



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Issue 11, November 2024

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.524

 9940 572 462

 6381 907 438

 ijirset@gmail.com

 www.ijirset.com

A Human-Centered Framework for Teaching and Learning that Uses Generative AI to Promote Self-Regulated Learning Development in K–12 Environments via Domain Knowledge Learning

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ABSTRACT: Discussions concerning generative AI tools in education have increased since the introduction of generative artificial intelligence (AI). In order to spur improvements in educational practices, this study presented a human - centered learning and teaching framework that makes use of generative AI technologies for self-regulated learning development through domain knowledge learning. The approach demonstrates how generative AI tools may modify teaching and learning processes to become more human-centered and modernize educational practices. It highlights how teachers are becoming more adept facilitators and humanistic storytellers who create tailored lessons and work to advance each student's unique learning. The framework, which draws on neuroscience ideas, directs students to use generative AI tools to improve their attentiveness, promote active learning, get instant feedback. A case study covering the improvement of primary pupils' writing skills in the Chinese language within a K–12 educational setting demonstrates the framework's practical implementation. The outcomes of a 60-hour teacher development program are also reported in this article. In particular, giving in-service teachers examples of how to apply the suggested framework improved their comprehension of generative AI principles and helped them incorporate them into their instruction. It also raised their perceived capacity to create AI-integrated courses that would improve students' focus, involvement, self-assurance, and contentment.

I. INTRODUCTION

The emergence of artificial intelligence (AI) has brought about significant change in a number of fields, including education. The ability of generative AI to produce text, music, images, videos, and programming codes is one of its defining characteristics [1]. In spite of its enormous promise, generative AI has not yet been fully incorporated into educational settings [2, 3, 4]. This lack of integration is particularly noticeable in contrast to its quick uptake in industries like software engineering, healthcare, and business operations [5, 6]. The lack of focus on the role of educators in the implementation and coordination of AI tools is the cause of this gap [2], [7]. A strong framework that facilitates teaching and learning is necessary for the incorporation of generative AI tools into educational practices. current frameworks. Through the facilitation of self-regulated learning (SRL), generative AI offers opportunities to enhance the educational experience in K–12 school environments. In order to develop lifelong learners who can successfully negotiate the changing demands of the twenty-first century, SRL is crucial [10]. It gives students the tools they need to approach learning tasks strategically, make goals, engage in their academic journey deliberately, and critically reflect on their experiences. Generative AI can write interactive learning prompts to help students learn domain-specific knowledge once it is incorporated into K–12 schooling. To suit the demands of each unique learner, generative AI systems (like ChatGPT) can offer personalized learning experiences and real-time feedback [4], [7].

II. LITERATURE REVIEW

A. Current Frameworks for Generative AI in Education

The application of generative AI in educational contexts has become a more prominent focus of research and practice in recent years [4], [7]. To help educators and policymakers fully utilize the promise of generative AI tools, a number of frameworks have been established.

To promote a comprehensive grasp of AI's significance in education, UNESCO has taken the lead in developing AI competency frameworks for educators and learners. Both teacher and student frameworks place a strong emphasis on respecting human rights, preserving privacy and dignity, and empowering human agency [8]. It is still difficult to put these concepts into practice in regular educational contexts, though. The UNESCO standards don't include comprehensive, doable instructions that educators may easily implement in a variety of school settings. Teaching and learning, human and societal well-being, transparency, justice, and accountability are among the principles outlined in the Australian Framework for Generative Artificial Intelligence in Schools [13], which is specifically designed for the educational setting. including safety, security, and privacy. The framework's comprehensive approach to teaching and learning is admirable since it covers a number of topics:

- 1) the strengthening of educational practices through effective integration;
- 2) teaching strategies that foster a critical understanding of AI;
- 3) the use of teacher expertise to supplement academic instruction rather than replace it;
- 4) the development of critical thinking abilities to promote intellectual growth;
- 5) learning designs that put students' needs first; and 6) the upholding of academic integrity to ensure the moral use of AI in educational settings.

