



DIDACTIC REQUIREMENTS FOR THE FORMATION OF STEAM COMPETENCIES IN TEACHING NATURAL SCIENCES IN ELEMENTARY GRADES

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Abstract

This study examines the didactic requirements necessary for the effective formation of STEAM (Science, Technology, Engineering, Arts, and Mathematics) competencies in the teaching of natural sciences to elementary school students. Expert validation confirmed the relevance and feasibility of the proposed didactic requirements, emphasizing the need for tiered scaffolding and expanded use of digital tools. Guided by a mixed-methods research design, the study combined theoretical analysis of educational literature and curriculum standards with an empirical intervention in three public schools involving 120 students and 15 teachers. The study concludes that a systematically designed and contextually adapted didactic framework can substantially enhance STEAM competency development in early science education, with implications for curriculum design, teacher training, and sustainable implementation in primary schools.

Keywords: STEAM education, didactic requirements, natural science teaching, elementary grades, competency-based learning, inquiry-based learning, design thinking, arts integration, interdisciplinary approach, primary education pedagogy, collaborative learning, educational innovation.

Introduction

In the rapidly evolving landscape of modern education, the integration of science, technology, engineering, arts, and mathematics—collectively known as STEAM—has emerged as a key strategy for developing the skills necessary for success in the 21st century. The early school years are a critical period for fostering curiosity, creativity, and problem-solving abilities, making the formation of STEAM



competencies in elementary natural science education especially important. In this context, didactic requirements play a fundamental role in ensuring that the teaching process is systematic, engaging, and aligned with developmental characteristics of young learners. The inclusion of STEAM principles in the teaching of natural sciences not only strengthens subject knowledge but also cultivates interdisciplinary thinking, enabling students to apply scientific concepts in real-life situations. This approach demands carefully designed learning activities, teaching methods, and educational resources that promote active participation, collaboration, and inquiry-based exploration. Furthermore, the didactic framework must account for the integration of modern digital tools, experimental practices, and creative problem-solving tasks that support the holistic development of a child's intellectual and emotional capacities. Therefore, identifying and implementing didactic requirements for the formation of STEAM competencies in elementary natural science education is not merely a methodological necessity—it is a strategic priority in preparing students for lifelong learning and innovative thinking. By combining scientific accuracy, pedagogical effectiveness, and child-centered learning principles, educators can create a dynamic and motivating environment where young learners become active constructors of knowledge and capable participants in the technological and scientific advancements of the future. The literature converges on STEAM as an interdisciplinary framework that blends scientific inquiry with technological tools, engineering design, artistic creativity, and mathematical reasoning to cultivate higher-order thinking and real-world problem solving in young learners. In elementary contexts, scholars emphasize constructivist and socio-constructivist underpinnings: children build understanding by actively exploring phenomena, dialoguing with peers and teachers, and iteratively refining ideas. Motivation theories (e.g., interest development and self-determination) further support STEAM's experiential, choice-rich tasks, which can heighten curiosity and persistence when appropriately scaffolded for developmental readiness. Research distinguishes several integration models relevant to didactic planning: subjects address a shared theme while learning goals remain discipline-specific, concepts and practices are intentionally linked across disciplines (e.g., data handling in math applied to a science investigation using digital sensors), real-world problem frames learning, and disciplinary boundaries soften as students use whatever knowledge is needed to design solutions. For



primary grades, reviews recommend starting with multidisciplinary or light interdisciplinary structures before attempting fully transdisciplinary projects, given time constraints, teacher expertise, and developmental factors. Backward design and curriculum mapping are consistently cited as necessary to maintain coherence with standards while avoiding “activity-rich, concept-poor” experiences. Teacher readiness is a decisive factor. Effective STEAM teaching draws on TPACK (technological–pedagogical–content knowledge), classroom management for hands-on work, and facilitation of discourse (questioning, revoicing, pressing for evidence). Professional learning models shown to help include: collaborative planning cycles with lesson study or coaching focused on a shared phenomenon. Practice-based workshops where teachers experience inquiry/design as learners and then co-develop rubrics and mini-lessons. Resource banks (task cards, phenomenon lists, materials kits) aligned to standards and local contexts to reduce planning load.

