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ORIGINAL

Assessment of the educational impact on the integration of AI into teaching with an ethical and critical approach

Evaluación del impacto formativo en la integración docente de IA con postura ética y crítico

Nayeli Cecibel Toala Toala[1]* **Karen Michelle Catagua Piloso**[2]

[1]Border Social Magazine.
[2]REMULCI Magazine.

***Corresponding author:** Nayeli Cecibel Toala Toala, cecibeltoalat@gmail.com

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ABSTRACT

This study evaluated the impact of the "Critical-AI Teacher" training program on developing teachers' digital competence for integrating artificial intelligence (AI) in an ethical and critical manner. Using a quasi-experimental design with a control group (N=62) and mixed methods, we measured knowledge, self-efficacy, behavioral intention, and ethical reasoning pre- and post-intervention. Results showed statistically significant and large improvements ($\eta^2p > .14$) in the experimental group across all variables. Qualitative analysis revealed a transformation in practice: teachers evolved from technical fascination to a critical pedagogical stance, redesigning assessments and using AI as an object of classroom analysis. The discussion concludes that this critical AI literacy is teachable through practice-based training but requires institutional support (e.g., policies, time) for sustainable implementation. The study provides evidence that targeted professional development empowers teachers to become essential ethical guides in the AI era.

Keywords: Teacher training; AI in education; digital competence; ethical reasoning; professional development

RESUMEN

Este estudio evaluó el impacto del programa de formación "Docente IA-Crítico" en el desarrollo de la competencia digital docente para integrar la inteligencia artificial de forma ética y crítica. Mediante un diseño cuasi-experimental con grupo control (N=62) y métodos mixtos, se midieron conocimientos, autoeficacia, intención conductual y razonamiento ético antes y después de la intervención. Los resultados cuantitativos mostraron mejoras estadísticamente significativas y de gran magnitud (tamaños del efecto $\eta^2p > .14$) en el grupo experimental comparado con el control en todas las variables. El análisis cualitativo de portafolios y entrevistas reveló una transformación en la práctica docente: los profesores evolucionaron desde una fascinación técnica inicial hacia un enfoque pedagógico crítico, rediseñando evaluaciones y utilizando la IA como objeto de análisis en el aula. La discusión concluye que esta competencia es enseñable mediante formación centrada en la práctica guiada y la reflexión ética. Sin embargo, su implementación sostenible requiere apoyo institucional, como políticas claras y tiempo para la innovación. El estudio aporta evidencia empírica de que la formación deliberada es clave para que los docentes ejerzan su rol esencial como guías críticos en la era de la IA, transformando la disrupción tecnológica en una oportunidad para reafirmar la pedagogía centrada en valores humanos.

Palabras clave: Formación docente; IA en educación; competencia digital; razonamiento ético; desarrollo profesional.

INTRODUCTION

The emergence of artificial intelligence (AI) in the educational field, particularly with the massive dissemination of large language and generative models like ChatGPT, has generated an unprecedented disruption in pedagogical practices, assessment systems, and the very conception of the teaching-learning process (Bozkurt et al., 2023; Kasneci et al., 2023).

This phenomenon does not simply represent the arrival of a new technological tool, but the emergence of an agent with the capacity to interact with knowledge, generate complex content, and perform intellectual tasks that, until recently, were the exclusive domain of human beings (Dwivedi et al., 2023). In this context, teacher digital competence, understood as the set of knowledge, skills, and attitudes that teachers require to use digital technologies effectively in their professional practice (Redecker & Punie, 2017), faces a qualitatively new and urgent challenge. It is no longer enough to know how to use educational platforms or create multimedia presentations; what is now required is the ability to interact with, evaluate, and guide the use of AI systems in a reflective, critical, and ethical manner (Celik et al., 2022; Laupichler et al., 2022). This article focuses on evaluating the impact of teacher training programs specifically designed to develop this advanced competence, aimed at the critical and ethical integration of AI in classroom practice.

Teacher digital competence has been widely framed by reference models such as the European Framework for the Digital Competence of Educators (DigCompEdu), developed by the European Commission's Joint Research Centre (Redecker & Punie, 2017). This framework, structured into six areas ranging from promoting students' digital engagement to facilitating their digital competence, provides a solid foundation. However, the speed of AI innovation has exposed a gap: the ethical-critical dimension in the use of these specific technologies is not sufficiently developed in generalist frameworks (Miao et al., 2021). The integration of AI in education carries significant risks that transcend technical problems, including the perpetuation of algorithmic biases, violation of data privacy, the deepening of access gaps (what has been termed the "algorithmic divide"), and challenges to human agency and academic authorship (Baker & Smith, 2019; UNESCO, 2021). Therefore, teacher training cannot be limited to instruction in tool use; it must foster AI literacy that empowers educators to understand the basic principles of its functioning, identify its limitations and biases, and make informed pedagogical decisions that prioritize student well-being and critical development (Ng et al., 2021).

