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AN INNOVATIVE PRE-SERVICE TEACHER EDUCATION MODEL INTEGRATING "SMART EDUCATION, LEARNING–RESEARCH DUALISM, AND THREE-STAGE PROGRESSION"

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ABSTRACT

In response to the demands of digital transformation in education, this paper develops an innovative pre-service teacher education model that integrates "smart education, learning–research dualism, and three-stage progression." Combining theoretical modeling with empirical validation, the model uses smart education technology as its supporting environment and the interactive learning–research dualism as the core of competence development, and it designs a three-stage progressive pathway of "foundation building, professional deepening, and innovative integration." The effectiveness of the model was examined through a two-year quasi-experimental study at a provincial normal university (experimental group n = 126; comparison group n = 118) using a mixed-methods approach. The data show that the experimental group improved its TPACK (Technological Pedagogical Content Knowledge) score by 37.2%, raised its teaching problem-solving ability by 42.8%, and produced 3.1 times the total research output of the comparison group. The findings indicate that the model addresses the structural problems of traditional teacher education—fragmented technology use, the separation of learning from research, and an unclear development pathway—and offers a systematic solution for teacher education transformation in the new era.

Keywords: smart education; learning–research integration; progressive cultivation; teacher education

1.0 INTRODUCTION

Against the backdrop of accelerating digital transformation in education worldwide, teacher education faces serious structural challenges. The Education Trends 2023 report of the Organisation for Economic Co-operation and Development (OECD) indicates that 78% of member countries have systematically incorporated artificial intelligence into their teacher education systems. China's industry standard Teachers' Digital Literacy (2023) explicitly requires teachers to possess the ability to teach in a data-driven manner. The realities on the ground, however, reveal three deep-seated contradictions.

The first is the problem of "suspended technology," manifested in a marked disconnect between hardware investment and integration into educational practice. According to the Ministry of Education's Annual Report on Educational Informatization (2022), smart classrooms had been installed in 75.6% of normal universities nationwide, yet the proportion in which technology was deeply integrated into teaching processes was only 31.2% (Ministry of Education, 2023). This disconnect reflects the widespread practice of "valuing equipment over application": smart

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blackboards are often used merely as substitutes for traditional projectors rather than to support personalized learning design. An empirical study by Wang et al. (2023) found that only 39.7% of pre-service teachers could independently design a smart teaching plan, indicating that the cultivation of technological competence remains superficial.

The second is the binary separation of learning from research, which reflects a structural defect in competence development. Theoretical study and educational research have long been kept apart, leaving pre-service teachers weak in research competence. A curriculum review of 12 normal universities by Li (2021) found that only 18.3% of specialized courses used a "research-oriented pedagogy." Data from the OECD Teaching and Learning International Survey (TALIS) 2018 show that the rate at which new teachers in China conduct teaching action research (16.8%) is markedly lower than in Singapore (43.5%) and Finland (38.1%) (OECD, 2019). The underlying cause is the "missing paradigm" criticized by Shulman (1987)—the three-way separation among subject knowledge, pedagogy, and situated practice.

The third is the ambiguity of the development pathway, which stems from the absence of systematic program design. Traditional teacher education has not established a progressive system that follows the laws of professional growth. A longitudinal study of 820 pre-service teachers across six provinces by Zhang (2022) found that the group that had not received progressive cultivation showed a 44.3% rate of occupational burnout within three years of entering the profession, twice the rate of the systematically trained group (21.7%). Berliner's (2004) theory of teacher development stages holds that novice teachers must progress through "routine execution, situational adaptation, and strategic innovation," yet current teacher education generally lacks clear stage-specific competence benchmarks (for example, teaching practice is often concentrated into a rushed final year).

Existing research has notable limitations. Most prior work focuses on the application of technological tools (Gu, 2022) and has not built an integrated model of the laws of teacher development and technological empowerment in the digital age; explorations of learning–research integration are concentrated in graduate education (Li, 2021), leaving a methodological gap in pre-service cultivation; and research on progressive cultivation still follows the knowledge-accumulation paradigm (such as PCK theory), lacking a systematic design for competence progression in a digital environment.

The question, therefore, is how the deep coupling of smart education technology, learning–research dualism, and a three-stage progressive pathway can resolve the structural difficulties of traditional teacher education and build a new model of teacher cultivation adapted to the digital ecology. Answering this question is of urgent practical significance for implementing the national strategy of digital transformation in education.

2.0 THEORETICAL FRAMEWORK OF THE NEW MODEL

The new model is formed through the deep coupling of three core elements—smart education, learning–research dualism, and three-stage progression—and its theoretical framework rests on the knowledge-creation spiral model, communities of practice theory, the stage theory of teacher professional development, and the zone of proximal development.