Methods

This study employed a qualitative–quantitative mixed-methods design to identify, justify, and validate the didactic requirements necessary for the effective formation of STEAM competencies in teaching natural sciences to elementary school students. The qualitative component focused on the analysis of pedagogical theories, curriculum documents, and teacher practices, while the quantitative component involved empirical testing of a didactic model in classroom settings. This dual approach allowed for both theoretical grounding and practical verification of proposed requirements. The research was conducted in three public elementary schools, involving: Students: 120 learners from grades 2–4 (aged 7–10), selected through stratified random sampling to ensure diversity in academic performance and socio-cultural backgrounds. Teachers: 15 natural science educators with at least three years of teaching experience, selected based on their willingness to integrate STEAM principles into classroom practice. Experts: 6 curriculum and pedagogy specialists consulted during the validation of the didactic requirements. Document Analysis Protocol – to examine national curriculum standards, STEAM-related policy documents, and instructional guidelines for elementary natural science. Teacher Observation Checklist – developed to track the presence of STEAM-related teaching practices (e.g., inquiry-based learning,



integration of digital tools, collaborative activities). Student Competency Rubric – designed to measure key STEAM competencies, including: Scientific inquiry skills, creative problem solving, collaboration and communication, integration of arts in scientific representation, application of mathematical reasoning in science task. Semi-Structured Interview Guide – for gathering teacher perspectives on the practicality, challenges, and perceived benefits of the didactic requirements. STEAM Project Task Cards – used during the intervention phase, containing integrated natural science activities (e.g., building simple weather instruments, designing plant growth experiments with artistic presentation).

The research was implemented in four stages: First is theoretical analysis: reviewed existing literature on STEAM education, focusing on early grade natural science teaching. Extracted key didactic principles and requirements, mapping them to primary school developmental characteristics. Second is pre-implementation diagnosis: administered baseline student competency assessment. Observed regular science lessons to identify current integration levels of STEAM elements. Third is model development and implementation. Designed a didactic model incorporating identified requirements: clear competency targets, inquiry–design integration, arts-based modeling tasks, structured collaboration routines, formative and performance-based assessment, conducted a 6-week classroom intervention where participating teachers applied the model during natural science lessons. Fourth is evaluation and validation. Post-intervention competency assessment of students. Comparative analysis of pre- and post-intervention scores using descriptive and inferential statistics. Thematic analysis of teacher interview transcripts to refine the list of didactic requirements. Expert panel review to validate final requirements for clarity, feasibility, and alignment with curriculum standards. Quantitative data (student scores) were analyzed using paired t-tests to measure competency gains, with significance set at $*p* < 0.05$. Qualitative data (observations, interviews) were coded using thematic analysis to identify recurring patterns and insights related to implementation feasibility. Triangulation of findings from multiple sources ensured reliability and validity of conclusions.

Results

Initial classroom observations revealed that natural science lessons in the participating schools were predominantly textbook-centered and teacher-led, with



limited integration of STEAM elements. Inquiry activities were present in 28% of lessons, but they were typically short and not connected to broader design or problem-solving tasks. Arts integration was minimal, mostly limited to drawing diagrams in workbooks. Digital tools were used only for content presentation, not as active learning resources. Baseline student competency assessments showed: scientific inquiry skills – mean score: 45% of expected level, creative problem solving – 39%, collaboration and communication – 42%, integration of arts in science – 31%, application of mathematical reasoning – 36%. Following the 6-week intervention using the didactic requirements framework, all targeted STEAM competencies showed statistically significant improvement (*p* < 0.05).