Nevertheless, this framework could not be specific enough for real-world use, particularly precise instructions on how to use AI tools in a range of classroom scenarios. Comprehensive solutions are needed for the successful integration of AI into teaching methods and curriculum [14], but they are not offered.

B. Generative AI: Empowering Lifelong Learning

Individualized learning has been accelerated by generative AI [2, 3], and [17]. Generative AI lays the groundwork for ongoing engagement and skill development, which are critical for long-term educational success, by guaranteeing that learning experiences are customized [7], [9]. Chiu's research [7] explores the various ways AI affects education, emphasizing four key ways AI helps foster lifelong learning.

In the first role, generative AI is used to personalize tasks according to the ability level of each student. However, pupils may become overly reliant on generative AI and adopt a passive learning style as a result of personalization [18]. Therefore, in K–12 education, it is essential to teach students about the fundamental AI technologies in addition to implementing generative AI tools. and embeddings. To avoid becoming overly reliant on technology, students must understand these ideas in order to appreciate AI's potential and limitations. AI's capacity to improve human-computer relationships is its second function. According to Michel-Villarreal et al. [19], students' communication abilities can be enhanced by utilizing AI chatbots [20]. But in order to foster empathy, emotional intelligence, and understanding—qualities that AI cannot yet offer—teacher-led conversations must be added to human-computer interactions. AI's third function is to provide feedback on pupils' work. Instant feedback can aid students in understanding complex topics and identifying areas for development in K–12 education [21]. Teachers should, however, provide thorough feedback that takes into account the more qualitative aspects of students' work, like inventiveness and critical analysis.

C. TPACK Framework and Generative AI in Education

An essential model for comprehending how technology is incorporated into teaching methods is the TPACK framework [25], [26], and [27]. The idea of PCK was first presented by Shulman [25], who emphasized the significance of instructors having a comprehensive grasp of the material they teach as well as the pedagogical approaches that are most effective for presenting it. Technology knowledge, or TK, was first presented by Mishra and Koehler [26], who suggested that in order to teach effectively in the digital age, one must comprehend how technology may be integrated with pedagogical approaches and CK. Thus, PK, CK, and TK are the three main types of knowledge that make up the TPACK framework. Additionally, it encompasses four hybrid forms of knowledge—PCK, technical pedagogical knowledge, TCK, and TPACK—that arise at the nexus of the fundamental forms [26, p. 1025]. The four aspects of CK that are the focus of our investigation are CK, TCK, PCK, and TPACK. TCK investigates the

affordances of generative AI for SRL, PCK includes lesson preparation techniques that incorporate generative AI to support SRL, and CK supports students' learning and SRL objectives. In order to create student-centered courses that leverage generative AI to support SRL in a unit teaching and learning, TPACK combines all three aspects into a coherent approach.

D. SRL via Generative AI

For students to be guided through domain-specific learning processes, Zimmerman's three SRL phases—performance, self-reflection, and forethought—are crucial [10], [34]. Each SRL phase can be improved by including generative AI into a curriculum since it offers personalized learning resources and real-time feedback that encourages reflection on learning objectives and methods. Nevertheless, there is currently no systematic method in place in K–12 educational settings to combine TPACK and generative AI in order to promote SRL.

In order to provide individualized learning objectives and resources, generative AI can be utilized in the planning phase of SRL to assess students' prior knowledge and preferred methods of learning [35], [36]. Strategic planning and intrinsic motivation are established with the help of this tailored learning [19].

