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The 3D STEAM Leadership model: A Conceptual Framework for Developing Empathic Future Leaders through STEAM Education in Primary Schools

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Abstract

This article aims to highlight the beneficial impact of STEAM-based activities during primary education and, more specifically, to demonstrate how such experiences can prepare students to develop the competencies required of future leaders. The emphasis on these characteristics stems from their critical role in shaping children's personal development and identity formation, as well as their practical significance in cultivating conscientious citizens capable of leading toward a more equitable and sustainable world. STEAM education — integrating science, technology, engineering, arts and mathematics — is increasingly recognized as an effective approach for enhancing both cognitive and creative skills. Empirical evidence indicates that STEAM-based pedagogies foster critical and analytical thinking, creativity and imagination, problem-solving, perseverance and resilience, as well as self-efficacy and motivation in young learners. Moreover, recent studies emphasize how embedding empathy and social-emotional learning (SEL) within STEAM contexts increases the meaningfulness of learning, encourages perspective-taking, and helps students to envision the social impact of their work. Through collaborative, design-oriented, socially relevant STEAM projects (often under the "STEAM for Social Good" paradigm), learners exercise empathy, social responsibility, and a culture of contribution — qualities identified as essential for the leaders of tomorrow. Building on these dimensions, this article proposes an integrative conceptual framework that unites three strands of literature: (a) STEAM pedagogy, (b) social-emotional learning and development of empathy in childhood, and (c) leadership theories relevant to early childhood and primary education. From this synthesis emerges a novel theoretical model — The 3D STEAM Leadership Framework (3D-SLM): Empathy → Empowerment → Emerging Leadership. According to this model, STEAM challenges enhance empathy (through collaborative problem solving and empathy-driven design), strengthen self-awareness (through iterative cycles of reflection and trial & error), and cultivate social responsibility (through STEAM-for-Social-Good initiatives). Ultimately, these processes contribute to the emergence of leadership capacities and ethical agency in children.

Keywords: STEM/ STEAM education; Student leadership; Empathy and empowerment; Metacognition; 3D STEAM leadership framework; 3D-SLM

1. Introduction

The contemporary socio-political landscape presents numerous challenges at all levels of communal life, and advances in psychology, along with improvements in adult life, underscore the imperative to cultivate character through ducation from the earliest developmental stages of childhood [1], [2]. Education in the 21st century is shaped by intricate social, technological, and cultural shifts that demand from students not only cognitive skills, but also capacities for self-regulation, collaboration, and leadership presence. By "leadership presence," we refer to an individual's ability — having first identified their own strengths and talents, as well as the areas in which they struggle and require attention — to turn outward toward others with empathy, and to support them within a framework of cooperation and genuine care [3]. In this way, the foundations of healthy interpersonal relationships are laid, making constructive collaboration, multifaceted thinking, and ultimately the creation of projects aligned with specific goals possible. As Scott [3]

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underscores, current educational systems often deprive learners of the kinds of experiences that would prepare them for more fulfilling lives and productive work. She further highlights the urgent need to reaffirm the role of education in equipping both young and adult learners to address complex societal, economic, and environmental challenges. Within this context, STEAM education emerges as a dynamic approach combining creativity, problem-solving, and interdisciplinary synthesis. Students are not merely called to understand concepts, but to function as designers, researchers, and active members of a learning community. This approach fosters the development of capacities that transcend the narrow confines of academic success, promoting a holistic form of learning with emphasis on cooperation, responsibility, and respect for diversity. Recent studies integrating computational thinking, STEM/STEAM, and metacognitive awareness show that embedding metacognition within STEM/STEAM instruction enhances learners' capacity for self-regulated learning, problem-solving, and adaptive thinking [4].

At this point, we want to emphasize the significance of digital technologies in the field of STEAM and Leadership education. ICTs support education for all, provide new techniques for effective teacher training, enhance memory retention, promote cooperation, increase transparency, develop learner-centered strategies, develop new teaching techniques, and speed up learning. Additionally, through virtualization, mobilization, artificial intelligence, and new learning environments-worlds, give new instruments for knowledge representation and support educational activities and techniques. More specifically, ICTs are very effective and productive in the field of ADHD training. They facilitate and enhance the processes of assessment, intervention, and education through mobile devices, which spread educational activities throughout the world [30], and through a variety of ICT applications, which are the main drivers of education [31-36]. While games turn education into a multimodal, incredibly amiable, and enjoyable interaction, the use of AI, STEM, and ROBOTICS raise educational procedures into new levers of adaptation, creativity, and performance [37-41]. Furthermore, the adoption, improvement, and fusion of ICTs with theories and models of metacognition, mindfulness, meditation, and emotional intelligence cultivation [42-54] places the development of mental abilities at the center of educational procedures and policies, which accelerates and improves educational practices and outcomes, particularly in of STEAM and Leadership education.

