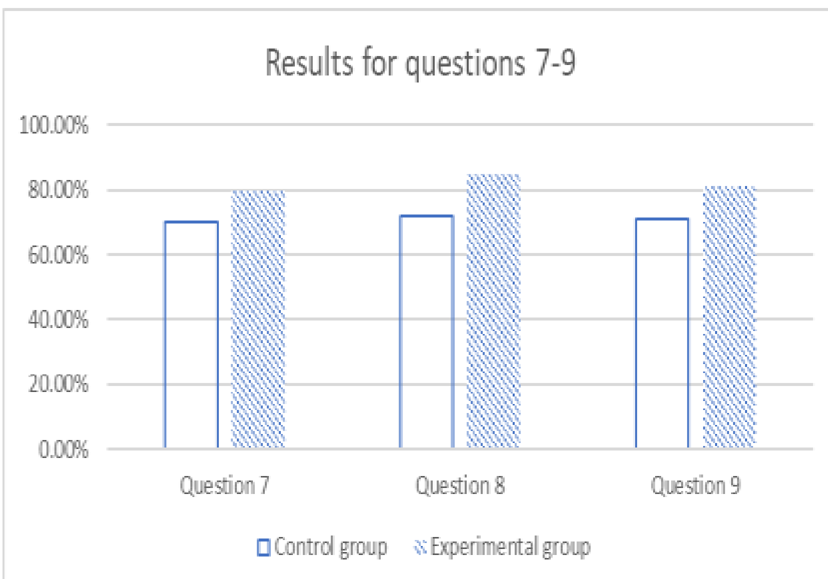

Fig. 3. Results for Questions 7-9: Scientific Reasoning and Inquiry

Finally, questions 10 to 12 focused on the analysis of data, making sense of diagrams and tables, and deriving conclusions concerning the matter of decreasing CO_2 emissions. The experimental group achieved 88% correct solutions, while the control group received only 68%.

This result indicates that students who had STEM-integrated lessons were more capable of dealing with scientific information by analyzing, synthesizing, and evaluating. Their capability has been demonstrated by performance which indicates improving skills in the interpretation of graphical data and resolving problems based on evidence.

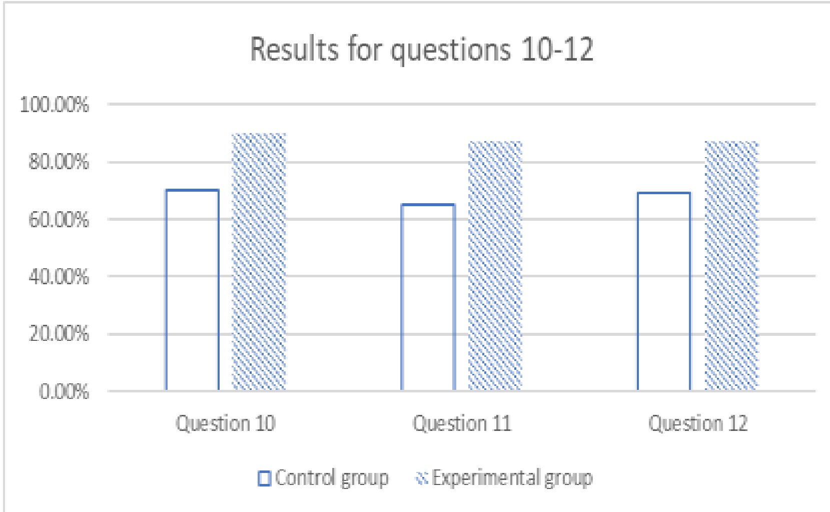

Fig. 4. Results for Questions 10-12: Data Interpretation and Decision-Making

These results are a strong indication of the effectiveness of the STEM-integrated method in improving not only factual knowledge but also higher-order thinking and scientific literacy. The experimental group of students revealed that they have better skills in the application of knowledge, data interpretation, and scientific reasoning - these are essential proficiencies for dealing with today's complicated world.

