International Journal of Evaluation and Research in Education (IJERE)
Vol. 15, No. 4, August 2026, pp. 3322~3333
ISSN: 2252-8822, DOI: 10.11591/ijere.v15i4.39473

A model for enhancing teacher training by integrating internet of things, cloud computing, and robotics in a blended learning

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Article Info

Article history:

Received Mar 12, 2026
Revised May 25, 2026
Accepted Jun 26, 2026

Keywords:

Blended learning
Digital portal
Integration IoT and cloud
Learning content
Robotics
Teachers' development
T-LMDE model

ABSTRACT

Despite educational digitalization, a divide persists in integrating robotics and the internet of things (IoT) into classroom practice. Both pre-service and in-service teachers struggle to translate theory into application due to the lack of unified methodological frameworks. This gap demonstrably undermines student academic performance. The present study introduces the teachers-oriented, learning content, methodological approaches, digital support, expected outcomes (T-LMDE) model to bridge this divide through the synergistic integration of key dimensions. The model integrates robotics and IoT with cloud computing, utilizing the Arduino IoT cloud for data analytics and remote control. Delivered via a blended-learning portal, the curriculum provides didactic materials and feedback mechanisms, enabling educators to master complex engineering solutions. The model's efficacy was empirically validated with 31 participants across two modalities: a 15-week course for pre-service teachers and an 80-hour intensive program for in-service educators. Using a quasi-experimental, mixed-methods design, data were analyzed via paired t-tests and qualitative thematic scrutiny. Findings confirm the model's positive impact on professional transformation and competency advancement, shifting educators from content consumers to "teachers-as-designers".

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1. INTRODUCTION

The digital transformation of education hinges not merely on embedding innovative technologies into instructional practices but also on cultivating teachers' digital competencies. Educators must transcend mere tool utilization to internalize these technologies within their pedagogical repertoire, thereby equipping learners with novel skill sets [1]. Contemporary digitalization aligns closely with industry 4.0 paradigms. Whereas prior emphases on digital literacy centered on information retrieval and processing, current imperatives integrate foundational engineering cognition technologies, such as robotics and the internet of things (IoT), that operationalize principles of intelligent devices and systems.

Cloud computing-based IoT systems possess distinct characteristics as computational resources and data storage infrastructures, offering significant opportunities for real-time data optimization, operational efficiency, informed decision-making, and scalability [2]. The convergence of IoT technology with robotics, synthesized in the recently emergent concept of the internet of robotic things (IoRT), is driven by the urgent need to integrate internet-based communication and collaboration into autonomous and intelligent robotic systems. This integration facilitates the automation and management of complex systems with minimal human intervention within the educational sphere [3]. The integration of cloud computing to address challenges in IoT technology deployment, such as ensuring system functionality, availability, compliance, and efficiency across diverse environments, offers extensive resource capabilities [4]. Researchers highlight that escalating industrial demands have amplified the significance of robotics education in contemporary higher education institutions, grounded in IoT fundamentals [5]. Notably, while industrial advancements proliferate, their assimilation into curricula lags considerably. A study analyzing educational programs in European nations reveals that IoT and edge computing receive less instructional emphasis than artificial intelligence (AI); to mitigate this disparity, interdisciplinary courses should be embedded within degree programs, alongside hands-on experience in developing production-oriented innovative projects [6]. Practical cases from university implementations illustrate the adoption of IoT in engineering curricula [7], [8]. Nevertheless, pedagogical and methodological frameworks remain scarce for teacher training programs and professional development of in-service educators. The implementation of this trajectory within computer science and science, technology, engineering, and mathematics (STEM) education encounters several substantial barriers, including deficits in teacher professional expertise, inadequate curricular frameworks, and limited material and technical infrastructure [9], [10]. A primary challenge involves the necessity of upgrading both in-service teacher professional development and the foundational training of pre-service pedagogical personnel within university settings to align with contemporary technological demands.

Empirical studies involving school teachers underscore that among the multifaceted challenges of teaching computer science, enhancing pedagogical education and establishing robust connections with lifelong learning communities are of paramount importance [11]. Furthermore, it is argued that professional development courses for educators should transcend mere technical skill acquisition. Instead, they must focus on cultivating integrated competencies that synthesize methodological and subject-specific knowledge, aimed at elevating the quality of the instructional process through information and communications technology (ICT)-mediated interventions such as practical workshops, online courses, and collaborative frameworks [12].

