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Integrating the Engineering Design Process into STEM-Based Physics Education: A Systematic Literature Review of Research Trends, Implementation, and Effectiveness

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Abstract: Research on integrating the Engineering Design Process (EDP) into STEM-based physics education has expanded, but prior reviews have generally examined STEM or EDP broadly, while a recent physics-focused review primarily synthesized learning impacts. An integrated map linking publication trends, implementation contexts, student-designed products, outcome measures, and evidence of effectiveness remains limited. This systematic literature review addresses that gap by analyzing peer-reviewed studies published from 2021 to 2026. Following PRISMA 2020, searches of Scopus and SpringerLink identified 1,442 records; 27 studies met the eligibility criteria. Study characteristics were extracted using a structured form and synthesized through descriptive frequency analysis and qualitative thematic synthesis. Effectiveness was determined from the direction and consistency of statistically supported quantitative findings and analytically supported qualitative findings rather than from the frequency of outcome variables alone. The evidence shows that quantitative designs were most common (40.74%), studies were concentrated in Turkey, China, and Indonesia, and 92.59% were conducted at elementary or secondary levels. Regular classrooms accounted for 62.96% of implementation contexts. Student products were dominated by engineering structures, robotics and automated systems, and energy-related devices. Cognitive outcomes, especially higher-order thinking skills, were assessed most frequently, while affective and performance outcomes received less attention. Across heterogeneous designs, STEM-EDP produced predominantly positive findings for problem-solving, critical and creative thinking, engagement, self-efficacy, engineering design, collaboration, and product performance. However, short-term classroom interventions and limited higher-education and cocurricular evidence constrain generalization. These results provide a context-process-product-outcome map for designing and evaluating STEM-EDP physics learning.

Keywords: Engineering design process; Physics education; STEM; Systematic literature review

Introduction

Physics education is expected to develop conceptual understanding together with critical thinking, creativity, problem-solving, collaboration, and evidence-based decision-making. These competencies are particularly relevant when students must apply physical principles to technological and environmental problems. However, the science performance reported in PISA 2022 indicates that Indonesian students continue to experience difficulty applying scientific knowledge in unfamiliar contexts (OECD, 2023). This condition supports the use of learning designs that connect physics

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concepts with authentic investigation, design decisions, and the evaluation of workable solutions.

Integrated STEM education connects scientific knowledge, technological tools, engineering practices, and mathematical reasoning around a problem that cannot be resolved through a single discipline (Kelley & Knowles, 2016; Martín-Páez et al., 2019). Within this framework, the Engineering Design Process provides an iterative sequence for defining constraints, generating alternatives, constructing and testing prototypes, evaluating evidence, and revising solutions (Hynes et al., 2011; Moore et al., 2014). This sequence is compatible with physics learning because abstract concepts can be examined through measurable design performance, such as force balance, energy conversion, electrical control, fluid behavior, and motion.

Empirical findings nevertheless show variation in the outcomes and conditions of STEM-EDP implementation. Abdurrahman et al. (2023) reported gains in systems thinking through a renewable-energy makerspace, Safitri et al. (2024) found improvements in creative and critical thinking, and Xi et al. (2024) showed that integrating EDP with the conceive-design-implement-operate model strengthened STEM competence. In contrast, qualitative work in an interest-based after-school setting indicates that participation, identity, and social support can shape outcomes that are not adequately represented by achievement tests alone (Murthi et al., 2024). Indonesian research also demonstrates that STEM projects may influence problem-solving, higher-order thinking, collaboration, self-efficacy, and science-process skills, but these variables are commonly studied separately and through different instruments (Devi et al., 2024; Martawijaya et al., 2023; Purwaningsih et al., 2020; Rasmi et al., 2025).

Previous evidence syntheses have reviewed EDP across STEM education or K-12 science classrooms and have identified common design stages, implementation challenges, and positive learning outcomes (Arık & Topçu, 2022; Hafiz & Ayop, 2019; Winarno et al., 2020). A recent physics-focused review synthesized 23 studies and emphasized the contribution of STEM-based EDP to creative thinking, critical thinking, and problem-solving (Syukri et al., 2026). That review establishes the relevance of STEM-EDP in physics; however, a more differentiated synthesis is still required to connect publication and geographical trends with educational levels, formal and non-formal contexts, physics topics, student-designed products, research designs, outcome measures, and the direction of evidence across cognitive, affective, and performance domains. Without this mapping, it remains difficult to determine where the evidence is concentrated, which dimensions are under-assessed, and how design tasks should be aligned with physics content and learner level.