Generative AI can offer real-time feedback during the performance phase, enabling students to keep an eye on However, young learners are still developing their metacognitive and cognitive abilities [37], [38]; accordingly, they may experience frustration or confusion when working with AI. Thus, teachers play a vital role in providing emotional support and motivation to help students to overcome challenges [39]. In the self-reflection phase, students engage in self-evaluation to assess their own performance and reflect on their interactions with generative AI, enabling them to better plan for subsequent learning tasks [40]. This reflection is a key step toward consolidating learning and preparing for the future. However, the absence of an integrated TPACK and generative AI framework for SRL in K–12 education has left teachers without a clear strategy to harness AI's full potential in promoting SRL. A dedicated framework could guide teachers in effectively

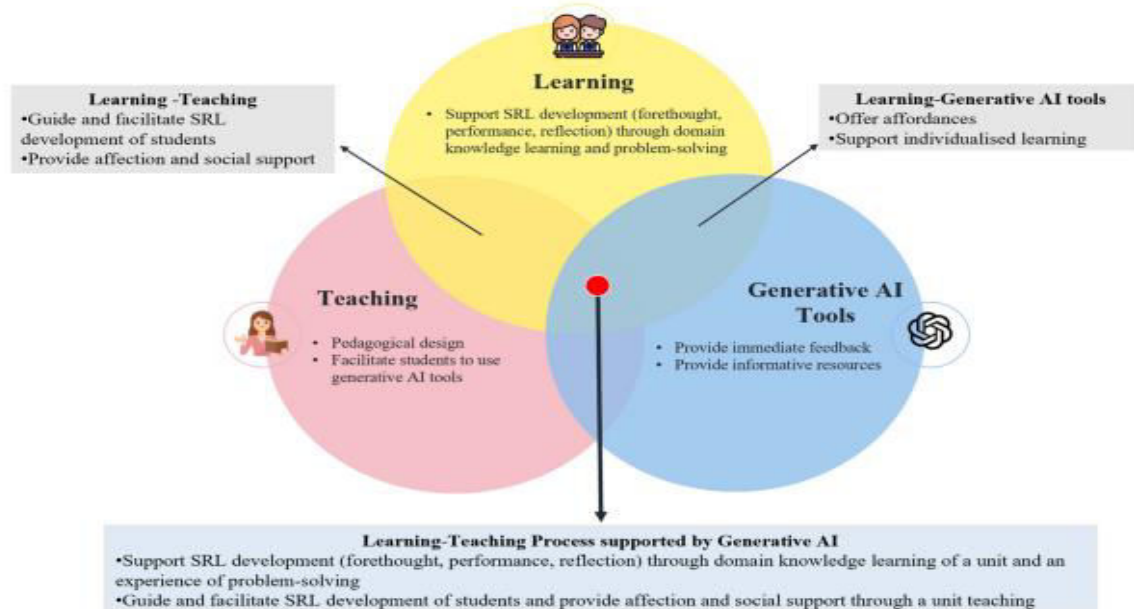


Fig. 1. HCLTF that uses generative AI in K–12 settings

AI to promote and assist SRL. A human-centered teaching approach would be guaranteed by such a framework, which would also give students the abilities and perspective they need for lifelong learning.

In light of this, this study developed a human-centered learning and teaching framework (HCLTF). In K–12 contexts, this paradigm leverages generative AI to construct SRL through domain knowledge learning. In order to give in-service

primary teachers the conceptual understanding of generative AI and the abilities needed to use generative AI tools for developing differentiated instructional materials and supporting students' individualized learning, a 10-week teacher development program was also implemented.

The course covers generative AI basics (such as tokens, self-attention mechanisms, transformers, supervised and unsupervised learning, reinforcement learning, and generative AI ideas) as well as the use of generative

An overview of generative AI (including its ideas, tokens, self-attention mechanisms, transformers, supervised and unsupervised learning, and reinforcement learning) and its application to course design are covered throughout the program. The program's design was guided by the integration of the TPACK and ARCS models. The pedagogical design of a variety of case studies covering topics including programming, general studies, mathematics, Chinese and English languages, and more was guided by the suggested HCLTF. The following three questions were addressed in order to assess the effectiveness of the teacher professional development program.

