A conceptual framework for the integration of educational robotics in school

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Abstract: This work presents the Educational Robotics Integration Model (ERIM), a conceptual framework for the integration of educational robotics in school settings. It addresses the pedagogical, technical, and social dimensions that underpin effective implementation. The framework is structured around five interdependent dimensions considered important by research on educational robotics: learning objectives, instructional methods, learning artifacts, evaluation methods, and teachers training and community. These dimensions need to be purposefully designed to align with one another, ensuring a cohesive and systemic approach to the use of robotics in education that maximizes learning outcomes. Each dimension is introduced with a concise overview based on research literature. By addressing the challenges and opportunities of aligning pedagogical goals with technological capabilities, the framework offers actionable insights for advancing the field of educational robotics. It aims to provide educators, researchers, and policymakers with a structured and adaptable approach to integrating robotics into school curricula.

Keywords: ERIM Model, educational robotics, instructional alignment, school, education.

1. Introduction

Educational robotics (ER) has gained significant attention in recent years due to its potential to enhance learning outcomes (Alonso-García, Rodríguez Fuentes, Ramos Navas-Parejo, & Victoria-Maldonado 2024; Sapounidis et al., 2023). Numerous countries have therefore started to incorporate ER into classrooms and extracurricular activities, such as robotic competitions. Nevertheless, ER is still underutilized in compulsory education due to structural and pedagogical barriers. Teachers often lack clear guidelines for integrating robotics into curricula, and many are unfamiliar with its pedagogical applications (Chevalier et al., 2016). This growing interest has also led to a substantial body of scientific research dedicated to exploring the pedagogical impact, implementation strategies, and long-term benefits of ER in education. Most studies on the integration of ER in school tend however to focus on isolated aspects of ER, leading to fragmented results. There is a notable lack of holistic models that guide teachers in designing, implementing, and evaluating robotics-based learning activities.

This paper therefore aims to propose a comprehensive model for implementing ER in schools. The resulting model is called Educational Robotics Integration Model (ERIM).

The paper presents the theoretical rationale of the model. A case study on how the model can be applied for the development of an ER activity can be found on Aris[1].

2. Literature review

One way to classify ER activities is to consider the role that the robots take in the activities. There are three primary ways of using robots in education:

- Tutors – Robots that deliver learning experiences autonomously.
- Peers – Robots that collaborate with students in learning tasks.
- Tools – Robots that serve as cognitive artifacts to support student learning.

For this paper, the focus will be on robots used as learning tools, aligning with Papert's constructionist approach, where robots act as "objects-to-think-with" (Papert, 1980). These robots do not engage in social interactions but are used as pedagogical instruments to enhance several competencies.

2.1. Learning objectives

Achieving learning objectives is central to any activity, so educators must clearly define what they aim to teach and how. Research shows that robots can support various competencies as pedagogical tools, with ER used mainly to promote STEM learning (Sapounidis et al., 2023). Robotics has proven particularly effective in mathematics – for example, introducing concepts such as distance, angles, or spatio-temporal relationships (Mitnik et al., 2008; Julià & Antolí, 2016). A review by Benitti (2012) found that 80% of ER applications focus on mathematics and physics. However, ER also extends beyond STEM, contributing to areas like language learning (Chang et al., 2010) and arts education (Negrini, 2019).

In addition to subject-specific benefits, ER fosters transversal skills such as collaboration and communication (Ardito et al., 2014), creativity (Yang et al., 2020) or attentional control and executive functions (Marras et al., 2024). It also supports algorithmic thinking, logical reasoning, digital literacy, and computational thinking (Alonso-García et al., 2024). Still, the presence of a robot alone does not improve learning; intentional instructional design is essential (Wu et al., 2015).

2.2. Instructional Methods

In the late 1970s, Papert introduced the integration of robotics in education and proposed constructionism as its theoretical foundation (Papert, 1980). This paradigm emphasizes experiential learning, active knowledge construction, and the use of cognitive tools. ER activities should thus follow a student-centered approach, fos-

[1] https://aris.supsi.ch/entities/publication/17c008e7-64a9-47bd-affb-8370105be5d5

tering joy, playfulness, experimentation, and exploration rather than teacher-led instruction (Marras et al., 2024).