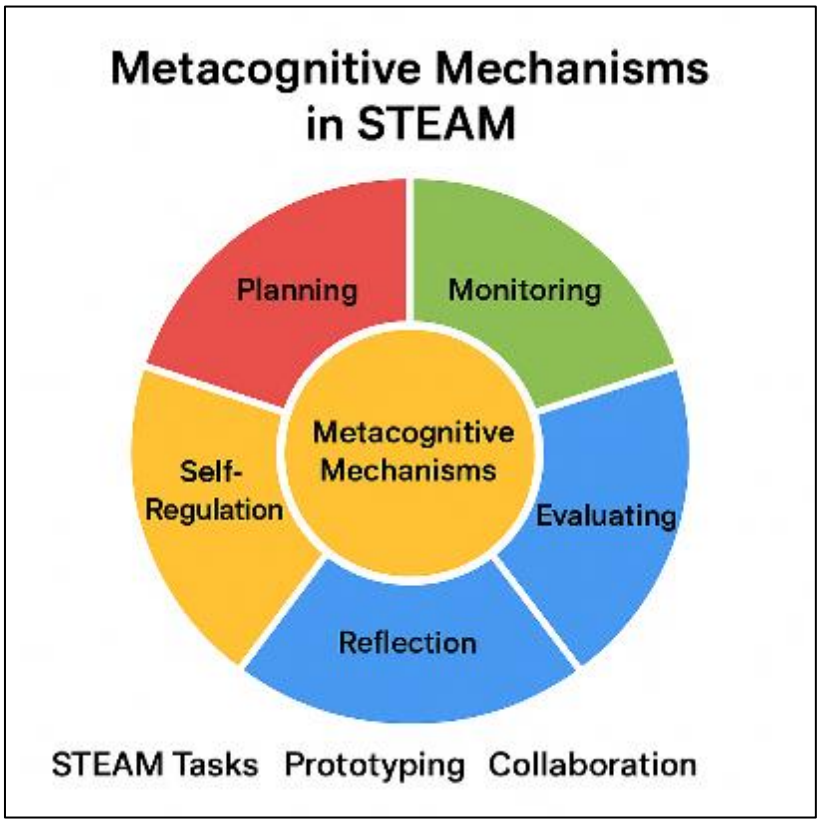

Figure 1 Metacognitive Mechanisms in STEAM activities

Despite the significant technopedagogical potential of the STEAM framework, both international and local research underscore the need to enhance the leadership dimension through human-centered approaches that nurture empathic understanding, reflection, and personal empowerment in students. Contemporary societies demand individuals capable of deep self-understanding and empathy, able to make responsible decisions and act as agents of positive change. At

this point, the crucial role of metacognition becomes evident — the ability to think about one's own thinking, to reflect, self-evaluate, and strategically adapt one's learning path [5]. Metacognition represents a foundational pillar of autonomy and leadership, enabling learners to understand how they learn, which strategies serve them best, and which challenges they need to address. In a STEAM environment — inherently reflective, experiential, and collaborative — metacognitive functions (e.g., planning, monitoring, controlling, evaluating one's thinking) assume a central role. Indeed, research on collaborative problem-solving demonstrates how socially mediated metacognition aids not only individual regulation but also group-level cognitive coordination and successful collaborative outcomes [6]: recent work in collaborative metacognition. A student developing metacognitive skills becomes not merely a performer of tasks, but a co-creator of their learning journey — capable of evaluating alternative solutions, identifying errors, recognizing emotional and cognitive dimensions, and adjusting behavior accordingly [7]. It is precisely at this intersection that the theoretical gap this work seeks to address becomes visible: while existing leadership models (transformational, servant, democratic, socio-emotional) offer valuable foundations, none systematically integrate STEAM education with metacognition and the development of leadership capacities in childhood and adolescence. To address this, the present article proposes the 3D STEAM Leadership Framework, a conceptual framework that merges empathic, cognitive, and metacognitive development within the learning process. The term "Three-Dimensional" was selected to highlight the multilayered nature of STEAM leadership development, which — much like 3D modeling in STEAM disciplines — requires depth, perspective, and the interplay of multiple components rather than linear progression.