2.1 The Technology Support System of Smart Education

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In this model, smart education is not merely the application of tools but a systemic transformation of the educational ecology. At its core is the construction of a data-driven closed-loop system (shown in Figure 1): teaching behavior data are collected through intelligent environments (such as AI classrooms and virtual training platforms), a learning analytics engine generates personalized intervention strategies, and teaching optimization and adaptive adjustment of the environment are ultimately achieved. The key technological supports include: (1) an intelligent lesson-preparation system (such as the "Shishuo Wenjiao" large language model developed by Shandong Normal University), which automatically generates differentiated teaching designs and addresses the inefficiency of traditional lesson preparation; (2) a virtual teaching-research platform (such as the National Smart Education Platform for Primary and Secondary Schools), which supports cross-school collaborative lesson study, with a resource utilization rate of 100%; and (3) a digital profiling system that dynamically tracks the competence trajectories of pre-service teachers and provides an empirical basis for progressive cultivation.

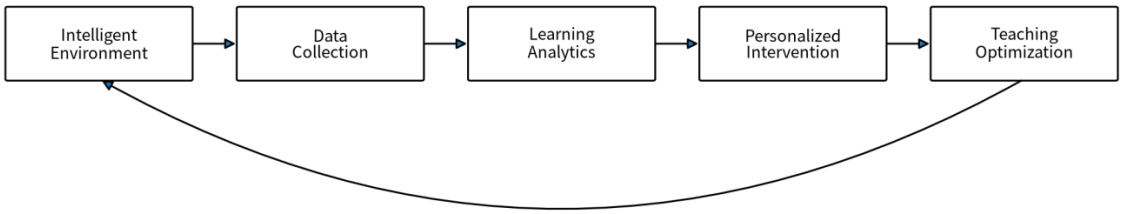


Figure 1. The data closed-loop system of smart education.

2.2 Competence Development Innovation Through Learning–Research Dualism

The learning–research dualism breaks with the traditional linear model of "learning first, researching later" and establishes a dynamic "theory–practice–research" transformation mechanism. Its theoretical foundations include the knowledge-creation spiral model (Nonaka & Takeuchi, 1995) and communities of practice theory (Lave & Wenger, 1991). Through the cycle of "socialization, externalization, combination, and internalization," the former achieves the two-way conversion of tacit educational knowledge and explicit research competence; the latter, through "legitimate peripheral participation," drives the identity transformation of pre-service teachers from consumers of knowledge to educational researchers.

2.3 Three-Stage Progression: A Systematic Design of the Development Pathway

The design of the three-stage progression derives from the stage theory of teacher professional development (Berliner, 2004) and Vygotsky's zone of proximal development, and it emphasizes the gradual and situated nature of competence development (Hu, 2024; Huang et al., 2025). Its core logic is: (1) the law of cognitive development, a spiral ascent from basic cognition (remembering/understanding) to higher-order thinking (analysis/creation); (2) the needs of professional growth, matching the role transformation of pre-service teachers from "novice" to "expert" (as in Berliner's stages from "routine execution" to "strategic innovation");

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and (3) the integration of digital competence, embedding smart education technology deeply into the competence goals of each stage.

The deep coupling of these three core elements forms the new model, as shown in Figure 2.

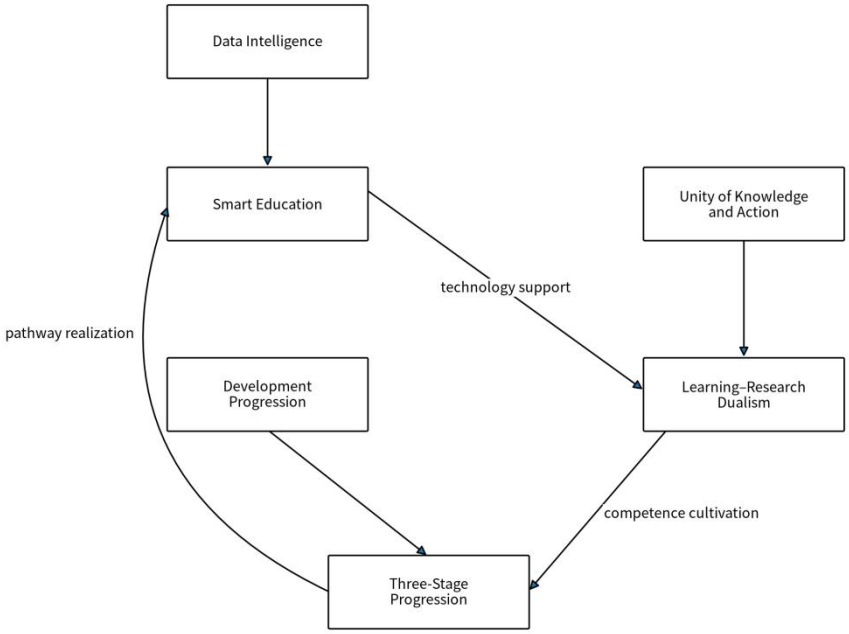


Figure 2. The coupling relationships among the core elements of the new model.