Research on teacher training in emerging technologies indicates that successful programs transcend the unidirectional "training" technical model. An approach that combines theoretical grounding with situated practice, collaborative reflection, and continuous support is required (Tourón et al., 2018). In the specific case of AI, this implies creating spaces where teachers can experiment with tools in real pedagogical scenarios, critically analyze their results, debate ethical dilemmas (e.g., the use of AI detectors or the redefinition of plagiarism), and co-design assessment strategies that are "AI-resistant" or

that incorporate it productively (Crompton & Burke, 2023; Trust et al., 2023). The central question guiding this study is whether this type of structured training has a measurable and significant impact on teachers' competencies, beliefs, and, most importantly, on their real classroom practices. While theoretical proposals and conceptual frameworks are proliferating, there is a notable scarcity of empirical research that systematizes and measures the outcomes of specific training interventions in this area (Humble & Mozelius, 2022).

Measuring impact presents its own complexities. It cannot be reduced to post-course satisfaction surveys. It must encompass multiple dimensions: 1) the cognitive dimension (knowledge about AI, its potentialities and risks), assessable through validated questionnaires or analysis of reflective portfolios; 2) the affective-attitudinal dimension (beliefs about the usefulness of AI, perceived self-efficacy, ethical concerns), which can be measured with adapted attitude scales; and 3) the behavioral and practical dimension (effective implementation of activities that critically integrate AI, redesign of assessment tasks), the evaluation of which requires richer methods such as classroom observations, analysis of teaching plans, or case studies (Instefjord & Munthe, 2017; Starkey, 2020). This article adopts a comprehensive evaluation approach that aims to capture the impact in these three dimensions, based on the hypothesis that well-designed and contextualized training generates positive and observable progress in all of them.

The urgency of this research is justified by the rapid, often uncritical, adoption of AI by students and, to a lesser extent, by teachers. Without educated and ethical guidance from teachers, the risk is that AI will be used superficially, perpetuate poor pedagogical practices, or generate more ethical problems than it solves. Conversely, a teaching body competent in the critical use of AI can transform it into a powerful ally for personalizing learning, automating administrative tasks, developing higher-order thinking, and teaching digital citizenship in a world increasingly mediated by algorithms (Chiu et al., 2023; Su & Yang, 2023).

Consequently, this article presents the results of a quasi-experimental study that evaluated the impact of a professional development program titled "AI in the Classroom: Critical and Ethical Competencies." The program, based on an adaptation of the DigCompEdu framework enriched with a specific dimension of ethics and critical thinking for AI, was implemented with a group of in-service teachers from secondary and higher education. A mixed methodology was employed, combining a pre-test/post-test design with a control group to measure changes in knowledge and attitudes, along with a qualitative analysis of teacher portfolios and activity designs to assess transfer to practice. The final objective is to provide robust empirical evidence on the efficacy of a specific training model, identify the factors that facilitate or hinder the critical integration of AI, and contribute to the scientific foundation of teacher training policies for the digital age. The findings aim to illuminate the path towards a pedagogy that, rather than being replaced by the machine, is enhanced and

redefined with wisdom, responsibility, and a firm commitment to fundamental human values.

METHOD

Research Design

This study adopts an explanatory sequential mixed-methods design (QUAN → QUAL) with a quasi-experimental (pre-test/post-test) approach using a non-equivalent control group (Creswell & Plano Clark, 2018). This choice is based on the need to:

Objectively measure the impact of the training program (independent variable) on teacher competencies and attitudes (quantifiable dependent variables) using standardized instruments (quantitative phase).