The model is structured around three pillars — Empathy, Empowerment, and Emerging Leadership — operating as sequential yet interdependent stages of developmental maturation. The first pillar, Empathy, lays the groundwork for social learning and human-centered leadership. Empathy — understood as the capacity to recognize and understand the emotions and needs of others — is deeply connected to metacognition, since it requires learners to reflect on their own reactions, biases, and thought strategies. Through collaborative learning activities, students practice social metacognition — awareness of how their thoughts and actions influence the group — a fundamental element for any form of responsible leadership. In collaborative tasks, metacognitive awareness at both the individual and social level correlates with enhanced group coordination and more effective problem-solving [8]. The second pillar, Empowerment, concerns enabling students to assume initiative, actively participate in decision-making, and activate metacognitive strategies to solve problems. Empowerment presupposes awareness of one's own capabilities, limitations, and objectives — a deep metacognitive process that allows students to gain confidence, adaptability, and clarity in how they operate within a group. This aligns with theoretical models of meta-learning, according to which learners progressively build higher-order metacognitive and self-regulatory skills, especially when supported by intelligent or digital learning environments [9]. The third pillar, Emerging Leadership, refers to the emergence of leadership behaviors through conscious, metacognitively guided choices. In a STEAM environment, leadership does not manifest as domination, but as the capacity to coordinate, innovate, reflect, and support peers. Students who actively engage metacognitive strategies can lead more effectively, because they understand their role, anticipate the consequences of their actions, and develop a coherent, responsible personal identity. Indeed, empirical investigations link metacognition with problem-solving performance, critical thinking, and higher-order learning outcomes [5] [7]. Thus, the 3D STEAM Leadership Framework aspires to offer an educational framework that cultivates not only creative and collaborative learning, but also self-awareness, critical thinking, and social responsibility. By systematically combining empathy, empowerment, and metacognitive leadership development, the model aims to shape well-rounded, conscious, and socially sensitive future leaders.

2. Literature Review / Theoretical Framework

2.1. STEAM as a Pedagogical Approach

Over the past decade, STEAM education (Science, Technology, Engineering, Arts, Mathematics) has gained significant momentum worldwide and is increasingly recognized as a multidisciplinary pedagogical approach that enhances experiential, creative, and inquiry-based learning. Internationally, STEAM initiatives have expanded rapidly, with educational systems adopting integrated and project-based practices aligned with the demands of 21st-century skills [10]. In Greece, recent studies also report a growing interest in STEAM practices, particularly in early childhood and primary education settings [11]. However, comparative analyses highlight persistent challenges, noting that Greece still lacks a cohesive national strategy and a systematic infrastructure supporting STEAM implementation (European Schoolnet, 2023). Even so, the active participation of Greek schools in Scientix and other European STEAM programs indicate emerging developmental progress and fosters optimism regarding the potential pedagogical benefits for primary-level learners. Contemporary research underscores that STEAM promotes learning through open-ended problem-solving, design thinking, and the integration of scientific and artistic practices, offering substantial opportunities for students' cognitive and social development [10]. Furthermore, the STEAM framework is closely

associated with the cultivation of 21st-century competencies—creativity, critical thinking, collaboration, communication, and metacognition—which are essential for thriving in an increasingly complex socio-technological landscape characterized by rapid change [4]. These authors emphasize that students engaged in STEAM tasks activate high-level metacognitive processes, such as planning, monitoring, and evaluating their reasoning. At the preschool and primary levels, research indicates that participation in STEAM activities enhances children's social interaction, group collaboration, and emotional adaptability. A collective case study conducted in early childhood settings highlights that STEAM interventions strengthen social negotiation, conflict resolution, and cooperative learning [11]. The inclusion of the Arts component further enriches creativity and imagination, providing children with opportunities for experimentation, multiple representations, and innovative ideation. This artistic dimension makes STEAM a fertile context for the emergence of spontaneous leadership behaviors, as children assume roles, articulate ideas, coordinate small-group tasks, and reveal their natural strengths and capacities [10]. Despite its documented value, systematic reviews note that most STEAM research remains focused primarily on cognitive learning outcomes. Far fewer studies examine socio-emotional, metacognitive, or leadership-related outcomes, particularly in younger age groups [12], [13].