These theories must be put into practice through structured vehicles. The study designs a three-dimensional implementation framework (Table 1), whose internal logic is: (1) curriculum integration is the starting point of the knowledge spiral, in that inquiry-based courses trigger socialization and externalization; (2) project-driven work realizes the combination process, as micro-research projects integrate fragmented knowledge into solutions; and (3) practice-based feedback completes the internalization loop, as reflective reports promote the conversion of theory into personal practical wisdom.

Table 1. The three-dimensional vehicles of the learning–research dualism and representative cases.

Integration dimension	Implementation vehicle	Case and theoretical mapping
Curriculum integration	Inquiry-based teaching design course	The "research–exhibit–debate–revise" pedagogy at Dezhou University: a "socialization" group discussion case leading to "externalization" of a teaching model.

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Project-driven work	Micro-research projects (e.g., using AR to overcome electromagnetism misconceptions)	A teaching aid developed and granted a national patent: "combination" integrates AR technology, subject knowledge, and pedagogy into an innovative solution.
Practice-based feedback	Reflective reports from educational observation	The ecological education practice at Neijiang Normal University: "internalization" converts theory into personal wisdom through teaching journals.

2.3.1 Foundation Stage (Years 1–2)

The foundation stage focuses on the dual goals of constructing a subject knowledge graph and cultivating the "genes" of digital literacy.

At the level of curriculum restructuring, the introductory course Introduction to Smart Education (including a 16-hour AI ethics module) is embedded in the general education curriculum, and a practical unit on "digital subject tool application" is added to the foundational subject courses. A representative case is the mathematics program's deep integration of the dynamic geometry software GeoGebra to achieve visual teaching of abstract concepts (for example, demonstrating the idea of limits through transformations of function graphs); this practice has been shown to raise conceptual understanding by 23.7% (Henan Teacher Education Curriculum Reform Research Center, 2024).

In smart practical training, the intelligent evaluation system for micro-teaching provides quantitative diagnosis of teaching behavior. Its core algorithm generates a competence radar chart through multimodal data analysis (clarity of speech, frequency of interaction, poise and manner, and so on). For instance, the diagnostic system developed by Shandong Normal University can automatically identify weaknesses in questioning strategies and, together with classroom observation data collected during educational fieldwork (such as curves of changes in student engagement), cultivates pre-service teachers' basic awareness of research (Shandong Provincial Education Department, 2025). This dual-track mechanism of "technology empowerment plus on-site evidence" markedly strengthens the coordinated development of disciplinary foundations and digital literacy, laying the competence foundation for subsequent stages (Hu, 2024).

2.3.2 Intermediate Stage (Year 3): Professional Deepening

The research goals of this stage are to deepen the conversion of PCK (Pedagogical Content Knowledge) into TPACK (Technological Pedagogical Content Knowledge), to improve teaching design and implementation ability, and to develop the ability to identify and study educational problems (analysis and inquiry).

At the level of curriculum upgrading and integration, the traditional PCK course is upgraded into a "Smart PCK Design" workshop. A representative case is the Physics Teaching Theory

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workshop in the physics program, in which students use the PhET simulation software to design a virtual laboratory activity on "simple harmonic motion." They must not only design the experimental procedure but also anticipate the misconceptions students may hold (such as believing that the restoring force always points in the same direction as displacement) and, using the real-time data and visualization functions of the simulation (such as dynamic displays of force vectors and energy conversion), design guiding questions to help students analyze data and correct misconceptions. At the same time, students learn to use simple learning analytics tools (such as Wenjuanxing and basic Excel analysis) to analyze the student feedback data collected after trial teaching of their own activities and to optimize their plans accordingly. This directly promotes the development of TPACK.

Project-driven work, as the core vehicle for integrating learning and research, systematically introduces micro-research projects. In technology application, for example, there is the design of an AI-based personalized homework recommendation system (for computer/educational technology students). Student teams analyze common error types for a given knowledge point, use a machine learning library (such as Scikit-learn) to train a simple error-pattern classifier, and design a Web prototype that recommends targeted exercises based on students' incorrect answers (Yan, 2025). The project involves needs analysis, learning the algorithm (combination), prototype development, small-scale testing (internalization), and writing a reflective report (externalization). In teaching research, there is the analysis of the causes of difficulties in solving applied mathematics problems among upper-primary students and the study of teaching strategies (for mathematics students) (Zhou & Bie, 2025). Through literature review, test paper analysis, and student interviews (socialization), students identify key types of obstacles (such as difficulty extracting information and weak modeling ability), design and implement an intervention lesson incorporating visualization tools (such as mind maps and line-diagram apps), collect and analyze pre- and post-test data (combination), and produce a research report (externalization). The school provides small grants and a dual-mentor system (a university subject professor plus a frontline teaching researcher).