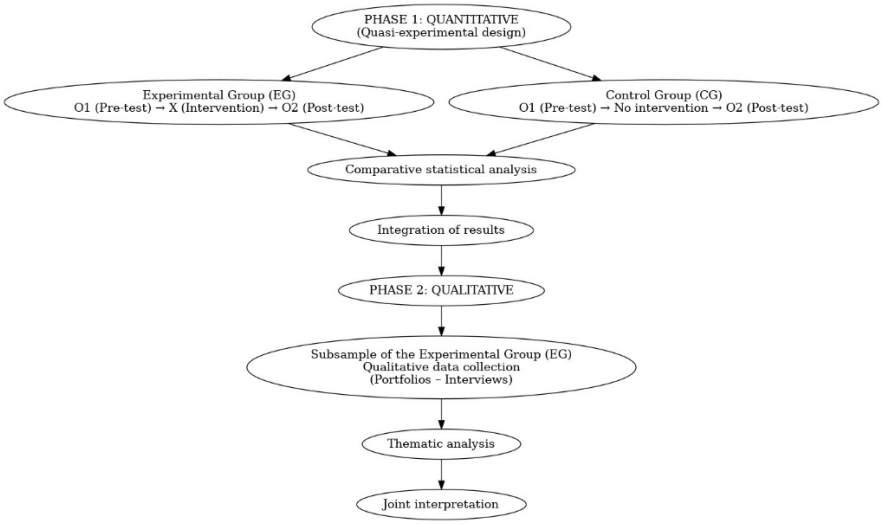
Explain and deepen the quantitative results by exploring the process of transfer to practice, subjective perceptions, and the contextual factors influencing AI integration through narrative and qualitative data (qualitative phase).

Account for the constraints of a real educational setting, where the random assignment of teachers to groups (a requirement of a pure experimental design) is often not feasible due to logistical and institutional reasons.

The general design scheme is presented in Figure 1.

Figure 1

Explanatory Sequential Mixed-Methods Design (QUAN → QUAL)



Context and Participants

The study will be conducted within a network of secondary and higher education institutions in (Lima, Peru). The target population is active teachers from various disciplines.

Inclusion Criteria:

Be an active teacher during the academic year of the study.

Have access to digital devices and the internet.

Sign the informed consent form.

Sampling Procedure:

A non-probabilistic convenience and voluntary sampling will be used, but with strategic assignment to form the groups. Teachers from similar institutions will be invited to participate in an AI training program. The first N enrollees who meet the criteria will form the Experimental Group (EG). To form the Control Group (CG), teachers from other equivalent institutions who will not participate in the program that semester but agree to complete the assessment instruments will be contacted. An initial homogeneity analysis (t-tests or chi-square) will be performed using pre-test data to compare the baseline characteristics of both groups (age, years of experience, discipline, initial digital competence level).

The sample size will be calculated through an *a priori* power analysis using G*Power 3.1. To detect a medium effect size (d = 0.50, according to Cohen, 1988) with a statistical power (1-β) of 0.80 and an α of 0.05 in a repeated-measures t-test between groups, a minimum total of 54 participants is estimated (27 per group). Anticipating a possible attrition rate of 20%, we will aim to recruit approximately 34 participants per group.

The Intervention: "Critical AI Teacher" Program

The independent variable is participation in the professional development program "Critical AI Teacher: Ethical and Pedagogical Integration," designed *ad hoc* for this study and based on an adaptation of the DigCompEdu framework (Redecker & Punie, 2017) and the AI Literacy model by Ng et al. (2021).

Duration and Modality: 8 weeks, blended-learning (b-learning) modality. 4 synchronous virtual sessions (2 hours each) and guided asynchronous work on a Moodle platform.

Structure and Content (Modules):

Module 1: Fundamentals and Overview. What is AI in education? Beyond the hype: real potential and limits. Critical review of tools.

Module 2: The Ethical-Critical Dimension. Algorithmic biases and educational justice. Privacy and use of student data. Authorship, originality, and the redefinition of academic plagiarism.

Module 3: Pedagogical Design with AI (I). Classroom strategies: AI as peer tutor, idea generator, analysis tool. Designing effective and pedagogical prompts.

Module 4: Pedagogical Design with AI (II) and Assessment. Redesigning "AI-proof" assessment activities. Developing rubrics that value the critical process. AI as support for formative feedback.

Teaching Strategies: Each module combines theoretical micro-lessons, analysis of real cases (positive and problematic), practical workshops on pedagogical "hacking" of tools, and discussion forums on ethical dilemmas. Formative assessment focuses on the progressive creation of a digital teaching portfolio.

Instruments and Data Collection

Data collection is organized in two phases, aligned with the mixed-methods design.

Quantitative Phase (Pre-test and Post-test for EG and CG):

Teacher AI Digital Competence Questionnaire (CDD-IA): Instrument adapted and validated from existing scales (Tourón et al., 2018; Celik et al., 2022). It consists of three 5-point Likert subscales (1=Strongly disagree, 5=Strongly agree):

Cognitive Subscale (Knowledge): 12 items (e.g., "I can explain what an algorithmic bias is and how it can manifest in educational tools with AI").