- 1) How well did the teacher development program help teachers understand the concepts of generative AI?
- 2) How well did the teacher development program improve teachers' understanding of the CK, TCK, PCK
- 3) How much did the teacher development program improve instructors' perceptions of their capacity to create lessons that would boost students' interest, relevance, self-assurance, and contentment?

III. PROPOSED FRAMEWORK

A. Introduction to the Proposed Framework

Figure 1 shows the suggested HCLTF. Three overlapping circles that stand for the disciplines of learning, teaching, and generative AI make up the Venn diagram that visually represents the framework. The three domains and the three regions where they intersect are described in the section that follows.

Education: The learning domain places students at the center of the educational process by adhering to human-centric concepts. It highlights how the three SRL steps are facilitated. Setting objectives, keeping track of learning procedures, and reflecting on learning results are all ways to empower students to take charge of their education. Table 1: Results of testing on the morality of AI algorithms

Teaching: Pedagogical strategies that smoothly incorporate generative AI into learning environments are the focus of the teaching domain. This area entails helping educators use generative AI into their lesson plans while making sure the technology supports improved content delivery and is in line with pedagogical objectives. The ARCS model is utilized within this framework to help teachers think of ways to improve students' motivation throughout the learning process.

Generative AI: This field is concerned with giving users instant feedback and technological affordances. Generative AI is a tool that can be utilized in this situation to provide pupils with personalized feedback.

Teaching and Learning: The emphasis switches to the guiding and facilitating responsibilities of teachers at the intersection of the learning and teaching domains. By offering social and affective support to create a positive learning environment, teachers play a crucial role in guiding students through the SRL process [41].

Learning–Generative AI: At the nexus of the learning and generative AI fields, neuroscience-based pedagogical implications are applied to improve students' SRL by boosting their attention, engagement, error-feedback, and reflection [42]. As a result, students are urged to actively identify and fix mistakes in AI-generated work.

Central Zone—Learning, Teaching, and Generative AI: The intersection of these three areas is the cohesive core of both teaching and learning.

The framework domains should operate in concert here to produce a seamless and engaging learning environment that promotes SRL and gets students ready for the challenges of the twenty-first century.

Stage	Teaching	Learning	Article Version	Comparison Table	Generative AI (e.g. ChatGPT)
Stage 1	Topic Preparation	Determining the topic			
Stage 2	Spoken to Written Language Revision	Narrating creatively and Transcribing simultaneously on a computer	Student's initial written draft of oral composition		
		Spoken to Written Language Revision	Student revising oral language text to written language		
			Revised by generative AI v1	Student version vs. generative AI version comparison Table 1	Spoken to written language
Stage 3	Structure Refinement	Using prompts to instruct generative AI	Student's essay v1		Providing immediate feedback on the comparison results
		Comparing and revising versions (human VS machine)	Student's essay v2		
		Making revisions based on the comparison results	Revised by generative AI v2	Student version vs. generative AI version comparison Table 2	Refining structure
Stage 4	Word Refinement	Using prompts to instruct generative AI	Student's essay v3		Providing immediate feedback on the comparison results
		Optimising the article structure	Revised by generative AI v3		
		Using prompts to instruct generative AI	Student's essay v4	Student version vs. generative AI version comparison Table 3	Refining words
Stage 5	Reflection and Review	Reflection and Review			

Fig. 2. Five stages of primary grade five students' Chinese writing underpinned by the proposed framework

B. Case Study: Generative AI Tools as Partners for Enhancing Primary Students' Chinese Writing

This case study illustrates how the HCLTF can be used to create educational activities that use generative AI (like ChatGPT) to help fifth-grade Chinese language learners. writing in Hong Kong, wherein teachers assist students in collaborating using ChatGPT through a five-phase lesson plan that includes topic preparation, revision of spoken to written language, structure refinement, word refinement, and reflection and review (refer to Fig. 2).

Stage 1—Topic preparation: During this phase, the instructor gives out essay subjects and lays out the requirements in detail.

