

Effects of a Multi-Component AI-Supported Experiential Learning Environment on Pre-Service Teachers' Self-Efficacy, Occupational Anxiety, Professional Attitudes, and Reality Shock Expectations

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Abstract

This study examined the effects of a Multi-Component AI-Supported Experiential Learning Environment (MC-AI-ELE) on pre-service teachers' classroom management self-efficacy, occupational anxiety, attitudes toward the teaching profession, and reality shock expectations. A randomized controlled design with pretest, posttest, and follow-up measurements was employed. Participants were 439 final-year pre-service teachers from four public universities who completed all measurements. The experimental group participated in an eight-week intervention integrating modular instructional content, an AI-supported digital assistant, case-based simulations, modular assessments, and mentoring. Follow-up data were collected 45 days after the intervention. Data were analyzed using a 2×3 mixed-design analysis of variance, with the Aligned Rank Transform procedure used to assess the robustness of the findings. Significant but small group-by-time interactions were identified for classroom management self-efficacy, occupational anxiety, and attitudes toward teaching, whereas the interaction for reality shock expectations was not significant. Classroom management self-efficacy increased and occupational anxiety decreased from pretest to posttest in the experimental group, but these improvements were not maintained at follow-up. No significant improvement favoring the experimental group was observed in attitudes toward teaching. Overall, MC-AI-ELE provided short-term benefits, while sustained change may require continued implementation and integration with authentic school-based experiences.

Introduction

The transition from pre-service teacher education to professional practice represents a critical stage in teachers' career development. Although teacher education programs provide prospective teachers with pedagogical knowledge and opportunities for teaching practice, beginning teachers may encounter institutional, instructional, and interpersonal demands for which they do not feel adequately prepared. Difficulties in adapting to school culture, managing classrooms, responding to student behavior, communicating with parents, and fulfilling administrative responsibilities may intensify the challenges associated with this transition [1–5]. The discrepancy between expectations developed during teacher education and the conditions encountered in professional practice is commonly conceptualized as reality shock [6]. This discrepancy may have implications for teachers' emotional adjustment, professional commitment, perceived competence, and adaptation to the profession [7–9].

Preparing pre-service teachers for this transition requires attention to both professional competencies and affective outcomes. Reality shock expectations (RSE) and occupational anxiety (OA) may reflect concerns about prospective professional demands, whereas classroom management self-efficacy (CMSE) indicates the extent to which pre-service teachers believe they can manage classroom processes effectively [5, 10, 11]. Attitudes toward teaching profession (ATTP) constitute another relevant dimension because they are associated with professional motivation, commitment, and adaptation [12]. Examining these outcomes together may therefore provide a more comprehensive account of pre-service teachers' preparedness for the transition to professional teaching.

In response to the persistent theory–practice gap in teacher education, increasing attention has been directed toward learning environments that allow pre-service teachers to engage with situations resembling those encountered in actual schools [13]. Simulation-based and practice-oriented learning experiences are particularly relevant because they enable participants to examine professional problems, make instructional decisions, and consider the consequences of alternative courses of action in controlled settings [14–18]. AI-supported systems may extend these experiences by providing adaptive guidance, feedback, and opportunities for reflection during the learning process [19–21]. These developments provide a basis for designing integrated learning environments that combine experiential activities with digital and human support.

Nevertheless, the existing literature has predominantly examined AI literacy, technology acceptance, technology-integration competencies, or individual technological applications. Experimental evidence regarding integrated AI-supported environments designed specifically to prepare pre-service teachers for the professional transition remains limited [20, 22]. In particular, relatively little is known about whether a multi-component environment combining modular instructional content, case-based simulations, an AI-supported digital assistant, modular assessment, and mentoring can simultaneously influence professional self-efficacy, occupational anxiety, professional attitudes, and reality shock expectations. The limited use of follow-up

measurements also restricts conclusions regarding whether any immediate changes associated with such interventions are sustained over time.