2.2. Child Leadership & Student Agency in Contemporary Education

Within contemporary educational discourse, leadership is no longer conceptualized as a privilege reserved for a select group of students but rather as a capacity that can be intentionally cultivated in all learners. The notion of student leadership encompasses influence, responsibility, collaboration, and the active co-construction of learning processes and classroom culture [14]. This body of research demonstrates that leadership in childhood emerges naturally through everyday interactions, particularly when children collaborate on shared projects and engage with common challenges. Emergent leadership frequently arises in collaborative learning environments such as STEAM projects, where children distribute roles, take initiative, and coordinate group activities. Peer leadership, similarly, focuses on mutual influence among students and on fostering a positive, inclusive classroom climate. In addition, servant leadership—a model grounded in care, support, and service toward others—has increasingly been adapted to educational settings. Studies examining its classroom application report improvements in group cohesion, empathy, and students' sense of social responsibility [10]. Self-leadership also constitutes an essential dimension of children's development. It involves goal setting, self-regulation, organization, and reflective thinking. Research conducted in professional development interventions shows that when educators cultivate students' metacognitive skills, children display increased autonomy and enhanced decision-making capacity [15]. However, the literature highlights a notable gap: although emergent, peer, servant, and self-leadership have each been studied individually, they are rarely examined in combination with STEAM and SEL practices within a unified research framework [4] [16].

2.3. Empathy, SEL & Education

Empathy is defined as the ability to understand and respond to others' emotions and needs, encompassing both cognitive (perspective-taking) and affective components. The CASEL framework (Collaborative for Academic, Social, and Emotional Learning) identifies five core socio-emotional competencies: self-awareness, self-management, social awareness, relationship skills, and responsible decision-making [17]. Studies consistently demonstrate a positive association between empathy and leadership effectiveness, as empathetic students are better able to recognize peers' needs, support group functioning, and coordinate collaborative activities with sensitivity and care [14]. Within STEAM contexts, recent reviews show that integrating socio-emotional learning elements can enhance cooperation, inclusion, and students' sense of community [18].

Greek research teams have also developed robust theoretical models of metacognition and meta-learning [9], emphasizing that metacognitive functioning forms the foundation for self-regulation and personal growth across educational stages. Although the combined integration of SEL and metacognition in STEAM environments appears highly promising, the literature indicates that most existing studies do not examine systematically how these competencies translate into specific leadership outcomes [10].

In summary, the international and Greek literature suggests that:

- STEAM supports creativity, collaboration, and metacognition;
- SEL enhances empathy, social competence, and responsible decision-making;
- child leadership emerges through collaboration, metacognitive engagement, and shared problem-solving.

Yet, to date, no model has systematically connected STEAM + SEL/empathy + metacognition + emergent child leadership within a single coherent framework, particularly for younger learners. This gap underscores the need for the development of the Three-Dimensional STEAM Leadership Model (3D-SLM).

3. Proposed Theoretical Framework (Conceptual Model)

The 3D STEAM Leadership Model (3D-SLM): Empathy → Empowerment → Emerging Leadership

The proposed 3D STEAM Leadership Model (3D-SLM) integrates three foundational dimensions of learning in early and primary education:

- the interdisciplinary and collaborative nature of STEAM learning;
- the social-emotional and metacognitive mechanisms activated through such activities; and
- the emergence of child leadership as a developmental outcome of these processes.

The model argues that the development of leadership skills in young learners is neither incidental nor a secondary by-product. Instead, it can be anticipated, structured, and intentionally supported through a developmental triad: Empathy → Empowerment → Emerging Leadership. This triad reflects a progressive pathway in which social-emotional engagement and metacognitive growth foster increasingly sophisticated forms of self-regulation, collaboration, responsibility, and leadership.