One way to apply constructionism is through the project method (Kilpatrick, 1918), where students work on complex tasks requiring a concrete product. Projects encourage inquiry, problem-solving, and collaboration, with tasks often divided into manageable sub-tasks. Another widely used approach is Problem-Based Learning (PBL), in which students tackle real or simulated problems involving an initial state, a goal, and the challenge of finding a solution path. Such problems vary in structure and complexity (Jonassen, 2004) and help students develop inquiry skills, critical thinking, and collaborative knowledge construction.

2.3 Learning tools

Chevalier et al., (2020) argued that ER activities generally consist of three main components as learning tools: (1) educational robots, (2) interfaces allowing users to program or communicate with the robot, often via a programming language, and (3) designated environments or "playgrounds" for interaction.

2.3.1 Educational robots

A wide variety of educational robots has been developed, each with distinct features, interaction modes, and learning applications (Giang, 2020). This diversity allows educators to select tools suited to different objectives, age groups, and complexity levels. Design choices affect usability and learning outcomes: some robots, like LEGO SPIKE[2], require assembly, while others, such as Thymio[3], are ready to use. They also differ in sensors, actuators, setup time, interaction devices, programming options, and target age. Visual design ranges from technical to playful or neutral styles (Chevalier et al., 2016).

2.3.2 Interfaces to program or communicate with the robot

A key element of ER tools is the interface through which learners program or interact with the robot. Interfaces may be tangible, using physical blocks to control actions, or software-based on computers and tablets. Programming environments typically fall into visual or text-based categories. Visual programming uses graphical components (e.g., Scratch, VPL, Blockly, MakeCode), while text-based relies on written code (e.g., Java, Python, Visual Basic) (Myers, 1990). McGill and Decker (2018) further classify languages into block-based symbolic (VPL), block-based text (Scratch, Blockly), hybrid, and text-based. The first three, to varying degrees, belong to the broader family of visual programming (Negrini et al., 2024).

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[2] LEGO Mindstorms and LEGO Spike are robots of the LEGO Group based in Billund, Denmark.

[3] Thymio is an open-source educational robot designed by researchers from the EPFL, in collaboration with ECAL, and produced by Mobsya, a nonprofit association based in Renens, Switzerland (https://learn.epfl.ch/en/initiatives/thymio/).

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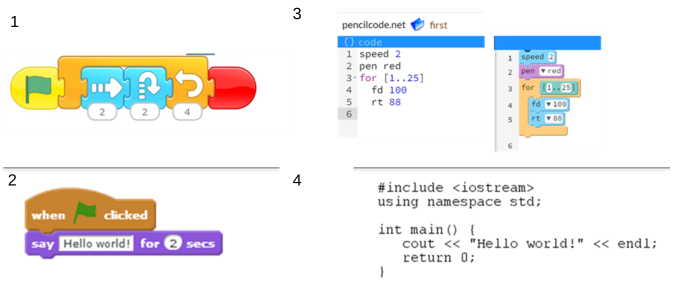
Figure 1. *An example of a block-based symbolic (1), a block-based text (2), a hybrid (3) and a text-based (4) language (Negrini et al., 2024).*



2.3.3 Designated environments or "playgrounds" for interaction

Finally, most ER scenarios involve a playground, which refers to the setting or environment where the problem is situated (Chevalier et al. 2020). Modifications within this space can involve introducing a new element, triggering an event, or gaining additional insight into the environment itself. When a modification meets the criteria defined by the problem, it is considered a solution. The individual or team solving the problem must be capable of comprehending and interpreting the task, generating ideas to address it, using an interface to implement those ideas as actions performed by the robot, and assessing whether the robot's behavior effectively solves the problem.

2.4 Evaluation Methods

A key factor in effectively integrating ER into school curricula is the availability of validated assessment tools. While robotics has been shown to foster diverse skills, evaluation often relies on traditional tests or anecdotal observations (Marcianò, 2017).

Recent literature stresses the need for instruments that capture the multidimensional nature of ER, aligning with varied objectives, pedagogies, and student profiles (Toh et al., 2016).

One often overlooked aspect is self-efficacy, or belief in one's ability to complete tasks (Bandura, 1977). In robotics, students' confidence in interacting with and applying concepts strongly influences success (Ford et al., 2023). To address this, the Robotics Learning Self-Efficacy Scale (RLSES) was developed and validated in Taiwan (Tsai et al., 2021) and Italy (Agus, 2025).

