



A METHODOLOGY FOR INTEGRATING THE PHYSICS COURSE IN GENERAL SECONDARY EDUCATION THROUGH STEM COMPONENTS AND IMPROVING ITS DIDACTIC SUPPORT

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Abstract

The instructional value of the STEM approach in teaching physics in general secondary schools lies in linking theoretical content with a real-world problem, an experiment, a technological tool, an engineering solution, and mathematical analysis within a unified instructional process. The study is theoretical and design-oriented. Drawing on structural-functional analysis, pedagogical modelling, instructional design, and methods for aligning tasks with activity outcomes, it systematises a methodological model comprising objective, theoretical-methodological, content-integrative, technological-procedural, didactic support, and outcome-assessment blocks. Assessment is interpreted through cognitive, practical-performance, technological, engineering-creative, mathematical-analytical, communicative, and reflective criteria.

Keywords: STEM education; interdisciplinary integration; STEM project; physics experiment; modelling; engineering design; virtual laboratory; didactic support; assessment criterion.

Introduction

In general secondary education, physics is not only a subject that explains the laws governing natural phenomena, but also the scientific foundation of modern technologies, energy systems, electronics, transport, communications, robotics, and engineering. Therefore, mastery of formulas and definitions alone is not a sufficient learning outcome for the school physics course. Students need to be



able to apply physics knowledge to real-life situations, understand a problem, develop an experimental plan, process measurement results mathematically, select an appropriate technological tool, and justify the advantages and limitations of the solution they have developed. Conceptual approaches to integrated STEM education emphasise precisely this need to connect subject content with authentic problems and practical activity.

The instructional potential of the STEM approach in physics education is manifested not in simply placing the Science, Technology, Engineering, and Mathematics components side by side within a single task, but in transforming them into a functional system that supports a deeper understanding of physics content. For example, when studying an electric circuit, a physical law represents the Science component; a multimeter or simulation represents Technology; designing a lighting circuit represents Engineering; and calculating electric current, voltage, resistance, and power represents Mathematics. When these activities are linked to a common problem and an intended product, students recognise the need to apply their knowledge in practice. Research on implementing STEM design challenges in teaching also identifies the application of scientific and mathematical knowledge in developing an engineering solution as an important condition [1].

Local scientific and methodological studies have developed specific strands of STEAM/STEM-based project learning in the natural sciences, interdisciplinary integration in the physics course, experimentation, digital tools, and competency-based assessment [2, 3, 4]. However, linking lesson objectives, physics content, interdisciplinary connections, projects and experiments, engineering design, digital resources, and assessment criteria within a single reproducible methodological framework presents teachers with a distinct design task. This article addresses precisely that task by discussing a methodology for integrating the content of the physics course in general secondary education through STEM components and organising learning activities based on STEM projects, physics experiments, modelling, and engineering design.



Literature Review

The Instructional Essence of Integrated STEM in Physics Education

T. R. Kelley and J. S. Knowles describe integrated STEM education as an approach that connects the content and practices of two or more STEM fields within an authentic context [5]. This interpretation shows that integration in a physics lesson should not be limited to listing the names of subjects, but should bring together the knowledge and activities needed to solve a problem within a single task. L. Thibaut and colleagues identify content integration, problem-centred learning, inquiry, design, and collaboration as important features of integrated STEM practices [6]. Thus, STEM integration in a physics lesson involves engaging students in measuring, calculating, modelling, constructing, testing, and drawing conclusions by connecting a physical law with information drawn from other subjects.

School physics offers extensive opportunities for interdisciplinary integration. Mechanics is closely connected with mathematics; thermal phenomena with chemistry, ecology, and geography; electricity and magnetism with technology, robotics, and computer science; optics with geometry, biology, and digital imaging; and energy with ecology, economic calculations, and engineering. O. Q. Dehqonova links the improvement of subject integration in physics education to contextualising physics content in real life and visualising it [4]. Such integration broadens the range of situations in which students can apply a physics concept, but its didactic value emerges only when it is supported by objectives, activities, and assessment criteria defined in advance by the teacher.

