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Designing a low-code course for scientific and digital literacy in middle school

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ABSTRACT

Over the past decade, scientific disinformation has been intensified by the COVID-19 pandemic and the proliferation of social media. The emergence of generative Artificial Intelligence (AI) tools has worsened the spread of misinformation and poses risks to scientific literature through low-quality journals. Promoting both scientific and digital literacy in education is now more critical than ever. Our pilot study explores how to enhance classroom instruction to foster student motivation while developing these literacies. We present an innovative course design featuring interdisciplinary, low-code STEM projects and collaborative learning. Designed for middle school students, the pedagogical scenarios span three difficulty levels. Teachers trained in the program praised its creativity and interdisciplinary approach, though concerns were raised about schools' technological readiness. A pre- and post-implementation STEM interest survey revealed that the pilot group's interest in Engineering and Technology increased compared to the control group, highlighting the course's potential to spark lasting engagement in STEM fields.

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Introduction

Lack of scientific literacy remains an underestimated problem. Although the expression "scientific literacy" dates back to the 1950s, the idea that mastery of scientific knowledge is vital for modern life predates this (Feinstein, 2011). The urgency of the issue became evident during the COVID-19 pandemic, which exposed deficiencies in public understanding (Nutbeam & Lloyd, 2021), revealed societal unpreparedness for public emergencies (Abdel-Latif, 2020), and highlighted the consequences of online misinformation and "fake news" (Roozenbeek et al., 2020).

These challenges are now amplified by the public release of generative Artificial Intelligence (AI) tools, such as ChatGPT and Midjourney, capable of producing human-like text and images. Such tools may intensify the spread of scientific (mis) information about vaccines, drugs, and diseases, particularly through platforms such as TikTok, YouTube, and X (formerly Twitter) (Suarez-Lledo & Alvarez-Galvez, 2021). Beyond accidental misinformation, intentional misuse of AI by political or economic actors, cybercriminals, or organized "disinformation farms" poses serious threats to communities and public services (Meyrowitsch et al., 2023). Concerns also extend to academia, where AI-generated scientific literature risks proliferating in predatory journals (De Angelis et al., 2023).

Addressing such interconnected social challenges requires multidimensional strategies. Do Nascimento et al. (2022), for example, argue that managing health-related "infodemics" demands advancing both scientific and digital literacy. STEM education plays a central role in this regard: it can strengthen these literacies and prepare students to navigate complex societal issues. However, despite favorable labor market conditions, many countries face shortages of STEM graduates (López et al., 2023). Teachers and educators thus need to foster supportive instructional and social contexts that enhance students' performance in STEM curricula (Han et al., 2021).

Yet, student interest in STEM is in decline (Thomas & Watters, 2015). This raises a pressing question: how can classroom instruction better spark motivation and competence, thereby advancing STEM literacy? One promising direction lies in innovative teaching strategies that integrate emerging technologies and combine scientific with digital literacy (Ng, 2013). Pedagogical scenarios offer such an approach: as structured instructional units, they organize sequences of activities, embed teacher guidance, and incorporate formative assessment, all while connecting learning to societal challenges relevant to students (Maha et al., 2020).

In this context, the research outlined in this paper focuses on proposing an innovative course design, along with its pedagogical learning scenarios, that incorporates low-code development across STEM subjects and integrates collaborative and inquiry-based learning methodologies within an interdisciplinary project. This holistic approach seeks to equip educators with the skills and insights to navigate the

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dynamic challenges inherent in today's educational landscape. The course design is grounded in active learning methodologies. Specifically, we propose a project in which students collaborate while learning to program using a low-code approach to create quizzes, games, and other tools related to Science topics. With guidance from teachers from both subjects, this approach aims to strengthen students' digital and scientific literacy. This course design was implemented on an exploratory basis with students from a single class. Figure 1 presents the research framework.

The fundamental impact of this pilot study is directed toward enhancing classroom teaching by equipping students with the vital 21st-century competencies (Salas-Pilco, 2013) of critical thinking, collaboration, communication, self-management, technology literacy, problem-solving, and creativity, considered essential for students to flourish and thrive in their academic endeavors and future vocations in the STEM field (National Research Council, 2010). The aim is to make students capable not only of adapting to new work tools but also of being motivated to pursue STEM disciplines in their future educational and career paths.

The main contributions of this study are a model showing how low-code links computational thinking to inquiry-based STEM learning, and a set of adaptable classroom scenarios and open digital resources that progress from simple activities to more complex projects. Relative to prior work on block-based and low-code programming, our study's main theoretical contribution is to reframe these environments as vehicles for scientific and digital literacy, not only for introductory programming or generic computational thinking. Existing research with Scratch, MIT App Inventor, and related low-code tools has predominantly focused on teaching basic programming concepts or computational thinking. The majority of documented interventions are situated in higher education or adult-learning contexts (e.g., introductory CS/IT or healthcare IT courses for university students, and non-computer-major courses) (Matook et al., 2024; McHugh et al., 2024; Sońta & Przegalinska, 2024).

The paper is organized as follows. The Background section introduces the central theoretical constructs—scientific and digital literacy, and active learning methodologies—and reviews prior work on low-code programming initiatives in education. The Methods section then presents the research design and procedures employed in the study. This is followed by a Results section that reports outcomes from both the teacher workshop and the pilot implementation with students. The Discussion section interprets these findings in relation to existing literature and the study's aims. Finally, the Conclusion summarizes the key contributions and highlights directions for future research.

Background

Scientific literacy and digital literacy

Defining scientific literacy is complex, with diverse and sometimes conflicting interpretations. Rather than offering an exhaustive review—several already exist (Pardo & Calvo, 2004; Roberts, 2007)—this paper highlights how definitions have evolved alongside technological change. Norris and Phillips (2003) identified 11 characteristics of scientific literacy, from understanding concepts to applying knowledge in problem-solving and sustaining lifelong engagement with science.

Holbrook and Rannikmae (2009) distinguish two main perspectives: scientific literacy as mastery of concepts, and as a tool for navigating a changing world. National Academies of Sciences, Engineering, and Medicine (2016) supports the latter, stressing that online access to information disrupts traditional knowledge gatekeeping and intensifies the problem of misinformation. Accordingly, new competencies are required for evaluating scientific claims in personal and societal decision-making (Allchin, 2014). Howell and Brossard (2021) propose a multidimensional framework—civic, digital media, and cognitive scientific literacy—to meet this challenge. This aligns with calls to expand literacy to multimodal forms such as blogs, podcasts, and digital storytelling (Holsanova, 2020; Unsworth et al., 2022; Yeo & Nielsen, 2020), echoing Lemke's (1998) insight that meaning-making in science extends beyond language. Digital tools can further enhance motivation, cognition, and authentic learning experiences (Ng, 2013; Webb, 2005), fostering literacy through students' technological engagement.