It is widely acknowledged that the professional proficiency of educators is empirically demonstrated through the successful transmission and transformation of knowledge to their students. In this context, it is observed that the most significant achievements in robotics, intelligent systems, and IoT integration within Kazakhstan's secondary education sector are concentrated among students in specialized lyceums and intellectual schools. Conversely, there is a marked disparity in academic preparedness between these institutions and students in regional schools compared to their counterparts in major urban centers of Kazakhstan [13]. International studies indicate that this challenge is not merely localized but is a pervasive global phenomenon. In their research, Sinha [14] notes that the velocity of technological advancement frequently outpaces the adaptive capacity of educational systems to integrate new knowledge, a systemic issue prevalent in both developing and developed nations. Consequently, addressing this challenge requires a shift beyond the mere provision of technical infrastructure toward the strategic design and implementation of effective trajectories for the acquisition of emerging knowledge.

Given the need for comprehensive efforts to foster engineering and technical proficiency, as well as to enhance the professional development of both pre-service and in-service teachers, the implementation of a systemic educational model becomes imperative. Among existing scholarly contributions, the technological pedagogical content knowledge (TPACK) framework, originally proposed by Koehler and Mishra [15], stands out for its integration of pedagogical content knowledge with technological expertise. This established model conceptualizes teacher competence as the ability to effectively synthesize subject-matter content with technological affordances and pedagogical objectives, thereby ensuring that complex material is presented in an accessible manner for learners. This framework is interpreted through various structures within current research, and the methodology underpinning the present study is fundamentally rooted in the principles of this model. The 3S-TPACK model, which focuses on enhancing pedagogical education in robotics and IoT through a modified structure, emphasizes the need to improve instructional efficacy by adhering to the principles of support, stimulate, and seek regarding subject-matter, content-related, and technological concepts, while also fostering a positive attitude toward the integration of robotics and IoT in the educational process [16]. However, an analysis of recent work indicates that the support element within this framework is primarily organizational in nature and fails to articulate a coherent architecture for a content-technological ecosystem for educators.

Furthermore, the existing literature insufficiently addresses the methodical mechanisms required to facilitate the transformation of knowledge acquired by teachers into tangible, original pedagogical products. Simultaneously, there is an urgent need to re-evaluate the alignment of robotics and IoT instruction with current paradigmatic perspectives in the field. In this context, the integrated constructive robotics in education (ICRE) model, proposed by Alam and Mohanty [17], defines robotics as a strategic paradigm that fundamentally transforms the educational ecosystem. This model conceptualizes technology not merely as an auxiliary tool, but as a framework for the reconstruction of the entire educational architecture.

The predominance of theoretical concepts in the ICRE model, coupled with the inadequate conceptualization of the support element within the 3S-TPACK structure, results in a noticeable gap between theoretical paradigms and practice-oriented models.

The teachers-oriented, learning content, methodological approaches, digital support, expected outcomes (T-LMDE) model, proposed to address this identified research gap, operationalizes theoretical principles through four interrelated components. Learning content encompasses professional knowledge grounded in the integration of IoT, robotics, and cloud computing, specifically tailored for teacher self-directed learning and curriculum design. The digital support portal refines the concept of "support" within the 3S-TPACK framework by elevating it to a technological level. This portal functions not merely as a repository but as a comprehensive digital ecosystem that integrates visual simulators, interactive modules, and feedback systems to assist educators in developing bespoke instructional scenarios. Methodological approaches provide structured algorithms and strategies for embedding emerging technologies into the school curriculum. The expected outcome, the core pillar of the model, serves not only to assess teachers' knowledge but also to demonstrate their capacity to produce original, practical instructional scenarios. Through this model, the teacher transitions from a passive participant to an active designer of the educational process and a content creator. Consequently, the proposed model aims to transform existing pedagogical approaches into an infrastructure-oriented, practical framework, thereby facilitating professional development and ensuring the effective application of acquired skills within the school environment.

The primary scientific problem of this study is focused on the theoretical and empirical substantiation of the effectiveness of the comprehensive T-LMDE model for improving the training of both pre-service and in-service teachers in the integration of robotics, IoT, and cloud computing. To determine the effectiveness of this comprehensive model, the following research questions (RQ) have been formulated to evaluate the three interrelated components contained within it:

– Did the participants demonstrate statistically significant improvements in learning outcomes and mastery of content when comparing pre-test and post-test results? (RQ.1)
– To what extent did the digital support portal serve as an effective learning environment for the participants? (RQ.2)
– Was there evidence of professional transformation among pre-service and in-service teachers following the implementation of the model, and what were their perspectives regarding the integration of acquired knowledge into the instructional process? (RQ.3)

The novelty of this research contributes to the field by integrating IoT, robotics, and cloud computing into secondary education to enhance teacher training. It proposes the T-LMDE pedagogical model and evaluates its effectiveness through a three-level assessment (cognitive, resource, and performance levels). Empirical results from two separate teacher populations confirm the model's viability as a comprehensive framework for professional growth.