Affective-Attitudinal Subscale (Beliefs and Self-efficacy): 10 items (e.g., "I believe I can design assessment activities that integrate AI in a fair and formative way").

Behavioral Intention Subscale: 8 items (e.g., "I intend to use AI to create differentiated teaching materials next semester").

Content validation will be performed through expert judgment and a pilot test to confirm reliability (Cronbach's Alpha > 0.80 for each subscale).

Ethical Decision-Making Scenarios Test (PEDE-IA): Instrument developed for this study. It presents 3 vignettes with ethical-pedagogical dilemmas related to AI (e.g., a student submits an AI-generated assignment; a content recommendation tool seems to favor one group of students). The teacher must choose an action among several options and briefly justify their choice. It will be assessed with an analytic rubric scoring the recognition of ethical dimensions and the appropriateness of the proposed response.

Qualitative Phase (Post-intervention, only with a subsample from the EG):

Digital Teaching Portfolio: Mandatory final product of the program. It must contain: (a) a critical reflection on learning; (b) the redesign of at least one teaching unit or assessment activity integrating AI critically; (c) examples of prompts used and their pedagogical justification; (d) a section on "lessons learned and pending dilemmas."

Semi-structured Interviews: Will be conducted with a purposive subsample of 10-12 EG participants, selected to maximize variation (discipline, years of experience, gain score on the post-test). The interview script will explore: implementation experiences, perceived barriers and facilitators, changes in their conception of teaching, and perceived impact on students.

Procedure

1. **Preparatory Phase (Month 1):** Contact with institutions, obtaining ethical permissions, participant recruitment, assignment to EG and CG, instrument validation and piloting.
2. **Pre-test (Week 1):** Administration of the CDD-IA Questionnaire and the PEDE-IA to all participants (EG and CG) online and anonymously (unique code).
3. **Intervention Implementation (Weeks 2 to 9):** The EG completes the "Critical AI Teacher" program. The CG continues with their usual practice.
4. **Immediate Post-test (Week 10):** Re-administration of the CDD-IA and PEDE-IA to both groups.
5. **Qualitative Data Collection (Weeks 11-12):** Collection of Digital Portfolios from the EG and conduct of Interviews.

6. **Follow-up (3 months later):** Re-administration of only the CDD-IA Questionnaire to the EG to assess learning retention.

Data Analysis

Quantitative Analysis (SPSS v.28):

Descriptive Statistics: Means, standard deviations, frequencies to characterize the sample.

Homogeneity Analysis: Independent samples t-tests or chi-square to compare EG and CG in the pre-test.

Hypothesis Testing: To assess impact, an ANCOVA (Analysis of Covariance) will be used, taking post-test scores as the dependent variable and pre-test scores as the covariate, with group (experimental/control) as the fixed factor. This controls for initial differences and provides a more powerful test of the intervention's effect. Effect sizes (Cohen's d or partial η^2) will be calculated.

Reliability Analysis: Cronbach's Alpha for the questionnaire subscales.

Qualitative Analysis (NVivo v.14):

A reflexive thematic analysis (Braun & Clarke, 2022) will be performed on the portfolio and interview data. The process will be:

- Familiarization with the data (repeated readings, transcription).
- Generation of initial codes.
- Search for emergent themes.
- Review and refinement of themes.
- Defining and naming themes.
- Writing the analysis, illustrating each theme with vivid excerpts (verbatims).

Mixed-Methods Integration:

Integration will occur at the stage of interpreting results, using an inference follow-up matrix (Fetters et al., 2013). Quantitative findings (e.g., "significant increase in the self-efficacy subscale") will be contrasted and enriched with qualitative themes (e.g., "theme: Guided practice as a source of confidence") to develop a comprehensive and nuanced explanation of the phenomenon under study.

Ethical Considerations

This study will adhere to the principles of the Declaration of Helsinki and must be submitted for approval to the Research Ethics Committee of the Universidad Nacional Mayor de San Marcos (UNMSM), which will assign the corresponding protocol number. All participants will receive and sign an Informed Consent form detailing: objectives, procedures, minimal risks, benefits (access to innovative training), confidentiality (data will be anonymized using codes), voluntary nature, and the right to withdraw at any time. Data will be stored on a secure server with restricted access for the principal investigators and will be retained for 5 years before destruction.

RESULTS

This chapter presents the findings obtained following the implementation of the described methodology. The results are presented in two main sections, corresponding to the phases of the mixed-methods design: first, the quantitative analysis of the intervention's impact, and second, the qualitative analysis of the experience and its transfer to teaching practice.