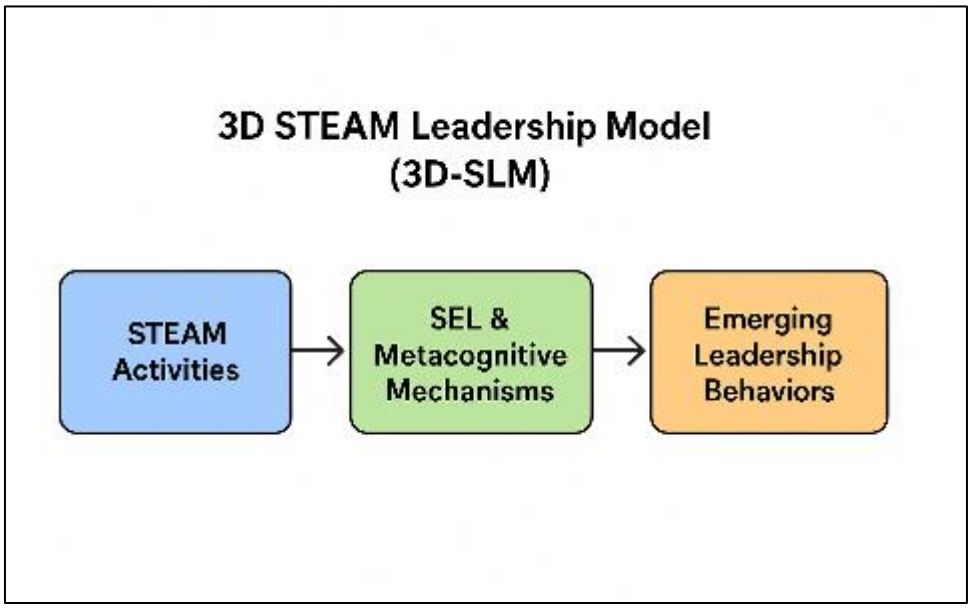

Figure 2 The 3D STEAM Leadership Model

3.1. Schematic Representation of the Model

The model can be conceptualized as a three-level developmental flow: STEAM Activities → SEL & Metacognitive Mechanisms → Emerging Leadership Behaviors. A more detailed representation is as follows:

3.1.1. STEAM Challenges / Learning Activities

- Collaborative group tasks
- Design thinking and creative prototyping
- Project-based and inquiry-based learning
- Experimentation, iteration, and role-based participation

Research shows that STEAM environments foster problem-solving, collaboration, and reflective thinking, offering fertile conditions for both cognitive and socio-emotional development [10],[4].

3.1.2. Social-Emotional & Metacognitive Mechanisms

- Empathy and social awareness
- Self-regulation and metacognitive monitoring
- Responsible decision-making

- Collaboration and conflict-resolution skills

SEL research [17] demonstrates that empathy, perspective-taking, and responsible decision-making are predictive of prosocial behavior and peer cooperation. Metacognitive functions—planning, monitoring, and evaluation—have been identified as core mechanisms of self-leadership and agency in children [15].

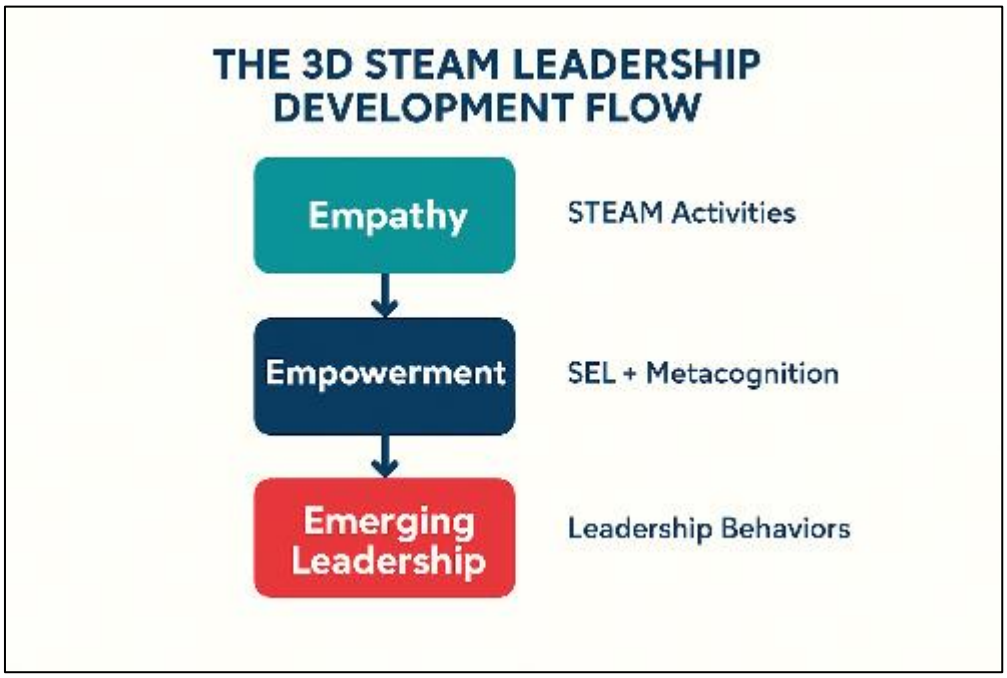

Figure 3 The 3D STEAM Development Flow

3.1.3. Emerging Leadership Behaviors

- Taking initiative
- Organizing group roles
- Supporting and encouraging peers
- Creative and ethical leadership
- Student agency and collective responsibility

Leadership in childhood often emerges spontaneously within collaborative tasks and shared challenges [14].

