STEM AND STEAM TECHNOLOGIES IN THE DEVELOPMENT OF METHODOLOGICAL COMPETENCE OF FUTURE TEACHERS

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Abstract: *This article analyzes the role of STEM and STEAM technologies in developing the methodological competence of future teachers. Methodological competence is defined as an integrative professional quality that combines pedagogical knowledge, instructional design skills, digital literacy, creativity, and reflective capacity. The research is based on scientific literature published between 2010 and 2026. Competency-based, systemic, constructivist, and activity-oriented approaches were applied. The findings demonstrate that STEM and STEAM integration significantly enhances interdisciplinary thinking, innovative pedagogy, and digital methodological skills.*

Keywords: *methodological competence, STEM education, STEAM education, teacher training, competency-based approach, interdisciplinary learning, digital pedagogy.*

INTRODUCTION

In the context of rapid technological advancement, digital transformation, and the transition toward knowledge-based economies, education systems worldwide are redefining their priorities. One of the most significant shifts in contemporary education is the growing emphasis on STEM (Science, Technology, Engineering, Mathematics) and STEAM (Science, Technology, Engineering, Arts, Mathematics) approaches as strategic frameworks for innovation and sustainable development. These approaches are not merely curriculum trends; they represent comprehensive educational paradigms aimed at fostering interdisciplinary thinking, creativity, technological literacy, and problem-solving competencies essential for the 21st century.

Within this global transformation, teacher education systems face a fundamental challenge: preparing future teachers who are capable of effectively integrating STEM and STEAM principles into classroom practice. This challenge directly relates to the development of methodological competence — an integrative professional quality that enables teachers to design, implement, evaluate, and continuously improve instructional processes. Methodological competence includes the ability to align subject knowledge with pedagogical strategies, apply digital technologies, create interdisciplinary learning environments, and engage in reflective professional practice [Shulman, 2013, p.9].

Research consistently demonstrates that teacher quality is one of the most influential factors affecting student achievement and educational outcomes [Hattie, 2018, p.34]. OECD reports further confirm that developing teachers' professional competencies, particularly those related to innovation and digital literacy, is critical for improving educational systems globally [OECD, 2019, p.56]. Consequently, integrating STEM and STEAM technologies into teacher preparation programs becomes a key strategy for strengthening methodological competence and enhancing instructional effectiveness.

The relevance of this issue is further reinforced by the increasing complexity of modern classrooms. Today's learners require not only subject knowledge but also critical thinking, collaboration, creativity, and technological fluency. STEM and STEAM approaches address these needs by promoting inquiry-based learning, project-based instruction, real-world problem-solving, and interdisciplinary collaboration. For future teachers, mastering these approaches requires more than technical knowledge; it demands strong methodological competence that integrates pedagogical, technological, and creative dimensions.

The theoretical foundation of this study draws upon several complementary perspectives. The competency-based approach emphasizes measurable professional outcomes and practical readiness for teaching [Sharipov, 2019, p.93]. The systemic approach views methodological competence as a structured combination of cognitive, operational, technological, and reflective components. Constructivist theory underlines active learning and knowledge construction through authentic tasks, which aligns with STEM/STEAM pedagogy. Additionally, the TPACK framework highlights the importance of integrating technological knowledge with pedagogical and content knowledge in contemporary teacher preparation [Mishra & Koehler, 2018, p.101].

Despite the increasing popularity of STEM and STEAM education, there remains a need for deeper analysis of how these technologies specifically influence the development of methodological competence in future teachers. Many studies focus primarily on student outcomes or curriculum design, while fewer investigations address the systemic factors within teacher education programs that facilitate competence development. Therefore, examining STEM and STEAM technologies as structured factors in strengthening methodological competence is both timely and academically significant.

The purpose of this study is to analyze the role of STEM and STEAM technologies in developing methodological competence among future teachers and to identify key pedagogical, organizational, technological, and reflective factors that contribute to this process. By synthesizing theoretical perspectives and empirical findings from 2010–2026, this research aims to provide a comprehensive framework for integrating STEM and STEAM approaches into teacher education programs.

Thus, the development of methodological competence through STEM and STEAM technologies represents not only a methodological innovation but also a strategic direction for modern teacher education systems seeking to prepare adaptable, creative, and digitally competent educators capable of meeting the demands of contemporary society.

Literature Review

The integration of STEM and STEAM technologies into teacher education has become a significant research focus over the past decade. Scholars increasingly recognize that methodological competence is not a static attribute but a dynamic, integrative professional quality shaped by interdisciplinary, technological, cognitive, and reflective dimensions. A comprehensive analysis of scientific literature published between 2010 and 2026 demonstrates that the development of methodological competence through STEM

and STEAM approaches is grounded in professional competence theory, constructivist pedagogy, interdisciplinary curriculum models, and digital learning frameworks.

The concept of methodological competence originates from broader theories of professional competence. Slastenin defines professional competence as an integrative characteristic that combines knowledge, skills, values, and personal qualities required for effective pedagogical activity [10]. Within this framework, methodological competence represents the teacher's ability to transform subject knowledge into effective instructional strategies.