Step 2—Spoken to written language revision: The instructor leads class discussions and helps students generate ideas verbally [43]. Students use programs that offer speech-to-text capability, such Google Docs, to transfer their ideas from spoken to written form while they prepare their essays. After that, the students polish their spoken language drafts to conform to written language standards by eliminating colloquialisms, substituting more formal language, and adding the appropriate punctuation. After that, the students edit their spoken language drafts into a more formal written language using ChatGPT (Version 1). Through prompts, they learn how to engage with the AI interface, compare their work to the AI's output, and reconcile any discrepancies. To compare the student version, a comparison table is made.

Stage 3—Structure refinement: To help the students grasp essay structure more thoroughly, the instructor starts this stage by introducing structural knowledge and setting up more conversations.

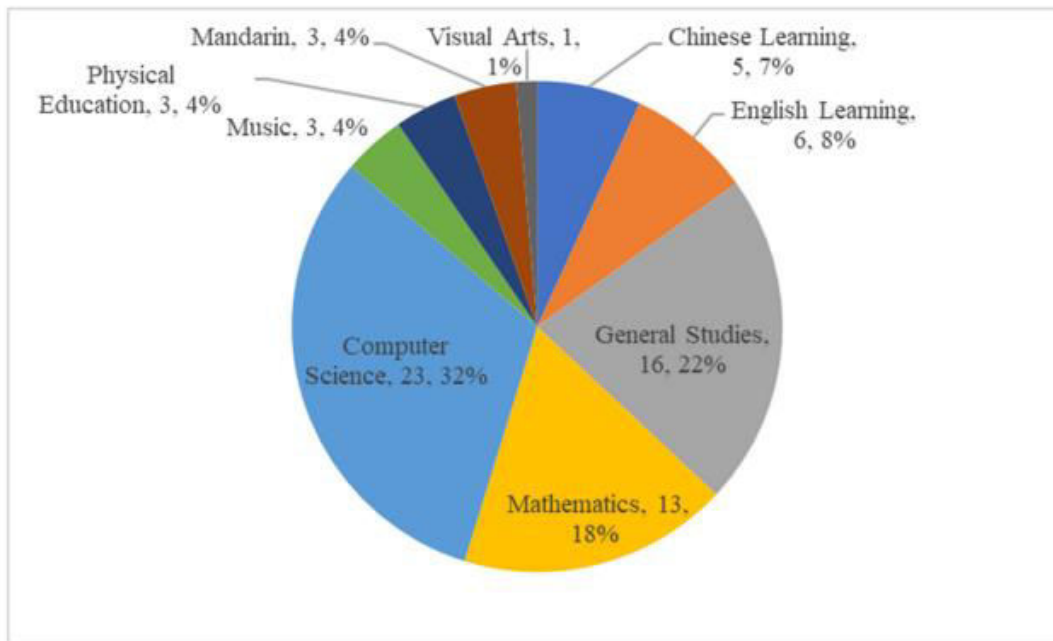


Fig. 3. Distribution of subjects taught by teachers.

Word refinement, or stage four, is concerned with linguistic accuracy. The instructor still offers direction and helps students improve their language and word choice.

The pupils concentrate on improving the words and expressions they use in their writings. They can then request that ChatGPT use sophisticated rhetorical strategies, like personification or metaphors, into their work. Lastly, they evaluate their changes against ChatGPT's recommendations (v3) to choose the best way to express themselves.

Step 5: Reflection and review: During this phase, the instructor leads a conversation to encourage introspection, offers feedback on the students' essays (v4), identifies their strong points, and makes suggestions for enhancements. The students provide an overview of their educational experiences as well as the information and abilities they have acquired during their interactions with ChatGPT.

IV. RESEARCH DESIGN

This study is a component of a bigger initiative that incorporates generative AI into course designs with the goal of empowering inservice K–12 instructors. Both quantitative and qualitative data analyses were used in this mixed-methods investigation.

