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Fostering Digital Literacy Through Creative Learning Approaches with Educational Robots

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Abstract

In our increasingly digitalized world, fostering digital literacy in education has become essential. Given the need to prepare students for the challenges and opportunities of the 21st century, this study investigates how creative learning approaches in conjunction with educational robots can significantly contribute to the development of these skills. Building on insights from prior research and existing literature, this study addresses key challenges in integrating digital tools into education, such as variability in resources and teachers' confidence in delivering STEM content. A literature-based approach was employed to explore effective pedagogical methods and to develop a framework for teacher training (TT) tailored to incorporating educational robots. The findings emphasize the importance of inquiry-based and experiential learning strategies, highlighting their potential to enhance students' engagement, creativity, and collaboration while building critical Computational Thinking (CT) skills. Additionally, the analysis identifies core components for successful TT, including fostering content knowledge, pedagogical strategies, and confidence in using educational robots. These results provide a foundation for developing targeted training modules aimed at equipping teachers with skills needed to implement innovative STEM and digital literacy programs. The study concludes by outlining plans for future research, focusing on implementing and evaluating the proposed training framework in real-world educational settings, ensuring its scalability and effectiveness. This research contributes to advancing STEM education and digital literacy through creative, technology-enhanced learning methods.

Keywords: Educational Robots; Digital Literacy; STEM Education; Teacher Training; Technology Integration

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1. Introduction

In today's rapidly changing world, fostering digital literacy and STEM competencies is essential for preparing students to succeed in the twenty-first century (Hörmann et Sabitzer, 2020). STEM education not only equips learners with critical thinking, problem-solving abilities, and innovation but also prepares them to participate productively in scientific practices and discourse (DeJarnette, 2012; Erdogan et al., 2017). Effective STEM instruction must go beyond teaching content knowledge, embracing inquiry-based approaches, hands-on experiences, and opportunities for students to engage in authentic, developmentally appropriate scientific processes (Duschl et al., 2007; Inan, 2019). These approaches allow students to actively explore, collect data, ask questions, and test scientific ideas while connecting prior knowledge to new experiences (Eshach & Fried, 2005; Frances et al., 2009). Moreover, young children's natural curiosity, combined with their high capacity for cognitive development in the early years, makes this an ideal time to introduce STEM learning, helping to set a strong foundation for future success (Buchter et al., 2017; Shonkoff & Philips, 2000). Importantly, early exposure to STEM has been shown to reduce gender-based stereotypes and break down barriers to participation (Davidson, 2011; Kazakoff et al., 2013). The process of scientific inquiry in STEM education includes active exploration and participation, allowing students to engage in hands-on activities, interact with peers and mentors, and use the authentic tools of science (Duschl et al., 2007; Inan & Inan, 2015). Such experiences are particularly impactful when they align with students' natural interests and curiosity, fostering excitement and deeper engagement with the subject