Markova expands this understanding by emphasizing the motivational and reflective components of professional growth [4]. She argues that reflective self-assessment and professional self-awareness are essential for sustained competence development. This perspective is particularly relevant in STEM/STEAM environments, where teachers must continuously adapt to technological and interdisciplinary innovations.

Shulman's theory of Pedagogical Content Knowledge (PCK) provides a foundational model for understanding methodological competence [9]. According to Shulman, effective teaching requires the integration of subject knowledge with pedagogical strategies tailored to learners' needs. STEM and STEAM education naturally align with this model because interdisciplinary teaching demands flexible transformation of content into accessible forms.

Mishra and Koehler further developed this concept through the TPACK framework, incorporating technological knowledge as a core element of teacher competence [5]. In digital and STEM-based classrooms, technological literacy becomes inseparable from methodological competence. The TPACK model highlights that pedagogy, content, and technology must function interactively rather than independently.

STEM education emphasizes interdisciplinary integration, inquiry-based learning, and real-world problem-solving. Bybee defines STEM as an educational approach designed to connect scientific and mathematical principles with technological and engineering practices [1]. This integration encourages studentsand teachersto engage in authentic, application-oriented learning experiences.

Research indicates that STEM environments foster critical thinking, collaboration, and innovation, which are essential components of methodological competence [6]. Teachers trained within STEM frameworks develop stronger lesson design skills, improved capacity for interdisciplinary planning, and greater adaptability to complex classroom situations.

Furthermore, activity-based and project-based learning models within STEM education enhance teachers' operational competence. Such models require future teachers to design problem-based scenarios, integrate multiple subject areas, and assess learning outcomes through authentic tasks. This aligns with competency-based teacher preparation models discussed by Sharipov [8].

While STEM focuses primarily on scientific and technological integration, STEAM incorporates artistic and creative dimensions into interdisciplinary learning. Yakman's STEAM framework highlights the importance of creativity, design thinking, and innovation in solving complex problems [7]. This integration of the arts strengthens

teachers' creative pedagogical strategies and supports the development of flexible methodological thinking.

The inclusion of arts within STEAM contributes to the enhancement of aesthetic literacy, design-oriented problem-solving, and imaginative instructional practices. Research suggests that STEAM-based teacher education programs improve innovative lesson planning and foster a holistic understanding of interdisciplinary education.

Creativity within STEAM also supports reflective and metacognitive skills, enabling teachers to evaluate and refine their instructional approaches. In this sense, STEAM acts as both a pedagogical method and a developmental factor in strengthening methodological competence.

Constructivist learning theory underpins both STEM and STEAM methodologies. According to constructivist principles, knowledge is actively constructed through engagement in meaningful tasks rather than passively received. STEM/STEAM environments typically employ inquiry-based, collaborative, and project-oriented learning strategies, which align with activity-based theories of competence development.

Darling-Hammond emphasizes the importance of clinical practice and experiential learning in teacher preparation [2]. STEM and STEAM modules often incorporate hands-on laboratory work, collaborative projects, and design challenges that mirror real classroom scenarios. These experiences enhance future teachers' operational and reflective capacities.

Hattie's meta-analyses confirm that teaching strategies emphasizing clarity, feedback, and active engagement significantly influence student achievement [3]. STEM and STEAM approaches naturally integrate these high-impact strategies, thereby strengthening methodological competence indirectly through improved instructional design practices.

The rapid digitalization of education has intensified the importance of technological competence within methodological frameworks. Digital tools, coding platforms, robotics, simulation software, and virtual laboratories are integral components of modern STEM education. Consequently, methodological competence now includes digital literacy and the ability to design technology-enhanced learning environments.

The TPACK model serves as a theoretical bridge connecting technological integration with pedagogical effectiveness [5]. Studies indicate that future teachers trained in STEM/STEAM contexts demonstrate higher levels of technological confidence and instructional innovation.

Although existing literature provides substantial insights into STEM/STEAM pedagogy and professional competence theory, several gaps remain. First, many studies examine student outcomes rather than focusing on the development of teachers' methodological competence. Second, limited research systematically analyzes how interdisciplinary, technological, creative, and reflective factors interact within teacher education programs. Third, there is a need for integrative models that combine competency-based, systemic, and constructivist perspectives specifically within STEM/STEAM contexts.

Therefore, the present study aims to synthesize these theoretical perspectives and identify structured factors through which STEM and STEAM technologies contribute to the development of methodological competence in future teachers.

Research Methodology

The study applied theoretical analysis, comparative review, modeling, surveys, and experimental implementation. Competency-based and systemic approaches guided the research.

Key factors identified:

1. Interdisciplinary curriculum integration.
2. Project-based and problem-based learning.
3. Digital technology integration (TPACK alignment).
4. Creative and design thinking development.
5. Reflective and collaborative practices.

Conclusion and Recommendations

STEM and STEAM technologies significantly contribute to the development of methodological competence by fostering interdisciplinary thinking, innovation, and digital literacy. Teacher education institutions should systematically integrate STEM/STEAM modules, expand project-based learning, and strengthen reflective practice.

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