Since the 1980s, terms like "computer literacy," "internet literacy," and "media literacy" have reflected their technological moment, converging under the broader umbrella of

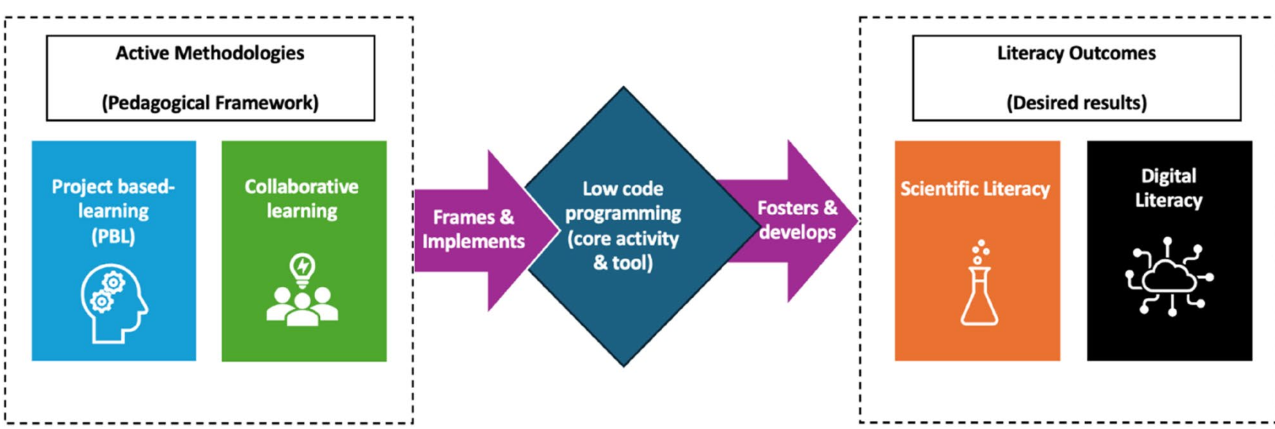

Figure 1. Research framework.

"digital literacy" (Selwyn, 2022). Prensky's (2001) distinction between "digital natives" and "digital immigrants" underscored generational divides, warning that educators unfamiliar with digital practices would struggle to connect with younger learners. This remains pertinent, particularly given the older average age of teachers and digital skill gaps revealed during the COVID-19 pandemic (Ferri et al., 2020; Sánchez-Cruzado et al., 2021).

However, the assumption that young people are inherently skilled is contested. Studies show Gen Z often feels unprepared for digital workplaces (Magee, 2023; Strauss, 2019), and that factors such as ethnicity, gender, and socio-economic background better predict digital competence (Junco et al., 2010). Some research even finds older "digital immigrants" outperform younger cohorts through active learning (Evans & Robertson, 2020). As Warschauer (2002) emphasizes, literacy—not age—determines digital proficiency.

Digital literacy is thus seen as a skill set that must be intentionally cultivated (Scherer & Siddiq, 2019). Closely tied to Information and Communication Technology (ICT) literacy, it encompasses the ability to explore, create, and communicate with technology and is widely considered a core 21st-century competency. Broader frameworks such as "metaliteracy" (Mackey & Jacobson, 2011) and "new literacies" (Rowsell & Walsh, 2011) extend this to include media, information, cyber, and visual competencies, highlighting the multimodal, evolving nature of literacy in civic, economic, and personal contexts. From a sociocultural perspective, digital literacy also entails meaningful participation in digital communities (List, 2019), reflecting Wenger's theory of communities of practice and emphasizing collaborative learning through shared digital artifacts.

Course design for active and digital-based learning

When developing a course design that emphasizes active learning and fosters scientific and digital literacy, it is crucial to recognize the diverse challenges teachers may face in its implementation, including limited time, inadequate training, and a shortage of materials. Addressing these hurdles necessitates providing high-quality teaching and learning resources to support educators effectively (Ješková et al., 2022). The course design and pedagogical scenarios we propose in this paper are grounded in two key theoretical frameworks, and we will explore their core concepts below: active learning methodologies and Bloom's digital taxonomy (Churches, 2007).

A diverse set of methods, practices, strategies, and tools falls under the umbrella of active methodologies, all aimed at directly engaging students in the teaching and learning processes (Moya, 2017). Hao et al. (2021) stress that active learning diverges from traditional passive lectures by strongly emphasizing real-world application, experiential learning, and collaborative engagements. According to the authors, this approach is geared toward the overarching aim of preparing students for enduring accomplishments and future roles beyond the academic setting. In an active learning setting, students are encouraged to nurture their curiosity, tailor the lesson pace to their preferences, and boost creativity, contributing to heightened student involvement, motivation, excitement, and attention (Jesionkowska et al., 2020). The rationale for prioritizing active learning in our course design is grounded in compelling evidence indicating that active learning strategies enhance educational outcomes, especially in science, engineering, and mathematics disciplines (Mehanni et al., 2019). Given the digital nature of our learning process, Ramadhani and Fitri (2020) argue that integrating diverse active learning models is essential. Therefore, we placed particular emphasis on three key concepts within active learning: project-based learning, collaborative learning, and the flipped classroom approach.

Project-based learning (PBL) is a dynamic instructional approach centered on students, highlighting interactivity and being rooted in the belief that learning is most impactful when situated in real-life challenges. This methodology asserts that students play an active role in their learning journey, with collaborative interactions and knowledge sharing as key drivers of their success (Kokotsaki et al., 2016). PBL methodologies exhibit a shared set of characteristics. These include the initiation with a driving question, collaborative inquiry guided by teachers to achieve learning goals, and the creation of products or artifacts addressing the driving question (Krajcik & Blumenfeld, 2006). What differentiates PBL from other learning methodologies is the creation of a tangible end product that directly addresses the unit's guiding question, serving as both a concrete representation of student learning and a valuable educational artifact (Krajcik & Shin, 2014). According to Cattaneo's (2017) systematic review of active learning pedagogies, project-based learning is consistently portrayed in the literature as a school-wide initiative fostering environments with higher levels of student direction. Educators employ a collaborative framework to organize inquiry-based activities and scientific projects involving community stakeholders, thereby supporting problem-solving and knowledge generation in authentic contexts, broadening students' horizons beyond the classroom, and incorporating real-world experiences. Condliffe (2017) highlights the consensus among various authors that the public presentation of outcomes resulting from project-based learning experiences underscores the projects' authenticity and practical relevance.

Helle et al. (2006) argue that Project-based learning is a form of collaborative learning that involves students working together in groups and with the teacher (Davidson & Major, 2014). In this context, the group collectively decides on task distribution by assigning shared responsibilities to all members or allocating specific roles based on individual skills and strengths. Numerous studies support the effectiveness of small-group activities in fostering student engagement with the material (Adkins, 2018), and there is consensus that students working in small groups tend to achieve higher learning outcomes than those working individually (Van Leeuwen & Janssen, 2019). As collaboration is recognized as a 21st-century skill, there is growing interest in collaborative learning, particularly when integrated with technology (Andersen & Rustad, 2022).

Arslan (2020) suggests that peer interaction and collaboration emerge as the most beneficial elements of flipped classrooms compared to traditional direct lectures. The concept of a flipped classroom, introduced by Bergmann and Sams (2012), reverses the conventional classroom instruction model. Unlike the traditional approach, where students receive lectures and direct instruction during class time and then complete homework outside of class, in a flipped classroom, students engage with instructional content before class. This typically includes watching prerecorded video lectures or reading materials (Sohrabi & Iraj, 2016). Class time is then used for interactive, collaborative activities, such as discussions, problem-solving, and hands-on exercises, enabling students to apply the knowledge acquired from the pre-class materials (Akçayır & Akçayır, 2018).