Accordingly, the present study investigated the effects of a Multi-Component AI-Supported Experiential Learning Environment (MC-AI-ELE) developed to support pre-service teachers' professional preparation and adaptation. The intervention integrated modular instructional content, an AI-supported digital assistant, case-based simulations, modular assessments, and mentoring support within a unified experiential learning framework (see "Appendices" in the supplementary file). Using a randomized controlled design with pretest, posttest, and follow-up measurements, the study examined changes in CMSE, OA, ATTP, and RSE. The following research questions guided the study:

1. Do CMSE levels differ across time and group interaction between the experimental and control groups participating in the MC-AI-ELE process?
2. Do OA levels differ across time and group interaction between the experimental and control groups participating in the MC-AI-ELE process?
3. Do RSE differ across time and group interaction between the experimental and control groups participating in the MC-AI-ELE process?
4. Do ATTP differ across time and group interaction between the experimental and control groups participating in the MC-AI-ELE process?

Theoretical Framework

Transition to the Teaching Profession, Reality Shock, and Occupational Anxiety

The transition from teacher education to professional practice is a multidimensional adaptation process in which pre-service teachers must reconcile the expectations developed during their preparation with the demands of actual school environments. This transition is often accompanied by uncertainty, stress, and adjustment difficulties, particularly during the early years of teaching [9, 10]. The discrepancy between professional expectations and workplace realities is commonly conceptualized as reality shock and may involve cognitive and emotional responses such as disappointment, confusion, uncertainty, and anxiety [6, 7, 8, 23].

Within teacher education, reality shock is closely related to the tension between idealized perceptions of teaching and the complexity of professional practice [24, 25]. Beginning teachers may simultaneously face demands involving classroom management, instructional decision-making, student behavior, parent communication, and administrative responsibilities [3–5]. Such demands are also associated with OA, CMSE, ATTP [10].

OA refers to pre-service teachers' concerns and uncertainties regarding their future professional roles, competencies, and classroom practices [5]. Limited professional experience, role ambiguity, and performance expectations may heighten these concerns [10]. RSE and OA therefore represent related but distinct aspects of professional transition: RSE concerns anticipated discrepancies between expectations and professional realities, whereas OA reflects concerns about one's ability to cope with future professional demands.

From this perspective, preparation for teaching requires more than increasing awareness of professional challenges. Pre-service teachers also need opportunities to encounter realistic professional situations, consider alternative responses, and develop a more informed understanding of the demands they are likely to face. Learning environments that provide such opportunities may support cognitive and emotional adaptation by making professional situations more familiar and manageable before entry into full-time teaching [15].

Experiential Learning, Simulation-Based Applications, and Classroom Management Self-Efficacy

One of the persistent challenges in teacher education is the gap between theoretical preparation and the complexity of professional practice [26]. Although pre-service teachers acquire pedagogical knowledge during their university education, opportunities to apply this knowledge in low-risk but professionally realistic situations may remain limited. Difficulties in transferring theoretical knowledge to classroom contexts may contribute to uncertainty, perceived inadequacy, and anxiety [9, 25]. Experiential learning therefore provides an important basis for preparing pre-service teachers for professional decision-making in situations resembling those they may encounter in schools [17].

According to Kolb [27], learning develops through a cyclical process involving concrete experience, reflective observation, conceptualization, and active experimentation. In teacher education, this perspective suggests that professional preparation can be strengthened when pre-service teachers do more than receive information and are instead required to engage with situations, evaluate possible responses, reflect on their decisions, and consider alternative courses of action.

Simulation-based learning provides one way of creating such experiences in a controlled environment. Previous studies indicate that simulations can support classroom management, instructional decision-making, problem-solving, and professional self-efficacy among pre-service teachers [14–18]. Simulations may also contribute to reducing the theory–practice gap by exposing participants to realistic professional demands while allowing them to examine the consequences of different decisions before assuming full responsibility in authentic school settings [17, 28]. When combined with structured feedback and reflection, such experiences may also reduce uncertainty and performance-related stress [14, 18].

These processes are particularly relevant to CMSE, which refers to teachers' perceptions of their ability to organize learning environments, manage student behavior, and establish effective instructional processes [29]. Bandura's [30] self-efficacy framework emphasizes mastery experiences as a particularly important source of efficacy beliefs. Although simulation does not fully reproduce actual classroom practice, repeated opportunities to make decisions, solve problems, and receive feedback may provide experiences through which pre-service teachers can develop stronger beliefs about their capacity to manage classroom situations. Experiential and simulation-based learning may therefore be especially relevant for outcomes that are closely connected to perceived professional competence, such as CMSE [15, 17].

