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ORIGINAL RESEARCH

Impact of DECODE model and STEM strategies on in-service teachers' professional development in Tamil Nadu, India

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Abstract

In the context of growing educational demands, continuous professional development has become essential for in-service teachers. This study investigates the impact of a professional development program based on the DECODE Model and STEM strategies aimed at enhancing critical thinking skills among 37 in-service science and mathematics teachers in Tamil Nadu, India. The intervention included hybrid-mode workshops facilitated by both Taiwanese and Indian experts, comprising three structured sessions: Demonstration, Co-teaching and Co-training, and Debrief. A validated 35-item rating scale was administered before and after the workshop to measure five stages of professional growth: knowledge base construction, model observation, practice reflection, implementation of changes, and expertise acquisition and dissemination. Results from a paired samples t-test indicated a statistically significant improvement in participants' professional development scores ($t = -4.515$, $p < .001$). The study concludes that the DECODE Model is an effective framework for empowering in-service teachers with innovative pedagogical skills and promoting reflective teaching practices in STEM education.

Keywords: Critical thinking skills · DECODE · In-service teachers · Professional development · STEM · Technology

INTRODUCTION

In the growing climate of education, continuous professional development for teachers is more important. While students are continuously adapting to social, technological, and pedagogical shifts, teachers are also expected to update and become lifelong (Tang & Choi, 2009) Professional development is not only provide teachers information about research and instructional practices, it also nurtures a growth mindset, increasing positive job-related satisfaction, and supporting a broader impact on student learning (Smet, 2021). Well-designed professional development programs engage teachers in learning opportunities that include reflection on practice, collaboration with colleagues, and sustained, focused professional learning opportunities related to a number of various aspects of best practice in the contemporary educational environment (Labone & Long, 2014). Quality professional

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development is a mechanism for teachers to remain alongside of the latest technologies, new and inclusive appropriations and approaches to teaching, and methods for enhancing engagement through different pedagogies (Aithal & Aithal, 2024) all of these always lead to greater energy in the classroom setting. Schools that prioritize continuous development for their educators are not just modeling a culture of excellence (Detert et al.,2001), they are also empowering their educators to respond to the needs of the diverse students represented in today's classrooms and to respond to various issues and factors related to ad hoc working conditions that readily change within the educational system (Kirk et al., 2015)

Theoretical Background

Constructivist, social learning, and teacher professional development theories provide a theoretical background for this study. These theories explain how teachers acquire pedagogical skills using collaborative learning, reflection, and effective practice through hands-on experience. According to constructivist learning theory, knowledge is built through experience, interpersonal interaction, and reflection; it does not occur by the mere act of being taught (BADA, 2015). Constructivist approaches are used in science and mathematics education to implement inquiry-driven, problem-solving approaches to teaching that assist teachers with creating meaningful learning environments for their students to develop critical and creative thought and problem-solving skills.

Social learning theory supports constructivist theory by stating that observed behaviour, modelling of behaviour, and working together are how people learn (Desimone, 2009). Within professional development programs for teachers, the use of demonstration lessons, collaboration with colleagues, and co-teaching provide teacher participants opportunities to observe effective instructional practice and to implement those strategies into their regular classroom practices. These types of collaborative learning experiences encourage teacher reflections about instructional practices, the sharing of pedagogical ideas, and the creation of a shared body of professional knowledge.

Guskey's Professional Development Model, which refers to professional development as a cycle of learning through knowledge development, implementation of instructional practices, reflection and sharing expertise (Guskey 2002) is based on a theoretical framework that reflects the need for continuous, meaningful professional development for teachers. Professional development should be non-disruptive (only for a short period) to schools based on the engagement of teachers (active participation), and provide opportunities for teachers to try new teaching methods in authentic learning environments.