For domain-specific skills, especially computational thinking (CT), a range of tools exists, including questionnaires, tests, observations, interviews, and product analyses (Babazadeh & Negrini, 2022). Widely used tools include the CT Test (Román-González, 2015), its adaptation for younger learners (Zapata-Cáceres et al., 2020), and the CTLS – Computational Thinking Level Scale (Korkmaz et al., 2015), which assesses CT Perspectives through self-reports. Research shows that combining tools enhances assessment, since no single instrument covers all CT dimensions (Román-González et al., 2019).

ER assessment should also value creativity, collaboration, and reflection. Qualitative tools such as journals, rubrics, and digital portfolios can complement standardized instruments like RLSES, CT Test, and CTLS, especially in long-term projects.

2.5 Teacher training and support

Despite its pedagogical potential, the integration of ER into formal education remains uneven. Barriers include the lack of didactic materials, high costs, limited awareness of pedagogical benefits, teachers' low confidence in computer science, insufficient professional development, time constraints, and inadequate technical or pedagogical support (Reyes Mury et al., 2022). Moreover, successful adoption depends on factors such as curriculum alignment, school environment, and broader educational philosophy (Papadakis et al., 2021).

Integration efforts must therefore prioritize educators. Teachers play a decisive role in ER's success, yet professional development is often limited to short training sessions, leaving many without sufficient follow-up support (Reyes Mury et al., 2022). Sustained professional development should extend beyond initial training, addressing teachers' needs, self-efficacy, and pedagogical beliefs, while fostering long-term engagement. Initiatives such as the CAS in ER (Negrini, 2019) and the Robotic Camp (Negrini, Marras & Giang, 2025) represent steps toward more structured and continuous training.

Equally important is the creation of communities of practice (CoPs) that connect teachers, trainers, and researchers. These networks allow educators to share knowledge, exchange experiences, and access ongoing support. In Switzerland, for instance, the Roteco community provides materials, events, and workshops on ER. Early evaluations show strong interest, with over 60% of participants reporting that Roteco adds significant value to their teaching practice (Reyes Mury et al., 2022).

3. Conceptual framework for educational robotics integration

While many studies have examined individual dimensions of ER, none have proposed a comprehensive model for its school implementation. ER serves multiple objectives through diverse methods, tools, and assessments, but this diversity can leave teachers uncertain about how to integrate it. Simply placing a robot in the classroom does not enhance learning; activities must be well-planned, structured, and pedagogically aligned (Wu et al., 2015).

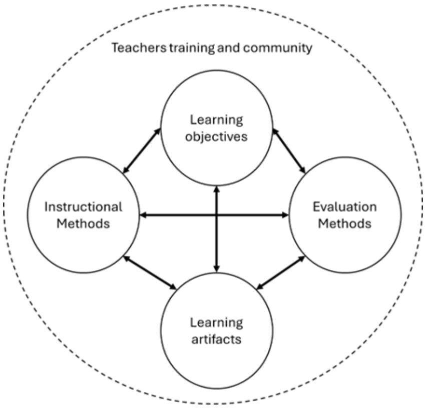
In pedagogy it is well established that effective learning activities should be designed with three key components in mind: intended outcomes, instructional processes, and assessment. Misalignment occurs when instructional methods do not support the intended learning goals or when assessments fail to measure what was taught. Research suggests that explicitly designing activities with alignment in mind leads to more effective learning (Cohen, 1987).

With the increasing integration of educational technology in classrooms, researchers have explored how alignment can be maintained when digital tools are introduced (Antonenko et al., 2017). While studies have examined alignment in screen-based learning technologies, ER presents unique challenges that require new frameworks for integration.

Lauwers (2010) proposed an extended alignment model that can be applied to ER. He suggested adding a fourth component, the tool, to account for how tools influence learning objectives, instructional strategies, and assessment methods. His work laid a foundation for understanding the role of ER in education, but, as Giang (2020) highlights, it primarily addressed alignment from a developer's perspective, focusing on how ER tools should be designed rather than how teachers should integrate them effectively.

Therefore, based on these reflections and on the actual research in the field of ER, we developed a comprehensive alignment model, the ERIM model (Figure 2), that integrates all the previously mentioned dimensions, providing a structured framework to help teachers and researchers effectively design and implement ER activities.