A. Participants

A cohort of 31 in-service primary school teachers was gathered for the study. A deliberate sampling strategy was applied. The researchers invited instructors who indicated interest in taking part in the teacher development program after reaching out to the administrators of a number of nearby elementary schools during the recruitment phase. With 16 female teachers and 15 male teachers, the participants' gender distribution was almost equal. In terms of educational background, the majority of participants ($n = 21$) had bachelor's degrees, while the remaining participants ($n = 10$) had master's degrees. Two or more subjects had to be taught by the participating teachers. The participants' subject distribution is shown in Fig. 3: The most often taught subjects were computer science, general studies, mathematics, and languages.

B. Procedure

The educators were asked to take part in a six-week program that comprised: 1) a 30-hour course designed to provide a basic grasp of artificial intelligence (AI) (including its definition, the five stages of machine learning, supervised learning, and unsupervised learning) and deep learning (including data augmentation, data cleansing, neural networks, computer vision, convolution neural networks, and recurrent neural networks), as well as generative AI concepts; and 2) a 30-hour course on incorporating AI into the design of courses in subjects like computer science, music education, general studies, mathematics, Chinese and English language instruction, and more. The teachers finished a number of tests during the program to evaluate their development and the effectiveness of the instruction. These tests included a pretest and post-test to gauge their comprehension of AI concepts, assess their prior and post-course knowledge of TPACK, and gauge their self-perceived competency in course design, particularly with regard to raising students' attention, relevance, confidence, and satisfaction.

The teachers were expected to write a self-reflective essay about their experiences and the lessons they learned during the last week of the program.

C. Data Collection and Analysis

Data Collection: Questionnaires, introspective writing, and AI concept tests were among the data sources. Ten multiple-choice questions make up the pre-AI and post-AI concept examinations. The authors created it to evaluate teachers' knowledge of tokens, self-attention, embeddings, prompting engineering, transformers, and other fundamental AI ideas as well as the ramifications of generative AI. The test's Cronbach's alpha value is greater than 0.6, suggesting a moderate degree of consistency in the assessment of conceptual knowledge of artificial intelligence [46]. Below is an example of an item from the test. Regarding tokens in the context of huge language models, which of the following statements is true?

- 1) The smallest textual units that a big language model can process are tokens.
- 2) In a big language model, the number of words is directly correlated with the number of tokens.
- 3) Words, word fragments, or punctuation can all be represented using tokens.

V. RESULTS

A. Effect of the Teacher Development Programme on Concept Test Scores

The average variations between the tests for preconcept and postconcept. There was no breach of the normalcy assumption (Shapiro-Wilk test, $p > 0.05$). The difference between the pretest and posttest scores ($M = 3.581$, $SD = 1.205$ and $M = 4.871$, $SD = 1.648$; paired-samples t-test) was significant ($t(30) = 3.616$, $p < 0.001$, 95% CI [0.562, 2.019]). The findings demonstrate that the teacher development program improved the teachers' comprehension of AI principles.

B. Effect of the Teacher Development Programme on TPACK Evaluation Scores

The descriptive statistics of instructors' opinions about TPACK are displayed in Table I. The teacher development program resulted in statistically significant increases in the teachers' CK ($Z = -4.562$, $p < 0.001$), PCK ($Z = -4.632$, $p < 0.001$), TCK ($Z = -4.396$, $p < 0.001$), and TPACK ($Z = -4.561$, $p < 0.001$), according to a Wilcoxon signed-rank test.

These findings show that teachers' knowledge and abilities in the CK, PCK, TCK, and TPACK domains were much improved by the teacher development program. The curriculum enhanced the teachers' theoretical comprehension of how technology integrates with pedagogy and content, as well as their practical use of this knowledge, according to the statistically significant gains in the survey scores.