Based on this framework of practice, the DECODE Professional Development Model (Demonstration, Co-Teaching/Co-Training, Debrief) is a systematic collaborative framework for developing teachers' collaborative teaching practices through the use of the DECODE Professional Development Model (Cheng et al., 2022) (Wahono et al., 2022). Integrating STEM pedagogical practices into the DECODE Model allows for the use of the model with an interdisciplinary approach, the incorporation of technology, and inquiry-based learning, thereby developing teacher's pedagogical skills and facilitating students' critical thinking (Maspul, 2024),(Yang et al., 2026). Therefore, the DECODE Model combined with STEM-based pedagogies creates a powerful professional development pathway for teachers to implement innovative instructional methods aligned with current educational reform.

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Literature Review

Professional development (PD) for in-service teachers has generated increasing global interest, as education systems around the world seek to prepare learners with 21st-century competencies such as: critical thinking, creativity, problem solving, and digital literacy (Almazroa & Alotaibi, 2023). High quality PD helps teachers to reconceptualize their pedagogical knowledge, implement innovative instructional strategies, and create reflective practices of professional growth (Darling-Hammond et al.,2017). Sustained, collaborative, and practice-based PD models have been shown to significantly increase teacher efficacy and learning outcomes for students, and, in this area (Roth et al., 2018), STEM-based pedagogies and structured PD models like DECODE have emerged as promising PD models for strengthening teachers' instructional capacity **(**Wahono et al., 2022).

Professional Development and Teacher Growth

Professional development (PD) for teachers is an ongoing, cyclical process that consists of knowledge acquisition, classroom-based practice, reflective practice, and dissemination of knowledge and practice (Guskey, 2002). Coherence, active learning, collaborative learning, and discipline-specific focus characterize an effective PD program (Desimone, 2009). In such programs, teachers engage in simple, low-stakes experimentation in the classroom, reflect on the process of each instructional episode and student response to instruction, while revising their practice, and become classroom experts. Awareness of the need for formal PD programs for teachers in India has also been heightened through curricular reform, the inclusion of technologies, and the growing emphasis on competency-based learning or assessment (Ministry of Education [MoE], 2020).

STEM Education and Critical Thinking

STEM education supports inquiry, experimentation, engineering design, and scientific reasoning. Research has shown that classroom learning that integrated elements of STEM instruction dramatically improved students' higher-order thinking skills and problem-solving abilities (NAE & NRC, 2014). For teachers, attending professional development focused on STEM methods deepened their pedagogical content knowledge, supported interdisciplinary curriculum planning, and helped them structure activity-based, student-centered learning opportunities. In addition, STEM focused professional development helps to prepare teachers to deploy digital tools, simulations, and AI-based learning platforms as part of their learning environments, which are increasingly vital for teaching science and mathematics (Li et al., 2019).

Models of Professional Development: The DECODE Approach

The DECODE Model—Demonstration (DE), Co-teaching/Co-training (CO), and Debrief (DE)—is a collaborative, practice-based professional development (PD) model that supports teachers' professional learning. It was created and validated in Taiwan, and the model is premised upon learning-by-doing, co-learning, and reflective dialogue-based learning (Cheng et al., 2022). Collaboration exposes teachers to best practices in instruction in the demonstration phase. Coteach and co-train require teachers, along with one another, to plan and teach lessons together, supporting active learning and collective professionalism. Debrief, is where teachers

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engage in structured reflective practice to evaluate instructional strategies, action plan for trouble spots, and develop their quality instructional practice (Rajasekaran et al., 2024) The research indicates that the DECODE model is a significant predictor of teacher improved instructional confidence, improved reflective awareness, and improved ability to implement inquiry-based and technology-integration lessons (Jannah et al., 2025). Additionally, in conjunction with STEM pedagogy approach, it can promote critical thinking pedagogical practice.

Professional Development in the Indian Context

There is a growing tendency in Indian education towards competency based and technology enabled pedagogical practices suggested by National Educational Policy (NEP) 2020. Yet, in-service teachers do not have a structured process for professional learning and continuing education about STEM-based instructional practices (Sinha & Karsten Krauskopf, 2025). These studies demonstrate the need for hybrid, collaborative, and reflective professional development approaches to address the diverse contexts, content areas, and workloads of teachers (Charania et al., 2023). STEM professional development portfolios delivered in conjunction with global experts broadened teachers' cross-cultural understanding, pedagogical innovation, and motivation.