The Interrelationship between Projects, Experiments, and Engineering Design

One of the central features of the STEM approach is that students participate not as performers who follow ready-made instructions, but as active seekers of solutions. In substantiating the instructional potential of organising project-based learning activities in the natural sciences, Z. Sangirova emphasises the unity of the objective, activity, and product within a project task [2]. In physics education, this unity is directly connected with experimentation: a model or device is developed on the basis of a physical law, tested, measured, and subsequently



improved. K. T. Suyarov's approach to developing students' research-learning skills through physics experiments [4] reinforces the need to transform laboratory work from an exercise in reproducing procedures into a setting for inquiry and decision-making.

As a mechanism linking projects and experiments, engineering design involves identifying a problem, defining requirements and constraints, generating ideas, preparing a drawing or schematic, creating a prototype, testing it, identifying shortcomings, and making improvements. K. Lesseig and colleagues show that STEM design problems require students to apply scientific and mathematical knowledge when developing an engineering solution [1]. Therefore, engineering design in a physics lesson should not be equated with merely 'making a model'; it is a cyclical activity that requires controlling physical factors, measuring outcomes, and redesigning on the basis of evidence.

Competency-Based Assessment

Competency-based assessment also extends beyond checking the final answer. Understanding a physics concept, planning an experiment, using an instrument, processing data mathematically, creating a model, working in a group, and analysing one's own errors require different forms of evidence. J. Usarov substantiates the need to develop key and subject-specific competencies in physics education [7], while U. Rosidin and colleagues emphasise that assessment directed towards higher-order thinking and integrated with STEM serves to monitor activities involving analysis, evaluation, and creation [8]. These perspectives provide the theoretical and methodological foundation for a multi-criteria rubric.

Research Results

The first research result was the systematisation of a six-block methodological model for integrating the physics course through STEM components. The model interconnects the objective, theoretical-methodological, content-integrative, technological-procedural, didactic support, and outcome-assessment blocks. Each block is described in Table 1.



**Table 1 Functional Structure of the Methodological Model for STEM-
Based Physics Teaching**

Model block	Core content	Implementation tools	Expected instructional outcome
Objective	Applying physics knowledge in practical situations; developing inquiry and engineering activity	Curriculum, competency requirements, problem situation	A student who actively develops a justified solution
Theoretical-methodological	Competency-based, integrative, activity-based, problem-based, project-based, and systems approaches	Didactic principles; scientific and methodological sources	Scientifically grounded design of a STEM lesson
Content-integrative	Purposefully connecting a physics topic with STEM components	Integration map, interdisciplinary task, context	Transfer of theoretical content to real-life and technological activity
Technological-procedural	Problem → plan → experiment/model → measurement → analysis → presentation → reflection	Project method, experiment, engineering design, simulation	Student inquiry and design-and-construction activity
Didactic support	Lesson plans, mini-laboratory, project brief, digital resources, and tasks	Virtual laboratory, sensor, Arduino, PISA-type task, portfolio	Provision of tools to support teacher and student activity
Outcome-assessment	Multi-criteria assessment of STEM competencies and feedback	Test, rubric, observation, project defence, reflection	Comprehensive assessment of knowledge, process, and product

The central methodological principle of the model is the ‘primacy of physics content’. A device, model, digital tool, or presentation used in a STEM task is not an end in itself; it should support the understanding and application of physical phenomena and laws. This requirement distinguishes project activity from ordinary handicraft, simulation from illustrative animation, and mathematical calculation from the mechanical substitution of values into formulas. The scientific value of a student-created product is determined not only by whether it works, but also by the physical factors on which it is based, how measurements were made, and the evidence used to explain it.

The operating mechanism of the content-integrative block is expressed through the sequence ‘topic – physics concept – real-life problem – STEM components – practical activity – expected outcome’. This sequence enables teachers to design



instruction for a topic by starting with physics content and the learning outcome, rather than first choosing a tool or an interesting project. For example, in a topic on thermal conductivity, the real-life problem arises from the need to retain heat in a house or container for longer. The Science component represents the laws of heat transfer; Technology represents a thermometer or sensor; Engineering represents an insulation model; and Mathematics represents a time–temperature table and graphical analysis. The final product is not the scale model itself, but an engineering recommendation supported by experimental evidence.

The model's blocks are not completed once in a linear sequence. Evidence obtained from the outcome-assessment block returns to the content and process through feedback (Figure 1). If a student provides only a superficial explanation of a physics concept, an additional experiment or contextual question is introduced in the next activity; if the student struggles to construct a graph, mathematical-analytical support is strengthened; if a prototype does not work, the process returns to the engineering design stage so that the causes can be investigated. The model is therefore not a closed 'lesson plan', but an open methodological system that can be readjusted in response to student outcomes.