Krathwohl (2002) highlights that Bloom's original Taxonomy, designed as a structure for classifying statements indicating the expected or intended learning outcomes resulting from instruction, presented definitions for the six major categories in the cognitive domain: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. These cognitive skills are categorized into a continuum, spanning from lower-order thinking skills (LOTS) to higher-order thinking skills (HOTS). A subsequent revision of Bloom's taxonomy by one of his students (Anderson & Krathwohl, 2001) involved shifting the terminology to verbs and introducing a new higher-order thinking category at the highest level. The revised taxonomy is structured as follows: remembering, understanding, applying, analyzing, evaluating, and creating. Churches (2007) put forward Bloom's Digital Taxonomy, intending to define learning objectives tailored for a technology-enhanced teaching environment. It goes beyond the cognitive domain, providing approaches and tools to support conceptual understanding as well (Amin & Mirza, 2020). According to Harris et al. (2020), active learning encourages students to engage with higher levels of Bloom's taxonomy, pushing them to cultivate a deeper command of curricular knowledge through the application of concepts, analysis of data, and the creation of original syntheses or knowledge.

Low-code programming

The concept of low-code emerged in the realm of business application development. According to Prinz et al. (2021), the term was originally introduced by the US company Forrester Research (Richardson et al., 2014) to characterize business application development platforms that substantially reduce the need for manual programming by integrating visual tools. Low-code is a software development approach facilitated by a low-code platform, enabling developers to build software applications with minimal to no conventional hand-coding. The methodology predominantly relies on a graphical user interface (GUI) for tasks such as dragging and dropping application components and seamlessly connecting them (Prat, 2021). Varajão et al. (2023) observes that the adoption of low-code, extreme low-code, and no-code software is anticipated to expand globally, influencing the business landscape and playing a pivotal role as facilitators of digital transformation.

Within the educational context, low-code learning has demonstrated its efficacy as a valuable tool for improving the computer skills of both students and teachers (McHugh et al., 2024; Sońta et al., 2024). Even though the predominant focus of studies exploring low-code platforms like MIT App Inventor in educational settings has been in higher education, investigations in early education suggest that these platforms offer a valuable introduction to programming (Georgiev, 2019). Fagerlund et al. (2021) contend that teaching programming serves not only as a goal by itself but also as a means to foster computational thinking. Recognized as a 21st-century skill (Zhang & Nouri, 2019), computational thinking is most notably defined by Wing (2006), who popularized the term. Wing describes computational thinking as the ability to solve problems, design systems, and comprehend human behavior, drawing on foundational concepts in computer science. A low-code approach enables students to acquire fundamental programming skills while developing practical, functional applications. Indeed, Matook et al. (2024) emphasize that a low-code platform provides students with real-world experiences in instructional systems design (ISD) while facilitating technology-mediated learning.

Many low-code platforms use block-based programming languages, providing a user-friendly approach that eliminates the need for users to enter complete programming statements manually (Papadakis et al., 2016). Instead, users choose blocks from categorized menus, removing the need for beginners to memorize or type code names (Turbak et al., 2014). Block languages fall under the category of visual programming languages, where blocks are color-coded by their collections, and their shapes dictate that they can only be connected in ways that adhere to proper syntax, resembling a jigsaw puzzle where pieces naturally interlock (Vasek, 2012). In block-based coding, users construct interactive narratives, games, and multimedia content by dragging and dropping pre-designed code blocks.

MIT App Inventor stands out as one of the most widely used low-code platforms in education, serving as the cornerstone of the teaching scenarios we designed. Born out of a project within the now-closed Google Labs, MIT App Inventor is an online development platform intended for constructing mobile phone applications. Within the MIT App Inventor user interface, there are two main editors. The design editor simplifies the arrangement of mobile app interface elements through intuitive drag-and-drop functionality. Complementing this, the blocks editor provides a visual platform that enables app creators to articulate the logic of their applications (Patton et al., 2019). MIT App Inventor has also introduced the AI Companion feature—a mobile application that allows app developers to conduct real-time testing during development. This functionality streamlines the development workflow, providing immediate feedback and troubleshooting opportunities to ensure the app functions as intended and delivers the desired user experience.

Tinmaz et al. (2023) underscore UNESCO's recommendation that a comprehensive curriculum overhaul is necessary across all educational tiers in the face of a digital and AI-dominated landscape, calling for a "shift from basic digital literacy to higher order (computational) thinking skills."

We argue that this paradigm shift should extend to scientific literacy. Not only that, new curricula should prioritize integrating digital literacy to enhance scientific literacy, thereby contributing to a holistic promotion of STEM subjects and careers.

Method

Study's context

This study is part of the larger research project PAFSE (Partnerships for Science Education). The project represents an educational initiative that tackles public challenges, having secured approval under the Horizon 2020: Science with and for Society (H2020-SwafS-2018–2020) call for projects. The project's primary goal is to establish seven science education clusters by fostering partnerships among schools, formal and informal education organizations (e.g., universities, research centers, libraries, and science clubs), and various societal actors (e.g., companies, civil society organizations, government institutes, NGOs, and start-ups). These partnerships aim to enrich STEM education by focusing on public health topics and to boost students' interest in Science, Technology, Engineering, and Mathematics (STEM) curricula and professions. The project also offers a collaborative educational platform (E-me platform) to support teaching and learning activities, along with a repository (Photodendro) to store teaching resources and share teaching and learning experiences. The consortium comprises nine institutions spanning four European countries: Portugal (Nova University, University of Minho, Lisbon School of Engineering, Portuguese Road Safety Association), Greece (Panepistimio Ioanninon, Institouto Technologias Ypologiston Kai Ekdoseon Diofantos), Cyprus (University of Cyprus), and Poland (University of Im. Adama Mickiewicza Woznan). Each consortium partner is tasked with developing educational scenarios on public issues. This study is part of the project team's work, which is focused on formulating scenarios using low-code development environments.

Design

The formulation of the course design and the pedagogical scenarios by our team adhered to a structured model stipulated by the larger project, consistent across all project partners. The course design was organized into distinct sections, encompassing the following key elements: context and its relevance to public health education, estimated duration, classroom organization requirements, prerequisite knowledge and skills, general content glossary, pedagogical glossary, indicative literature, competences/learning goals, assessment methods, digital learning objects (DLOs) and digital educational resources (DERs), teaching-learning activities, and supplementary learning resources and educational activities. While developing the course design, our team used the ADDIE instructional design model (Cheung, 2016; Peterson, 2003) as a framework, encompassing the key stages of Analysis, Design, Development, Implementation, and Evaluation. In the first stage (Analysis & Design), we defined the learning objectives and selected pedagogical approaches, focusing on the most suitable active methodologies for the proposed pedagogical scenarios. The alignment of the educational proposal with the national curricula in ICT disciplines and the framework of competences to be developed in students at the corresponding educational level was ensured. In the second stage (Development), we explored different low-code platforms to determine the most appropriate one for the proposed course. Among the platforms explored, we experimented with MIT App Inventor and created test apps. Simultaneously, we developed pedagogical scenarios, incorporated an interdisciplinary framework, and created instructional and supplementary materials. In the final stage (Evaluation), we conducted a teacher training workshop, from which we received feedback on the pedagogical scenarios and on preparation for implementation in their classrooms. A detailed overview of the tasks our team conducted to shape the course design is shown in Figure 2.