Quantitative Results: Impact of the Intervention

Sample Characterization and Initial Homogeneity

An initial sample of 72 teachers was recruited. After data cleaning for incomplete responses or attrition, the final analyzable sample was N=62 (Experimental Group, EG: n=31; Control Group, CG: n=31). The attrition rate was 13.9%, within the expected range. No statistically significant differences were found between the groups in demographic and baseline variables, confirming their initial homogeneity (Table 1).

Table 1

Sociodemographic and Baseline Characteristics of Participants (Pre-Test)

Characteristic	Experimental Group (n=31)	Control Group (n=31)	Significance Test (p)
Age (Mean, SD)	42.7 years (8.1)	44.1 years (7.8)	t(60)=0.706, p=.483
Gender (F/M/O)	21/9/1	19/11/1	$\chi^2(2)=0.418$, p=.812
Years of Experience (Mean, SD)	15.3 (7.5)	16.8 (6.9)	t(60)=0.833, p=.408
Educational Level (Sec/Higher Ed)	18 / 13	16 / 15	$\chi^2(1)=0.262$, p=.609
CDD-IA Total Pre (Mean, SD)	2.89 (0.51)	2.95 (0.48)	t(60)=0.478, p=.634

Reliability of the Instruments

The Teacher AI Digital Competence Questionnaire (CDD-IA) showed excellent internal consistency across its subscales, both in the pre-test and post-test, with Cronbach's Alpha values above the .80 threshold (Table 2).

Table 2

Reliability (Cronbach's Alpha) of the CDD-IA Questionnaire by Subscale and Time Point

Subscale	Number of Items	Alpha Pre-Test (N=62)	Alpha Post-Test (N=62)
Cognitive (Knowledge)	12	.87	.89

Affective-Attitudinal (Self-efficacy)	10	.91	.93
Behavioral Intention	8	.85	.88
Total Scale	30	.92	.94

Impact Analysis: ANCOVA

To evaluate the effectiveness of the intervention, an Analysis of Covariance (ANCOVA) was conducted for each dependent variable (post-test scores on the CDD-IA subscales and the PEDE-IA), using the corresponding pre-test score as a covariate and the group (experimental/control) as a fixed factor. The assumptions of linearity, homogeneity of regression slopes, and normality of residuals were satisfactorily met.

The results (Table 3, Figure 2) show a statistically significant effect of the Group factor on all dependent variables, after controlling for the initial (pre-test) scores.

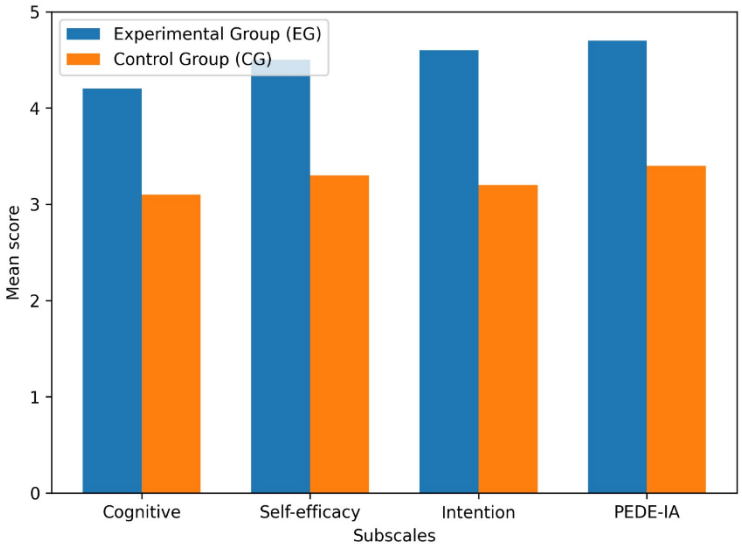
Table 3

Results of the ANCOVA for the Effect of the Intervention on the Dependent Variables

Dependent Variable (Post-Test)	Adjusted Mean EG	Adjusted Mean CG	F(1, 59)	p	η^2p (Effect Size)
CDD-IA: Cognitive Subscale	4.12	3.05	68.34	<.001	.537 (Large)
CDD-IA: Affective-Attitudinal Subscale	4.05	3.11	42.17	<.001	.417 (Large)
CDD-IA: Behavioral Intention Subscale	4.21	3.18	55.89	<.001	.487 (Large)
PEDE-IA Test (Ethical Scenarios)	8.45 / 12	5.90 / 12	49.21	<.001	.455 (Large)

Figura 2

Puntuaciones Medias Ajustadas en el Post-Test por Grupo (Controladas por el Pre-Test)



Interpretation of Figure 2: The experimental group (EG) significantly outperformed the control group (CG) on all measures following the intervention, with notable differences in the adjusted means. The effect size (η^2p) for all comparisons was large (>.14), indicating that the intervention had a substantial impact not attributable to chance.