matter (Inan, 2019). However, many teachers in primary and early childhood education report feeling unprepared to teach STEM topics due to limited training and confidence (Jamil et al., 2017). Research has shown that when teachers lack self-efficacy in STEM, they tend to avoid these topics in their classrooms, ultimately limiting students' exposure to critical STEM concepts (Jamil et al., 2017). This highlights the need for robust professional development programs that not only improve teachers' knowledge and skills but also build their confidence in delivering STEM instruction (Hapgood et al., 2020; Nugent et al., 2010; Tytler, 2020). Teachers who engage in inquiry-based professional development programs that are well-structured and hands-on tend to develop stronger abilities to present authentic STEM experiences in their classrooms (Snow-Renner & Lauer, 2005; Wenglinsky & Silverstein, 2006). These programs also help teachers interpret children's experiences with scientific phenomena, assess their understanding, and connect their observations to relevant concepts (Chalufour, 2010). Such training is particularly important given the growing emphasis on STEM in primary education, where many teachers remain apprehensive about their ability to engage students in meaningful STEM activities (Brenneman et al., 2009; Clements, 2021). Additionally, anxiety about STEM topics, especially mathematics, is prevalent among educators, and this anxiety can negatively influence student outcomes, particularly for girls (Beilock et al., 2010). To address these challenges, TT programs must focus on equipping educators with the skills to adapt STEM instruction to meet diverse student needs and interests while fostering positive attitudes toward STEM subjects (McClure et al., 2017). Creative solutions are required that bridge traditional learning environemnts and the digital world to develop the essential 21-century competencies (Adera, 2025). By integrating STEM education with creative learning approaches such as robotics and programming, educators can address these challenges while also making STEM content more engaging and accessible. Research shows that the inclusion of programming and robotics in STEM education not only promotes Computational Thinking (CT) skills and concepts but also fosters creativity, motivation, and collaboration among students (Hinterplattner et al., 2021, 2024; Tengler, 2020; Tengler et al., 2020). Inquiry-based approaches using tools like robotics enhance student engagement, encourage collaborative problem-solving, and help students connect theoretical knowledge with practical applications (Frances et al., 2009; Schacteret al., 2016). Moreover, technology-driven instruction provides opportunities for children to participate actively in scientific inquiry and experimentation, helping them develop a deeper understanding of STEM concepts (Schacter & Jo, 2017). Teachers play a pivotal role in this process. When confident and enthusiastic about STEM topics, they inspire similar enthusiasm in their students, laying the groundwork for long-term engagement with STEM fields(Brenneman et al., 2009; Duschl et al., 2007). Conversely, a lack of challenge or engagement in STEM education can lead to frustration or disengagement among students, underscoring the importance of thoughtful, well-designed instruction (Hinterplattner et al., 2022). Ultimately, the success of STEM education depends on the development of both students' and teachers' competencies. By combining inquiry-based teaching, robust professional development, and creative learning tools like robotics, educators can lay the foundation for a future-ready generation equipped with the critical digital and STEM skills needed to thrive in an increasingly complex world (Chalufour, 2010; Hinterplattner et al., 2021, 2024; Tengler, 2020; Tengler et al., 2020).

