



METHODOLOGY FOR DEVELOPING STUDENTS' TECHNICAL CREATIVITY THROUGH A STEAM APPROACH IN PHYSICS EDUCATION

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Abstract

Knowledge of physical laws does not, in itself, ensure the ability to apply them to solve a technical problem. This article presents a STEAM-based methodology for developing technical creativity among students at higher technical education institutions. Drawing on theoretical analysis, functional comparison and pedagogical modelling, it explains the relationships among the goal-setting, theoretical–methodological, content, technological–activity, digital–didactic, assessment–diagnostic and outcome–reflective blocks. Learning activities are organised as a cycle of problem formulation, construction of a physical model, mathematical or schematic justification, testing through an experiment or simulation, project development and reflective assessment. The methodology specifies the use of the 5E model in mechanics, energy auditing in thermodynamics, circuit design in the electric current unit, visual–cognitive modelling in optics, and the Predict–Simulate–Explain approach in quantum optics. An optical filter project based on a laboratory investigation of Malus's law illustrates how the methodology operates in practice. The article distinguishes six criteria of technical creativity, evidence from processes and products, and the functions of diagnostic, formative and summative assessment. The principal outcome is a methodological system that aligns physics content, learning actions, technical products and assessment evidence.

Keywords: STEAM approach; technical creativity; physics education; learning project activities; methodological model; digital modelling; assessment rubric; reflection.



Introduction

The practical value of physics teaching in higher technical education is not determined solely by students' ability to recall laws and formulae. Students need to explain how a device operates, select a physical model for a technical situation, test calculation results experimentally and propose a justified solution. Pedagogical perspectives on aligning educational aims, learning activities and intended outcomes in advance call for these objectives to be addressed through an integrated methodological system [1]. The problem addressed in our research concerns the separation of theory, practical classes, laboratory work and independent study. Solving a prescribed problem or following laboratory instructions does not, in itself, demonstrate the development of a new technical proposal. Our earlier research examined the relationship between practical, laboratory and independent activities and technical creativity [2]. The methodological task now is to integrate these activities into a coherent project cycle across the units of general physics. The purpose of this article is to explain the relationships among a STEAM-based methodological model, unit-specific learning project activities and an assessment system. The analysis clarifies the structure of the model, the leading activity in each unit, the physical basis of the product developed by students, and the evidence needed to assess it.

Literature Review

N.N. Azizxo'jayeva discusses pedagogical technologies in relation to educational content, forms of instruction and pedagogical skills [1]. This perspective highlights the need not merely to state an objective separately, but to make it evident in lesson content and assessment. Our work on technical creativity, in turn, focuses on applying physics knowledge to practical tasks and independent activities [2]. Among representatives of the Russian school of pedagogy and psychology, M.I. Makhmutov identifies a problem situation as an important condition for organising cognitive activity [3]. L.S. Vygotsky's ideas about collaboration and the zone of proximal development explain the role of guided support in complex tasks [4]. In a physics project, these approaches involve helping students understand the problem, select a model and gradually reach an independent decision, rather than providing a ready-made solution.



J. Dewey identifies the relationship between experience and education as an important foundation of learning activity [5]. M. Sanders explains interdisciplinary connections in terms of integrative STEM education [6]. Studies edited by R.M. Capraro, M.M. Capraro and J.R. Morgan examine the alignment of project outcomes, interdisciplinary tasks and assessment [7]. D. Henriksen analyses design thinking as a means of connecting science, art and creative projects [8]. These perspectives do not replace one another: problem-based learning initiates inquiry, collaboration supports activity, experimentation tests the model, project work transforms knowledge into a product, and design makes the solution understandable. In our methodology, these functions are adapted to the characteristics of the different physics units.

Methodology and Research Design

The article is based on a systematisation of the theoretical and methodological results developed in Chapter II of our dissertation. Conceptual analysis clarified the structure of technical creativity; functional comparison differentiated the STEAM components and unit-specific methods; and pedagogical modelling connected aims, activities, products and diagnostic evidence. The literature discussion was confined to the selected theoretical foundations and is not presented as an independent systematic literature review. The analytical procedure involved defining the model blocks, specifying activities across five physics units, developing the project cycle and aligning assessment evidence with the criteria. The optical filter task is presented as a methodological example illustrating these connections. The article does not claim to report a new educational experiment; the sample, statistical results and effectiveness indicators from Chapter III were excluded from the scope of this analysis.

Research Results

Result 1. A Methodological Model of Technical Creativity

Technical creativity was understood as the ability to develop a new or improved technical solution on the basis of physical laws, experimentation and a mathematical or digital model, to justify the solution and to evaluate it reflectively. Accordingly, the model was organised into seven blocks (Table 1).