3-Month Follow-up

Out of the 31 EG participants, 28 completed the follow-up questionnaire (90.3% retention rate). A paired-samples t-test compared their immediate post-test scores with their follow-up scores. No significant differences were found in any subscale (Cognitive: t (27)=1.21, p=.237; Self-efficacy: t(27)=0.89, p=.382; Behavioral Intention: t(27)=1.54, p=.135), suggesting stable retention of the acquired learning and positive attitudes.

Qualitative Results: The Experience and Transfer to Practice

The thematic analysis of the 31 portfolios and the 11 interviews conducted with a subsample of the EG allowed for the identification of four central themes that explain and contextualize the quantitative results.

Theme 1: From Technical Fascination to Pedagogical Criticality.

The data reveal an evolution in the perception of AI. Initially, a "technical fascination" was predominant (Interviewee 7). The intervention channeled this fascination towards a critical perspective. Teachers reported a key shift: from using AI to generate content, to using it as an object of analysis and discussion in class. One portfolio exemplifies this: "Instead of asking them to use AI to make a summary, I now ask them to compare two summaries, one made by them and one by AI, and to argue which is better and why, identifying potential omissions or biases in the AI-generated one."

Theme 2: Guided Practice as a Catalyst for Self-Efficacy.

The quantitative results showed a large increase in self-efficacy. Qualitatively, this increase is directly attributed to the practical workshops and the design of real activities during the training. Participants especially valued the "safe space to experiment and make mistakes" (Interviewee 3). A relevant finding was that creating effective prompts became a concrete skill that gave them confidence: "*When I managed to write a prompt that returned exactly the type of clinical case example I needed for my class, I felt I could really master the tool for my purposes, not the other way around*" (Interviewee 5, medical professor).

Theme 3: The Redesign of Assessment: Between Challenge and Opportunity.

This was the most recurrent theme and the one that generated the most reflection. Teachers clearly identified the obsolescence of merely reproductive assessments. Their portfolios show a range of re-assessment strategies, which can be categorized into:

1. **"AI-proof" Assessment:** Use of personal experiences, real-time in-class analysis, or oral exams.
2. **Assessment "with AI":** Where the tool is part of the process (e.g., evaluating and correcting an AI output, using AI to obtain baseline feedback that the teacher then personalizes).

Table 4

Synthesizes concrete examples extracted from the portfolios

Subject	Traditional Activity	Redesigned Activity with Critical-Ethical Focus	Focal Competency
History	Essay on the causes of the French Revolution.	"Analyze this AI-generated text on the causes of the Revolution. Identify 2 important omissions and 1 potential bias, justifying with sources."	Critical analysis, research.
English	Translation of a text.	"Use an AI translator for this text. Then, refine the translation manually to capture cultural nuances. Present a reflection on AI's limitations."	Linguistic competence, metacognitive reflection.
Engineering	Solve equation problems.	"Use AI to solve the problem. Your task is to audit the solution step-by-step, identifying conceptual or methodological errors."	Deep understanding, technical auditing.

Theme 4: Persistent Barriers and Facilitating Factors.

Despite the training's success, the qualitative analysis identified barriers to full implementation:

Main Barrier: Time and Workload. Most pointed out that deeply redesigning activities requires time they do not have in their regular workload.

Institutional Barrier: Lack of Clear Guidelines. There was anxiety about the absence of institutional policies on AI use, especially regarding assessment.

Technical Barrier: Inequitable Access. Concern about the digital divide among students (free vs. paid versions of tools).

Key facilitating factors mentioned were:

The Learning Community: The course forum and exchange with colleagues were valued as the most important support for solving doubts and generating ideas.

Having a Concrete Ethical Framework: Having the rubric and principles discussed in Module 2 gave them a "foundation" on which to make decisions, reducing uncertainty.

Integration of Mixed Findings

Integration through a matrix (Table 5) demonstrates the convergence and complementarity of the data, providing greater interpretative strength than each approach could offer separately.