1) CK

a) The course highlights the significance of comprehending AI in education and offers knowledge on the subject that may be shared with students. (T1) b) I've been much more aware of the potential of generative AI in the classroom thanks to this course. It is a tool that can truly change the way we teach and the way our kids learn, not just another catchphrase. I'll share my knowledge of AI with my pupils and assist them in realizing its increasing significance in our society. (T17)

2) PCK

- a) To support the emergence and evolution of pedagogy, teachers' comprehension of AI must be deepened. This course taught me a lot. (T23)
- b) After completing this program, I recognize the potential of AI to transform [how] we teach. I have learned a great deal about how AI can assist in customizing our teaching strategies for each individual student. The framework we have been introduced to is very useful and emphasizes the significance of keeping our students at the center of their educational journey. By utilizing AI, we can establish a learning environment that not only acknowledges but also celebrates each student's unique needs and potential (T16).

3) TCK

- a) I was concerned that machines might replace humans in our occupations, and terms like "transformers" and "tokens" were unfamiliar to me. However, I learned from this course that's not the case. (T14)

4) TPACK

- a) Understanding the technology and the subject matter is not enough to successfully incorporate AI into our instruction. I now know that employing AI tools successfully necessitates striking a cautious balance. I now feel confident enough to strategically use AI into my lesson planning thanks to this training. (T29)
- b) AI can help me identify areas in which a student may be having difficulty so that I can provide the appropriate support at the appropriate moment. Technology is a tool to help this trip, not the journey itself, as the TPACK framework reminds me.

TABLE I
DESCRIPTIVE STATISTICS OF TEACHERS' PERCEPTIONS OF TPACK

	M	SD	Z	p
Post-CK	4.258	.588	-4.562	< 0.001
Pre-CK	3.301	.663		
Post-PCK	4.234	.602	-4.632	< 0.001
Pre-PCK	2.952	.823		
Post-TCK	4.258	.614	-4.396	< 0.001
Pre-TCK	3.218	.939		
Post-TPACK	4.215	.636	-4.561	< 0.001
Pre-TPACK	2.774	.908		

C. How the Teacher Development Program Affects Teachers' Perceived Capability to Use Generative AI in the Classroom Under the ARCS

TABLE II
DESCRIPTIVE STATISTICS OF TEACHERS' PERCEIVED ABILITY TO DESIGN COURSES UNDER ARCS

	M	SD	SE	t	p
Post-Attention	4.366	.598	.107	7.762	< 0.001
Pre-Attention	3.151	.950	.171		
Post-Relevance	4.226	.669	.120	8.161	< 0.001
Pre-Relevance	3.000	.878	.158		
Post-Confidence	4.333	.644	.116	7.652	< 0.001
Pre-Confidence	3.108	.900	.162		
Post-Satisfaction	4.366	.663	.119	6.966	< 0.001
Pre-Satisfaction	3.290	.811	.146		

From the presurvey (M = 3.151, SD = 0.950) to the postsurvey (M = 4.366, SD = 0.598), there was a statistically significant increase in attention (t(df) = 7.762, p < 0.001). With a Cohen's d of 0.87, the impact size was substantial. Relevance: t(df) = 8.161, p < 0.001 Participants reported a considerable improvement from the pre-survey (M = 3.000, SD = 0.878) to the post-survey (M = 4.226, SD = 0.669). With a Cohen's d of 0.84, the impact magnitude was substantial. Between the pre-survey (M = 3.108, SD = 0.900) and post-survey (M = 4.333, SD = 0.644), there was a substantial increase in confidence (t(df) = 7.652, p < 0.001). With a Cohen's d of 0.89, the effect size was substantial. From the pre-survey (M = 3.290, SD = 0.811) to the post-survey (M = 4.366, SD = 0.663), there was a substantial improvement in satisfaction (t(df) = 6.966, p < 0.001).

VI. DISCUSSION

A framework for incorporating generative AI tools into the HCLTF to direct the practices of in-service teachers was put out in this study. The study's findings demonstrate that the teacher development program improved the in-service teachers' perceived capacity to incorporate AI technologies into curriculum design, improved their pedagogical tactics, and considerably raised their conceptual knowledge of generative AI. These results are consistent with other research's growing consensus regarding the significance of professional development for aspiring educators in the generative AI era [31], [48], and [49].