2. Digitalization Project in Steyr

2.1 Background

The city of Steyr has launched a digitalization initiative to transform the educational landscape across its 16 public schools, including nine primary schools, six middle schools, and one polytechnic school. The project is supported by a dedicated budget for acquiring classroom digital equipment. To lead the project, a STEM education researcher was appointed as the project leader. In collaboration with global tech company Dynatrace and Johannes Kepler University Linz, a multidisciplinary team was established, combining the aspects of education, information technology (IT), research, and business. Furthermore, these project partners were chosen for their established programs promoting early interest in STEM, advancing gender equality, and fostering essential digital skills (Blinded reference). Therefore, this partnership is unique in Steyr and demonstrates how cities, private companies, and research institutions can collaborate to advance digital skills and future-ready education.

The initiative aims to embed the subject Digital Education (German: "Digitale Grundbildung") in schools while achieving the key objectives: (1) Promoting Digital Literacy, (2) Enhancing Engagement, (3) Fostering Collaboration, (4) Supporting Differentiated Learning, and (5) Ensuring Equal Accessibility (see Figure 1).

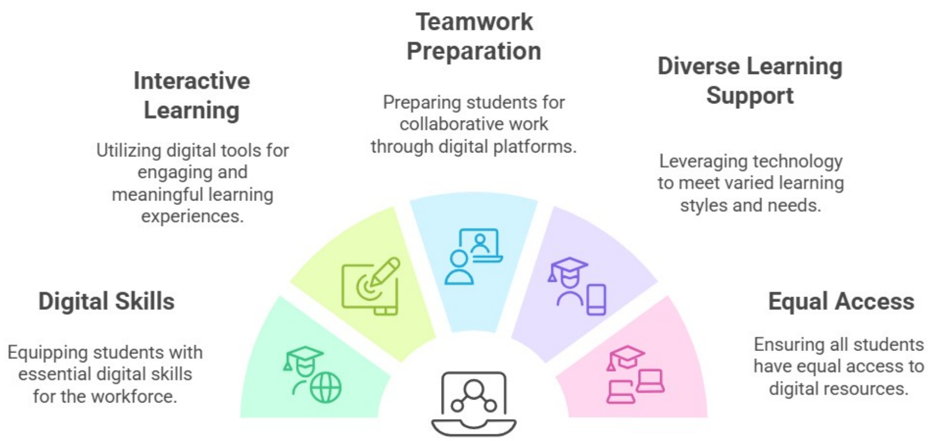

Figure 1. Key objectives of the Digitalization project in Steyr.

To ensure efficient utilization of the budget, a key focus was placed on integrating teacher training (TT) into the project. Each participating school is required to have at least two teachers attend professional development TT sessions aimed at implementing STEM and Digital Education in their classrooms.

The project workflow (illustrated in Figure 2) is designed to ensure high-quality instruction and establish best practices for effectively integrating technology into classrooms. Additionally, the initiative includes the development of free digital teaching materials tailored for all grade levels. These materials are intended not only for the participating schools but also for broader distribution, amplifying the project's impact beyond Steyr.

Figure 2. Overview of the project plan and its stages of the Digitalization Project in Steyr.

This collaborative effort in Steyr serves as a potential model for other Austrian cities, showcasing how investments in education and technology today can shape the future. It aims to inspire similar initiatives nationwide, expanding access to digital literacy, digital skills, and its benefits. The project is supported by ongoing research, which informs both planning and implementation. The initial research phase focuses on TT, assessing educators' STEM knowledge, evaluating schools' readiness for STEM integration, and identifying effective training strategies. This foundation enables the project to address educators' specific needs and improve the overall quality of STEM education in Steyrs schools. Previous research within this project highlighted the importance of high-quality teacher preparation as a cornerstone for fostering strong STEM education from the outset (Hinterplattner et al., 2025).

2.2. Findings from Previous Research

The previous research explored the state of STEM education in elementary and secondary schools in Steyr, shedding light on several critical challenges and disparities that affect the delivery of STEM content (Hinterplattner et al., 2025). The study emphasized the significant variability in STEM resources and equipment available to schools, with some institutions being well-equipped and others facing significant limitations due to outdated or insufficient digital tools. These disparities were further reflected in the varying levels of teacher preparedness for delivering STEM education. While some educators had received specialized training, many others had not been exposed to STEM-focused professional development, resulting in a wide range of comfort and competency levels among teachers. Many educators expressed a clear desire for more support structures and professional development to help them integrate STEM into their teaching effectively. The integration of STEM into school curricula was similarly inconsistent. While some schools were able to offer project-based learning opportunities or dedicated STEM classes, others lacked the necessary resources or infrastructure to fully engage students in these subjects. Despite these limitations, a strong interest in STEM education was evident among teachers, many of whom recognized the importance of fostering students' interests and skills through interdisciplinary approaches and hands-on learning. However, the lack of resources and standardized methods of collaboration posed significant barriers to consistent and widespread implementation of STEM initiatives across schools. Finally, the research highlights the need for sustainable partnerships and collaboration, an area the current project aims to strengthen by fostering connections between local government, industry, and academia. This collaborative model, as demonstrated in the pilot project, offers a scalable and replicable framework for advancing digital literacy and STEM education.