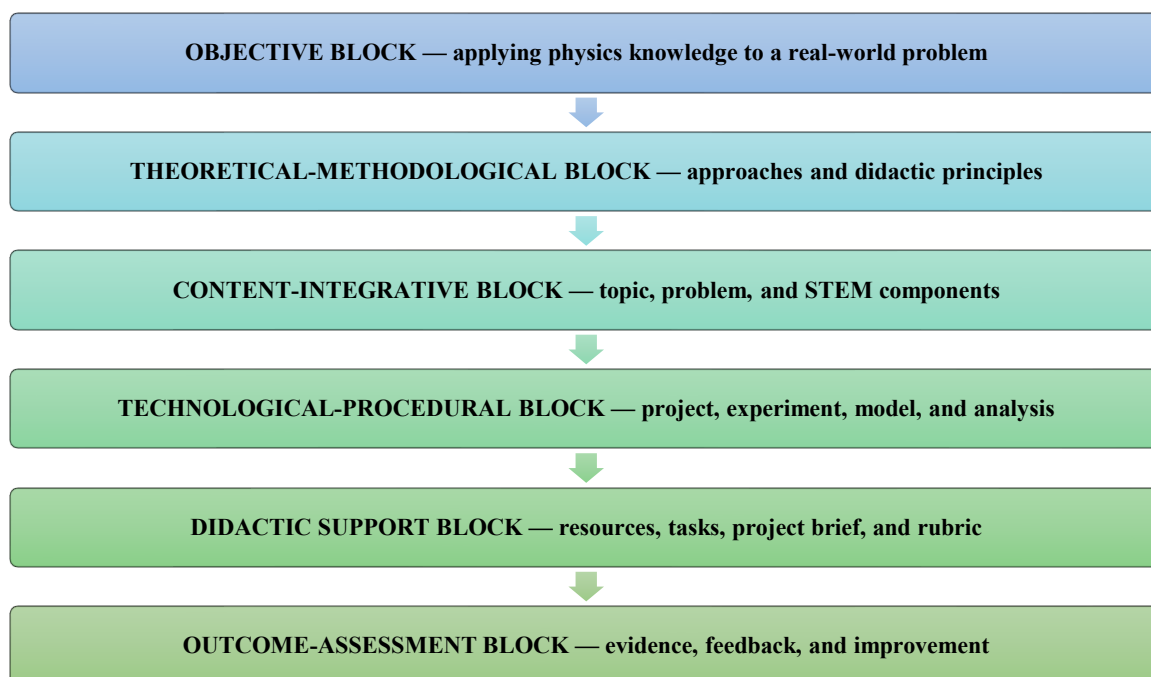


Figure 1. Blocks and Feedback in the Model for STEM-Based Integration of the Physics Course



The second result is the clarification of a step-by-step algorithm that translates the model into classroom practice. Rather than beginning by announcing the topic, the lesson starts with a real-life, technical, or environmental problem that students can understand. The problem should create a need to learn the physics content. Questions such as ‘Which material retains heat for longer?’, ‘How can electricity be saved in the classroom?’, ‘Why does a simple electric motor rotate?’, or ‘How does the positioning angle of a solar panel affect the result?’ encourage students to investigate the phenomenon. At the next stage, students identify the physical quantities and laws needed to solve the problem, after which the STEM components are defined according to their functions.

Planning a project or experiment is identified as a separate stage in the algorithm, because the difference between following ready-made instructions and conducting independent inquiry becomes particularly evident during planning. Students select equipment and materials, identify variables, establish safety rules, agree on a measurement procedure, and prepare a simple drawing of the intended product. The teacher’s role is not to provide a ready-made solution, but to guide students towards a scientifically grounded decision through questions such as ‘What will you measure?’, ‘Which conditions will you keep the same?’, and ‘How will you compare the results?’ Such an algorithm moves students from the role of task performers to that of researchers and designers.

An important feature of the algorithm is that the creation and testing stage is not a one-off event. In engineering design, a prototype’s failure to work on the first attempt is not regarded as a failure of the learning activity; rather, it provides evidence for identifying the cause of the error and correcting it. For example, if no rotation is observed in an electric motor model, students analyse the quality of the contacts, the number of turns, the balance of the wire, or the position of the magnet. One factor is then changed, and the device is tested again. This cycle links a physics concept with an engineering decision and turns error into a learning resource.