Table 1. Blocks of the methodological model and their functions

Model block	Methodological function and outcome
Goal-setting	Define learning outcomes related to understanding a technical problem, providing a physical justification and developing a solution.
Theoretical–methodological	Coordinate systems, competency-based, activity-based, problem-based, project-based and reflective approaches.
Content	Connect mechanics, thermodynamics, electric current, optics and quantum optics with professional and technical tasks.
Technological–activity	Organise student activity through the stages of problem formulation, modelling, calculation, experimentation, project work and reflection.
Digital–didactic	Select sensors, simulations, virtual laboratories and electronic resources as tools for measurement and analysis.
Assessment–diagnostic	Collect criterion-referenced evidence through tests, project specifications, observation, laboratory reports and rubrics.
Outcome–reflective	Defend a diagram, model, prototype or technical proposal, identify limitations and make improvements.

The blocks are connected through feedback: experimental results may prompt revision of the model or calculations, while a question during the project defence may lead to further investigation. Assessment goes beyond recording the final product and informs the next task and the instructional support required.

Result 2. Integration of STEAM Components and Physics Units

Within STEAM, Science provides physical explanations; Technology contributes measurement and technological tools; Engineering generates technical solutions; Art supports visual clarity and ergonomic presentation; and Mathematics provides calculation, graphing and error analysis. Each unit uses a combination of these actions suited to its content (Table 2).



Table 2. Learning project activities across physics units

Physics unit	Leading method	Student activity and product
Mechanics	5E model, case studies, inquiry-based laboratory work	Develop a mechanical model or mini-project using force diagrams, motion graphs and the Atwood machine experiment.
Thermodynamics	Energy auditing	Define the system boundary and energy balance; use measurement results to propose ways to reduce heat losses.
Electric current	Project-based learning, circuit design	Calculate circuit parameters using Ohm's and Kirchhoff's laws and measure resistance with a Wheatstone bridge; propose a safe, energy-efficient circuit.
Optics	Visual–cognitive modelling, design thinking	Observe polarisation and test Malus's law; prepare an optical filter model, a graph and a design solution.
Quantum optics	Predict–Simulate–Explain	Make predictions, conduct a virtual experiment and analyse graphs of the photoelectric effect; develop a photocell or photodetector concept based on a physical explanation.

The 5E model in mechanics connects engagement, exploration, explanation, application of knowledge in a new situation and evaluation. Energy flows take priority in thermodynamics, circuit operation and measurement quality in the electric current unit, and visual models of phenomena in optics. In quantum optics, limited opportunities for direct observation make parameter manipulation and graphical interpretation of results central to learning. Across all units, lectures establish the physical basis of the problem, practical classes represent it quantitatively or schematically, laboratory work tests it, and independent projects lead to an improved solution. The Art component is not reduced to decorating completed work: circuit readability, graph clarity, ease of device use and the logical organisation of a presentation are integral to the solution [8].



Result 3. A Six-Stage Learning Project Cycle

The operation of the methodological cycle is illustrated by linking a laboratory investigation of Malus's law in the optics unit to an optical filter project. The following sequence is an example of how to organise student activity, not a report of measurement results.

Stage 1 – motivation and problem formulation. Students are presented with a situation involving glare reduction or the control of light transmission. Each student writes a prediction about how rotating the analyser affects intensity. The general question 'Which filter is better?' is reformulated as an investigation of the relationship between angle and intensity. The teacher does not announce the answer, but asks students to explain the physical basis of their predictions.

Stage 2 – the physical model. Students connect the concepts of polarised light, the electric field vector and the analyser axis. The relative orientation of the polariser and analyser is represented in a diagram. The appearance of the phenomenon is distinguished from its physical explanation: observing a reduction in light intensity does not, in itself, justify its dependence on angle.

Stage 3 – mathematical and schematic justification. The expected relationship is expressed by Malus's law:

$$I = I_0 \cos^2 \varphi \quad (1)$$

Here, I_0 is the intensity of the linearly polarised light incident on the analyser, I is the intensity of the transmitted light, and φ is the angle between the polarisation direction and the analyser axis. Students use the model to explain the expected variation and prepare a measurement setup diagram and a table for recording results.

Stage 4 – experimentation and testing. The analyser angle is varied and intensity values are recorded. The light source and the positions of the instruments are kept unchanged during the comparison. Results are entered in a table with their units, plotted on a graph and compared with the theoretical relationship.



Rather than concealing measurement discrepancies, students discuss their possible causes and ways to investigate them.

Stage 5 – technical project development and defence. The group translates its physical conclusion into a concept for an optical filter or screen protector. The project specification includes the problem, physical basis, diagram, measurement table, graph and limitations of use. The central requirement is not the filter's appearance, but an evidence-based explanation of the chosen arrangement and design decision.

Stage 6 – reflective assessment. Students compare their initial predictions with their final explanations, discuss differences between the model and the experiment, and propose improvements to the solution. The project is revised in response to questions from the teacher and peers. Alongside the group product, each student's physical explanation and responses during the defence are recorded. The general applicability of this cycle lies not in transferring the same experiment to every unit, but in using the product of one stage as the basis for the next. In the electric current unit, this basis comprises the circuit diagram and measurement record; in thermodynamics, the energy balance; and in quantum optics, simulation data and a graph.