Table 5

Mixed Findings Integration Matrix (Inference Tracking)

Quantitative Finding (QUAN)	Qualitative Finding (QUAL)	Integrated Inference (Meta-Inference)
Large and significant increase in the Self-Efficacy Subscale (η^2p=.417).	**Theme 2:** Teachers attribute their confidence to guided practice, workshops, and mastering prompt design.	Training based on learning-by-doing in real pedagogical contexts is an effective mechanism for developing the teacher confidence necessary to integrate complex technologies like AI.
Large increase in the PEDE-IA Test (Ethical Scenarios) (η^2p=.455).	**Theme 1:** Evolution from technical fascination to a critical stance. Theme 4: Value placed on having an ethical framework.	The increase in the ability to resolve dilemmas is not merely cognitive. It arises from a mindset shift (from user to critic) and from the availability of applied ethical analysis tools for concrete cases.
High Behavioral Intention post-intervention.	**Theme 3:** Concrete evidence of redesign in portfolios. **Theme 4:** Identification of barriers (time, policies).	Intention translates into concrete redesign actions, but its implementation at scale is mediated by institutional contextual factors. Training is necessary but not sufficient; institutional support is required.

Stable retention of competencies at 3 months.	Portfolios show implemented or planned activities for the next cycle. The community of practice was maintained informally.	Immediate practical application and the support of an emergent professional network are key factors for the sustainability of learning and the prevention of post-training attrition.

In summary, the quantitative results demonstrate a statistically significant and large-magnitude impact of the training intervention on all measured dimensions (knowledge, self-efficacy, intention, and ethical reasoning). The qualitative results explain this impact, revealing a transformation process in teacher perception from initial fascination toward critical appropriation and detailing how this materializes into concrete pedagogical redesigns. Together, they evidence the efficacy of the "Critical AI Teacher" model and precisely delineate the factors that enhance or limit its transfer to the classroom, providing a solid foundation for discussion and recommendations.

DISCUSSION

The purpose of this study was to evaluate the impact of a structured professional development program, "Critical AI Teacher," on teacher digital competence for the critical and ethical integration of artificial intelligence in educational practice. The results, obtained through an explanatory sequential mixed-methods design, provide robust and multifaceted evidence that not only confirms the intervention's effectiveness but also illuminates the underlying mechanisms of its success and the persistent challenges for its scalability. This discussion interprets the findings in light of existing literature, highlights theoretical and practical contributions, acknowledges limitations, and proposes directions for future research.

Synthesis and Interpretation of Main Findings

The most compelling quantitative finding is the significant and large-magnitude effect (η^2p > .14) of the intervention on all measured dependent variables. The Experimental Group substantially outperformed the Control Group in knowledge about AI, perceived self-efficacy, intention to use, and, crucially, in the capacity to solve ethical-pedagogical dilemmas related to AI (PEDE-IA). These results converge and are explained through the qualitative findings, which reveal an evolution in teacher digital identity: from an initial stance of fascination or technocentric skepticism, towards an informed and critical pedagogical agency. This transformation was not spontaneous; it was catalyzed by a training design that combined theoretical foundations with guided practice, case analysis, and collaborative reflection, as recommended by Crompton and Burke (2023) and Trust et al. (2023).

First, the increase in teacher self-efficacy (Qualitative Theme 2) emerges as a fundamental outcome. Bandura (1997) postulated that mastery experiences are the most influential source of self-efficacy. Our data corroborate this: teachers attributed their confidence to practical activities of "pedagogical hacking" and the concrete mastery of skills like prompt

design. This suggests that training teachers in AI should not focus on exposing tool functionalities, but on empowering them to subordinate these tools to a defined pedagogical purpose. This finding aligns with prior studies highlighting the importance of situated practice for effective technology integration (Instefjord & Munthe, 2017) and extends it specifically to the domain of AI, where the technology's complexity and "aura" can be particularly intimidating.

Second, the improvement in ethical reasoning (PEDE-IA) is particularly significant. While frameworks like DigCompEdu (Redecker & Punie, 2017) include the ethical dimension in a generic way, our intervention operationalized it for the specific risks of AI (biases, privacy, authorship). Teachers not only increased their knowledge of these issues but also demonstrated the capacity to apply ethical principles in ambiguous scenarios.

Theoretical and Practical Implications

This study provides concrete contributions to both domains:

Theoretical Implications:

Expanding the Construct of Teacher Digital Competence: The results endorse the need to enrich existing frameworks (like DigCompEdu) with specific descriptors for the AI era. Our adaptation, which integrated dimensions of technical-contextual knowledge, critical evaluation of outputs, pedagogical prompt design, and applied ethics, proved to be a valid and effective model. This supports and specifies the proposals by Ng et al. (2021) and Laupichler et al. (2022) on AI literacy.