The existing studies indicate STEM education's promotion of critical thinking and the importance of skilled teacher preparation. Collaborative professional development models like DECODE can increase teacher efficacy (Sui et al., 2024). The use of hybrid formats increases participation. However, there is little empirical evidence of DECODE exercise across communities of teaching in India, or its implementation with Indian science and mathematics teachers.

This gap indicates the need for research that studies the incorporation of research on the DECODE Model with STEM pedagogical facilitation of science and mathematics teachers in India, particularly how the DECODE Model may impact teachers' professional learning in a developmentally sequential fashion across stages of professional learning: knowledge building, observation, reflection, application of practice, and distribution of professional learning.

Based on the above information the researcher formed the research question for this study: How does the DECODE model integrated with STEM strategies influence the professional development of in-service teachers?

METHODOLOGY

A research team conducted a professional development program for In-Service teachers in Tamil Nadu India. The program focused on using the DECODE Model and STEM for Critical thinking Skills and was implemented with 37 In-Service teachers with different Science discipline and mathematics backgrounds. Participants' professional growth was assessed before and after the workshops using a rating scale with a five-point Likert format, across five stages of professional growth: constructing a knowledge base, observing models, being reflective of practice, implementing changes, and gaining knowledge and dissemination. The ratings scale consisted of 35 items related to professional growth. The ratings scale demonstrated strong internal consistency with reliability analysis using Cronbach's alpha yielding a score of 0.887 (N=37) across all items. The scale was also deemed valid through a face validity assessment.

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Phases of DECODE Workshop

The DECODE workshop, organised by the Taiwan research team and DECODE Model experts, trained In-Service teachers at Ottanchanthiram in collaboration with the Indian research team. It was conducted in a hybrid mode and comprised four sessions: DEmonstration-DE, CO-teach&CO-train, and DEbrief-DE.as shown in Figure 1.

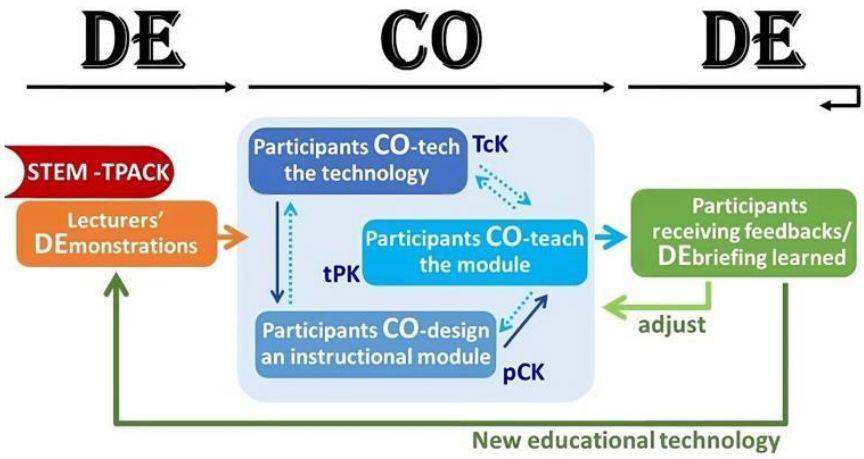

Figure 1. DECODE model (Adopted from Cheng et al.,2022)

DEmonstration-DE (Session 1)

Taiwanese experts introduced and demonstrated the Critical Thinking and STEM Approach, highlighting the importance of scientific inquiry and artificial intelligence in education. Participants explored the platforms to understand their features.

CO-teach&CO-train (Sessions 2 & 3)

Participants were grouped by subjects in these sessions, allowing for a wide variety of contributions. These sessions, which were offline and run by the Indian research team, took place in which we were asked to explore platforms, select topics, and plan collectively. The groups determined the final topics following consultation with the research team, wrote a lesson plan using a Critical Thinking and STEM Approach, and determined the leaders of the group that coordinated tasks.

DEbrief-DE (Session 4)

Participants presented their topics in a hybrid mode to a large audience, including Taiwanese experts, institution teachers and students, and the research team. Feedback from Taiwanese experts aimed to improve presentations and assess the professional development of In-Service teachers post-workshop.