3.2. Analytical Description of the Model's Mechanisms

3.2.1. How STEAM Activities Cultivate Empathy (Empathy)

Empathy in early and primary education develops through both emotional and cognitive routes. STEAM environments naturally promote dialogic interaction, joint problem-solving, and role-sharing, all of which require children to:

- Listen actively to peers' ideas
- Negotiate and distribute roles fairly
- Practice perspective-taking
- Offer peer support
- Design with empathy in mind (empathy-driven design)

Empirical work shows that collaborative STEAM tasks strengthen children's social engagement and mutual understanding [11]. These processes form the foundation of the first dimension of the model: Development of Empathy.

3.2.2. How STEAM Challenges Lead to Empowerment (Empowerment)

Empowerment is conceptualized not merely as confidence, but as metacognitive growth, self-awareness, and the ability to regulate one's behavior and learning trajectory. In STEAM environments:

- Trial-and-error fosters resilience and self-reflection
- Iterative design enhances metacognitive awareness
- Group collaboration strengthens social understanding
- Problem-solving requires responsible decision-making
- Children experience agency, voice, and choice

Metacognition is a critical predictor of autonomous learning and self-leadership [9]. This corresponds to the second dimension: Development of Empowerment.

3.2.3. How Empathy + Empowerment Lead to Emerging Leadership (Emerging Leadership)

When empathy-based interactions and metacognitive empowerment operate together, leadership behaviors begin to surface naturally. These include:

- Initiating group solutions
- Supporting and motivating peers
- Coordinating roles and workflow
- Demonstrating responsibility
- Sustaining group cohesion
- Generating innovative ideas
- Promoting collaboration

The literature links empathy directly with ethical and socially responsible leadership [19]. This reflects the third dimension: Development of Emerging Leadership.

Table 1 Core Components of the 3D STEAM Leadership Model (3D-SLM)

Dimension	Definition	Indicative Behaviors
Empathy	Ability to understand others' needs, emotions, perspectives; foundation for social awareness.	Active listening, perspective-taking, supportive peer interactions.
Empowerment	Development of agency, metacognitive awareness, self-regulation and confidence through reflective STEAM engagement.	Planning, monitoring progress, decision-making, perseverance, autonomy.
Emerging Leadership	Naturally occurring leadership behaviors arising through collaboration and shared problem-solving.	Initiative-taking, organizing roles, guiding peers, ethical and collective responsibility.

3.3. Empirical Foundations of the Proposed Model

Although no existing theoretical framework integrates STEAM, SEL, metacognition, and emergent child leadership into a unified structure, numerous studies provide partial support for each component:

- STEAM → collaboration, creativity, metacognition [10], [4]
- SEL → empathy, responsible decision-making [17]
- Student leadership → emerges through cooperation [14]
- Self-leadership & metacognition → autonomy & agency [15]
- Empathy → foundation for ethical leadership [19]

This model's originality lies in unifying these components into one coherent developmental framework: Empathy → Empowerment → Emerging Leadership.