Competency Area	Pre-Test Mean (%)	Post-Test Mean (%)	Gain (%)
Scientific Inquiry Skills	45	72	+27
Creative Problem Solving	39	70	+31
Collaboration and Communication	42	75	+33
Integration of Arts in Science	31	68	+37
Application of Mathematical Reasoning	36	66	+30

Key gains were most pronounced in arts integration and collaboration, suggesting that structured, arts-based modeling activities and role-based teamwork routines strongly supported these competencies. Interviews with teachers revealed several perceived benefits of the didactic requirements: reported higher motivation, especially among students who previously showed low interest in science. Linking science with arts, mathematics, and technology helped students make more meaningful connections. Collaboration norms reduced off-task behavior and improved group productivity. However, challenges noted included: completing both inquiry and design phases within a single lesson was difficult and teachers needed more ready-to-use STEAM kits and project materials. The final list of didactic requirements was reviewed by a panel of six experts, who rated them as highly relevant (mean relevance score: 4.8/5) and feasible with support (mean feasibility score: 4.2/5). Suggested refinements included: providing tiered scaffolds for different ability levels, expanding digital tool use beyond presentation to



include data collection and analysis, creating assessment templates for rapid formative feedback. The validated didactic requirements for forming STEAM competencies in elementary natural science teaching are: explicit learning targets linked to observable STEAM skills. Integrated inquiry–design cycles that move from exploration to creation. Arts-based modeling as a core representational strategy. Structured collaboration roles and talk routines. Multiple assessment methods capturing both product and process. Gradual release of responsibility to promote independence. Cultural and contextual relevance in project design.

Discussion

The findings of this study confirm that the systematic application of didactic requirements can significantly enhance the formation of STEAM competencies in elementary natural science education. The notable improvement across all measured competency areas—particularly in arts integration and collaboration—supports previous research highlighting the value of multimodal representation and structured teamwork in fostering young learners’ engagement and interdisciplinary thinking (Bequette & Bequette, 2012[1]; Perignat & Katz-Buonincontro, 2019)[5]. This aligns with Vygotsky’s socio-constructivist framework, which posits that learning is mediated by social interaction and guided participation. Teachers reported that such structures not only increased the quality of group work but also supported equitable participation, ensuring that quieter students contributed meaningfully to the learning process. The increase in scientific inquiry and problem-solving skills reflects the impact of integrating inquiry-based learning with design thinking cycles, consistent with findings by Capraro, Capraro, and Morgan (2013)[2] that iterative cycles promote deeper conceptual mastery and transfer of learning. In this study, even students with initially low performance were able to engage in hypothesis formulation, testing, and refinement when scaffolded through guided prompts and stepwise activities. However, the challenges identified—particularly time constraints and resource preparation—echo broader concerns in STEAM literature regarding the sustainability of complex, interdisciplinary projects in rigid curricular schedules (Henriksen, 2014)[3].

Another important implication is the role of digital tools. While the intervention incorporated technology primarily for presentation and documentation, expert feedback stressed the need to expand its use for data collection, simulation, and



collaborative design. This resonates with contemporary STEAM frameworks advocating technology as a cognitive partner rather than a passive display tool (Mishra & Koehler, 2006)[4]. The expert validation process reinforced the feasibility of the didactic requirements but also underscored the necessity of tiered scaffolding to address diverse learning needs. This finding aligns with the principles of Universal Design for Learning (UDL), suggesting that flexible pathways and differentiated supports are essential for ensuring that all students can access and benefit from STEAM learning experiences. In summary, the study provides evidence that clearly defined, systematically implemented didactic requirements can meaningfully advance STEAM competencies in early science education. By merging inquiry, design, and creative expression within a structured and supportive framework, educators can cultivate not only content knowledge but also the habits of mind necessary for innovation. Future research should explore longitudinal effects of such interventions and investigate low-cost strategies for maintaining quality integration in resource-limited settings.

Conclusion

The formation of STEAM competencies in teaching natural sciences in primary school is a crucial step toward preparing students for the demands of the 21st century. The findings of this study demonstrate that effective implementation of STEAM education requires well-defined didactic requirements, including interdisciplinary curriculum design, inquiry- and project-based learning, technology integration, and teacher professional development. When these requirements are met, students not only gain a deeper understanding of natural science concepts but also develop critical skills such as creativity, problem-solving, collaboration, and adaptability. Overall, the integration of STEAM into natural science education in primary schools fosters student engagement, nurtures curiosity, and bridges the gap between theoretical knowledge and practical application. By establishing strong didactic foundations, educators can ensure that young learners not only acquire scientific knowledge but also develop the interdisciplinary competencies essential for success in an increasingly complex and innovation-driven world.



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