To conduct an initial assessment of the pedagogical scenarios, an accredited workshop was designed for educators. The workshop/training course, titled "Low-code Development for Fostering STEM in Gamified and Multimodal Environments," unfolded over about 16 synchronous hours. Employing a blended learning (b-learning) approach, the workshop featured face-to-face sessions hosted at our university's site and online sessions facilitated through Zoom Colibri. The workshop was structured into five sessions, each spanning approximately three hours, and drew on the active participation of 15 teachers representing five Portuguese schools. Following the workshop, participants were invited to complete a questionnaire aimed at evaluating both the workshop experience and the learning scenarios presented. The research inquiry comprises a combination of multiple-choice and open-ended questions. Qualitative data from the open-ended questions were analyzed using a thematic approach. Responses were read in full and examined in relation to the key areas addressed by the study, such as perceived pedagogical value of the course, challenges in implementation, infrastructure and equity issues, and suggestions for improvement. Recurring ideas across these areas were identified and organized into overarching themes that guided the reporting and interpretation of teacher feedback in the Results and Discussion sections.

A Student Interest and Choice in Science, Technology, Engineering, and Mathematics (STEM) survey was administered to a pilot class both before and after the scenario was implemented. The instrument was adapted from the SIC-STEM Survey developed by Roller et al. (2018), benefiting from prior validation. The survey investigates factors influencing academic and career decision-making within the framework of Social Cognitive Career Theory (SCCT). As outlined by Lent et al. (2006), SCCT comprises four interrelated models—Interest, Choice, Performance, and Satisfaction—all of which are shaped by self-efficacy beliefs, outcome expectations, and personal goals. In this study, the SIC-STEM questionnaire was used to assess students' interests and aspirations in Mathematics, Sciences, and Engineering/Technology. The instrument comprises 45 items (15 per domain) covering study interest, career aspirations,

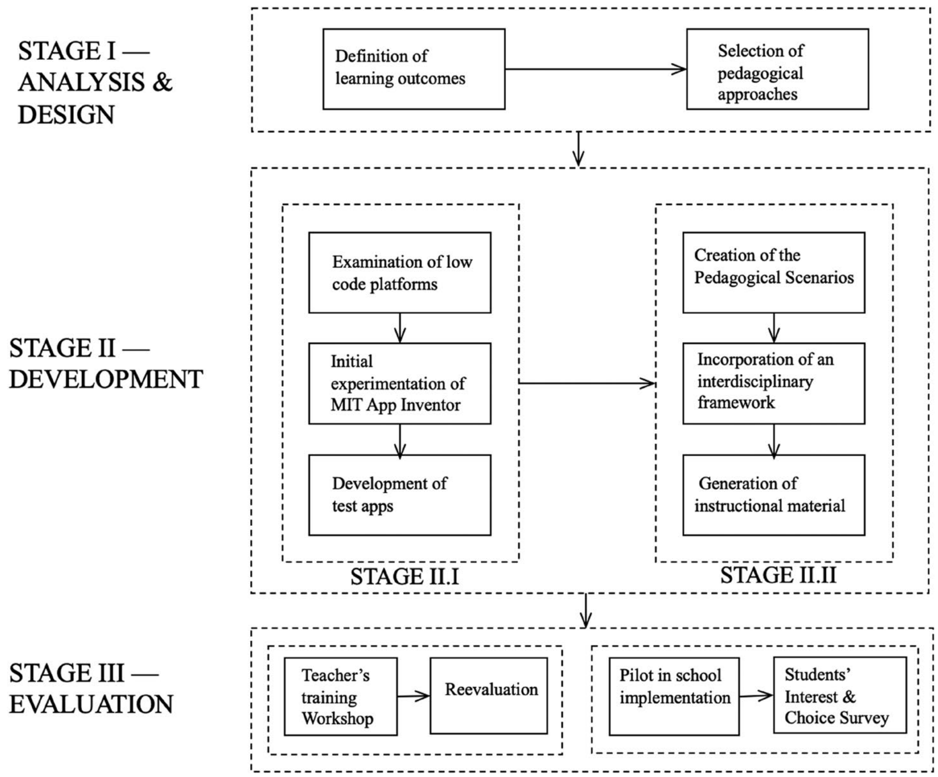

Figure 2. Task breakdown in low-code course design.

outcome expectations, and self-efficacy, rated on a five-point Likert scale (1 = strongly agree to 5 = strongly disagree). Additional questions capture sociodemographic data, extra-curricular activities, and family background. The questionnaire was translated into Portuguese by bilingual experts, reviewed for cultural accuracy, and pre-tested with 14 students across grades 7–9. Feedback from this pilot led to minor adjustments before the full application. Using LimeSurvey, it was then administered to 907 students from 20 mainland Portuguese schools at two time points—before and after participation in the project activities (median interval: 91 days). Analysis involved descriptive and inferential statistics. Analyses were performed with SPSS 29.

Variables were described using the mean, standard deviation (SD), and 95% Confidence Interval (95% CI). A Mixed ANOVA with an interaction between group (project vs. control) and phase (paired samples: pre-scenario vs. post-scenario) was used to assess the effect of the educational scenario. The interaction term group*phase allows us to assess whether the pre-post evolution scenario differed significantly between the groups. The assumptions of the mixed ANOVAs (normality, homogeneity of variances, and sphericity) were assessed and met. Paired Student's t-test was used for the comparison pre-post scenario within each group. Cohen's d was used as a measure of effect size for pre-post scenario differences, adopting the conventional thresholds of 0.2 (small), 0.5 (medium), and 0.8 (large) (Cohen, 1988). A 5% significance level was considered.

Regarding participants and sample size, a total of 34 ninth-grade students, aged 13 to 15, participated in the study: 26 in the study group and 8 in the control group. This sample was selected considering the exploratory nature of the study, which aimed to generate fundamental insights rather than statistically generalizable results.

Ethical considerations were taken into account. The research was conducted in accordance with the ethical guidelines established by the Ethics Committee for Research in Social Sciences and Humanities (approval reference CEICSH 165/2023), and informed consent was obtained from the students' legal guardians.

Course structure and learning objectives

Our proposal outlines a course structure that integrates low-code programming to advance scientific literacy. Specifically, students are encouraged to develop mobile applications during their ICT classes using MIT App Inventor, focusing on public health topics chosen by science teachers, such as nutrition and physical activity. This course design accommodates three proficiency levels—basic, intermediate, and advanced, corresponding to the seventh, eighth, and ninth grades of compulsory basic education in Portugal. The students within these levels are approximately 12, 13, 14, and 15 years old, respectively. In Portugal's educational norms, seventh-grade classes are configured to accommodate a minimum of 24 and a maximum of 28 students. In contrast, eighth- and ninth-grade classes are stipulated to accommodate 26–30 students. Focusing on ICT classes, the course design emphasizes interdisciplinary collaboration with science educators.