2. THE PROPOSED PEDAGOGICAL MODEL

The study proposes a comprehensive pedagogical model structured around four core components specifically designed for both pre-service and in-service teachers, as shown in Figure 1. The learning content within this framework is operationalized through the mastery of a diverse array of advanced knowledge and skills. These competencies encompass the fundamentals of complex systems, resulting from the sophisticated integration of cutting-edge technologies in computer science, including cloud computing, the IoT, and robotics.

The first module of the learning content commenced with the design of robotic systems and focused on programming within the Wokwi simulator, as well as working with Arduino-based hardware and software environments. As an innovation in the model's content, the subsequent sections were expanded to include the development of IoT systems, incorporating not only Arduino-compatible microcontrollers but also accessible boards from the ESP series.

Connection of themes were continued modules as analysis of data and remote control through the integration of IoT and cloud computing. During these stages, the operational capabilities of the Arduino Nano 33 IoT, ESP32, and ESP8266 were demonstrated and experimentally applied. Furthermore, the functional characteristics and specifications of network communication protocols, including message queuing telemetry transport (MQTT), ZigBee, and LoRaWAN, were rigorously analyzed. The utility of cloud computing as a flexible resource for data processing and IoT programming was detailed, alongside instructional training on the Arduino IoT cloud and Blynk IoT cloud platforms. Given that the Arduino IoT cloud primarily supports its proprietary hardware family, the Blynk IoT cloud was employed as a parallel alternative for networking encapsulating security payload (ESP) boards, facilitating rapid and efficient IoT system programming.

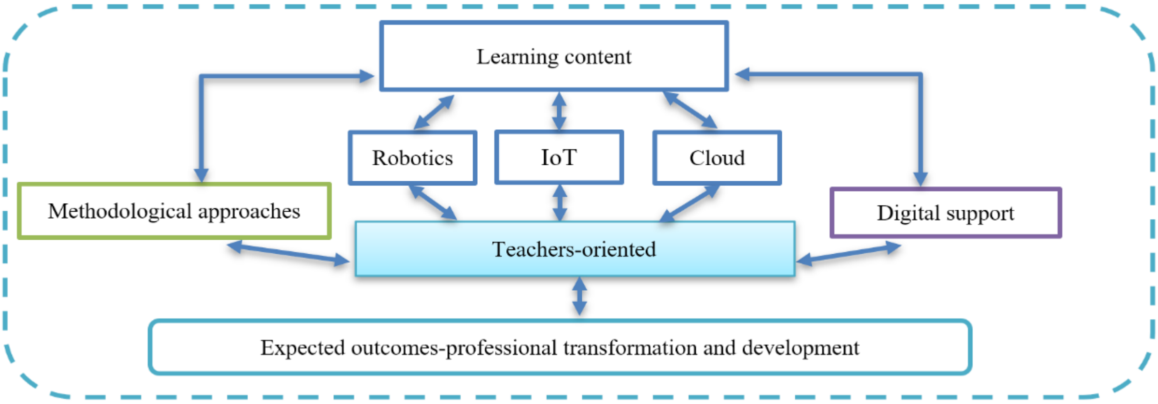

Figure 1. T-LMDE model structure

The practical implementation of the model was carried out through a blended learning format. Research exploring a blended learning in-service training program for STEM teachers indicates that this format was highly regarded by participants [18]. The didactic advantages of blended learning include the optimization of instructional processes through the integration of traditional and digital learning formats, the enhancement of self-directed learning skills by providing participants with opportunities for independent work, and the comprehensive utilization of various interactive teaching methods [19]. Studies on the application of digital technologies in education involving both pre-service and in-service teachers demonstrate that tools such as learning management systems, collaborative web services, and supplementary video tutorials have proven effective in online educational contexts [20]. The delivery format for the graduate cohort was structured as 45% offline and 55% online instruction. A similar distribution between synchronous and asynchronous learning was maintained for the professional development course.