For the deepening of smart education, the digital profiling system tracks students' progress during projects (such as volume of reading, number of plan revisions, and quality of data analysis) and provides formative feedback (Luo & Yang, 2024). The virtual teaching-research platform is used for remote collaboration among project teams and for sharing staged results.

2.3.3 Advanced Stage (Year 4): Innovative Integration

The goal of the advanced stage is to cultivate an innovative spirit and critical thinking, to build the ability to conduct educational research and teaching reform independently (evaluation and creation), and to achieve a transition toward a quasi-research teacher.

In frontier guidance and reflection, a seminar on educational frontiers and critical reflection is offered. Expert lectures are invited (on, for example, AI ethics and new advances in the learning sciences), and the emphasis is on guiding students in critical discussion (such as "Where are the boundaries of smart education technology application?" and "What are the possible risks of data-driven decision-making?") (Li Q., 2025). Students are required to draw on their own practice or research experience to write a critical reflective essay (externalization). For innovative research in the field, teaching practice becomes the ultimate testing ground and the incubator of innovation for the learning–research dualism.

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For example, a Chinese-language intern, addressing the low efficiency of essay grading, tried a hybrid model in which speech recognition plus an AI-assisted grading tool performed an initial review and the teacher then provided in-depth commentary and face-to-face feedback. By comparing data from the experimental and traditional classes (grading time, students' willingness to revise, and the degree of improvement in writing), the effectiveness of the model was verified and a generalizable research-based internship report was produced (Peng, 2023).

In the transformation and dissemination of results, students are encouraged to integrate their graduation design/thesis closely with their internship research projects. Outstanding results (such as teaching designs, research reports, and developed resources/tools) are disseminated through the virtual teaching-research platform, academic conferences (such as the pre-service teacher innovation forum), and even patent or software copyright applications (combination to socialization) (Jiang et al., 2025). The school establishes a "Future Teacher Innovation Award" as an incentive.

3.0 RESEARCH METHODS

3.1 Research Design

This study used a non-randomized quasi-experimental design to assess the effectiveness of the new model in a natural teaching setting. The research site was a local provincial normal college.

The experimental group comprised 126 undergraduates from the 2022 cohort across four teacher education programs (mathematics, physics, Chinese language and literature, and primary education). Starting in the first year, the integrated "smart education, learning–research dualism, three-stage progression" model was implemented systematically. The curriculum, teaching methods, practical activities (practical training, observation, and internship), and resource platforms were all restructured and strengthened according to the theoretical framework described above.

The comparison group comprised 118 undergraduates from the 2021 cohort in the same four programs. They followed the university's traditional teacher education model—conventional courses (without systematic smart education or learning–research integration modules), teaching methods centered on knowledge transmission and skill training, segmented practical arrangements (observation and internship relatively concentrated and weakly linked to research), and conventional teaching technology (such as PowerPoint and basic multimedia) rather than a systematic smart education platform.

For the control variables, the two groups showed no significant difference in college entrance examination scores in the relevant subjects at admission ($p > 0.05$). The main specialized courses were taught by the same group of teachers, ensuring a consistent baseline of teaching quality. The teachers in the experimental group received systematic training before implementing the new model. The level and type of internship schools for the two groups were largely matched.

The research period was two years (September 2022 to July 2024), fully covering the experimental group's foundation stage (Years 1–2) and intermediate stage (Year 3) and extending into the beginning of the advanced stage (the first semester of Year 4).

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3.2 Data Collection Tools and Methods

A mixed-methods approach was used to collect data from multiple sources to ensure triangulation.

3.2.1 Quantitative data

TPACK level: The Chinese version of the TPACK Competence Evaluation Scale, revised by Xie (2020), was used. The scale contains seven dimensions—TK (Technology Knowledge), CK (Content Knowledge), PK (Pedagogical Knowledge), PCK, TCK (Technological Content Knowledge), TPK (Technological Pedagogical Knowledge), and TPACK—with 47 items in total, scored on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). The overall Cronbach's α was 0.92, and the α coefficients of the dimensions ranged from 0.79 to 0.88, indicating good reliability and validity. The scale was administered to both groups before the experiment began (pre-test, T0), at mid-experiment (1.5 years, T1), and at the end of the experiment (2 years, T2).

Teaching problem-solving ability: The self-developed Teaching Problem-Solving Ability Test was used. It contains five case questions based on authentic teaching situations (for example, "How can technology help lower-secondary students understand abstract geometric concepts?" and "How can activities be designed to address the problem of scattered classroom attention among lower-primary students?"). Each case required students to propose a solution and explain its design rationale. Three experienced teacher education experts (who did not take part in the experimental teaching) used a double-blind method to score independently according to a preset rubric (examining accuracy of problem analysis, innovativeness and appropriateness of the solution, reasonableness of technology integration, theoretical basis, and clarity of expression), with a maximum of 20 points per question; the mean was taken as the score for that question, for a total of 100 points. The test was administered to both groups only at the end of the experiment (T2). The inter-rater reliability (ICC) was 0.85.