RESULTS AND FINDINGS

Table 1 presents the results of a paired samples t-test comparing pre-test and post-test scores on a professional development rating scale administered to 37 in-service teachers participating in the DECODE Model and STEM strategies workshop. The test statistic ($t = -4.515$) with 37 degrees of freedom shows a statistically significant difference between pre- and post-workshop scores ($p < .001$) as per Figure 2. This indicates that the teachers' professional development

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scores improved significantly after the intervention, reflecting positive growth across measured stages such as knowledge base construction, model observation, practice reflection, implementation of changes, and expertise acquisition and dissemination.

Table-1 Paired sample T-Test

Paired Samples T-Test				
Measure 1	**Measure 2**	**t**	**df**	**p**
Pre-Test	Post-Test	4.515	37	< .001

The implementation of the DECODE Model and STEM for Critical Thinking Skills professional development program for in-service teachers in Tamil Nadu, India, yielded several significant outcomes. Analysis of the pre- and post-workshop rating scale data revealed substantial improvements across all five stages of professional growth. The knowledge base construction stage showed a marked increase, with teachers demonstrating enhanced understanding of STEM concepts and critical thinking strategies.

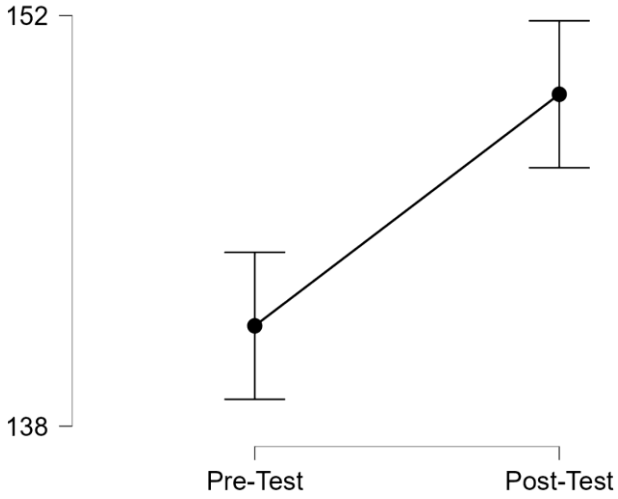

Figure 2. Pre & Post Test score

In the observation phase of the model, we saw participants demonstrate an enhanced ability to identify and analyze effective pedagogical practices that included STEM elements and/or critical thinking. The data during the practice reflection stage indicated that teachers developed a more sophisticated ability to self-evaluate and identify next steps in improving their pedagogical practices. The practice reflection stage also indicated that implementation of changes was one of the strongest areas of growth. Participants reported increased confidence and competence in planning lessons and engaging in classroom activities that incorporated STEM and/or critical thinking pedagogies. This was evidenced through the quality and innovative thinking demonstrated in the group presentations overlapping during the DEbrief-DE sessions.

The acquisition and dissemination of professional development is a stage that also provided favorable outcomes in that the participants showed a readiness and willingness to share their developed knowledge and skills with others on their campus. This suggested the possibility of an even wider transformation to a larger audience beyond the immediate participants in the study. Further qualitative comments made by the Taiwanese experts in the DEbrief-DE session confirmed the quantitative data collected. The Taiwanese experts in the practice reflection phase of the DEbrief noted tremendous development of participants' abilities to use critical

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thinking and applied STEM approaches to lesson planning, and the presentations were additional documentation of innovative applications of artificial intelligence and scientific inquiry approaches in a diverse range of subject areas. The findings indicate that the DECODE Model and the STEM for Critical Thinking Skills program advanced the professional development experience for in-service teachers participating in the study; it provided in-service teachers peace of mind, and the abilities and ways of thinking to enhance their professional practice as educators.