Regarding methodological approaches, the course utilized a blended learning framework guided by practice-oriented and project-based learning (PBL). This aligns with existing research emphasizing the necessity of synthesizing theoretical concepts with hands-on practice in the development of intelligent systems [21]. Throughout the course, teachers developed robotic projects using the Arduino platform, progressing from basic indicators, control elements, and sensors to system automation via motors and actuators, culminating in remote object management and monitoring through network-connected microcontrollers. Within the PBL and practice-oriented sessions, participants executed projects such as "smart waste management systems", "remote-controlled weather stations", "smart lamps", and "automated water level controls". Subsequently, when prompted to identify potential research applications for these projects, participants independently explored strategies for their implementation within the K-12 instructional process.

The organization of digital support for educators through the portal will facilitate broader access to pedagogical content and enhance their professional proficiency. E-learning platforms, provided as a form of digital support, feature an improved structure driven by recent technological innovations. By integrating AI algorithms into these platforms, learners can refine their skills through services that design educational trajectories tailored to their specific learning characteristics, cognitive styles, memory capacity, and academic achievements [22]–[24].

In this regard, in our study the digital support for this study was operationalized through a custom-developed portal (www.cloud-iot-edu.kz). Within this ecosystem, teachers engaged with video lectures covering theoretical and practical materials, completed multi-level interactive assignments and assessments, and maintained synchronous feedback loops with instructors during online sessions. Learning tasks were structured according to the principle of scaffolded complexity, progressing from foundational to advanced levels. The portal's integrated learning analytics and automated grading systems provided a robust environment for real-time tracking of participant achievements and user progress. The analytics of participant results and the automated assessment system have established a user-friendly environment for monitoring the progress and achievements of portal users.

The instructional content of the model was reviewed and approved as a curriculum for master's students at the meetings of the Department of Informatics and the Faculty of Physics, Mathematics, and Information Technology (Protocol No. 1, dated September 5, 2025). Furthermore, it was reviewed by the Educational and Methodological Council of the Kh. Dosmukhamedov Atyrau University and officially recommended for publication by the University's Academic Council (Protocol No. 3, dated November 20, 2025). The program received positive evaluations from two reviewers from the Department of Informatics at the Kh. Dosmukhamedov Atyrau University and two scholars from the Department of Information and Technical Sciences at Alikhan Bokeikhan University in Semey.

3. METHOD
3.1. Research design
In the research design a quasi-experimental approach was adopted, incorporating both quantitative and qualitative analyses. The study was conducted at Kh. Dosmukhamedov Atyrau University. The distribution of instructor-led sessions for both groups was maintained at a ratio of 45% offline to 55% online.

3.2. Participants
The study employed a purposive sampling method to evaluate the effectiveness of the proposed pedagogical model across different professional levels (N=31). Participants were categorized into two primary groups. The first cohort comprised 11 first-year students of master's degree (pre-service teachers) enrolled in the "7M01501–Computer Science and Informatization of Education" program. During the autumn semester of the 2025–2026 academic year, these future teachers were presented with innovative instructional content totaling 5 European credit transfer and accumulation system (ECTS) credits within the "Cloud computing and IoT technology" discipline. For the in-service teacher cohort, an intensive 80-hour professional development course titled "Cloud computing: integration of IoT and robotics" was organized in January 2026 for educators in the Atyrau Region, spanning a three-week duration. Although 40 teachers initially applied for the program, a purposive sample of 20 participants was selected for the research. A key feature of the sample is its interdisciplinary composition; while the majority of participants were informatics teachers, group 2 also included two STEM teachers (specializing in mathematics and chemistry). This approach allowed for an assessment of the model's adaptability to disciplines beyond informatics, ensuring its broader applicability within the educational spectrum.

3.3. Research procedures
The evaluation of the proposed model was conducted across three distinct dimensions, beginning with the cognitive level. This initial phase involved a differential analysis of knowledge dynamics through a pre-test/post-test comparative design, aiming to quantify the proficiency of both pre-service and in-service teachers in integrating robotics, IoT, and cloud computing. The survey structure was developed in alignment with the goals and objectives of the learning content and comprised questions derived from the thematic, information-technical, and motivational sections. The second resource level focused on assessing the effectiveness of the digital support system. In this stage, participants completed an anonymous survey evaluating metrics such as the usability of the digital portal, its support for the learning process, user activity and motivation, and overall effectiveness. Finally, at the productivity level, a comprehensive analysis of the participants' projects and proposals was performed. During this stage, projects developed by in-service teachers underwent criterion-referenced assessment by trainers and peers, while projects and proposals from graduate students were evaluated through a qualitative lens under systematic tutor-mediated oversight. Furthermore, during the experiment, trainers monitored the participants' performance of practical tasks during face-to-face sessions and oversaw the presentation of final projects to evaluate post-course impact.