Figure 2. *ERIM, a comprehensive alignment model for integrating ER activities in school.*



The model is structured around five dimensions: "learning objectives," "instructional methods," "evaluation methods," "learning artifacts," and "teachers training and community." Notably, the fifth dimension, teachers training and community, encompasses and supports all the other dimensions, highlighting the necessity for ongoing training and support across the dimensions. Below, we elaborate on each dimension in detail.

Learning objectives: as existing literature has shown, the learning objectives of ER activities can be several. Teachers could apply ER in a discipline with the aim to enhance a disciplinary skill (e.g. the concept of angles in mathematics, a vocabulary list in a foreign language or the names of various valleys within a particular geographic region). Teachers can however also decide to focus not on disciplinary skills but rather on transversal skills. In that case, ER could be used to enhance the communication or the collaboration in class, or to foster creativity through an ER project. Additionally, teachers may incorporate robotics to enhance CT, coding skills, or other competencies not explicitly mentioned here.

Instructional methods: Teachers should ask themselves what instructional methods to use to propose the ER activity. As we have observed, ER activities primarily utilize two educational methods aligned with Papert's constructionist approach: problem-based learning and project-based learning. Depending on the specific learning objectives, one method may be more suitable than the other. Additionally, important considerations include the context in which the problem or project is presented, as well as the degree of openness or structure involved. These factors can significantly influence the effectiveness of the learning experience.

Learning tools: Teachers should carefully assess which learning artifacts are best suited to their educational objectives. Should they opt for a ready-to-use robot, or would a constructible robot better support their students' learning experience? What type of programming language aligns with their students' skill levels and curricular goals? Additionally, what supplementary materials are needed to design an engaging and effective learning environment or playground for the robots? When choosing the learning tools, educators should be aware that their affordances may be supporting or inhibiting the desired learning objectives as well as the instructional methods. Thoughtful consideration of these factors ensures that ER activities are both pedagogically meaningful and accessible to students.

Evaluation tools: A further step involves defining how to assess whether the learning goals have been achieved. Educators must determine which assessment tools are best suited to measure the defined learning objectives. What types of evaluation instruments are available to assess students' progress and skill development? What indicators should be observed to track the development of the competences? Additionally, teachers need to decide how and when to conduct these assessments—should they be integrated into the learning process through formative evaluation, or should they be applied at specific milestones as summative assessments? Establishing clear, evidence-based assessment strategies ensures that ER activities effectively support student learning and skill acquisition.

Teacher training and support: The final dimension integrates all the previous ones, emphasizing the importance of collaboration and shared expertise. Teachers alone may find it challenging to address all the questions posed above, from selecting appropriate learning artifacts to identifying effective evaluation tools and designing meaningful ER activities. This is why a supportive community is essential. A community of practice can provide valuable resources, enabling teachers to analyze learning artifacts, discover appropriate evaluation tools, and access pre-designed didactic activities tailored to different educational contexts. Moreover, through collaboration with peers and experts, teachers can exchange best practices, seek guidance, and adapt successful ER implementations to their specific needs.

Additionally, teachers may choose to engage in specialized training programs that focus on implementing ER activities with specific tools or for targeted learning objectives.

4. Conclusions

The conceptual framework presented in this paper aims to provide a structured and adaptable approach for integrating ER in schools, ensuring that ER activities are pedagogically meaningful, well-aligned with learning objectives, and effectively assessed. By considering learning objectives, instructional methods, learning tools, evaluation strategies, and teacher support, this framework offers a comprehensive overview that can guide educators and researchers in designing impactful ER activities. These contributions help bridge the gap between research and classroom practice, providing practical insights for educators, researchers, and policymakers.

For educators: The framework serves as a practical guide for designing, implementing, and evaluating ER activities, ensuring they are aligned with curricular goals and effectively support student learning.

For researchers: This study highlights gaps in ER assessment methodologies and underscores the need for further research on ER's long-term educational impact. While some assessment tools exist for evaluating ER's impact, further research is needed to develop standardized and validated instruments for measuring ER's effectiveness across diverse educational settings.

For policymakers: The recommendations provided advocate for systematic ER integration, including funding, curriculum alignment, and development of professional community to support teachers.

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