Research output: The number of outputs in four areas was systematically recorded over the two-year period: publication of academic papers (journals and conferences), participation in research projects (institutional level and above), patent applications/grants, and development of teaching resources/software copyrights. The data were verified through the university's research system, academic affairs system, innovation and entrepreneurship platform, and student application materials.

3.2.2 Qualitative data

Semi-structured interviews: At the end of the experiment (T2), purposive sampling was used to select 15 students from each of the experimental and comparison groups (covering different programs and achievement levels) for one-on-one in-depth interviews of about 30–45 minutes each. The interview guide focused on perceptions and evaluations of the cultivation model, gains and challenges in technology application/teaching ability/research ability, views on the integration of learning and research, and changes in professional identity. All interviews were audio-recorded and transcribed.

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Classroom observation: In the key courses in which the new model was implemented in the experimental group (the Smart PCK Design workshop and the micro-research seminar) and in the regular classrooms of the comparison group, the researcher conducted non-participant observation (at least eight observations of each type of classroom, at least 45 minutes each), using a structured observation form to record teachers' teaching behavior (such as the type and depth of technology application and strategies for guiding research-based learning), students' learning states (such as engagement and quality of interaction), and the classroom atmosphere. Detailed field notes were also written.

3.3 Data Analysis Methods

3.3.1 Quantitative analysis

All statistical analyses were performed using SPSS 26.0, with the significance level set at $\alpha = 0.05$ (two-tailed). Descriptive statistics were used to calculate the means (M) and standard deviations (SD) of the TPACK dimensions and total score and of the teaching problem-solving test scores. Independent-samples t-tests were used to compare the experimental and comparison groups at T2 on the TPACK total and dimension scores and on the teaching problem-solving test. Chi-square tests (χ^2) were used to compare whether the two groups differed significantly in total research output and in the number of each type of output (papers, projects, and so on).

3.3.2 Qualitative analysis

The interview transcripts and observation notes were analyzed using thematic analysis. The steps were: 1) familiarization with the data; 2) generating initial codes; 3) searching for themes; 4) reviewing themes; 5) defining and naming themes; and 6) producing the report. NVivo 12 was used to support coding and management.

The focus of the analysis was to identify the core themes in the experimental students' experience of the new model (such as perceptions of technology empowerment, the experience of learning–research interaction, the feel of the progression pathway, self-assessment of competence growth, and challenges and suggestions) and to contrast them with the comparison students' experience; and to distill the differences in teaching models reflected in classroom observation and their effects on students' learning behavior.

4.0 RESULTS

4.1 Development of TPACK

Within-group development of the experimental group. Repeated-measures ANOVA showed that the experimental group's total TPACK score differed highly significantly across the three time points T0, T1, and T2 ($F(2, 250) = 85.417$, $p < 0.001$, $\eta^2 = 0.581$). Post-hoc tests (LSD) showed that the T1 score ($M = 3.82$, $SD = 0.42$) was significantly higher than T0 ($M = 3.21$, $SD = 0.51$, $p < 0.001$), and the T2 score ($M = 4.40$, $SD = 0.38$) was significantly higher than T1 ($p < 0.001$). This indicates that the new model effectively promoted a continuous, significant rise in the experimental group's TPACK.

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Between-group comparison (at T2). Independent-samples t-tests showed (Table 1) that the experimental group's total TPACK and all dimension scores were highly significantly higher than those of the comparison group ($p < 0.001$). The experimental group's total score ($M = 4.40$, $SD = 0.38$) was 37.2% higher than at T0 and significantly higher than the comparison group ($M = 3.38$, $SD = 0.45$). The differences were especially pronounced in the core TPACK dimensions: TPK ($t = 10.23$, $p < 0.001$), TPACK ($t = 11.05$, $p < 0.001$), and TCK ($t = 8.97$, $p < 0.001$). This indicates that the new model is particularly effective in promoting the deep integration of technology, subject content, and pedagogy.

Table 1. Comparison of TPACK dimensions and total score between the experimental and comparison groups (T2, independent-samples t-tests).