Group activity, as the organisational format of the algorithm, is managed by assigning roles such as researcher, designer, calculation specialist, technologist, presenter, and reflection facilitator. However, the group product is not accepted as complete evidence of individual learning. Each student’s explanation of the



physics, participation in measurement, calculations, or reflective conclusion must be recorded separately. This approach strengthens collaboration while preventing individual students from ‘disappearing’ behind the group outcome. Systematic analyses of the instructional difficulties teachers face when implementing STEM integration likewise identify clear planning, high-quality materials, and collaboration as important supporting factors [9, 10].

The third result consists not in applying separate methods in sequence, but in interconnecting the functions of projects, physics experiments, modelling, and engineering design within a single task. The project defines the problem, objective, and final product; the experiment tests the physical basis of the product or hypothesis; modelling isolates the principal factors of a phenomenon and enables prediction; and engineering design organises the cycle of creating, testing, and improving a solution. In this way, a ‘project’ does not remain merely a final scale model, an ‘experiment’ merely a laboratory instruction sheet, or a ‘model’ merely an illustrative representation.

For example, in the ‘Energy-Efficient House Model’ task, students draw on their physics knowledge of thermal conductivity to compare the heat-retention properties of different materials. Using containers or models under identical conditions, they measure temperature over time, enter the results in a table, construct a graph, and compare the dynamics of heat loss. The engineering decision is based not on the question ‘Which material looks attractive?’, but on measured results and a physics-based explanation. The house model or insulation solution is then improved. Using a sensor or spreadsheet strengthens the technological component, but where digital tools are unavailable, a simple thermometer and a hand-drawn graph can serve the same scientific purpose.

Energy-related tasks such as ‘How Does the Angle of a Solar Panel Affect Efficiency?’ or ‘Solar Oven’ offer opportunities to connect physics content with environmental and technological contexts. Xaliyarov has demonstrated the potential of STEM projects for developing competencies related to modern energy sources [11], while Sattorov has investigated the creation of laboratory equipment based on solar cells and its application in the educational process [12]. In such a task, students can change the angle or illumination conditions, record



voltage, power, or temperature, compare the results graphically, and provide a justified recommendation on the positioning of the device.

The fourth result is the representation of didactic support for STEM-based physics lessons not as a collection of separate materials, but as an integrated system that supports student activity from beginning to end (Table 2). The system includes sample lesson plans and instructional process maps, interdisciplinary integration maps, laboratory and mini-laboratory tasks, STEM project briefs, engineering design cards, virtual laboratories and simulations, sensors and Arduino tools, PISA-type contextual tasks, student portfolios, reflection sheets, and assessment rubrics. Each resource should serve the model's objectives and observable outcomes rather than merely increase the number of 'interesting activities'.

Table 2 STEM Didactic Support and the Assessment Evidence It Generates

Didactic resource	Main instructional function	Student activity	Assessment evidence
Lesson plan and instructional process map	Aligning the problem, physics content, stages, and assessment	Step-by-step project/experimental activity	Lesson process and completed tasks
Integration map	Defining in advance the connections between the topic and STEM components	Applying knowledge and methods from different subjects to a common problem	Interdisciplinary explanation, calculations, and product
Mini-laboratory	Observation, measurement, error, and drawing conclusions	Planning an experiment, taking measurements, and constructing tables and graphs	Laboratory worksheet and report
Project brief / design card	Clarifying the problem, objective, constraints, product, and criteria	Drawing, prototyping, testing, and improvement	Model, project brief, and test record
PISA-type contextual task	Applying knowledge in a real-life situation and making evidence-based decisions	Analysing text, tables, graphs, and the situation	Justified written solution and recommendation
Analytic rubric	Multi-criteria assessment of knowledge, process, and product	Knowing the criteria in advance and managing activity accordingly	Cognitive, practical, technological, engineering, mathematical, communicative, and reflective indicators



The didactic structure of laboratory tasks is not limited to a topic and an objective. The problem, physics concept, equipment, safety provisions, procedural stages, measurement table, graph or diagram, questions, conclusion, and reflection are planned in advance. Classroom laboratory activities are classified into types such as observation, measurement, comparison, non-standard, virtual, engineering, and project-based laboratory work. This classification helps teachers select activities appropriate to the lesson objective: precise measurement may be central to some topics, while creating a model, changing parameters in a virtual environment, or testing the functionality of a prototype may take priority in others.