Within the designed course, science educators actively worked with ICT teachers. Notably, science teachers are members and leaders of "Ciência Viva" science clubs in their respective schools. These clubs are part of a network that promotes hands-on science education and disseminates scientific knowledge. These community hubs engage families and the local population in innovative scientific applications to instill a passion for science and establish connections between schools and the community through strategic partnerships. The collaboration between science educators and ICT teachers manifests in science teachers providing thematic content, such as public health topics. These topics serve as focal points for students as they create mobile applications.

Aligned with the objectives of the project, the learning objectives of the course design are structured to encompass three progressively advancing levels across key competencies:

1. Proficiency in utilizing low-code environments and content-creation tools to express ideas and knowledge creatively.
2. Competency in effectively utilizing online tools to generate multimodal content.
3. Comprehensive understanding and characterization of core programming components, with practical application in block-structured programming and creation of apps/games from scratch.
4. Ability to articulate the fundamental principles of good hygiene, nutrition, and physical activity habits, encompassing their influence on daily routines and health outcomes. Furthermore, a nuanced understanding of their significant contribution to life expectancy and overall quality of life is emphasized.

When setting up the classroom, the key is to design a space that adapts to the learning process rather than forcing the learning process to conform to the space. Arslan (2020) also draws attention to the pivotal role of rearranging the physical environment, as suggested by several studies focusing on implementing the flipped classroom model. The optimal setting encourages collaborative group work, requiring students to have access to an ICT classroom equipped with operational computers, a stable internet connection, a Gmail account (used to log in to MIT App Inventor), and an Android device.

The estimated duration of the course is variable and contingent upon the weekly schedule of ICT teachers, typically allocating 40 min per week. Drawing on pilot experiences, we project a minimum requirement of 4 classes lasting 40 min each (sessions 1–4). Additionally, we envisage three 40–45-minute sessions for supplementary learning activities and school projects (sessions 5–7).

Beyond introducing new content, the proposed course design heralds a shift toward novel pedagogical viewpoints focused on active learning and student-centered approaches, which diverge from traditional methods. A concise glossary of 13 terms has been developed and provided to teachers to facilitate this transition. These terms encompass educational philosophies and strategies, including Constructivism, Constructionism, Problem-Based Learning, Project-Based Learning, Computational Thinking, Brainstorming, Collaborative Learning, Gamification, Learning through Storytelling, STEM, Multimodality, and the Flipped Classroom. To further support this exploration, indicative literature has also been provided. Supplementary to the pedagogical glossary, we've assembled a glossary of programming terms that aligns with the three distinct difficulty levels presented in the scenarios. This glossary encompasses key terms, including Information Technology, Information and Communication Technology, Low-code, Block coding, Algorithm, Programming language, and Event-driven programming.

Furthermore, a set of novel *Digital Learning Objects* (DLOs) and *Digital Educational Resources* (DERs) has been developed. These resources are accessible on the E-me platform. In particular, we have created animated, user-friendly, and interactive NOOCs (Nano Open Online Courses) utilizing Genially, an online tool specifically designed for digital content creation. These NOOCs are dedicated to MIT App Inventor and related concepts, with the main objective of communicating scientific concepts through engaging technological content. Additionally, informative multimodal resources incorporating images, videos, sound, and more were created. These resources cover the fundamentals of low-code programming, including content, challenges, and solutions.

Pedagogical scenarios

Five teaching scenarios were designed across three proficiency levels (basic, intermediate, and advanced). During the scenario design process, we considered Auster and Wylie (2006) course design model for active learning, giving particular consideration to the principles of class preparation. The authors posit that effective preparation for active learning involves focusing on content and process. Essentially, active learning demands planning for the delivery of content and how it is conveyed. As such, the subsequent description of the pedagogical scenarios is structured as follows: an articulation of the learning objectives and key topics, followed by an elucidation of the sequence of activities to be undertaken, including the flipped classroom activities and multimodal material assigned for students to complete/watch at home.

Pedagogical scenario 1: Introduction to key concepts

Across all three educational levels—basic, intermediate, and advanced—the first pedagogical scenario centers on a shared objective: introducing key theoretical concepts to support course design and develop proficiency with MIT App Inventor. This includes topics like Content Creation, Storytelling, Gamification, Programming, and Computational Science.

At the basic level, students begin in small groups to foster collaboration and discussion. Icebreaker questions like "How important is technology?" and "Do apps help in your daily life?" prompt reflection on technology's role. Students then learn foundational concepts such as what an app is, basic programming principles, and the idea of gamification.

In the intermediate level, students watch a video on how programming is perceived, followed by discussions and further videos on gamification. They explore the connection between storytelling and gamification by creating storyboards and linking them to multimodal content creation. Digital literacy and its integration into education and business are emphasized. The session concludes with students presenting programming concepts using quiz and presentation apps. At the advanced level, students recall prior coding experience or view an introductory video. Working in groups, they research programming languages and build mental maps. The focus remains on gamification and storytelling, which they relate to programming concepts. The activity ends with student-led presentations and quizzes to reinforce learning.

Following this, MIT App Inventor is introduced across all levels. Students independently set up accounts and begin programming through two key steps: creating a user interface and block coding. Topics vary by level—"hygiene habits" at basic, "nutrition habits" at intermediate, and "physical activity habits" at advanced. Intermediate and advanced students also complete flipped classroom tasks and participate in MIT's Hour of Code, sharing their learning online *via* #hourofcode to encourage reflection and community engagement.

Pedagogical scenario 2: Discovering coding

In the second pedagogical scenario, the focus shifts to block programming, with learning objectives tailored to students' proficiency levels. At the basic level, the goal is rapid exposure to core programming concepts such as block sequences, conditional logic, and loops. These ideas are introduced through hands-on, problem-solving activities. As students advance to the intermediate and advanced levels, the emphasis moves toward continuous coding exploration using MIT App Inventor's structured 4-step model: Build, Conceptualize, Customize, and Create. This progression allows students to apply coding knowledge practically, experiment with customization, and ultimately develop their own apps, reinforcing reflective and experiential learning.

At the basic level, the central activity involves watching a video and engaging in game-phase tasks. Teachers provide support through instructions and cues to enhance understanding. Group activities like "Turn and Talk" encourage peer discussions and app sharing. The session wraps up with a reflection on control structures and the role of scripts in guiding app behavior. At the intermediate level, students begin by collaboratively reviewing their flipped classroom work. The focus expands to include foundational computer science concepts, terminology, and real-world applications. Group discussions on shared app creations encourage reflection and feedback. Students then begin the MIT App Inventor "PaintPot" tutorial, learning to define apps, select components, and understand key concepts like event-driven programming and variable use. The advanced level mirrors the intermediate structure but adds complexity. In addition to "PaintPot," students explore three more tutorials—Mole Mash, Get the Gold, and Space Invaders—to analyze code, components, and design. This analytical task helps deepen their understanding of game development. The scenario concludes with students reflecting on their insights and applying them to design their own game apps, reinforcing hands-on practice and interface mastery.