Accordingly, this study updates and extends earlier reviews by systematically mapping STEM-EDP research in physics education published from 2021 to 2026. Its novelty lies in integrating five analytical dimensions within one review: research trends, implementation characteristics, student-designed products, effectiveness variables, and the direction of learning outcomes across cognitive, affective, and performance domains. The synthesis is intended to provide an empirical basis for researchers selecting outcome measures, teachers designing physics-based engineering tasks, and curriculum developers planning sustained STEM-EDP learning experiences.

To achieve this objective, the study addresses the following research questions: RQ1: What are the research trends in STEM-based Engineering Design Process implementation in physics education during the period 2021–2026? RQ2: What are the characteristics of STEM-EDP implementation in physics education in terms of educational level and learning context? RQ3: What types of products are designed by students through STEM-EDP implementation in physics education? RQ4: What variables are used to measure the effectiveness of STEM-EDP in physics education? RQ5: What do existing studies reveal about the effectiveness of STEM-EDP on students’ cognitive, affective, and performance domains?

Method

This study employed a systematic literature review and was reported in accordance with PRISMA 2020, which supports transparent identification, screening, eligibility assessment, and synthesis of evidence (Page et al., 2021). The review focused on empirical studies that explicitly integrated STEM education with an Engineering Design Process in a physics-learning context.

Identification

Scopus and SpringerLink were searched for peer reviewed publications dated 2021-2026. Scopus was selected because its multidisciplinary indexing supports retrieval across science education, engineering education, educational technology, and physics education, whereas SpringerLink provides complementary coverage of full-text education and STEM journals. Using both sources balanced broad citation indexing with publisher-level access, although the restriction to two databases remains a limitation because eligible studies indexed elsewhere may not have been retrieved (Gusenbauer & Haddaway, 2020). The search combined the terms “engineering design process” OR “EDP” with “STEM” AND (“physics” OR "physics education" OR "physics learning"). Related phrases, including "engineering design in physics education" and "STEM through the engineering design process," were also applied. The search produced 1,442 records: 577 from Scopus and 865 from SpringerLink.

Screening and Eligibility

After automated restrictions for publication year and document type, 851 records were removed, followed by 143 duplicate records. The remaining 448 records were screened by title and abstract, and 285 were excluded because they did not meet the review focus. Of 163 reports sought for retrieval, 122 could not be obtained, leaving 41 full-text reports for eligibility assessment. Fourteen reports were excluded because they did not implement STEM-EDP in a physics-learning context. The final synthesis therefore included 27 studies. These counts correspond to the PRISMA flow diagram in Figure 1.

Eligibility was determined using predefined criteria covering the study focus, publication type, language, publication year, accessibility, educational context, and methodological reporting (Table 1). Studies were excluded when EDP was not explicitly implemented, physics concepts were absent, the report was not a peer-reviewed journal article, the method was insufficiently described, or the full text was unavailable.

The PRISMA flow of study selection is presented in Figure 1.

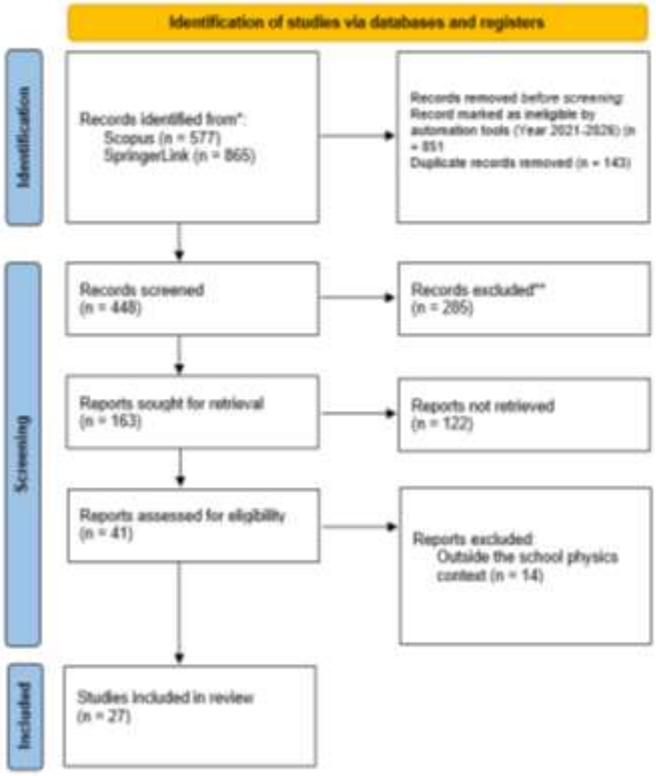

Figure 1. PRISMA flow diagram

Table 1. Inclusion and Exclusion Criteria

Category	Inclusion criteria	Exclusion criteria
Focus	STEM learning explicitly integrating an Engineering Design Process in physics	No explicit EDP implementation or not related to physics education
Publication type	Peer-reviewed journal article	Abstract, report, book chapter, proceeding, thesis, or non-peer-reviewed source
Language	English	Language other than English
Publication year	2021–2026	Published before 2021 or without a clear publication year
Accessibility	Full text available	Abstract only or inaccessible full text
Context	Formal or non-formal physics-learning setting	No physics concepts or learning context
Methodology	Research design and data collection described	Insufficient methodological information