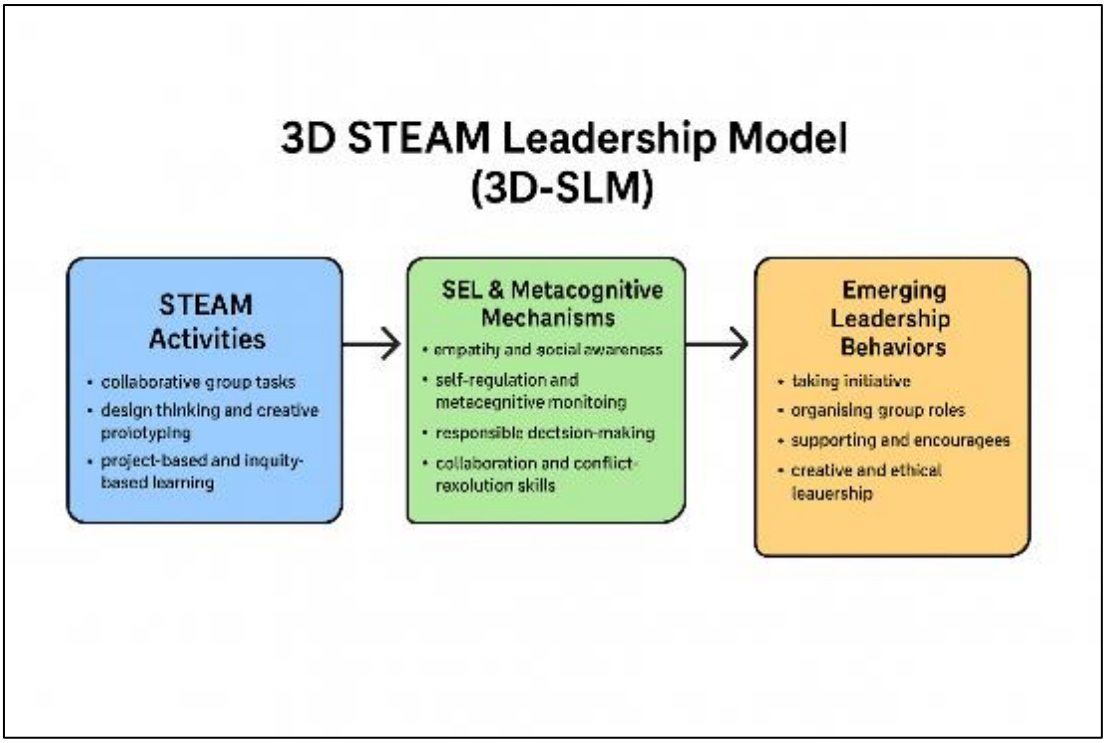

Figure 4 The 3D STEAM Leadership model (Analytical)

3.4. Predicted Outcomes of the Model (Model Outcomes)

Based on the mechanisms and developmental pathways described above, the 3D-SLM predicts that the systematic integration of STEAM, SEL, and metacognition will lead to:

- Increased collaboration and effective group interaction
- Enhanced student agency
- Greater responsibility and ethical conduct
- Deeper cognitive and emotional empathy
- Improved communication and conflict-management skills
- Development of creative, democratic, and inclusive leadership
- Strengthened metacognitive skills, enabling learners to direct their own learning processes

These outcomes can serve as theoretical hypotheses and as a basis for future empirical testing within educational settings.

4. Implications for Educational Practice

Based on the theoretical foundations of the 3D STEAM Leadership Model (3D-SLM), a series of pedagogical interventions can be designed to intentionally cultivate empathy, empowerment, and emerging leadership in primary learners through authentic STEAM experiences. The following proposals outline indicative, research-informed applications that align with the cognitive, socio-emotional and metacognitive processes described in the model.

4.1. STEAM Activities that Foster Empathy

Design thinking constitutes a central pedagogical strategy within STEAM, as it integrates creativity, human-centered reasoning, and problem-solving for real-world needs. Empathy-based design approaches encourage learners to identify authentic user problems, understand different perspectives, and design solutions that respond to emotional and functional needs. Research on empathy-driven design demonstrates that engaging children in user-centered problem framing strengthens perspective-taking, social awareness and compassionate reasoning [20] [21]. Within this context, learners can investigate issues in their school or local community—accessibility, safety, interpersonal challenges—and construct design solutions that promote prosocial objectives. Such activities deepen emotional understanding and contribute to the development of ethical dispositions essential for democratic citizenship.

4.2. Makerspace Collaborative Scenarios for Emerging Leadership

Makerspaces provide an inherently collaborative and exploratory environment where students construct physical or digital artifacts, negotiate roles, and manage shared tasks. Empirical studies indicate that makerspaces naturally promote distributed leadership, peer scaffolding, initiative-taking, and collaborative problem-solving [22], [23] Within such settings, children experience self-determination, agency, and collective responsibility. Leadership emerges organically—not as an assigned role but as a product of social interaction, shared goals, and the need to coordinate group efforts. These experiences reinforce the empowerment dimension of the model and cultivate an ethic of mutual support.

4.3. STEAM for Social Good

Linking STEAM learning to socially meaningful themes allow children to engage with authentic community issues and develop a sense of moral and civic responsibility. Research on STEAM for Social Good shows that problem-based projects with social impact elevate empathy, citizenship dispositions, and collective problem solving [24], [25]. Real problems—waste management, noise reduction, accessibility, environmental sustainability—help learners experience leadership as a relational and ethical capacity.