Pedagogical scenario 3: Digging into MIT App Inventor

In the third educational scenario, students deepen their app development skills using MIT App Inventor through activities tailored to their proficiency levels. At the basic level, students review key concepts such as how components and blocks work together. The teacher introduces the interface, explaining the roles of components, events, properties, and procedures. Students then follow a guided tutorial to create the "Magic Trick" app, which makes a rabbit appear from a hat. This hands-on activity reinforces learning while encouraging code exploration and modification. To assess understanding, students analyze and trace existing code, applying conditionals, lists, and loops. For homework, they complete the "Magic 8 Ball" tutorial to apply these skills independently. At the intermediate level, students explore more complex programming principles through the "Dancing Llama" tutorial and group work. They analyze and present previously studied apps—"Mole Mash," "Get the Gold," and "Space Invaders"—and are challenged to modify or create a new game based on their insights. The advanced level focuses on independent practice, creative development, and troubleshooting. Students refine their projects, engage with advanced programming techniques, and push their skills further, culminating in a self-directed app-creation experience.

Pedagogical scenario 4: Practice makes perfect/go full-on sensors

In the fourth pedagogical scenario, students deepen their app development skills by engaging with intermediate and advanced block-programming concepts. At the basic level, the lesson begins with a collaborative review of flipped classroom work, followed by group activities centered on building Part 1 of the MIT App Inventor tutorial app "PaintPot". Students complete five steps: (1) drawing a circle on touch and a line on drag, (2) adding menu options for color selection, (3) enabling size selection for drawing circles, (4) integrating the camera for background images, and (5) enhancing the user interface with feedback features. This project introduces students to essential programming functions, including shape drawing, customization, camera integration, and interactive user interface design. Alternatively, students can choose other tutorials like "Space Invaders," "PresidentsQuiz," or "MoleMash" to practice similar skills. At the intermediate level, students are given extended time for self-paced exploration and game development, allowing them to build on their knowledge and creativity. They are encouraged to reflect on their progress and apply their skills independently. At the advanced level, the focus shifts to sensor-based app development. Students are introduced to advanced programming principles involving the use of location and motion sensors. Theoretical topics include building location-aware apps, reading and saving location data, integrating maps *via* intents, understanding accelerometers, detecting tilt, and exploring sensors such as the pedometer and orientation sensor. Students engage in a hands-on project using the "Pushpin" tutorial, where they first design a visual display of current location data, then implement functionality to pin and save that location. The lesson concludes with an autonomous practice phase that supports independent learning through in-class and at-home tutorials. Recommended resources include "Where's My Car?" and map display guides in App Inventor, all designed to prepare students for a final research project.

Pedagogical scenario 5 lesson 5-forward: The final countdown

In the final phase of the course, students across all levels—basic, intermediate, and advanced—engage in a culminating Project-Based Learning (PBL) experience. The goal is to revisit and consolidate key block programming concepts while applying the methods practiced throughout the course. Each group begins by reviewing a visual mental map that summarizes core topics covered at all levels. They then create their own mental maps on paper, reflecting on their learning journey and organizing their understanding of programming principles. A central component of this phase is the "My Pitch in 5 min" presentation, which prepares students to communicate their research projects effectively. Five pillars guide this mini-pitch: Prioritize, Research, Plan, Personalize, and Produce. Storyboard templates and clear evaluation criteria help students structure their presentations. With this foundation, students move on to their final projects, supported by science teachers. These projects focus on public health themes—such as hygiene or nutrition—and integrate tools and concepts from the course to foster scientific literacy. Students are encouraged to choose subtopics that reflect their interests. The course concludes with a public showcase, where students present their work during an open school event. This allows them to share their innovative app ideas and programming skills with the broader school community.

Summary of pedagogical scenarios

Table 1 summarizes the pedagogical scenarios' goals, competencies, and assessment tools.

Results

Feedback from the workshop

As outlined in the methodology section, teacher training sessions were held within a 15-h workshop. The workshop's purpose was to prepare teachers to implement the pedagogical scenarios following the course design. A feedback questionnaire was administered, yielding a response rate of about 67%. Concerning the workshop's role as a training resource for implementing the scenarios, the feedback was overall positive, particularly regarding the organization and structure of the training, the methodologies utilized, and the content covered, as outlined in Figure 3.

In their responses to open-ended queries, teachers underscored the importance of digital training, with comments like "It enabled the transformation of creative ideas into programmable concepts" and "It allowed us to identify the basic expressions used in low-code programming". They also positively noted "Professional development within the realm of digital training," which contributes to the development of digital literacy among teachers. Educators further emphasized the interdisciplinary approach, expressing that "Collaborative efforts between ICT and the Natural Sciences were particularly interesting" and highlighting the significance of "Sharing experiences with colleagues and participating in exchanges across various schools."

In response to queries about challenges in implementing the scenarios, the majority of responses centered on technological constraints within the schools, specifically the school network (internet). Another point raised was the challenge of aligning the subject curriculum with the time required to implement the scenarios. Nevertheless, when asked for suggestions to enhance the scenarios, teachers believed that the workshop "offered a diverse and comprehensive set of scenarios and guidance on their utilization" and pointed out that the scenarios are "already quite good."

Student Interest and Choice in Science, Technology, Engineering and Mathematics (STEM) survey

The results from the Student Interest and Choice in Science, Technology, Engineering, and Mathematics (STEM) survey are reported in Table 2 and Figure 4.

Table 1. Summary of pedagogical scenarios' competencies and assessment strategies.

Scenario	Core learning goals	Targeted competencies	Assessment methods
1. Introduction to Key Concepts	Understand foundational concepts (apps, programming, gamification, storytelling); build familiarity with MIT App Inventor.	Scientific literacy, digital literacy, collaboration, and reflective thinking.	Group discussions, storyboards, mental maps, short quizzes, and presentations.
2. Discovering Coding	Explore block programming, control structures, and game design; progress from guided tasks to creative app building.	Computational thinking, problem-solving, creativity, and digital fluency.	Tutorial completion (e.g., PaintPot), peer review of apps, and reflective discussions.
3. Digging into MIT App Inventor	Apply programming principles through increasingly complex tutorials; modify and create apps independently.	Advanced coding skills, critical analysis, and independent learning.	Code tracing, app modification tasks, group presentations, and homework tutorials.
4. Practice Makes Perfect/ Go Full-on Sensors	Deepen app development; integrate sensors and advanced features.	Applied coding, systems thinking, innovation, and autonomous learning.	Tutorial projects (PaintPot, Pushpin, Space Invaders), sensor-based app prototypes, and self-assessment.
5. The Final Countdown	Consolidate learning in a PBL capstone project; communicate and showcase outcomes.	Project management, communication, teamwork, and interdisciplinary integration.	Mental maps, 5-min pitches, final projects, and public showcase.