First, teachers acquire a greater understanding of the principles and constraints of big language models by studying the theoretical foundations and real-world applications of generative AI. For example, the ability of generative AI models to comprehend natural language depends critically on the idea of embeddings, which are the high-dimensional vector spaces where lexical items are mapped to capture semantic importance. Therefore, ChatGPT exhibits competence in the area of language activities, but it has limitations when it comes to handling tasks requiring abstract reasoning, such solving mathematical puzzles. Additionally, teachers can create a range of related questions by using strategies like few shots. When creating exams, this feature can be quite helpful.

Second, the program assisted the teachers in adopting innovative paradigms for instruction in place of more conventional ones.

Lastly, the teachers reported an increased ability to create classes that can improve students' focus, relevance, confidence, and satisfaction, indicating that the teacher development program gave them the skills and resources they needed to help their students learn in a more interesting and meaningful way.

Teachers can increase student motivation and promote SRL by integrating generative AI into their lessons.

The study's findings add to the continuing discussion on educational innovation between researchers and in-service teachers. Future K–12 practitioners can use the planned HCLTF as a guide. Inspired by TPACK, the HCLTF offers a comprehensive knowledge of how material, pedagogy, and generative AI may work together to produce student-centered learning experiences.

The study's conclusions have three ramifications for future research and application in the field of generative AI integration in K–12 educational environments.

First, this study's findings can help academics and designers understand the need for useful and doable frameworks to direct the incorporation of generative AI into instructional strategies [15], [47]. This approach emphasizes the significance of creating flexible models that can direct K–12 practitioners in the future and adds to the continuing discussion on educational innovation [49], [51].

Second, while incorporating generative AI into the classroom, this study emphasizes the significance of human-centered concepts [9], [13]. The findings confirm the teacher's function as a social and emotional anchor in the learning process and warn against an over-reliance on AI technologies.

The fundamental human elements of education and learning, such empathy, ethical considerations, and social connections, are preserved and enhanced by this human-centered approach.

Lastly, this study shows the promise of generative AI when carefully and morally incorporated into K–12 educational environments for curriculum designers and EdTech stakeholders.

The findings point to a chance to develop programs that leverage AI to develop students' SRL skills in addition to helping teachers create individualized education. Additionally, EdTech stakeholders are urged to work with educators to develop resources that complement the HCLTF, guaranteeing that technology advances learning objectives without displacing the human components of instruction.

VII. CONCLUSION

Education is currently undergoing a revolutionary change as generative AI tools and improved AI literacy enable teachers to improve their teaching methods. The findings of this study add to the continuing discussion on educational innovation between researchers and aspiring educators.

Future K–12 practitioners can use the planned HCLTF as a guide. The study's conclusions urge more investigation and discussion among scholars, practitioners, curriculum designers, and EdTech stakeholders to guarantee that generative AI is integrated in a way that improves learning while staying true to human-centered educational principles.

The study also has three notable limitations. First, although the HCLTF was co-designed by researchers and in-service teachers and has been applied to the design of courses in Chinese language, English language, mathematics, general studies, computer science, and music education, its applicability to other subjects and the effects on students remain unknown. As such, the framework may not be fully representative of or adaptable to the diverse range of scenarios encountered in primary and secondary education settings. Further iterations and validation across a variety of educational environments and disciplines are necessary to ensure the HCLTF's robustness and generalizability.

To evaluate the dynamics between teacher-student interactions, teacher-teacher interactions, and the general school environment, a three-level approach could be used. The suggested HCLTF may be further understood in the future by broadening the participant pool and looking at other variables.

Lastly, the study placed less attention on the student experience and more on the viewpoint of professors. In order to comprehend how the incorporation of generative AI impacts students' learning experiences, engagement, and results, future research should incorporate their perspectives [16]. The foundation for incorporating AI into teaching and learning procedures in K–12 contexts should be refined and improved using input from students.

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