Dimension	Experimental (n = 126) M ± SD	Comparison (n = 118) M ± SD	t	p
TK (Technology Knowledge)	4.35 ± 0.41	3.65 ± 0.52	11.28	<0.001
CK (Content Knowledge)	4.48 ± 0.36	4.22 ± 0.40	5.18	<0.001
PK (Pedagogical Knowledge)	4.30 ± 0.39	3.88 ± 0.43	7.89	<0.001
PCK (Pedagogical Content Knowledge)	4.33 ± 0.37	3.79 ± 0.45	10.02	<0.001
TCK (Technological Content Knowledge)	4.28 ± 0.42	3.42 ± 0.49	14.52	<0.001
TPK (Technological Pedagogical Knowledge)	4.45 ± 0.35	3.20 ± 0.50	23.14	<0.001
TPACK (Integrated Knowledge)	4.52 ± 0.33	3.30 ± 0.47	24.19	<0.001
TPACK total	4.40 ± 0.38	3.38 ± 0.45	18.76	<0.001

4.2 Teaching Problem-Solving Ability

Independent-samples t-tests showed (Table 2) that the experimental group's score on the teaching problem-solving test ($M = 86.72$, $SD = 7.15$) was highly significantly higher than the

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comparison group's (M = 60.75, SD = 9.83, t = 23.62, p < 0.001), an improvement of 42.8%. Feedback from the expert raters indicated that the experimental students' solutions generally showed greater depth of problem analysis, more innovative and appropriate technology integration, clearer theoretical support, and sharper logic.

Table 2. Comparison of teaching problem-solving test scores (T2, independent-samples t-tests).

Group	n	M	SD	t	p
Experimental	126	86.72	7.15	23.62	<0.001
Comparison	118	60.75	9.83	23.62	<0.001

4.3 Research Output

Chi-square tests showed (Table 3) that the experimental group's total research output was highly significantly higher than the comparison group's ($\chi^2 = 67.35$, $p < 0.001$). Over the two years, the experimental group produced 153 research outputs, about 1.21 per person, while the comparison group produced 49, about 0.42 per person. The experimental group's total output was 3.12 times that of the comparison group.

The experimental group was significantly better in research project participation (institutional level and above, $\chi^2 = 32.18$, $p < 0.001$), academic papers/reports (published or presented at conferences, $\chi^2 = 25.64$, $p < 0.001$), and development outputs (teaching resource packages, software copyrights, patents, etc., $\chi^2 = 18.93$, $p < 0.01$). A Mann–Whitney U test ($Z = -7.02$, $p < 0.001$) further confirmed the significance of the difference. This indicates that the new model effectively stimulated students' research interest and participation and promoted diversified output.

Table 3. Comparison of research output between the experimental and comparison groups (two-year period).

Output type	Experimental (n = 126)	Comparison (n = 118)	χ^2	p
Academic papers/reports	48 (38.1%)	15 (12.7%)	25.64	<0.001
Research project participation	62 (49.2%)	18 (15.3%)	32.18	<0.001
Patent/software copyright applications	8 (6.3%)	2 (1.7%)	3.95	0.047
Teaching resource	35 (27.8%)	14 (11.9%)	10.23	0.001

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packages/tool development				
Total number of outputs	153	49	67.35	<0.001
Outputs per person	1.21	0.42		

4.4 Qualitative Findings

The thematic analysis of the interview and observation data yielded the following core findings, offering a deeper perspective for interpreting the quantitative results.

Theme 1: Perceptions of technology empowerment and competence growth. The experimental students generally reported that the smart education platforms (such as the intelligent lesson-preparation assistant, the virtual teaching-research platform, and the digital profile) greatly improved their learning efficiency and sense of direction. "The digital profile lets me see clearly where my strengths and weaknesses are in teaching skills and research participation, so I have a clearer sense of direction in my learning" (S-mathematics-experimental). "The virtual teaching-research platform lets us exchange ideas with students from other schools and even with frontline teachers, and seeing different teaching designs broadens my horizons a lot" (S-Chinese-experimental). Classroom observation also showed that experimental students displayed higher engagement and more complex cognitive activity (such as analyzing data and designing solutions) in technology-supported classrooms. Comparison students rarely mentioned a profound influence of technology support on their learning.

Theme 2: Learning–research interaction promotes deep understanding and a shift in thinking. The experimental students deeply experienced the challenge and value of project-driven work, especially the micro-research projects. "When I was doing that micro-research on applied problems, it felt really hard at first—reviewing the literature, designing questionnaires, interviewing students, analyzing data... but after I finished, I felt I understood much more deeply why students can't do applied problems, and I have more confidence when I design teaching" (S-mathematics-experimental). Several students said the experience cultivated a "research mindset" or "inquiry habit": when they encounter a teaching problem, they instinctively want to analyze the cause, look for evidence, and try to solve it rather than rely only on experience or intuition. Comparison students had fewer systematic research experiences and more often completed prescribed coursework and internship reports.

Theme 3: The progression pathway provides clear goals and motivation. The experimental students endorsed the three-stage design, seeing it as a clear roadmap for growth. "Laying the foundation and learning tools in Years 1 and 2, deepening through projects in Year 3, and trying innovation during the internship in Year 4—each step feels purposeful, and I know which direction to work toward" (S-physics-experimental). These stage-specific goals and challenges, combined with the feedback from the digital profile, strengthened their motivation and sense of achievement. Comparison students felt the cultivation process was rather "flat," lacking obvious stage goals and escalating challenges.