3.4. Measurement instruments
To ensure the content validity and scientific accuracy of the survey questions, which utilized a 5-point Likert scale, the instrument underwent an expert review by three experienced specialists in the fields of informatics and STEM. The experts verified and approved the survey items. Confirming their full alignment with the research objectives and the curriculum goals.

3.5. Data analysis
Quantitative data were subjected to statistical analysis using paired t-tests. Microsoft Excel's data analysis toolset was used as program software. Mean values and standard deviations (SD) were calculated. The significance level was set at $p<0.05$.

3.6. Ethical considerations
The study adhered to established ethical principles. Participants were fully informed of the research objectives and were assured that the collected data would be used exclusively for scientific purposes; their personal information was kept strictly confidential. The analysis results were reported only in the aggregate, ensuring that individual participants could not be identified.

4. RESULTS AND DISCUSSION
4.1. RQ1: indicators of participants in mastering the content of course

To address the first research question (RQ1), surveys were administered at the initial and final stages of the course to identify shifts in participants' academic achievements relative to the provided instructional content. The survey instrument consisted of 15 items categorized into content-related, motivational, and informational-technical dimensions. Responses were measured using a 5-point Likert scale. For the statistical processing of the data and to substantiate the scientific hypotheses, a paired-sample t-test for means was employed.

The comparative analysis of pre-test, as shown in Table 1 and post-test, as shown in Table 2, results revealed a significant increase in the arithmetic mean values (M2>M1), while the SD remained relatively stable (SD1≈SD2). This statistical trend demonstrates that the proposed model exerted a positive influence across the entire participant cohort rather than on isolated respondents. Furthermore, it indicates that while the overall group performance was elevated to a higher proficiency level, the internal variance in skill levels within the group persisted, reflecting a consistent upward shift in collective achievement.

Table 1. Pre-test results

Groups	Number of participants	Mean (M_1)	SD_1
Group 1: pre-service teachers	11	2.68	0.59
Group 2: in-service teachers	20	2.35	0.75
Total	31	2.47	0.7

Table 2. Post-test results

Groups	Number of participants	Mean (M_2)	SD_2
Group 1: pre-service teachers	11	3.83	0.65
Group 2: in-service teachers	20	4.49	0.74
Total	31	4.26	0.77

In the analysis conducted using the paired-sample t-test, the critical value for $\alpha=0.05$ was tcrit=2.04 with degrees of freedom df=30. The calculated test statistic was tstat=−11.67. Since the absolute value of the test statistic exceeded the two-tailed critical threshold |t stat|>t crit, the null hypothesis was rejected in favor of the alternative hypothesis. This confirms that the instructional content provided by the proposed model had a statistically significant positive impact on both pre-service and in-service teachers.

The quantitative findings corroborated the positive shifts observed during face-to-face sessions, specifically regarding the increased engagement and interest of participants from both cohorts in executing practical assignments and projects. Furthermore, these results underscore a demonstrable advancement in the participants' technical proficiency and their capacity for autonomous decision-making by the conclusion of the course. These positive developments can be attributed to the systematic and well-coordinated delivery of instructional content through a blended learning framework. During practical sessions, educators engaged in the hands-on assembly of robotics and IoT devices, and by connecting these systems to cloud-based platforms, they mastered complex technical concepts through physical interaction. This aligns with scholarly findings asserting that robotics is not merely a technological instrument but a catalyst for developing engineering cognition, fostering both cognitive and personal growth in educators [25], [26]. The visualization of data through the integration of robotics, IoT, and cloud computing, coupled with the capabilities of remote control, significantly enhanced the participants' engagement and technical proficiency. By incorporating IoT and cloud computing, the model elevates traditional robotics to the level of the IoRT. This aligns with global academic discourse, which posits that the integration of robotics with IoT and autonomous systems will fundamentally transform educational curricula, shifting the focus toward innovative thinking and representing a pragmatic transition from basic robotics to the mastery of advanced technological systems.

It is important to note that, during the acquisition of the course content, participants with higher levels of digital proficiency were able to overcome technical barriers, such as network configuration and debugging, more rapidly, thereby allowing for deeper engagement with the core learning material. This underscores the premise that digital competence serves as a prerequisite and a fundamental component for the effective assimilation of new knowledge [27]. During the initial stages of the practical implementation of IoT and cloud computing integration, some educators encountered certain technical challenges. The role of tutor support during face-to-face sessions proved critical in addressing these issues. Active engagement in the learning process during in-person classes, complemented by tutor-led scaffolding, exerted a significant influence on enhancing the participants' capacity for independent decision-making [28]. This result shows that the role of the human factor and individual consultations in mastering complex digital tools is still high.