Methodological Eligibility and Review Scope

During full-text eligibility assessment, methodological transparency was checked using review-specific criteria: each study had to report a recognizable research design, defined participants or learning context, documented data-collection procedures or instruments, and an identifiable analytical procedure. These checks were applied as eligibility criteria rather than as a formal risk-of-bias or critical-appraisal instrument. A separate standardized tool such as MMAT, JBI, or CASP was not applied because the primary objective of this review was descriptive and thematic mapping rather than pooled effect estimation or a quality-weighted effectiveness synthesis. Accordingly, statements about effectiveness refer to the direction and consistency of findings reported in the included studies and should not be interpreted as quality-adjusted effect estimates.

Data Extraction

A structured extraction form was used to record author and year, country, publication outlet, participants, educational level, learning context, physics topic, intervention characteristics, research design, student-designed product, measured variables, instruments, and reported findings. The extracted characteristics of all 27 studies are presented in Appendix 1 (Table 2). Using a common extraction structure reduced variation in coding and supported comparison across heterogeneous study designs.

Table 2. Characteristics of Studies Included in the Systematic Review

Author and year	Journal or index	Participants	Intervention or method	Outcomes	Study design	Product
Abdurrahman et al. (2023)	Heliyon (Q1	67 grade 11 students	Quasi-experimental / non-equivalent control group design (Pre-test and Post-test)	Students' system thinking skills	Quantitative	Vacuum cleaner design
Weng et al. (2022)	Frontiers in Psychology (Q1)	95 Secondary Three / Grade 9 students	Experimental intervention	Creativity, critical thinking, STEM interest, STEM identity, and the effect of textbook problem	Quantitative	Arduino-based traffic light system
Dung et al. (2023)	Journal Of Education And E-Learning Research (Q3)	40 grade 10 students	Case study	Physics and mathematics knowledge, communication, teamwork, problem-solving competency	Qualitative	Salinometer
Bampasidis et al. (2021)	Advances In Engineering Education (Q3)	3,649 secondary school students	Survey analysis using student and teacher questionnaires	Students' attitude, STEM skills, transversal skills, cooperation, school performance, satisfaction, and career perspective	Quantitative	Remotely operated underwater vehicle (ROV)
Duong et al. (2022)	Jurnal Pendidikan IPA Indonesia (Q3)	96 grade 11 rural high school students	Action Research, Case study	Students' engagement, understanding, creativity, product success, manufacturing time, operating time, cost, and equipment failure	Qualitative	Electrostatic Painting
Karatas-Aydin & Isiksal-Bostan (2023)	Thinking Skills and Creativity (Q1)	6 gifted elementary students, grade 5 - 6	Case study	STEM knowledge, engineering habits of mind	Qualitative	Bridge prototype
Souysaart et al. (2026)	Journal of Science and Mathematics Letters (Q4)	30 sixth-grade elementary students	One-group pretest-posttest	Problem-solving skills and scientific mindset	Quantitative	Wind-Powered Vehicle Design, Solar System Modelling, Boat Buoyancy Challenge
Afkarina et al. (2025)	Journal of Physics: Conference Series	32 grade 11 high school students	Case study	EDP skills: defining problem, gathering information, generating solutions, selecting solutions, and testing solutions	Qualitative	Hot air balloon prototype