The assessment system comprises seven criteria: cognitive; practical-performance; technological; engineering-creative; mathematical-analytical; communicative; and reflective. The cognitive criterion concerns explaining phenomena scientifically and applying knowledge to a new situation; the practical-performance criterion concerns planning an experiment, taking measurements, and using equipment; the technological criterion concerns selecting a digital tool for a specific purpose; the engineering-creative criterion concerns creating and improving a model or prototype; the mathematical-analytical criterion concerns calculations, tables, graphs, and error analysis; the communicative criterion concerns group collaboration and project defence; and the reflective criterion concerns identifying the causes of errors and determining the next action.

Each criterion is described through four levels: initial, basic, sufficient, and high. At the initial level, students perform activities with continuous assistance; at the basic level, they carry out essential actions by following instructions, but experience difficulties with independent analysis; at the sufficient level, they apply knowledge and skills to a new situation with relative independence; and at the high level, they independently analyse a problem, develop a scientifically grounded solution, compare alternatives, and propose an improvement strategy. From a methodological perspective, it is important to interpret these levels as descriptions of the quality of performance on a particular task rather than as permanent 'labels' attached to an individual.



The assessment rubric should be communicated to students before the lesson or project begins. This transforms the criteria from a tool used only for final judgement into a guide for managing activity. When students know in advance the requirements concerning the physical basis, measurement accuracy, model functionality, calculations, defence, and reflection, they can plan their time and group responsibilities purposefully. Contextual tasks, in turn, make it possible to observe how students identify evidence within information, apply results to real-life conditions, and formulate scientifically grounded recommendations.

Discussion

The principal scientific and methodological contribution of the systematised methodology lies in interpreting STEM not as a collection of separate methods, but as a framework that aligns physics content, student activity, products, and assessment evidence. An ‘interesting project’ or a ‘modern digital tool’ in a lesson does not, by itself, guarantee the quality of STEM education. If the product does not reveal a physical law, if measurement and analysis are absent, or if students are not required to provide their own explanations, the activity may appear modern while failing to support physics learning outcomes. For this reason, physics remains the scientific core of the Science component in the model, while the other components serve to apply, test, and transform that content into a practical solution.

A second important aspect is the distinction between a task that culminates in a ‘product’ and one that culminates in ‘evidence’. For example, constructing a periscope alone is not sufficient evidence of an understanding of the law of reflection. Students need to explain why the mirrors are positioned at a particular angle, how the light path changes, what limitations the model has, and how it should be modified under different conditions. Similarly, an energy-efficient house model should not be assessed solely on its aesthetic appearance; it should be supported by temperature data obtained with different materials and a physics-based explanation. This approach turns the product into evidence of scientific thinking.

The third aspect is the complementarity of experiments, models, and digital tools. A tangible model enables students to handle and manipulate a structure; a



mathematical model expresses quantitative relationships; a graphical model shows a trend; and a computer model makes it possible to modify multi-parameter or invisible processes rapidly. The methodology is not concerned with selecting one of these as the ‘most modern’, but with determining which representation provides stronger explanatory and verification evidence for a particular physics question. This approach makes it possible to preserve the underlying logic of STEM activity even in resource-constrained schools by using simple materials, a smartphone, or a printed table.

The fourth aspect is the connection between assessment and feedback. When a rubric is used solely to assign scores, its developmental potential is reduced. The methodology instead requires time to be allocated for identifying an error, explaining its cause, and revising a product or explanation. For example, if units are missing from a graph, the teacher does not stop at a general judgement of ‘incorrect’, but guides students towards clarifying which quantity each axis should represent and in which units. Students then revise the graph. In this way, assessment becomes not the final stage of a lesson, but a mechanism that determines the next learning action.