4.2. RQ2: effectiveness of digital support

The developed digital support portal provided participants with a systematic framework for accessing instructional content. By decoupling learning from geographical and temporal constraints, the portal enabled educators to engage with the material independently and according to their individual professional needs. To address the second research question (RQ2), an anonymous survey was administered at the end of the program to evaluate participants' perceptions of the efficacy of the digital support system. The survey instrument comprised 12 items designed to assess the digital portal across four primary dimensions: usability, pedagogical support, operational efficiency, and its impact on active-motivational orientation, as shown in Table 3.

Table 3. Results of the anonymous evaluation by respondents (users of the digital portal)

Indicators	Pre-service teachers (N=11) M+/-SD	In-service teachers (N=20) M+/-SD
Usability	4.79+/-0.85	4.88+/-0.69
Pedagogical support	4.82+/-0.84	4.86+/-0.75
Active-motivational orientation	4.64+/-0.83	4.81+/-0.71
Operational efficiency	4.67+/-0.82	4.85+/-0.78

The data indicates that both respondent cohorts assigned high ratings to the functionality of the digital portal. Thereby, it facilitates a highly accessible and user-friendly environment for digital educational platforms, enabling users to engage with learning materials at any time and from any location according to their individual needs, while also ensuring seamless feedback from instructors and systematic tracking of learner progress [29]. However, distinct differences were observed between the two participant groups. Within the in-service teacher cohort, higher mean scores across all four evaluation categories were accompanied by lower SD. These findings suggest that experienced teachers maintained a homogeneous and positive perspective regarding the digital portal's utility. Conversely, the evaluation metrics provided by pre-service teachers exhibited a relative variance. Although the students' mean scores remained high, the larger SD compared to the in-service group suggests that engagement with the portal within the framework of their academic discipline was non-uniform. Given that this variance was observed not only within the digital environment but also during traditional face-to-face sessions, it can be inferred that the portal objectively reflects the actual learning trajectories of the participants. While the relative uniformity of responses from experienced teachers can be attributed to their professional standardization [30], the greater variance in opinions observed among master's students is likely due to diverse levels of digital competence or varying individual interests among the learners [31].

Furthermore, qualitative feedback from in-service teachers regarding the digital portal underscores its practical value:

> "*The modules on the digital portal serve as essential and beneficial resources, providing critical methodological assistance to educators*." (Teacher A)
> "*Will the portal resources remain accessible after the course concludes? We intend to utilize them in our future practice*." (Teacher B)

From these responses, it can be concluded that the digital support system is effective for both cohorts. While experienced teachers perceive the portal as a source of practical solutions and professional resources, it appears that pre-service teachers approached it primarily as a requisite component of their academic curriculum. Regarding the RQ2, the data confirms high efficacy for both groups; however, in-service teachers demonstrate more pronounced professional and practical requirements for such a platform.

4.3. RQ3: professional transformation of teachers and connection of acquired knowledge with the educational process

To address the third research question (RQ3), participants' perspectives and proposals for integrating the instructional content into their professional practice (the school environment) were deliberated. At this stage, the primary course instructor highlighted that, based on co-design principles, respondents could utilize various frameworks, such as elective course syllabi or project-based models, to implement the content in practical settings. Following a comprehensive data analysis, three primary levels of school-system integration were identified, as shown in Table 4. To further the investigation, we proceed with a qualitative analysis, focusing on several unique case studies that demonstrate the versatility of the developed model.

Table 4. Strategies for integrating instructional content into the school environment

Integration into the educational process	Percentage (%)	Main performing group	Content
Elective course	48.4	Mostly master students	Lesson plans for implementing IoT, cloud computing, and robotics integration in schools.
Representation of project (PBL)	41.9	Experienced teachers and master students	Ideas for science and STEM projects for students, stages of implementation.
Start-up idea	9.7	Experienced teacher, young specialist and master student	A product project aimed at solving socio-economic problems.

Case 1: integrated strategy and synergy. One experienced teacher among the participants proposed a dual-track strategy, concurrently utilizing an elective course and a project-based model for students. In this scenario, the teacher suggested implementing a 34-hour elective curriculum for middle school students, culminating in a final project. The highest-quality projects would then be selected for participation in scientific research competitions. An example of a proposed student project is the "smart climate control system". The developmental roadmap for this project includes methods for integrating fans and relays into the system, enabling remote management via a cloud platform, and implementing data logging on an SD card.