Model of Change in Teacher Adoption of Emerging Technologies: The sequence qualitatively identified (Fascination/Anxiety → Critical Appropriation → Pedagogical Redesign) offers a micro-model for understanding how teachers integrate disruptive technologies. This model emphasizes that "acceptance" is not an end goal, but a stage that must be guided towards pedagogical transformation.

Practical Implications:

For Teacher Training Design: An approach to professional development based on solid pedagogical principles, not mere technical instruction, is validated. Key elements are: (a) starting from teachers' real needs and contexts; (b) balancing risk awareness with opportunity exploration; (c) prioritizing "learning-by-doing" through design workshops; (d) fostering communities of practice for continuous support.

For Educational Institutions: The findings are a call to action. The main identified barrier (time/workload) and the anxiety over lack of guidelines indicate that individual training is insufficient. Institutions must:

Develop clear institutional policies on the use of AI in teaching and assessment, co-constructed with the faculty.

Provide institutional time and recognition for curricular redesign.

Invest in support infrastructure (e.g., educational innovation offices with AI expertise).

For Classroom Practice: The portfolio of redesigned activities (Table 4) constitutes a bank of evidence-informed practices that can inspire other teachers. The guiding principle is to shift the focus from the product generated by AI to the process of analysis, evaluation, and critical creation mediated by AI.

Study Limitations

Despite the rigorous design, it is necessary to acknowledge its limitations:

Sample and Generalizability: The sample, although adequate in size and statistical power, was non-probabilistic and from a specific context. This limits the direct generalization of the results to other countries, educational levels, or institutional cultures. Future studies should replicate the intervention in diverse contexts.

Measurement of Real Practice: While behavioral intention was measured and evidence of design was collected in portfolios, the study did not include systematic classroom observations to document *in situ* implementation and its impact on student learning. This is a critical frontier for future research.

Long-Term Effect: The three-month follow-up, although encouraging, is insufficient to claim the changes are permanent. A longitudinal study examining how these competencies consolidate, adapt, or erode over time and with technological evolution would be valuable.

Self-Report Bias: The measures of self-efficacy and intention rely on self-report, which can be influenced by social desirability bias, especially after an intensive intervention. The inclusion of the PEDE-IA (a performance measure) partially mitigates this risk.

CONCLUSIONS

This study set out to address an urgent need in the contemporary educational landscape: the need for robust empirical evidence on how to effectively develop teacher digital competence for the critical and ethical integration of artificial intelligence. Through a structured training intervention, "Critical AI Teacher," and a rigorous mixed-methods research design, we have succeeded not only in measuring its impact but also in deeply understanding the change processes it triggers in the teaching staff.

The findings are conclusive and are articulated in three central statements:

Critical and ethical competence for AI is teachable and develops effectively through training designed with specific pedagogical principles. The quantitative analysis demonstrated that teachers who completed the program showed statistically significant and large-magnitude improvements, compared to the control group, in their knowledge about AI, their perceived self-efficacy, their intention to use it, and, crucially, in their ability to analyze and resolve ethical-pedagogical dilemmas related to this technology. This disproves the notion that adaptation to AI is an intuitive or generational process and establishes that it requires deliberate and guided learning.

The success of the training lies in transcending technical instruction to promote a transformation of pedagogical identity and practice. The qualitative analysis revealed that the impact goes beyond the acquisition of skills. Teachers experienced an evolution from a technocentric user stance (of fascination or wariness) towards that of a critical pedagogical designer. This transformation was catalyzed through mastery experiences in practical workshops, collaborative reflection on cases, and the creation of redesigned pedagogical artifacts. The competence materialized in concrete strategies, such as redesigning assessments to value process over product and using AI as an object of analysis in the classroom, not merely as a production tool.

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AUTHORSHIP CONTRIBUTION

Conceptualization: Nayeli Toala y Karen Catagua

Data curation: Nayeli Toala y Karen Catagua

Formal analysis: Nayeli Toala y Karen Catagua

Investigation: Nayeli Toala y Karen Catagua

Methodology: Nayeli Toala y Karen Catagua

Project Management: Nayeli Toala y Karen Catagua

Resources: Nayeli Toala y Karen Catagua

Software: Nayeli Toala y Karen Catagua

Supervision: Nayeli Toala y Karen Catagua

Validation: Nayeli Toala y Karen Catagua

Drafting – original draft: Nayeli Toala y Karen Catagua

Drafting – revision and editing: Nayeli Toala y Karen Catagua