2.3. Research Goals and Objectives

The findings of the previous research show the issues with fostering digital literacy in schools. The disparities in resources and TT highlighted in the research underscore the need for accessible, innovative tools like educational robots to bridge gaps and provide equitable opportunities for all schools to enhance their Digital Education offerings. The current project builds upon the previous research by emphasizing the importance of TT to ensure effective integration of digital tools into the classroom. This project aims to empower educators with the skills and confidence they need to use creative, hands-on methods to foster student engagement and digital literacy. Moreover, the previous study's focus on the variability of STEM curriculum integration and the strong interest among teachers in project-based learning aligns closely with the goals of the current research. By utilizing educational robots, the current project offers a creative approach that addresses the resource constraints faced by schools while engaging students in interactive, interdisciplinary learning experiences. In conclusion, the findings from previous research emphasize the urgent need to address challenges in STEM education, such as disparities in resources, inconsistent curriculum integration, and the lack of teacher preparation. These insights highlight the potential of creative, hands-on learning approaches, including the use of educational robots, to bridge these gaps and foster essential digital competencies. Building on this foundation, the current study seeks to leverage existing knowledge and research to develop targeted training modules for teachers, ensuring they are equipped to integrate educational robots effectively into their classrooms and provide meaningful learning experiences for students.

This study is guided by the following three research questions:

1. What pedagogical approaches are most effective for integrating educational robots into STEM and digital literacy education, as highlighted by existing literature and prior research?

2. What insights from previous studies can inform the development of TT programs for incorporating educational robots, such as Ozobots, into creative learning approaches?

3. How can findings from the literature and prior research guide the creation of training modules to promote digital literacy through inquiry-based and hands-on approaches with educational robots?

By addressing these questions, this study aims to design a scalable framework for TT that empowers educators to implement innovative, technology-supported learning approaches, fostering students' digital literacy and STEM engagement.

3. Materials and Methods

This research adopts a qualitative approach, primarily focusing on literature review and analysis of prior research related to STEM education, TT, and the use of educational robots. The study is designed to inform the development of a TT program for integrating educational robots into creative, hands-on learning environments that foster digital literacy and CT. The design process includes synthesizing insights from previous research, identifying gaps, and formulating pedagogical strategies for TT. The analysis will focus on the challenges identified in earlier studies, such as insufficient resources, lack of specialized training, and the need for more hands-on STEM activities in primary and secondary classrooms. By analyzing these challenges and insights, the study will identify key areas how educational robots can be effectively incorporated to teach digital literacy. The results from prior studies will also inform the design of training modules that integrate inquiry-based learning and promote creativity. The training modules will be designed to align with the best practices identified in literature, providing teachers with the knowledge and tools to apply creative learning approaches in their classrooms. The modules will be structured progressively, starting with foundational knowledge of educational robots and gradually advancing to more complex concepts and teaching strategies. Since the focus is on developing training materials based on literature and prior research, data collection will primarily involve secondary sources. These will include a detailed review of past studies and the compilation of relevant data from educational projects that incorporated robotics and TT. The analysis will focus on identifying trends, challenges, and successes that can inform the training module development process. The findings from these sources will be used to ensure that the proposed training program addresses existing gaps in teacher preparedness and provides practical, evidence-based solutions.

4. Results

4.1. Pedagogical Approaches for Integrating Educational Robots into STEM and Digital Literacy Education

The literature review and analysis of prior research highlighted several pedagogical approaches that are effective for integrating educational robots into STEM and digital literacy education. Inquiry-based learning emerged as a key strategy, as it promotes active exploration, critical thinking, and problem-solving skills. This approach aligns with the findings of Duschl et al. (2007) and Chalufour (2010), which emphasize the importance of engaging students in scientific practices through hands-on activities and authentic experiences. Studies also highlighted the significance of constructivist approaches that allow students to build their understanding through experimentation and collaboration. Educational robots, such as Ozobots, can serve as versatile tools in facilitating these approaches by enabling students to program, test, and refine their solutions in a dynamic and interactive environment (Hinterplattner et al., 2021; Tengler, 2020; Tengler et al., 2020). Additionally, creativity and collaboration were identified as critical components of effective pedagogy, with previous research demonstrating that educational robots foster teamwork, innovation, and motivation among students (Hinterplattner et al., 2024; Schacter & Jo, 2017). Moreover, the literature emphasized the importance of scaffolding students' learning experiences to ensure they progress from foundational concepts to more complex skills. Teachers play a pivotal role in this process by guiding students in connecting their prior knowledge with new STEM and digital literacy concepts (Wenglinsky & Silverstein, 2006).