Author and year	Journal or index	Participants	Intervention or method	Outcomes	Study design	Product
Uzel & Canbazoğlu Bilici (2022)	Journal of Turkish Science Education (Q2)	23 sixth-grade middle school students	Quasi-experimental / one-group pre-test and post-test	Problem-solving skills and engineering design skills	Quantitative	Thermometer, anti-freezing milk tank, home heating/thermal insulation design, cold weather protection design, and lemon carrying container
Tsai (2025)	Sustainability (Q1)	27 pre-service elementary teachers	Quasi-experimental / one-group pre-test and post-test	Engineering concepts, engineering design self-efficacy, computational thinking, programming self-efficacy, and participation perception	Quantitative	Educational buzz wire game machine
Yang (2025)	Thinking Skills and Creativity (Q1)	35 grade 5 primary school students	Quasi-experimental two-group pre-test and post-test	Engineering-based problem-solving performance, problem scoping, idea creation and design sketching, planning strategies, and quality of students' drawings	Mixed Method	Tallest straw tower, rubber-band-powered car, straw boat, high-speed motorboat, bird's nest, and prototype boat
Barajas-Salazar et al. (2025)	Frontiers in Education (Q1)	Middle school students	Mixed-method	STEM identity, self-efficacy, perceptions of engineering knowledge, understanding of EDP, and lesson-specific engineering knowledge	Mixed Method	Water filter prototype, model skyscraper, , alarm circuit, toothbrush-head robot, and solar oven
Wang & Samsudin (2025)	Foro de Educación (Q4)	100 primary school students	Quasi-experimental / non-equivalent groups pre-test and post-test	Energy concept mastery, ICT familiarity, attendance, and instructional condition	Quantitative	Minecraft-based digital energy design
Xi et al. (2024)	Educational Technology Research and Development (Q1)	64 eleventh-grade high school students	Quasi-experimental / pre-test and post-test nonequivalent group design	STEM knowledge, STEM attitudes, STEM skills, and epistemic network of STEM competence	Mixed Method	Creative Sky Ladder, 3D gear, and Arduino-controlled lifting system
Shahat et al. (2024)	Arab Gulf Journal of Scientific Research (Q2)	70 preservice science teachers	Descriptive cross-sectional study using Fair Tes	EDP performance stages, gender, science major, and teacher preparation program	Quantitative	Biofuel product, chocolate coffee cup, marshmallow tower, spoon catapult, Amazon fish tank,

Author and year	Journal or index	Participants	Intervention or method	Outcomes	Study design	Product
Şen et al. (2021)	Thinking Skills and Creativity (Q1)	7 gifted and talented students aged 12 - 13 years old at Science and Art Centre,	Case study	Computational thinking skills	Qualitative	Rubik's cube-solving robot using Lego Mindstorms EV3 and 3D robot models produced with Tinkercad and 3D printer
Khamhaengpol et al. (2021)	Thinking Skills and Creativity (Q1)	180 high school students	Descriptive quantitative study	Basic Science Process Skills, Engineering Design Process, observation skills, design completion, material selection, cost estimation, and shelter capacity calculation	Quantitative descriptive	Waterproof shelter prototype
Xu et al. (2026)	Thinking Skills and Creativity (Q1)	42 seventh-grade students Junior High School	Mixed-method case study	Creative thinking, digital work quality, learning performance, gender differences, and students' learning experience	Mixed Method	Vast Universe app and Ladybug Dash game app using App Inventor
Putra et al. (2023)	International Journal of Information and Education Technology (Q2)	17 fifth-grade elementary school students	Case study	Students' ability to identify problems, determine solutions, design models, create models, and recreate models for flood disaster mitigation	Qualitative	Speedboat / boat prototype for flood disaster mitigation
Gök & Sürmeli (2022)	Asian Journal of University Education (Q3)	40 seventh-grade secondary school	Pre-experimental / one-group pre-test post-test	Scientific creativity	Mixed Method	Electric energy-based moving toys.
Ergül & Çalış (2021)	Journal of Turkish Science Education (Q2)	28 eleventh-grade high school students	Case study	Engineering design skills	Qualitative	Electromagnet system for collecting and separating metal waste
Al-Hinai et al. (2026)	European Journal of STEM Education (Q1)	118 fourth-grade students from four public elementary schools	Quasi-experimental / pre-test and post-test	Problem-solving skills, motivation, responsibility, engagement, self-efficacy, collaboration, and gender differences	Quantitative	Skeleton model, animal shelter, recycled pen holder, floating paper boat, oil spill cleanup solution, and chocolate mold
Panergayo & Roleda (2025)	Journal of Baltic Science Education (Q2)	108 Grade 12	action research	Conceptual understanding, engineering design performance, scientific creativity, fluency, flexibility, originality, learning affordances, and constraints	Educational action research / mixed method	Shoebox glider prootype

Author and year	Journal or index	Participants	Intervention or method	Outcomes	Study design	Product
Özkul (2025)	Humanities and Social Sciences Communications (Q1)	37 fourth-grade elementary school students,	quasi-experimental pre-test post-test control group	Entrepreneurship skills, problem-solving skills, teamwork, creativity, engineering skills, STEM interest, and STEM career awareness	Mixed Method	Fossil mold, earthquake-resistant house, thermos, food-powered car, pelican egg protector, bridge, and boat
Murthi et al. (2024)	Research in Science Education (Q1)	26 middle school students	Qualitative study using interest-based afterschool maker program	STEM engagement, curiosity, engineering design process, capacity building, STEM learning, and understanding of STEM in daily life	Qualitative study	3D printed objects, LED greeting cards, paper circuits, motor-based products, robots, phone stand, calendar clock, and open-ended final projects
Putra et al. (2023)	Asia-Pacific Education Researcher (Q1)	12 grade 10 high school students	Case study	Critical thinking skills	Qualitative	Irrigation dam design
Sung & Kelley (2022)	International Journal of Science and Mathematics Education (Q1)	144 elementary students grade 3-6	Sequential analysis	EDP patterns, cognitive strategies, design tasks, problem phase, solution phase, questioning, managing, modeling, and predicting	Quantitative	Simple machine, canal, doggie door alarm, prosthetic leg device, water ilter, roller coaster, and solar tracker