Teacher preparation remains a decisive factor in implementing the methodological model. Planning interdisciplinary integration, creating open-ended tasks, managing group work, ensuring experimental safety, selecting appropriate digital tools, and conducting multi-criteria assessment require several instructional decisions to be made simultaneously. K. C. Margot and T. Kettler show that teachers value STEM’s connection with real life and its capacity to engage students, while also facing barriers related to time, resources, the curriculum, assessment, and pedagogical preparation [9]. Accordingly, the integration map, project brief, and rubric proposed in this article are regarded not as additional paperwork for teachers, but as methodological scaffolds that simplify the management of complex activities.

Practical Recommendations

Implementing the methodology does not require all topics to be transformed into complex STEM projects at once. Initially, it is advisable to select two or three tasks within a single section of the course that follow the sequence ‘physics



concept – real-life problem – measurable quantity – engineering solution – mathematical analysis – assessment evidence’. If the teacher consistently uses a project brief and a simple rubric in these tasks, extending integration to subsequent topics becomes easier. This approach establishes STEM not as an occasional celebratory event, but as a manageable element of everyday classroom methodology.

It is useful to prepare minimal-resource, standard, and digital versions of each task. The minimal-resource version may rely on simple materials and manually recorded measurements; the standard version on school laboratory instruments; and the digital version on a sensor, simulation, or spreadsheet. In all three versions, the physics question, measurable quantity, evidence, and assessment criterion remain the same. Such adaptation makes it possible to preserve the scientific core of the methodology despite differences in schools’ material and technical resources.

It is recommended that each laboratory task give students at least one opportunity to make a genuine decision: which material to compare, at what intervals to take measurements, which graph to select, which design to test, or which method to use to reduce error. The teacher establishes the boundaries regarding safety, time, and essential scientific conditions. This guided form of independence creates a methodological balance between ready-made instructions and a fully open-ended project.

Assessment should retain individual evidence alongside the group product. For example, after the project defence, each student may be asked a short question such as ‘Which physical factor had the greatest influence on the result?’, ‘Which measurement result changed your decision?’, or ‘What limitation does the model have?’ Including the initial plan, measurement table, final product, teacher or peer feedback, and revised version in a portfolio makes visible not only the student’s product, but also the process of development.

Limitations and Directions for Further Research

This article is limited to the theoretical, methodological, and design-oriented materials of the study. Therefore, the article itself does not draw independent empirical conclusions about the effectiveness, effect size, or consistency of the



proposed model across different regions. The model, algorithm, tasks, and rubrics provide a basis for designing the educational process, but their actual effectiveness needs to be examined separately in relation to the experimental design, teacher preparation, resources, student age, and consistency of assessment implementation.

Further research should compare the cognitive load, completion time, and resource requirements of tasks across different sections of physics; identify the conditions under which combinations of real and virtual experiments are effective; examine inter-rater agreement in rubric-based assessment; and investigate the relationship between individual and group outcomes. Assessing the transfer of knowledge to new situations by reapplying the same physics competency in different contexts is also a promising direction for the further development of the methodology.

Conclusion

The methodology systematised in this research article proposes a six-block model for the purposeful integration of the physics course in general secondary education with STEM components. The model brings lesson objectives, theoretical and methodological foundations, physics and interdisciplinary content, procedural stages of student activity, didactic resources, and the outcome-assessment mechanism together within a unified system. Its central requirement is the primacy of physics content: technology, engineering, and mathematics specifically serve to understand and investigate a physical phenomenon and translate that understanding into a practical solution.

A STEM-based physics lesson begins with understanding a problem situation and proceeds through identifying physical factors, planning a project or experiment, creating a model or device, taking measurements, carrying out mathematical and graphical analysis, presenting results, reflecting, and making improvements. The functional interconnection of projects, experiments, modelling, and engineering design within a single task moves students from the position of passive listeners to that of researchers and designers who make evidence-based decisions. Throughout this process, the leading criterion is not the product's external appearance, but its grounding in physics and its evidence-based defence.



The elements of didactic support, including lesson plans, integration maps, mini-laboratories, project briefs, engineering design cards, virtual resources, sensor-based tasks, PISA-type contextual tasks, portfolios, and analytic rubrics, complement one another. Cognitive, practical-performance, technological, engineering-creative, mathematical-analytical, communicative, and reflective criteria make it possible to interpret knowledge, process, and product comprehensively. Thus, the STEM approach is introduced into physics lessons not as a separate ‘additional activity’, but as a coherent methodological system for transferring physics knowledge to real-world problems, testing it through experimentation, applying it in engineering solutions, and improving those solutions through reflection.

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