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Theme 4: Challenges and suggestions. The experimental students mainly reported two challenges: 1) time pressure—project-driven and research tasks did increase the workload; and 2) stability of technology support, with occasional platform freezes and data synchronization delays. They suggested that the university provide more opportunities for cross-disciplinary collaboration and more reliable technical support.

5.0 DISCUSSION

Through a rigorous mixed-methods design, this study systematically examined the effectiveness of the integrated "smart education, learning–research dualism, three-stage progression" model. The results strongly support the value of the model in addressing the three structural difficulties described in the introduction.

5.1 Resolving "Suspended Technology": From Tool Application to Ecological Empowerment

The marked rise in the experimental group's TPACK, especially the large advantages in the TPK, TPACK, and TCK dimensions, indicates that the model successfully transformed smart technology from scattered "add-on tools" into an empowering element deeply integrated into the core of subject teaching. This transformation stems from the data-driven closed-loop ecology built by the model (Figure 1) and the spiral integration of technology and competence across the three stages. For example, on the teaching problem-solving test, the experimental students' solution innovativeness (such as using AR to visualize abstract concepts and designing layered tasks based on data analysis) and appropriateness (closely tied to disciplinary logic and student conditions) far exceeded the comparison group's conventional solutions (such as assigning more practice and explaining in detail), directly reflecting the deep empowerment of teaching core competence by technology. This effectively responds to the superficial technology application noted by the Ministry of Education report (2023) and by Wang et al. (2023).

5.2 Bridging the Learning–Research Separation: The Knowledge Creation Spiral Within a Community of Practice

The significant difference in research output (3.1 times) and the formation of a "research mindset" reflected in the interviews mark the successful operation of the learning–research dualism. Through the structured vehicles of curriculum integration (initiating socialization and externalization), project-driven work (realizing combination), and practice-based feedback (completing internalization) (Table 1), the model embeds educational research seamlessly throughout pre-service teachers' learning and growth rather than treating it as an extra task separate from teaching practice. The intermediate-stage micro-research projects (such as the applied-problem study and the use of AR to overcome misconceptions) are both vehicles for the SECI cycle and hubs connecting theoretical learning (such as PCK), technology application (such as simulation software and data analysis tools), and practical situations (observation/internship). In solving authentic educational problems, students naturally achieve the deep integration of theory, practice, and research, and their identity shifts from mere learners to reflective practitioners and educational researchers.

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5.3 Clarifying the Development Pathway: Progressive Growth Based on Developmental Laws

The continuous growth trend of the experimental group's TPACK (T0 → T1 → T2) and the students' recognition of the clear progression pathway in the interviews verify the soundness of the three-stage design. The design successfully adapted Berliner's (2004) stage theory of teacher development (routine execution → situational adaptation → strategic innovation) to the needs of digital competence cultivation, constructing stage-specific competence benchmarks that fit the pre-service teachers' role transition from novice to quasi-research teacher and resolving the ambiguous development pathway and missing stage goals of traditional cultivation.

The foundation stage (Years 1–2) centers on laying the groundwork. By embedding Introduction to Smart Education (including the AI ethics module) in general education and integrating digital tool application into foundational subject courses (such as GeoGebra visual teaching in mathematics), it cultivates both the subject knowledge graph and the genes of digital literacy, corresponding to the cognitive preparation phase before routine execution in Berliner's theory. In this stage, the multimodal data analysis of the intelligent micro-teaching evaluation system (clarity of speech, frequency of interaction, and so on) helps pre-service teachers establish basic norms of teaching behavior and awareness of technology application, building a solid foundation for competence progression; the empirical work of the Henan Teacher Education Curriculum Reform Research Center (2024) also confirms that such practice can raise conceptual understanding by 23.7%.

The intermediate stage (Year 3) focuses on professional deepening. Using the Smart PCK design workshop and micro-research projects as vehicles, it promotes the conversion of PCK into TPACK and cultivates the ability to identify and inquire into educational problems, matching the core needs of the situational adaptation phase. The dynamic tracking and formative feedback of the digital profiling system on project progress (volume of reading, quality of data analysis, and so on) let pre-service teachers clearly perceive the theory–practice–research conversion process, avoiding the disconnect between knowledge learning and practical application in traditional cultivation. For example, the PhET simulation design project in the physics program both integrates subject knowledge and technology tools and, through analysis of student feedback data, achieves iterative optimization of the teaching plan, directly promoting the development of core TPACK dimensions (Li J., 2024).

The advanced stage (Year 4) aims at innovative integration. Through innovative research projects during teaching practice (such as digital biological inquiry experiments and AI-assisted essay grading) and the critical reflection course, it forges independent research and teaching innovation ability, connecting to the competence requirements of the strategic innovation phase. This stage closely binds the graduation design to the internship research, closing the loop of the progression pathway and thoroughly changing the fragmented practice of a rushed final-year internship in traditional education. As an experimental student put it, "Laying the foundation in Year 1, doing projects in Year 3, and innovating in Year 4—each step has a clear direction." Such staged goals combined with precise feedback not only reduce the sense of professional uncertainty—in sharp contrast to the 44.3% burnout rate of the non-

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progressive group in Zhang's (2022) study—but also, through appropriately challenging tasks within the zone of proximal development, achieve a spiral ascent of competence.