Data Synthesis and Determination of Effectiveness

Data were synthesized through descriptive quantitative mapping and qualitative thematic synthesis. Frequencies and percentages were used to summarize publication year, country, physics topic, research design, educational level, learning context, product category, and outcome variable. Thematic synthesis was conducted by coding reported findings, grouping related codes, and developing analytical categories across cognitive, affective, and performance domains (Thomas & Harden, 2008). Because study designs, participants, interventions, instruments, and reporting formats were heterogeneous, statistical meta-analysis was not appropriate; the narrative synthesis was therefore reported in line with principles for synthesis without meta-analysis (Campbell et al., 2020). A quantitative finding was coded as positive when a study reported a statistically supported favorable change or between-group difference, and a qualitative finding was coded as positive when the conclusion was supported by systematically analyzed observations, interviews, documents, or artifacts. Findings were coded as mixed or conditional when results differed by indicator, group, or implementation condition, and as non-positive when no favorable change was reported. Consequently, “effectiveness” in this review refers to the consistency and direction of evidence, not a pooled effect magnitude.

Result and Discussion

RQ1. Trends in the Implementation of Engineering Design Process (EDP) in STEM-Based Physics Education

The 27 studies were examined according to publication year, geographical distribution, physics content, and research design. These dimensions indicate where STEM-EDP research has developed and where the evidence base remains concentrated.

Publication Trends Over Time

Figure 2 shows an increase in publications from 2021 to 2025, with the largest number appearing in 2025. Publications assigned to 2026 should be interpreted as a partial-year count and should not be compared directly with complete calendar years.

The increase indicates growing interest in design-centered STEM learning and in outcomes that require students to analyze problems, generate alternatives, and revise products. It may also reflect the broader shift toward competency-based science curricula and project-oriented assessment. Nevertheless, publication counts describe research activity rather than implementation quality, and the partial 2026 dataset limits claims about a continuing annual increase.

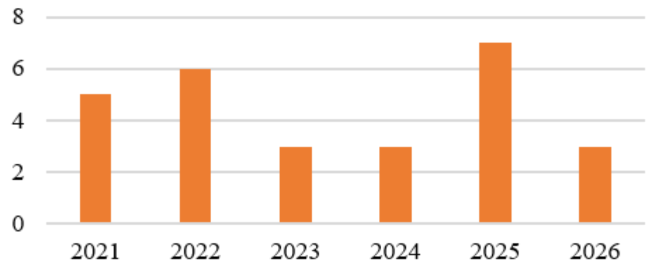

Figure 2. Yearly distribution of publications

Geographical Distribution of Studies

As shown in Figure 3, studies were distributed across several countries but were concentrated in Turkey, China, and Indonesia. Other studies were conducted in the United States, Vietnam, Taiwan, Thailand, Oman, Hong Kong, Greece, and the Philippines.

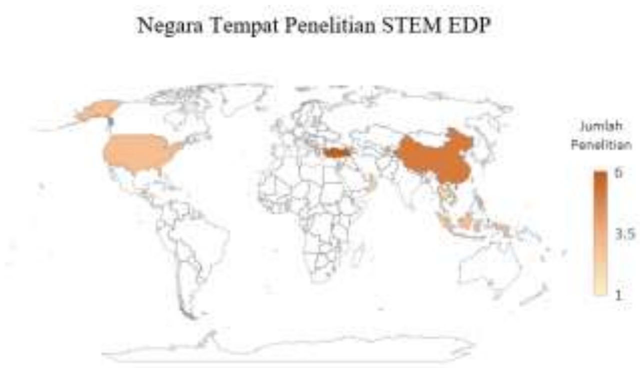

Figure 3. Distribution of countries in STEM-EDP physics education studies

The concentration in Asian settings can be interpreted in relation to curriculum reforms that emphasize STEM integration, problem-solving, engineering practices, and 21st-century competencies. In Indonesia, for example, STEM-PjBL and design-oriented studies have expanded across physics and science topics, including impulse and momentum, environmental problems, electricity, elasticity, and locally situated projects (Lestari et al., 2024; Martawijaya et al., 2023; Purwaningsih et al., 2020; Safitri et al., 2024; Subiki et al., 2023). This distribution should not be treated as direct evidence that Asian systems implement STEM-EDP more effectively. It may also reflect the databases, English-language criterion, journal-indexing patterns, and terminology used in the search.