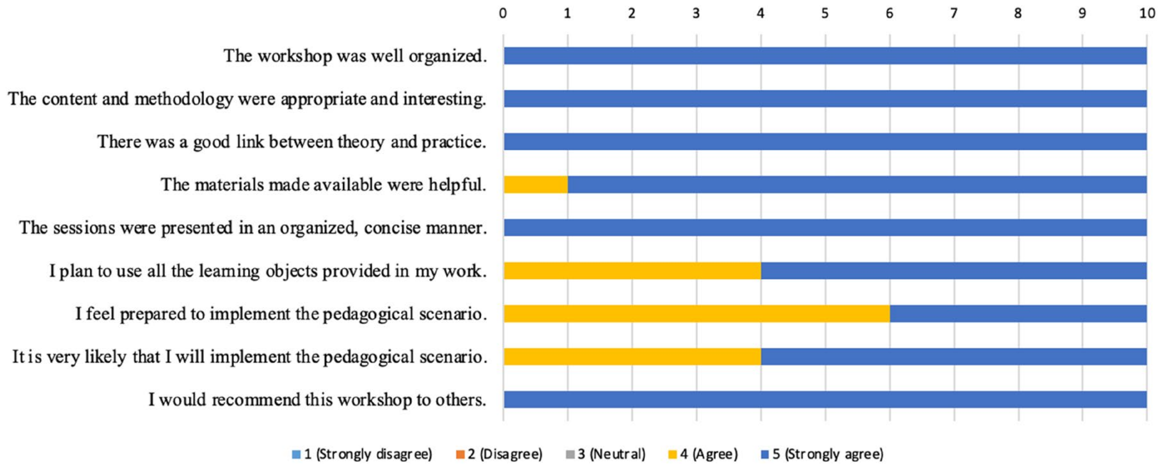

Figure 3. Closed-ended questionnaire results from the teachers taking part in the workshop.

Table 2. Results from the students' survey.

			Pre-scenario			Post-scenario					
Variable	Group	N	Mean	SD	95% CI	Mean	SD	95% CI	Student's t-test (pre-post) *p* value	Cohen's d	Interaction time * group *p* value
Mathematics	Project	9	2.94	0.65	2.44–3.44	3.30	0.50	2.92–3.69	0.046	0.621	0.074
	Control	8	3.26	0.86	2.54–3.98	3.29	0.77	2.65–3.94	0.563	0.037	
Sciences	Project	9	3.21	0.25	3.01–3.40	3.11	0.31	2.87–3.35	0.307	0.355	0.549
	Control	8	3.33	0.37	3.01–3.64	3.16	0.44	2.79–3.52	0.049	0.418	
Engineering and technology	Project	9	3.03	0.51	2.64–3.42	3.49	0.43	3.15–3.82	0.020	0.975	0.032
	Control	8	2.87	0.47	2.47–3.26	2.83	0.16	2.70–2.97	0.804	0.114	

In the Mathematics domain, the study group showed a statistically significant increase in mean scores from pre- ($M = 2.94$, SD = 0.65, CI = 2.44–3.44) to post-scenario ($M = 3.30$, SD = 0.50, CI = 2.92–3.69), $p < .05$, *Cohen's* $d = 0.621$. No significant change was observed in the control group ($p = .563$). The interaction effect between time and group was not significant ($p = .074$), suggesting that changes over time did not differ significantly between groups.

For Sciences, no significant pre-post change was observed in the study group ($p = .307$), whereas the control group exhibited a slight but statistically significant decrease ($p < .05$). However, the interaction effect between time and group was not significant ($p = .549$).

In the Engineering and Technology domain, the study group demonstrated a significant improvement from pre- ($M = 3.03$, SD = 0.51, CI = 2.64–3.42) to post-scenario ($M = 3.49$, SD = 0.43, CI = 3.15–3.82), $p < .05$, *Cohen's* $d = 0.975$, while the control group showed no significant change ($p = .804$). A significant time-by-group interaction was also observed ($p < 0.05$), indicating a greater increase in the study group than in the control.

Discussion

The main theoretical contribution of our study lies in presenting a holistic pedagogical approach that integrates active learning principles, interdisciplinary work, and the introduction of low-code programming to elementary school students. By emphasizing hands-on learning and collaboration, our approach offers educators a model for cultivating essential digital and scientific literacies to foster individuals capable of informed decision-making through technology. Additionally, the course promotes 21st-century skills such as teamwork, communication, and diverse perspectives, mirroring the collaborative nature of scientific research and the demands of today's workforce. The observed increases in interest in Mathematics and in Engineering and Technology are consistent with the learning mechanisms highlighted in our theoretical framework. By engaging students in project-based tasks that required them to solve authentic problems, work collaboratively, and publicly present their products, the course activated the kinds of experiential and socially mediated processes that active learning research associates with higher motivation and persistence in STEM (e.g., Cattaneo, 2017; Kokotsaki et al., 2016). Collaborative group work and peer interaction, central to both PBL and the flipped classroom design, likely enhanced students' sense of autonomy and relatedness, which previous studies identify as critical for sustaining engagement and deepening understanding (Arslan, 2020; Davidson & Major, 2014). Furthermore, the integration of low-code tools within these active learning structures supported progression to higher-order cognitive processes (analyzing, evaluating, creating) described in Bloom's revised and digital taxonomies, which may help explain why gains were particularly evident in domains where design, problem-solving, and creation were most salient.

While Ng (2013) highlighted the advantages of integrating the promotion of scientific literacy with digital literacy, there has been a notable scarcity of tangible initiatives that

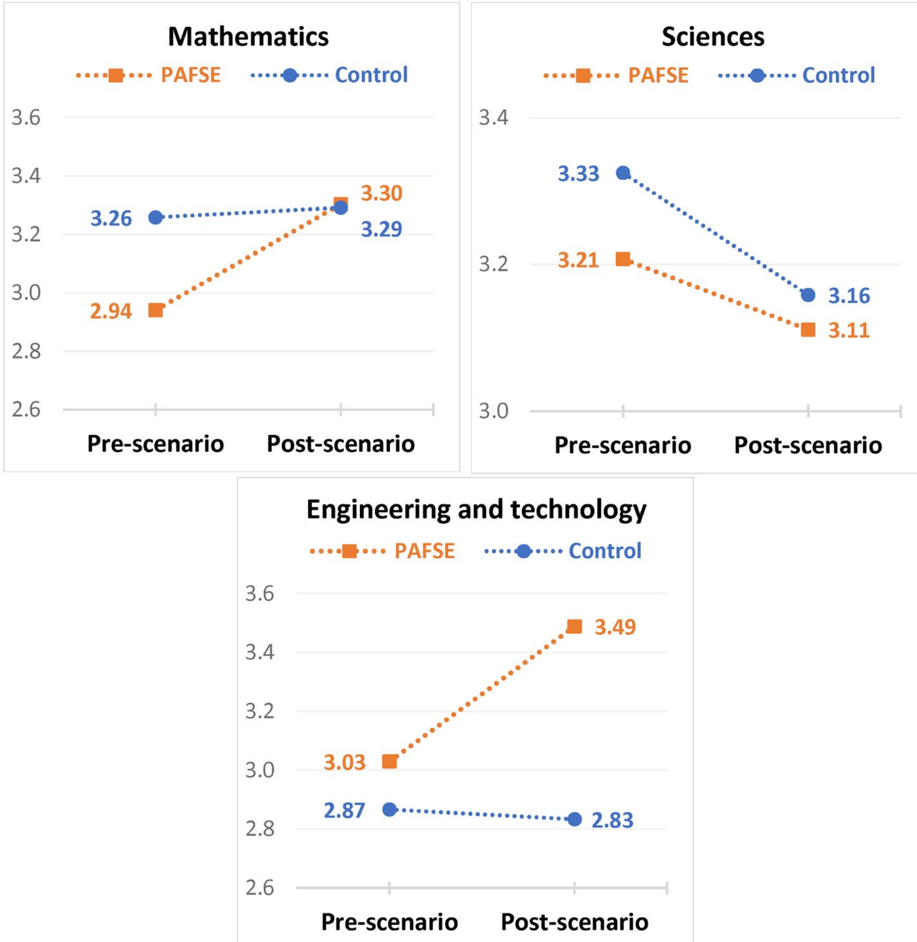

Figure 4. Results from the survey by subject.