Discussion

The effectiveness of the DECODE Model with STEM pedagogies, in terms of teachers' professional development, has been demonstrated by the results of the study amongst in-service science and mathematics teachers in Tamil Nadu, India. Participants reported across all five areas of professional development, construction of a knowledge base, observation of the model, reflection on practice, implementation of change, and developing and sharing expertise—that the program provided continued learning by teachers as well as significant pedagogical change. The large effect size (Cohen's d = 1.45) reinforced the practical significance of the study and agrees with previous studies that indicate there may be benefits to teachers with collaborative, practice-based PD models (Cheng et al., 2022; Jannah et al., 2025)

The hybrid format of the workshop, led by experts from both Taiwan and India, provided a culturally sensitive and flexible learning opportunity that responded to the many experiences and workloads presented by developing teachers. As teachers engaged in the workshop there were some structured demonstrations, co-teaching, and debriefing that we were able to successfully design to allow for engagement, collaboration with colleagues, and reflection, which are all important elements of PD and have been found to enhance teacher learning (Guskey, 2002; Desimone, 2009) . The dimension of implementing changes provided some of the strongest growth, which suggested teachers not only gained theoretical knowledge that could be put into practice, but also engaged with their innovation in a lesson plan, and there was transference into practice in the classroom incorporating innovative forms of critical thinking and STEM teaching. These findings engage with the claim that dedicated PD, which allows educators space for first-hand experiences to reflect upon in their practice, enhance professional teaching learning (Darling-Hammond et al.,2017).

In addition, participants' willingness to share their knowledge suggest the potential for continued positive impact, beyond the facilitators who attended the workshop, as they contribute to a wider professional learning environment in their schools. The use of artificial intelligence, and scientific practices in lesson plans, as noted in the DEbrief, demonstrates evidence that the program was able to provide teachers with 21st century instructional practices that meet the needs of modern education. Overall, the data highlights the importance of the DECODE Model in the context of India, especially in the current phase of pedagogical change requiring structured, collaborative, and STEM PD to achieve the outcomes set forth in India's National Education Policy 2020 (Ministry of Education [MoE], 2020; Sinha & Karsten Krauskopf, 2025)

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Implication

The results of the research demonstrate how effective structured professional development approaches like the DECODE model combined with STEM teaching strategies will enhance teachers' professional growth. Significant growth in teacher professional development through collaborative means (demonstration, co-teaching, and debriefing) can enhance how well teachers understand pedagogy, as well as their ability to effectively implement new instructional techniques within the classroom. A global hybrid international workshop clearly highlights the importance of working collaboratively across cultures in providing rigorous professional development for teachers. These results provide a basis for educational institutions and policymakers to further develop the DECODE framework into teacher preparation programs to promote technology-enhanced STEM education and alignment of teacher practices to Indian Federal Education Policy (NEP) 2020.

Future Direction

Future research could expand upon the current study by selecting a larger and more diverse sample of teachers (i.e., from different geographic locations and grade levels) in order to better generalize the results. Longitudinal studies would also be beneficial in determining any long-lasting effects of the DECODE model on classroom instruction and student learning outcomes. Furthermore, researchers could utilize new technologies, such as artificial intelligence, digital simulation, and virtual labs, within the DECODE framework. Qualitative exploration of teachers' experiences and challenges with implementing DECODE could help to gain insight into enhancing STEM education through professional development programs.

CONCLUSION

In conclusion, this study found that the DECODE Model, particularly in collaboration with any STEM strategies, is a valuable professional development framework (PD), teacher effectiveness can be enhanced for in-service science and mathematics teachers in Tamil Nadu, India. The action-research program improved teachers' critical thinking, confidence in the classroom, and willingness to use innovative pedagogies, both quantitatively and qualitatively. The hybrid program design and collaborative learning increased reflective practice and peer learning, both critical to sustaining professional learning. The positive outcomes suggest that structured PD programs can be useful in closing the gaps in teacher training and practice in India, prompted by teachers' ability to promote competency-based education and implement technology within the classroom to align with national initiatives.

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Author contributions: All authors have sufficiently contributed to the study and agree with the results and conclusions.

Ethical statement: The authors stated that the study was approved by the institutional ethics committee of NTNU on 20th June, 2023 (Approval code: 202205HS038). Written informed consents were obtained from the participants.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author

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