Physics Content

Figure 4 shows that mechanics and motion were the most frequently represented physics topics, followed by energy, electricity and electromagnetism, and fluid mechanics.

These topics offer observable variables and design constraints that can be linked to product performance. Mechanics supports structures and vehicles; electricity and electromagnetism support circuits, sensors, and automated systems; fluids support boats, filters, pumps, and salinometers; and energy topics support devices that can be compared through output, efficiency, or sustainability criteria. Topic selection therefore influences both the feasible product and the evidence students can collect during testing.

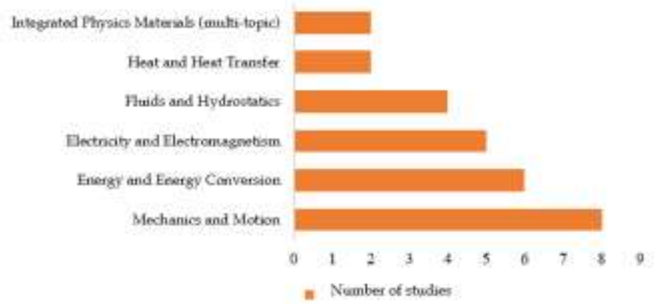

Figure 4. Distribution of physics topics

Research Design

Table 3 shows that quantitative studies were most common (40.74%), followed by qualitative studies (33.33%) and mixed-method studies (25.93%).

Table 3. Research Design Distribution

Research design	f	%
Quantitative	11	40.74
Qualitative	9	33.33
Mixed methods	7	25.93
Total	27	100.00

The predominance of quantitative designs reflects an emphasis on measurable learning outcomes and comparisons before and after intervention. Qualitative and mixed-method studies, however, provide information on design reasoning, collaboration, identity, engagement, and classroom interaction that cannot be inferred from test scores alone. The coexistence of these approaches supports a multidimensional evaluation of STEM-EDP, but it also produces methodological heterogeneity that prevents direct pooling of effect estimates.

RQ2. Contextual Characteristics of STEM–EDP Implementation in Physics Education

The implementation context was analyzed by educational level and learning setting. STEM-EDP appeared at all levels, but 25 of the 27 studies (92.59%) were conducted in elementary or secondary education, while only two involved university or pre-service teacher participants (Table 4).

The concentration at school level is consistent with the use of EDP as a pedagogical structure for connecting science content with tangible problems and products. Elementary studies generally used accessible materials and bounded design tasks, while secondary studies more often incorporated multiple variables, optimization criteria, sensors, robotics, or energy systems. The limited number of university studies should not be interpreted as evidence that EDP is unsuitable for higher education. University design work is frequently reported under engineering design, capstone, makerspace, project-based learning, or CDIO terminology rather than under the combined label "STEM-EDP physics," which may place it outside the search and eligibility criteria.

Table 4. Educational Level Distribution in STEM-EDP Studies

Educational level	f	%
Elementary school	8	29.63
Middle school	8	29.63
High school	9	33.33
University or pre-service teacher education	2	7.41
Total	27	100.00

The findings nevertheless show that the iterative structure of EDP can be adapted to different levels when constraints, materials, expected calculations, and evaluation criteria are adjusted to learners' prior knowledge. For curriculum planning, educational level should therefore determine the complexity of the design problem and the required evidence, not whether EDP is used.

Table 5. Learning Context Distribution in STEM-EDP Studies

Learning context	f	%
Regular classroom learning	17	62.96
Extracurricular or after-school program	6	22.22
Science camp or summer academy	2	7.41
Special program for gifted or talented students	2	7.41
Total	27	100.00

Regular classrooms accounted for 62.96% of implementations, followed by extracurricular or after-school programs, science camps, and specialized programs. Classroom use indicates that STEM-EDP can be incorporated into formal physics instruction, but scheduled lesson periods may limit repeated testing and redesign. Non-formal settings provide more flexible time, access to tools, and opportunities for sustained teamwork, although participation may be selective. The current distribution therefore supports classroom feasibility but provides less evidence about long-term iteration, voluntary participation, and transfer across settings.

RQ3. Student-Designed Products in STEM-EDP Implementation

The studies reported 54 product instances across six categories because several studies involved more than one artifact (Table 6). These products show how physics concepts were translated into objects, systems, models, or simulations that could be tested against explicit criteria.