4.2. Insights from Previous Studies on Developing TT Programs

The analysis of prior research conducted within the project revealed significant challenges in teacher preparedness for STEM education in Austrian schools. A lack of specialized training, coupled with limited confidence and self-efficacy among teachers has hindered the effective integration of STEM content, including robotics, into classrooms (Hinterplattner et al., 2024; Jamil et al., 2017). These findings underscore the need for TT programs that provide educators with the skills, knowledge, and resources necessary to implement inquiry-based and hands-on approaches effectively. Previous studies also highlighted the potential of educational robots to bridge these gaps by serving as accessible and engaging tools for teaching STEM concepts (Tengler,2020). However, to achieve this potential, teachers require targeted training that not only introduces them to the technical aspects of robotics but also equips them with strategies to integrate these tools into broader curricular goals. Therefore, training programs should emphasize the practical application of robotics in fostering digital literacy and CT while addressing common challenges, such as resource constraints and varying levels of teacher experience. Insights from prior research further suggested that TT programs should incorporate opportunities for hands-on practice, collaboration, and reflection. Teachers who participated in well-structured, inquiry-based training programs reported significant gains in their ability to design and facilitate authentic learning experiences, as well as increased confidence in adapting STEM content to suit their students' needs (Wenglinsky & Silverstein, 2006).

4.3. Guiding the Creation of Training Modules for Promoting Digital Literacy

The findings from the literature and previous research provided valuable guidance for designing training modules aimed at promoting digital literacy through inquiry-based and hands-on approaches with educational robots. These modules will be structured around the following key principles:

1. Hands-on, Inquiry-Based Learning: The modules will focus on engaging teachers in active exploration and experimentation with Ozobots, enabling them to experience the same inquiry-based learning processes they will later facilitate in their classrooms (Duschl et al., 2007; Inan & Inan, 2015).

2. Progressive Skill Development: The training will begin with foundational concepts, such as basic programming and understanding the functionality of educational robots, and gradually progress to more advanced topics, such as integrating robotics into interdisciplinary STEM projects (Chalufour, 2010; Schacter & Jo, 2017).

3. Practical Applications: Teachers will be provided with concrete examples and lesson plans that demonstrate how to use educational robots to teach STEM and digital literacy concepts creatively. These applications will be tailored to different classroom contexts, ensuring scalability and accessibility for schools

with varying resources (Hinterplattner et al., 2024).

4. Reflection and Collaboration: The training will include opportunities for teachers to collaborate with peers, share best practices, and reflect on their learning experiences. This collaborative aspect aligns with research emphasizing the importance of professional learning communities in supporting teacher growth and confidence (Wenglinsky & Silverstein, 2006).

By incorporating these principles, the training modules aim to empower teachers to create engaging, student-centered learning environments that foster digital literacy and CT. Ultimately, this approach seeks to address the gaps identified in previous research and ensure that all students, regardless of their school's resources, have access to high-quality STEM education. The elements are visually summarized in Figure 3.