5.4 Research Limitations

Limited sample representativeness and scope of generalization. The sample came only from four teacher education programs at one provincial normal university (mathematics, physics, Chinese language and literature, and primary education), without covering other programs such as arts or vocational and technical education, and it was concentrated in a single province. It can hardly represent the cultivation contexts of normal universities at different levels (for example, national-affiliated versus local) and in different regions (eastern coast versus western borderlands). Sample homogeneity may bias the effectiveness evaluation and limit direct cross-school and cross-program generalization.

Insufficient verification of the research period and long-term effectiveness. The two-year experiment covered only the foundation and intermediate stages and the beginning of the advanced stage (the first semester of Year 4) and did not follow the pre-service teachers into professional practice after graduation. Zhang's (2022) study has established that the first three years on the job are a critical period for the formation of professional resilience, yet this study has not assessed the model's effects on long-term indicators such as graduates' teaching adaptability, research conversion ability, and resistance to burnout, and so cannot fully judge its support across the professional life cycle.

A dimensional gap in the evaluation system. The current evaluation indicators are dominated by the three dimensions of "technology–teaching–research" (TPACK, teaching problem-solving ability, and research output) and lack systematic assessment of soft indicators such as teacher ethics, educational commitment, and digital ethical judgment. Ethical issues such as data privacy protection in smart education and educational equity in AI teaching, for example, are not included in the evaluation framework, yet these are core requirements for cultivating the "four-haves" good teachers of the new era.

Incomplete control of variables and confounding factors. Although core variables such as entrance examination scores and teachers were controlled, confounders remain. First, the experimental teachers may have produced a "Hawthorne effect" (greater teaching enthusiasm) after receiving specialized training; second, the influence of individual differences among pre-service teachers (prior technology background, learning autonomy) on competence development was not removed through covariate analysis and may overestimate the model's independent effect.

Insufficient stability and universality of the technology support system. The interviews revealed platform freezes and data synchronization delays in the experimental group, and the resources the model depends on—intelligent lesson-preparation systems, virtual teaching-research platforms, and the like—are concentrated in key provincial normal universities. Weak local institutions may be unable to adapt because of funding and hardware shortages and may face a digital divide.

5.5 Future Research Directions

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Expanding samples and scenarios to strengthen adaptability for dissemination. Extend the sample to different types of institutions—national-affiliated, local applied, and vocational-technical normal universities—covering arts, science, arts education, and vocational programs, and build a three-dimensional sample bank of "institutional level, program type, and regional characteristics." Develop tiered "basic" and "advanced" guides for the resource endowments of different institutions, for example using open-source tools (Arduino sensors, free analysis plug-ins) to replace costly equipment and improve universality.

Conducting longitudinal tracking to complete the effectiveness evaluation chain. Use a three-stage tracking design of "in-school cultivation, entry into the profession, and professional maturity," and build growth portfolios: add digital ethics logs and teacher ethics cases during the in-school phase; track teaching satisfaction, project approval rates, and burnout scores in the first one to three years after entry; analyze the causal relationship between the model and long-term effectiveness through structural equation modeling, and build a full-cycle evaluation model.

Building a multi-dimensional evaluation system to fill the competence gap. Add dimensions such as digital ethics and teacher ethics, develop a Pre-Service Teachers' Digital Ethical Literacy Scale, and combine it with situational tests of ethical dilemma handling; introduce multiple evaluators such as internship mentors, parents, and teaching researchers, and capture soft skills through 360-degree feedback to avoid the bias of valuing competence over character.

Optimizing the research design to isolate confounders precisely. Use randomized controlled trials (RCTs) to reduce selection bias; incorporate teacher training intensity and prior technology level as covariates and use ANCOVA to remove confounders; set up a placebo comparison group (receiving only technology training without the learning–research/progression design) to clarify the independent and interactive effects of the three elements.

Co-building a technology ecosystem to overcome the digital divide. Join universities, enterprises, and administrative departments in building an open-source technology resource pool, offering free lesson-preparation templates and lightweight teaching-research tools; establish a school–local collaborative support mechanism in which key institutions provide technical training and remote guidance to weak institutions to lower the threshold of application.

Deepening cross-domain integration to respond to new educational needs. Incorporate emerging technologies such as VR immersive training and large language model research mentors; explore a collaborative mechanism of "normal universities, basic education schools, and research institutions," turning authentic educational problems (such as "double reduction" homework design) into micro-research projects; embed ethical modules on AI educational equity and data privacy into the three-stage progression to cultivate the ability to judge technology ethics.

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