Table 6. Distribution of Product Categories in STEM-EDP Implementation

Product category	f	Examples
Engineering prototypes and structures	12	Bridge prototype, sky ladder, marshmallow tower, miniature dam, prosthetic leg
Vehicles, robotics, and automated systems	11	Wind-powered vehicle, remotely operated vehicle, robot, mini helicopter, traffic-light system, glider
Energy and electrical systems	10	Renewable-energy vacuum cleaner, electrostatic painting system, solar tracker, Arduino system
Environmental and disaster-mitigation products	8	Water filter, flood-mitigation boat, oil-spill cleaner, salinometer
Learning media, games, and digital simulations	7	Minecraft-EDP, App Inventor application, buzz-wire game
Physics concept models and demonstrations	6	Solar-system model, hot-air balloon, Archimedes-law demonstration
Total	54	Multiple products could be coded from one study

Engineering prototypes and structures were the largest category, followed by vehicles, robotics and automated systems, and energy or electrical systems. These artifacts require students to coordinate conceptual knowledge with constraints, materials, measurement, and revision. They are therefore well suited to eliciting higher-order thinking. However, the reviewed evidence does not support ranking one product category as producing the greatest improvement in higher-order thinking because the studies used different participants, durations, instruments, and comparison conditions, and no product-stratified meta-analysis was available.

A descriptive relationship was visible between physics topic, product type, and educational level. Mechanics and motion were commonly represented through structures, gliders, and vehicles; electricity and electromagnetism through circuits, robots, traffic lights, and automated devices; fluid topics through boats, filters, and measurement tools; and energy through renewable-energy or efficiency-oriented products. Elementary learners generally constructed simpler models with fewer interacting components, whereas middle- and high-school projects more often required controlled variables, coding, sensors, or optimization. This pattern is analytically plausible but should be interpreted as a mapping result rather than a causal effect of product complexity. Prior studies similarly indicate that project effectiveness depends on task structure, scaffolding, and assessment, not on artifact complexity alone (Alhayat, 2024; Safitri et al., 2024; Sumarni & Kadarwati, 2020).

RQ4. Variables Used to Measure the Effectiveness of STEM–EDP

Outcome variables were grouped into cognitive, affective, and performance domains. Because individual studies measured more than one variable, the total frequency exceeded the number of studies (Table 7).

Table 7. Variables Used to Measure STEM-EDP Effectiveness

Domain	Variable category	f
Cognitive	Thinking skills	23
Cognitive	Knowledge and conceptual understanding	8
Affective	Engagement and participation	6
Affective	Self-efficacy and perception	6
Affective	Attitude, interest, and identity	5
Affective	Motivation, satisfaction, and entrepreneurship	5
Performance	Technical, STEM, communication, and collaboration skills	12
Performance	EDP and engineering-design skills	8
Performance	Project or product performance	5
Total	All coded outcomes	78

Cognitive variables were assessed most frequently, especially critical thinking, creative thinking, problem-solving, systems thinking, and computational thinking. These constructs correspond to the analysis, generation, evaluation, and revision activities embedded in EDP. Conceptual understanding remained important because a successful product does not necessarily demonstrate scientifically valid reasoning unless design decisions are linked to physics principles.

Affective variables were less frequent than cognitive variables. This imbalance likely reflects the continuing priority given to academic outcomes and the relative convenience of administering short pretests and posttests. Engagement, identity, interest, and self-efficacy may require validated scales, observation across several design cycles, or longitudinal follow-up, making them more demanding to measure. Yet these variables are not secondary: design failure, group decision-making, and repeated revision depend on persistence and confidence. Studies of STEM projects and design-oriented learning show that self-efficacy, motivation, and creative disposition can change alongside cognitive outcomes (Devi et al., 2024; Pane et al., 2024; Sawu et al., 2023; Weng et al., 2022).

Performance measures included technical skills, STEM practices, communication, collaboration, engineering-design processes, and product quality. Their inclusion distinguishes STEM-EDP from instruction assessed only through written tests. Process rubrics can capture problem definition, planning, modeling, testing, evidence use, and redesign, while product rubrics can assess functionality and conformity to criteria (Alhayat, 2024; Uzel & Canbazoğlu Bilici, 2022). The relatively smaller number of product-performance measures suggests that several studies evaluated what students knew or reported without fully assessing what they produced and how their designs changed.

The evaluation trend is therefore multidimensional but uneven. Cognitive outcomes dominate, performance assessment is developing, and affective constructs remain comparatively underrepresented. A stronger evaluation design would combine concept tests, thinking-skill measures, process observations or EDP rubrics, product criteria, and affective measures aligned with the duration and purpose of the intervention.

RQ5. Effectiveness of STEM-EDP on Cognitive, Affective, and Performance Domains

The direction-of-evidence synthesis indicated predominantly favorable findings across cognitive, affective, and performance domains. This conclusion does not represent a pooled effect size or a quality-weighted estimate. It reflects convergence among statistically supported quantitative results and analytically supported qualitative findings, interpreted in relation to methodological heterogeneity and reporting limitations.