Case 2: interdisciplinary STEM integration (chemistry). In the context of interdisciplinary STEM integration, a notable case emerged during the qualitative interviews involving a chemistry teacher who had previously specialized in STEM education during their graduate studies. This participant proposed a sophisticated robotic system designed to facilitate high-precision chemical synthesis and enhance laboratory safety. The project utilizes an integrated hardware suite, including water sensors, DHT11/DHT22 temperature and humidity sensors, and the Arduino Nano 33 IoT board. The system is specifically engineered to address several critical laboratory functions through a unified technical approach. It enables the detection of ambient humidity in environments where maintaining anhydrous conditions is vital for chemical synthesis, while simultaneously providing instantaneous monitoring and registration of accidental water spills within the laboratory setting. Furthermore, the device is designed to track humidity levels during the storage of moisture-sensitive reagents and ensure rigorous control over temperature and moisture variables. Collectively, these features aim to guarantee product quality and maintain consistency throughout the chemical manufacturing process.

Case 3: shifts in learning paradigms and didactic continuity. A graduate student with significant prior experience in the educational sector proposed a conceptual shift, viewing robotics, IoT, and cloud computing not as discrete disciplines, but as a cohesive technological continuum. The respondent emphasized the application of PBL to guide students toward solving specific real-world problems through device construction, rather than through the rote memorization of theoretical concepts. The proposed pedagogical framework is structured across three hierarchical levels of cognitive and technical development, ensuring a seamless transition from foundational concepts to complex engineering. At the primary level (grades 1–4), the focus is centered on "recognition through play". By utilizing the CodiPlay application and specialized arcade-style games, the curriculum aims to foster an intuitive understanding of complex computational concepts, such as loops, conditionals, and variables, while simultaneously developing fine motor skills through LEGO WeDo and simple mechanisms to interpret fundamental mechanical laws like gears and levers. This foundation facilitates a transition to the intermediate level (grades 5–8), titled "foundations of IoT and robotics", where students engage with authentic engineering through the integration of physics and mathematics. During this stage, the pedagogical focus shifts from block-based programming to text-based coding in C/C++, manual circuit design, and breadboarding. Finally, the framework culminates in the advanced level (grades 9–11), "cloud systems and smart projects", which emphasizes professional programming and start-up initiatives. At this highest phase, the focus is placed on developing fully functional engineering prototypes and preparing students for competitive scientific research projects, effectively bridging the gap between classroom learning and professional engineering practice. During tutor-mediated discussions, it was noted that this respondent provided a comprehensive analysis of both domestic and international educational frameworks, offering systematic proposals for the evolution of current instructional paradigms.

Case 4: innovative project development. An experienced teacher, a new specialist, and a master student collectively demonstrated the potential of the entrepreneurial STEM trajectory by proposing the co-creation of products designed to solve socio-technical challenges. One prominent concept was "smart-track: an intelligent cargo tracking system." The implementation of this project was structured by the respondents into four developmental phases. The first phase involved problem identification, market analysis, and conceptualization of the solution. The second phase focused on prototyping, which included assembling a functional model using Arduino and ESP-based hardware, developing firmware to process sensor data, and integrating the system with the Arduino IoT cloud for remote management via a mobile application. The third phase addressed the development of emergency response algorithms, while the final phase culminated in the production of a market-ready model, its public presentation, and participation in specialized competitions.

Regarding post-course support, it was observed that the application of knowledge and experience acquired by teachers within their respective school environments was monitored. The digital portal remained accessible, and communication channels with trainers were maintained. Within a short period following the course (three months later), teachers began demonstrating their results in school practice. This situation is further discussed in the following case study 5.

Case 5: post-course impact analysis. Three months post-completion, an informatics teacher reported that they had supervised student research projects, further refining the “Smart Scout Robot”, which they had originally proposed as a final course project, and the “Smart Trash Bin”, which was developed during the practical sessions. Consequently, the student working on the “Smart Scout Robot” project secured second place in the “commander” competition, while another student participated in a regional research project competition with the “Smart Trash Bin” project. The teacher expressed appreciation to the trainers and the professional development course, noting that the program’s emphasis on engineering and creative design provided the necessary ideas for professional growth and fostered a commitment to ongoing work with students, as shown in Figure 2.