5. DISCUSSION

The findings from the research directly support the idea that STEM-integrated teaching has a positive influence on students' ability to read science materials. Although the differences in factual knowledge were minimal between the experimental and control groups (Questions 1-3), a large deviation became evident when students were given more challenging cognitive tasks. The students in the experimental group achieved more than the control group peers in tasks that needed the use of knowledge in real-life situations, scientific reasoning, and data interpretation.

This indicates that merging technology and interdisciplinary approaches not only positively influences students' motivation and involvement, but also their skills in relating abstract concepts to real-life phenomena. The organized utilization of sensors, interactive instruments, and guided inquiry gave students the opportunity to see and change scientific data, hence, facilitating more profound conceptual comprehension. The activities that involved dry ice sublimation, CO_2 measurement, and greenhouse effect interpretation were the sources of multiple domains of thinking such as observation, analysis, and evidence-based decision-making, to be activated.

They are the main parts of scientific literacy, and the emergence of them during the instruction is a great sign of its success. The discussion additionally points out the importance of the interdisciplinary teaching collaboration. The practical lessons, which had smoothly combined biology, physics, and mathematics, were stages on which a richer learning environment was set for students to make cross-curricular connections.

Besides, the inclusion of real-time data from sensors and inquiry activities from the students' side provided such situations that students are able to practice authentic scientific practices. Such practices are very much consistent with the nature of science and the scientific method, where learners conceive hypotheses, gather data, and change their understanding consequently. The authors English, King, and Smeed point out that design-based STEM learning fosters students to become critical and reflective thinkers while they deal with complicated challenges, thus driving them towards deeper conceptual understanding and creativity [3].

This hands-on nature of science education, typical for STEM methodology, has been proven to raise the level of student engagement as well as more advanced cognitive abilities like argumentation and evidence-based reasoning. As stressed, STEM education that includes integrated tasks and real-world scenarios extensively strengthens students' problem-solving skills and thus facilitates the process of becoming scientifically literate.

Interdisciplinary teaching teams are also very important for building meaningful integration. When educators from different fields join and co-plan as well as co-teach students are more likely to realize that concepts are interrelated. The experimental group's achievement in this study strongly supports the views of Margot and

Kettler who claim that the collaboration among subject-area educators is the most important factor for successful STEM implementation [2]. One such example is helping students acquire skills of data interpretation, scientific inquiry, and real-life application.
The whole issue brings out results that indicate that a blended STEM method does not only convey scientific concepts, but it also equips learners for the journey through complex social and environmental matters. Consequently, STEM teaching, which is enhanced with technology and interdisciplinary cooperation, is not only a pedagogical success, but it is the very mission for nurturing of being the responsible and informed ones.

6. CONCLUSIONS

Scientific literacy prepares future citizens to understand the world around them and face social and environmental challenges. It is crucial to develop policies that promote science and technology both within schools and in extracurricular settings. This will foster important connections between education and the scientific and technological community (research labs, engineers, companies, museums, associations, etc.). One key goal is to inspire more students to pursue scientific and technical careers that can easily be done by using different STEM approaches. Scientific literacy is essential because it provides the context for addressing societal issues. A scientifically literate population is better equipped to solve problems and make intelligent, informed decisions that influence their quality of life and that of future generations. On other hand science education strategies should focus on enhancing the overall scientific literacy of the public, rather than solely recruiting future scientists. This STEM approach should foster interdisciplinary collaboration.
The findings of this study clearly indicate the innovative potential of STEM-infusion pedagogy in enabling students to develop their scientific literacy. Students are equipped with different skills such as critical thinking, data analysis, and evidence-based conclusions through interdisciplinary, technology-aided learning experiences. These are not only the foundations for understanding scientific concepts but at the same time, the most important for making informed decisions in daily life.
Since the world is changing at such a rapid pace, STEM education is going to be an essential resource in education. If education systems aim to provide learners with the skills for addressing social and environmental issues of the future, they must ensure that STEM education is equitably accessible, support teacher training financially and adopt innovative teaching methods. Thise scientific approach must be the focus of the mission of raising a generation of informed and empowered individuals who will be able not only to contribute to the global green transition but also to become science-literate.

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