Cognitive Outcomes

The most consistent cognitive findings concerned problem-solving, critical thinking, creative thinking, systems thinking, and computational thinking. EDP repeatedly requires students to define a problem, identify constraints, apply physics concepts, generate alternatives, predict performance, interpret test data, and revise a solution. These operations explain why higher-order thinking was reported more often than factual recall. Indonesian and international studies similarly associate design-centered STEM projects with gains in critical, creative, and problem-solving outcomes (Martawijaya et al., 2023; Purwaningsih et al., 2020; Safitri et al., 2024; Xi et al., 2024). Nevertheless, differences in instruments and intervention duration mean that the magnitude of improvement cannot be directly compared across studies.

Affective Outcomes

Affective findings included increased engagement, motivation, STEM interest, self-efficacy, satisfaction, and learning ownership. Authentic design problems and visible product progress can make the purpose of physics concepts more explicit, while testing and redesign can normalize initial failure as part of learning. These mechanisms may support persistence and confidence, although affective effects were measured in fewer studies and were often based on short interventions. Longitudinal evidence is therefore needed to determine whether changes in interest, identity, or career orientation persist after the project ends.

Performance Outcomes

Performance outcomes concerned engineering-design skills, technical execution, communication, collaboration, and the construction of functional products. The design cycle enabled students to externalize their reasoning in sketches, models, prototypes, test records, and revisions. Collaborative projects also required task distribution and evidence-based negotiation. Positive performance findings therefore support assessing both the design process and the final artifact rather than treating product completion as the only indicator of success.

Evidence Limitations and Emerging Research Gap

The positive direction of findings must be qualified by the concentration of studies in short-term, formal classroom interventions, the use of heterogeneous measures, and limited reporting of comparable effect sizes. In addition, this review did not apply a standardized critical-appraisal instrument; therefore, the synthesis cannot distinguish findings according to formally assessed methodological quality. These conditions restrict conclusions about durability, transfer, relative effectiveness across products or educational levels, and the extent to which favorable findings are robust across stronger and weaker study designs.

Cocurricular, extracurricular, and extended project settings remain underrepresented even though they may provide sufficient time for repeated testing, failure analysis, redesign, and engagement with community problems. Higher-education studies are also scarce within the specific search terminology used in this review. These gaps limit the generalizability of existing findings beyond school classrooms and single instructional units.

Scientific inquiry and research-oriented competencies received less attention than cognitive achievement, affective response, or design performance. Future studies should examine how STEM-EDP supports question formulation, hypothesis development, measurement planning, uncertainty analysis, interpretation of data, and evidence-based justification. These competencies connect engineering iteration with scientific inquiry and would clarify whether students are merely building products or using physics evidence to improve them.

Research should consequently use multi-site and longer-duration designs, report intervention fidelity and effect sizes, combine outcome measures across domains, and compare classroom with cocurricular implementation. Such studies would permit stronger conclusions about sustained learning, transfer, equity of participation, teacher support, and the conditions under which STEM-EDP is effective.

Conclusion

This review mapped 27 STEM-EDP studies in physics education published from 2021 to 2026. Research was concentrated in elementary and secondary education and in regular classrooms, with limited representation from higher education and extended learning settings. The products most of---ten involved engineering structures, vehicles and robotics, and energy or electrical systems. Product choice was descriptively related to the physics topic and learner level, but the evidence did not permit a causal ranking of product categories. Across heterogeneous methods, the direction of evidence was predominantly positive for higher-order thinking, conceptual application, engagement, self-efficacy, engineering-design performance, collaboration, communication, and product development. Cognitive variables were measured most often, whereas affective outcomes and rigorous process or product assessment were less consistently represented. Effectiveness should therefore be interpreted as convergence in the direction of reported findings rather than as a pooled magnitude of impact.

The theoretical contribution of this review is a context-process-product-outcome map showing that STEM-EDP effectiveness depends on alignment among the learning setting, physics content, design cycle, product constraints, and assessment domain. Practically, physics teachers should select design tasks that make target concepts measurable, adjust product complexity to learners' prior knowledge, allocate time for testing and redesign, and combine concept tests with EDP-process, product-performance, collaboration, and affective measures. Curriculum developers should provide flexible project time, access to materials and digital tools, and assessment guidance that values evidence-based revision rather than product appearance alone. Further research should evaluate semester-long or year-long implementation in cocurricular, extracurricular, higher-education, and community contexts; use multi-site or comparative designs; report fidelity and effect sizes; and assess sustained scientific inquiry, transfer, participation equity, and teacher capacity.

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The authors declare no conflict of interest.

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