Result 4. Didactic Conditions and Evidence-Based Assessment

Seven conditions were specified for implementing the methodology: a professional or technical problem; STEAM integration within the task; regular project work and small-scale inquiry; inquiry-oriented laboratory work; purposeful digital modelling; collaboration and teacher facilitation; and reflective assessment. These conditions complement one another. For example, when a project task does not require justification through physical evidence, the activity may remain at the level of constructing a model. Technical creativity is observed through six criteria. Each criterion is linked to a specific student action and documented evidence (Table 3).



Table 3. Criteria of technical creativity and assessment evidence

Criterion	Observable action	Assessment evidence
Motivational and value-related	Formulate a problem, show initiative and express interest in a solution	Question, questionnaire, observation record
Cognitive and physics-related	Justify the choice of a law and model for a technical situation	Conceptual response, calculation, model explanation
Practical-experimental	Measure, construct graphs and analyse errors	Laboratory report, table and graph
Engineering-design	Develop a diagram or model and evaluate an alternative solution	Project specification, prototype, technical proposal
Digital-modelling	Control parameters and process data	Simulation record, digital model
Reflective-communicative	Defend results, identify errors and correct them	Defence response, reflection, improvement plan

Diagnostic assessment identifies prior knowledge, motivation and readiness for project work at the start of a module. Formative assessment reveals difficulties during experimentation, calculation and project development, providing a basis for guided support. Summative assessment considers the final test, project specification, presentation, experimental results and reflection together. Assessment thus addresses not only the existence of a final product, but also how it was developed. The general criteria are distinguished from the rubric for a particular STEAM project. The project rubric assesses problem formulation, physical justification, the engineering solution, experimentation or simulation, design and presentation, and reflection. For example, strong interest is a motivational indicator, but it does not compensate for an incorrect physical model. Evidence is therefore recorded separately for each criterion. Performance levels are described using a four-level rubric: unsatisfactory – below 60 points; satisfactory – 60–69.9; good – 70–89.9; and excellent – 90–100 points. At the highest level, students independently justify the problem, compare alternative solutions and explain limitations. At lower levels, the need for support with modelling, experimentation or reflection increases. The existence of a rubric does not, in itself, mean that its reliability has been tested.



Discussion

The distinctive feature of the proposed methodology is not the number of methods it includes, but the alignment of physics content, student activity and assessment evidence. Applying the same project template to mechanics and quantum optics without modification constrains their specific didactic characteristics. Selecting different leading methods for the five units makes it possible to account for differences in content while retaining a common cycle. A functioning device or an attractive presentation is not sufficient evidence of technical creativity. Students need to explain the physical basis of their solution, the measurement results and the reasons for improvement. Digital tools serve the same purpose: changing a parameter and explaining its consequences is more important than copying a ready-made graph. Collaborative support should reveal individual understanding rather than conceal it [4, 7].

Practical Recommendations

For each unit, a project specification should be prepared to connect lectures, practical classes, laboratory work and independent study. The physical problem, required resources, safety conditions, intended product and assessment criteria are specified in advance. Rather than supplying ready-made answers, the teacher provides support through guiding questions, diagrams or tables. Opportunities for revision are provided after reflection. The PDCA cycle is used to update the methodology: the task is planned, implemented, checked against evidence and improved in response to the difficulties identified.

Limitations and Directions for Further Research

The results presented are limited to the methodological model, task system and diagnostic resources. The optical filter example does not provide actual measurements or a predetermined effectiveness result. Criterion weights, inter-rater agreement and the magnitude of causal effects were not established within the scope of this article. Further investigations need to examine task feasibility, student independence and the alignment between process evidence and final grades.



Conclusion

Developing technical creativity through STEAM requires the coherent design of activities extending from learning a physical law to justifying a technical solution. The seven-block model connects the aims, content, resources, activity stages and assessment mechanisms of this process.

The 5E model in mechanics, energy auditing in thermodynamics, circuit design in the electric current unit, visual–cognitive modelling in optics and the Predict–Simulate–Explain approach in quantum optics are unit-specific forms of a common project cycle. Their outcomes are expressed not only through a completed object, but also through a physical model, calculations, experimental evidence and a reflective conclusion.

The six-criterion assessment system, together with diagnostic, formative and summative instruments, provides a basis for analysing process and product jointly. The practical significance of the methodology lies in guiding students away from reproducing a prescribed algorithm towards becoming active participants who defend their technical decisions with evidence and improve them.

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***Modern American Journal of Linguistics,
Education, and Pedagogy***

ISSN (E): 3067-7874

Volume 1, Issue 6, September, 2025

Website: usajournals.org

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