4.4. Sample STEAM Projects Integrating the 3D-SLM Pillars

Project 1 — "Design for Someone Who Needs Help" (Empathy-based Design Thinking)

Description:

Students identify an individual or group in need (a peer, family member, elderly resident, classmate with difficulties) and design a prototype to improve that person's daily experience. Model Connections:

- Empathy: identification of real needs; emotional understanding
- Empowerment: prototyping, testing, reflective cycles
- Emerging Leadership: coordination of tasks; role-taking; guiding decisions

Project 2 — "Community STEAM Challenge: Fix a Real Problem"

Description:

Learners address a concrete issue in their school or neighborhood and propose STEAM-based solutions with measurable impact.

Model Connections:

- Empathy: understanding community needs
- Empowerment: decision-making; initiative
- Emerging Leadership: organizing group processes; collaborative leadership

Project 3 — "Makerspace Team Lab: Build a Virtual Science Museum"

Description:

Teams design a digital museum containing Physics or Chemistry experiments (gravity, light reflection, velocity), adopting rotating roles: leader, designer, builder, tester, communicator.

Model Connections:

- Empathy: peer encouragement and inclusive collaboration
- Empowerment: technical autonomy; reflective improvement
- Emerging Leadership: role coordination; initiative; team cohesion

4.5. The Teacher's Role as a Facilitator of Leadership

The educator acts as a facilitator, mediator and mentor, shaping a climate of safety, dialogue and inquiry. Research on facilitative pedagogy shows that teacher scaffolding enhances student agency, collaboration and self-regulation [26]. By supporting metacognition, encouraging reflection, and empowering students to take ownership of decisions, the teacher nurtures emerging leadership without assigning hierarchical roles.

Table 2 Example Alignment of STEAM Activities with SEL and Leadership Outcomes

STEAM Activity	SEL / Metacognitive Mechanism Activated	Resulting Leadership Outcome
Design Thinking Challenge	Perspective-taking, empathy, reflective analysis.	Ethical decision-making, user-centered leadership.
Makerspace Team Roles	Social metacognition, collaboration, conflict resolution.	Peer leadership, coordination, shared responsibility.
Prototyping & Iteration Cycles	Monitoring, evaluation, resilience, self-regulation.	Initiative-taking, adaptive leadership, problem-focused guidance.
Community-Based STEAM Project	Social awareness, responsible decision-making.	Collective action, civic-minded leadership.
Inquiry-Based Experimentation	Planning, hypothesis testing, reflection.	Strategic thinking, role distribution, facilitative leadership.

Table 3 Comparative Overview of Research Fields Relevant to the 3D-SLM

Field	Key Contributions in Literature	What the 3D-SLM Integrates
STEAM Education	Enhances creativity, innovation, inquiry skills, collaborative problem-solving.	Connects STEAM processes with SEL and metacognitive development.
Social-Emotional Learning (SEL)	Develops empathy, social awareness, ethical reasoning, collaborative skills.	Positions SEL as a foundation for leadership emergence.
Metacognition	Supports self-regulation, autonomy, reflective learning, agency.	Bridges metacognition with empowerment and leadership behaviors.
Emergent Leadership	Leadership emerges naturally through interaction, shared goals, and social negotiation.	Links leadership development with empathy + empowerment cycles.

5. Conclusion

The 3D STEAM Leadership Model (3D-SLM) brings together four domains often examined separately in the literature—STEAM education, socio-emotional learning, metacognition, and emergent child leadership—into a unified developmental framework. Existing research provides strong support for each domain independently: STEAM enhances creativity and collaboration [10], SEL cultivates empathy and responsible decision-making [17], metacognition strengthens autonomy and self-leadership [15] and collaborative learning environments foster peer leadership [14]. The originality of the 3D-SLM lies not in proposing entirely new constructs, but in integrating these well-documented dimensions into a coherent model that explains how empathy → empowerment → emerging leadership may unfold within authentic STEAM learning. By shifting attention from purely cognitive outcomes to whole-child development, the model reframes STEAM as a powerful context for cultivating ethical, collaborative and reflective young leaders. Nevertheless, the framework remains theoretical; empirical validation is needed to examine its effectiveness and boundary conditions. Factors such as school climate, teacher expertise, and socio-cultural context may shape the degree to which these developmental pathways emerge. Yet the model offers a promising conceptual foundation for designing future research, interventions, and curriculum innovations.

Compliance with ethical standards

Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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