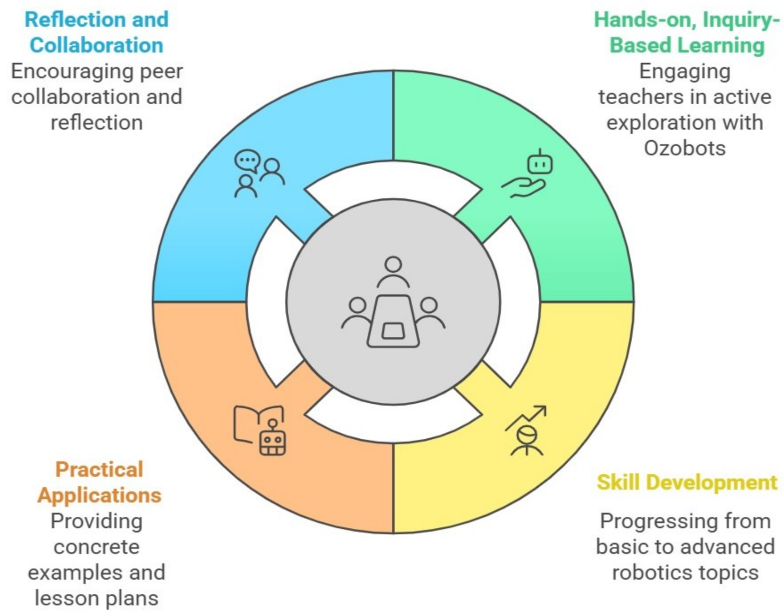

Figure 3. Key Principles of Training Modules for Promoting Digital Literacy.

5. Discussion

The findings of this study provide valuable insights into the integration of educational robots, such as Ozobots, into STEM and digital literacy education. By synthesizing prior research and literature, as well as leveraging insights from our previous work, this study highlights several critical factors that contribute to successful TT and effective implementation of creative learning approaches. The literature and prior research underscore the importance of inquiry-based and hands-on learning strategies for integrating educational robots into the classroom (Chalufour, 2010; Hinterplattner et al., 2021, 2024; Tengler, 2020; Tengler et al., 2020). These approaches not only foster deeper engagement with STEM content but also promote higher order thinking skills such as problem-solving, creativity, and collaboration. Moreover, the alignment of robotics-based learning activities with inquiry-based practices helps bridge the gap between abstract STEM concepts and practical application, making these concepts accessible and engaging for students.

One of the most significant challenges identified in prior studies is the lack of confidence and preparedness among educators to integrate robotics and digital literacy into their teaching. This study emphasizes the necessity of TT programs that are not only comprehensive but also adaptive to diverse teaching environments. The training framework developed in this study, visualized in Figure 2, focuses on equipping teachers with the content knowledge, pedagogical strategies, and practical experience required to incorporate robotics into their instruction effectively. The inclusion of mentorship and reflective practices further enhances the sustainability of the training outcomes. The disparities in resources and access to STEM education tools, as revealed in previous research, remain a significant barrier to equitable education. This study demonstrates that carefully designed TT programs, supported by inquiry-based and hands-on methodologies, can help mitigate these disparities. By focusing on the professional development of teachers, particularly in under-resourced schools, the project offers a scalable model for promoting digital literacy and STEM education at a broader level. While the study offers a comprehensive framework for integrating educational robots into STEM education, it is primarily based on existing literature and prior research. A limitation of the study is its lack of an empirical testing of the proposed TT program. This, however, is a key focus for the next phase of the project. As part of our future research, we plan to implement the training framework in diverse educational settings and evaluate its effectiveness through pilot programs. This will include analyzing the impact of TT on educators' confidence, skills, and ability to facilitate robotics-based STEM education, as well as measuring student outcomes in terms of digital literacy and engagement. Additionally, exploring the long-term effects of robotics-based learning on students' digital competencies and STEM-related interests will provide valuable insights for further refinement of the training modules. These future steps aim to build on the foundation established in this study, ensuring that the proposed approaches are both effective and adaptable across varying contexts.

6. Conclusions

This study explores a framework to equip teachers with skills and knowledge to help them utilize educational robots in their teaching. By addressing the challenges outlined in existing research, including a lack of teacher confidence and limited access to resources, this study presents a framework for TT that emphasizes inquiry-based and hands-on pedagogical approaches. The proposed training model offers a pathway for empowering educators to integrate robotics into their classrooms effectively, ensuring that students are equipped with the digital competencies required for future success. The findings underscore the importance of early exposure to STEM concepts and the role of innovative teaching tools in bridging gaps in education. The next phase of this project will involve implementing and empirically validating the TT framework across diverse educational contexts. By evaluating its impact on teacher efficacy and student outcomes, the study aims to provide robust evidence for scaling these practices and shaping the future of digital literacy education. This work not only addresses existing gaps in the field but also sets the stage for sustainable and equitablea dvancements in STEM education.

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