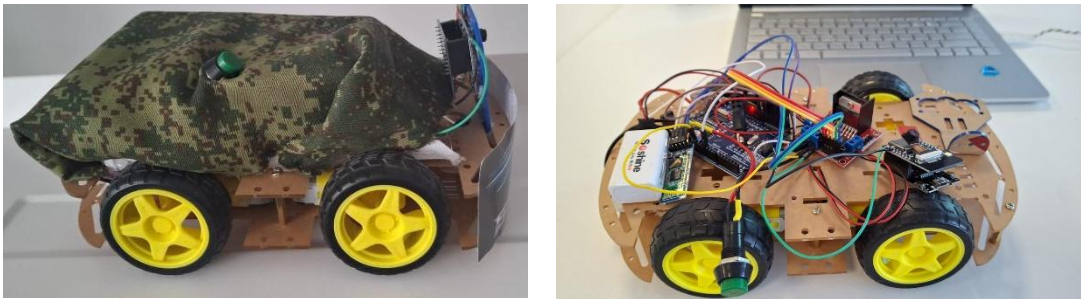

Figure 2. A student-designed scout robot prototype mentored by in-service teachers

During the development of the “Smart Scout Robot”, which integrated robotics, IoT, and cloud computing, learners implemented advanced functionalities, such as real-time video registration via an ESP32-CAM board and remote network-based control. In the “Smart Trash Bin” project, participants utilized an ESP8266 board to facilitate remote notification alerts via Telegram when the bin reached capacity. These results demonstrate that the model is not merely a theoretical construct but a pragmatic instrument that transforms pedagogical practice. A key finding of this study is that the model enables teachers to disseminate acquired knowledge to their students, effectively preparing them for research-oriented activities. This confirms that the proposed framework not only enhances individual teacher competence but also ensures effective knowledge transfer. This accelerated outcome is driven by the T-LMDE model’s content, the clear demonstration of methodological approaches for school integration, the accessibility of digital resources, and the synergy of factors fostering high intrinsic motivation.

Our findings indicate that traditional professional development courses often fail to significantly improve teacher motivation or professional readiness. This contradicts the prevailing view that social and financial incentives are the primary drivers of teacher performance [32]. This discrepancy suggests that our model offers essential resources by eschewing “formalistic” training in favor of professionally relevant content that hones practical skills aligned with educators’ actual needs [33], [34]. Consequently, in-service teachers become driven by authentic learning outcomes and the development of engineering and creative capabilities, both for themselves and their students, rather than by the pursuit of certificates or career advancement. Furthermore, pre-service teachers are better equipped with the knowledge, abilities, and skills necessary to organize and conduct high-quality professional activities.

Beyond the significance of the research, we acknowledge certain limitations. The small sample size should be considered when generalizing these findings to the broader population of teachers at a national or regional level; thus, a larger respondent pool is required for more comprehensive analysis. Furthermore, disparities in the technical infrastructure across different schools must be taken into account. Although the research identified a lack of adequate material and technical resources in some schools, this factor was beyond the primary scope of the current study. However, to ensure the effectiveness of the educational process in resource-constrained schools, the use of virtual simulators is highly recommended. In this context, didactic and methodological materials provided through digital support resources can serve as an effective solution for bridging the infrastructure gap.

5. CONCLUSION

This study aimed to enhance the professional training and development of educators, with the objective of integrating innovative technologies, specifically robotics, IoT, and cloud computing, into the educational process. Throughout the research, the theoretical and empirical effectiveness of the T-LMDE model was demonstrated through the comprehensive improvement of learning content, the utilization of diversified methodological approaches, and the systematic organization of digital support. Furthermore, the study underscored the model's capacity to bridge the gap between theoretical knowledge and practical application within school environments, consistently demonstrating its effectiveness through tangible pedagogical outcomes. Both quantitative and qualitative analyses demonstrate that the integrated application of these components enables teachers to overcome perceived barriers during the acquisition. The results obtained demonstrate the effectiveness of the proposed model and suggest its potential as a comprehensive framework for other teacher education programs and professional development courses.

This approach addresses critical social demands, ensuring that the younger generation is equipped to engage with modern education in the era of industry 4.0. To ensure long-term impact, the video, methodological, and interactive content hosted on the digital portal will remain accessible to the teachers as post-course longitudinal support. Future research efforts will focus on maintaining contact with the participants to monitor the sustained integration of course outcomes into school practice. Furthermore, iterative improvements to the functional capabilities with AI of the digital portal are planned.

FUNDING INFORMATION

This article describes the result of the scientific project "Development of a digital portal for enhancing teacher training through the integration of cloud computing and IoT technology". This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant No. AP22685192 "Development of a digital portal for enhancing teacher training through the integration of cloud computing and IoT technology").

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [MM], upon reasonable request.

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