effectively realize this dual goal. Our study makes a theoretical and practical contribution by introducing a replicable course design to promote an understanding of the interplay between technology and scientific principles. This addresses an observed gap and holds practical implications for influencing middle school students to pursue STEM disciplines. Middle school plays a critical role in shaping students' interest in STEM subjects (Le Thi Thu et al., 2021), with research showing that interest tends to decline with age—particularly from around age 10—during secondary school years (Regan & DeWitt, 2014). Engaging in STEM activities at this stage significantly increases the likelihood that students will choose STEM-related majors and careers later (Thomas & Larwin, 2023). Results from the Student STEM Interest and Choice Survey conducted during our pilot course implementation suggest that the course may be effective in boosting students' interest in Engineering and Technology. This is especially important given the current context: despite increasing job opportunities in STEM, many students continue to show low motivation to pursue these subjects (Culbertson et al., 2017), which presents a significant challenge to developing a workforce equipped to meet the demands of the digital age (Hsu & Fang, 2019). The results indicate a notable increase in students' interest in Engineering and Technology, but not in Science. One possible explanation is the course's strong emphasis on hands-on app development and problem-solving activities, which are more readily associated with engineering and digital technologies than with traditional science subjects. Another possible explanation may lie in existing disparities of interest across STEM fields, which are influenced by the academic environment (Su & Rounds, 2015). The learning environment may have primarily foregrounded practices and affordances that students perceive as technological and engineering in nature. Research on integrated STEM shows that many design-oriented interventions emphasize engineering and technology design practices, such as iteratively prototyping or optimizing artifacts, more strongly than core scientific practices like explaining phenomena or arguing from evidence (Kang, 2019). Interest development research treats STEM interest as domain-specific and closely tied to the kinds of activities that are made salient to learners, which means that design-based tasks and app creation could be particularly effective at triggering situational interest in engineering-related domains (Dohn, 2013), helping explain why significant gains emerged in Engineering and Technology interest but not in the Science dimension, even though scientific ideas were present in the scenarios.

A methodological consideration concerns the limited sample size of the pilot implementation ($N = 34$), particularly the control group of only eight students. This reduces statistical power and makes group comparisons less robust, limiting internal validity and generalization. The findings should therefore be seen as indicative rather than conclusive, with larger and more balanced samples needed in future studies to strengthen reliability.

In countries such as Portugal, where students choose their secondary education path (Science and Technology, Socio-Economic Sciences, Languages and Humanities, and Visual Arts) after the ninth grade, our course design has the potential to impact students at a crucial juncture, providing them with an immersive experience that bridges the gap between theoretical knowledge and real-world applications.

This study offers practical insights for both teaching practice and policy. Teachers can start small—using storyboarding or simple app tutorials—before progressing to project-based learning that links coding with scientific inquiry. Professional development should combine technical training with strategies for integrating STEM into real-world contexts. Our course design offers practical implementations through concrete pedagogical scenarios, Digital Learning Objects (DLOs), and Digital Educational Resources (DERs). These multimodal materials, which include videos and tutorials, have been collected and created by our team. Importantly, they are openly accessible on the E-me platform, enabling educators and learners to integrate them into their educational endeavors readily. In addition to the pedagogical and curricular considerations, the pilot also surfaced infrastructure and digital equity challenges—particularly schools' unreliable internet access and uneven hardware availability. These are not mere logistical issues but foundational to the success of a technology-intensive model. Reports (e.g., Antoninis et al., 2023; Gottschalk & Weise, 2023) have documented that lack of access to high-speed internet, insufficient devices, and limited institutional readiness diminish student engagement and widen achievement gaps, especially in under-resourced settings. Leadership and school policies also matter; Liu et al. (2024) show that where leadership prioritizes equitable resource allocation and teacher support, some of the adverse effects of infrastructure deficits are mitigated. For scaling the course, this suggests the need for contingency planning—offline or low-bandwidth versions of resources, ensuring students have access to functioning devices, and institutional investments in connectivity and support. Without attending to infrastructure and equity from the outset, there is a risk that implementing this model in less resourced contexts could reinforce existing disparities rather than help reduce them.

Conclusion

Overall, this paper introduces a novel course design aimed at cultivating scientific literacy by incorporating low-code development across STEM subjects. This paper also presents pedagogical learning scenarios that integrate active learning methodologies within interdisciplinary projects. Five pedagogical learning scenarios are outlined as a component of the course design. These scenarios integrate active learning methodologies through an interdisciplinary lens, employing a project-based learning approach. Our approach addresses the evolving demands of contemporary educational environments and equips educators with the skills and insights to navigate these challenges effectively.

From a theoretical standpoint, our study provides a model of how low-code environments can scaffold scientific literacy by linking computational thinking with inquiry-based STEM learning. In terms of practice, it offers ready-to-use pedagogical scenarios and openly available digital resources that teachers can adapt to different classroom realities, including gradual pathways from introductory activities to more complex projects. At the policy level, the findings highlight that successful adoption of such technology-rich models depends on targeted investments in infrastructure, equitable access to devices and connectivity, and sustained support for teacher professional development, so that course designs of this kind can be scaled without exacerbating existing educational inequalities.

It is important to recognize the limitations of this pilot study, particularly the small and limited sample of teachers involved in the workshop and students participating in the pilot implementation. To address these, a planned project activity involves adapting the workshop into short-duration online training sessions. These sessions will be designed for a mass audience of teachers, with projections indicating the participation of hundreds of educators nationwide. This initiative aims to disseminate and promote the course and its pedagogical scenarios on a broader scale.

Future work could involve expanding the pilot program to a larger scale and exploring how the course design and pedagogical scenarios can be adapted for younger learners, particularly at the elementary school level. Follow-up research should also compare the effectiveness of low-code versus no-code approaches, examining their relative potential to foster digital and scientific literacies. In addition, future studies could investigate the impact of these approaches on other dimensions of STEM learning not addressed here, such as mathematics engagement, problem-solving strategies, or students' attitudes toward scientific inquiry.

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Ethical approval

Research ethics approval was obtained by the Committee for Research in Social Sciences and Humanities (CEICSH), approval reference CEICSH 165/2023.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to aid translation and enhance the text's clarity. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Disclosure statement

The authors declare that they have no competing interests.

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Data availability statement

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality.

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