AI-Supported Feedback, Reflection, and Professional Learning

AI-supported learning environments may extend experiential learning by providing timely guidance, feedback, and opportunities for reflection during professional problem-solving. Previous research has shown that practice-oriented digital learning experiences can influence pre-service teachers' self-efficacy beliefs and their engagement with technology-supported learning processes [20, 31, 32]. However, the pedagogical relevance of AI in teacher education extends beyond technology use itself when it is embedded within activities that require learners to interpret professional situations and make instructional decisions.

AI-supported digital assistants can provide immediate explanations and feedback while participants work through professional problems, thereby supporting instructional decision-making and reflective thinking [20]. AI-supported systems may also personalize access to information, respond to participant questions, and help learners evaluate possible responses to situations encountered in teaching practice [21, 33]. In this sense, AI may function less as a stand-alone instructional technology and more as a source of scaffolded support within a broader experiential learning process.

Reflection is also important because professional learning does not depend only on exposure to experience but on how that experience is interpreted and evaluated. Schön's [34] reflective practitioner perspective emphasizes reflection on professional action as a means of developing more informed professional judgment. Within an AI-supported experiential environment, opportunities for self-assessment, feedback, and mentoring can complement simulated experience by encouraging participants to reconsider their decisions, identify alternative responses, and connect their experiences with broader professional knowledge.

Human support remains important within this process. AI-generated guidance can provide immediacy and accessibility, whereas mentoring can offer context-sensitive professional judgment and interpersonal support. When combined with simulations and self-assessment, these forms of support may create a more structured learning process in which participants encounter professional problems, receive feedback, reflect on their responses, and revise their understanding. Such an integrated

environment may therefore be particularly relevant to professional outcomes associated with uncertainty, perceived competence, and preparedness for the transition to teaching [19].

Integrative Theoretical Rationale for MC-AI-ELE

Taken together, experiential learning theory, social cognitive theory, and reflective learning provide complementary explanations for how a multi-component AI-supported experiential learning environment may support pre-service teachers' professional preparation. The experiential learning perspective emphasizes active engagement with realistic professional situations; social cognitive theory highlights the importance of experience, feedback, and perceived capability; and reflective learning emphasizes the evaluation and reinterpretation of professional decisions [27, 30, 34].

Within MC-AI-ELE, case-based simulations provide opportunities to engage with realistic professional situations and make decisions in a controlled setting. Modular instructional content provides conceptual knowledge that can be used when interpreting these situations. The AI-supported digital assistant offers immediate guidance and feedback, while self-assessment encourages participants to reflect on their decisions and monitor their learning. Mentoring adds a human source of professional feedback and support. The combination of these components is therefore intended to create a cycle of exposure, decision-making, feedback, reflection, and reconsideration rather than a learning environment based solely on content delivery.

These mechanisms may be related to the four outcomes examined in the present study in different ways. CMSE is closely connected to perceived competence and may therefore be responsive to opportunities for practice, problem-solving, and feedback [15–17]. Similarly, exposure to realistic professional situations accompanied by structured feedback and reflection may help reduce uncertainty and anxiety associated with anticipated professional demands [14–18]. Such experiences may also provide pre-service teachers with opportunities to confront the discrepancy between their expectations of teaching and the complexity of professional practice, which is central to the conceptualization of reality shock [9, 25]. ATP represents another relevant dimension of professional preparation because attitudes toward teaching are associated with professional motivation, commitment, and adaptation [12]. Taken together, these considerations provide a theoretical basis for examining whether the intervention is associated with changes across these distinct dimensions of professional preparation.

The present study therefore examined whether an eight-week MC-AI-ELE integrating modular instructional content, case-based simulations, an AI-supported digital assistant, self-assessment, and mentoring was associated with changes in CMSE, OA, ATP, and RSE across pretest, posttest, and follow-up measurements. By examining these outcomes together, the study assesses the effects of the intervention on both perceived professional competence and the affective and expectation-related dimensions of the transition to teaching.

Method

The study employed a randomized controlled experimental design incorporating pretest, posttest, and follow-up measurements. By randomly assigning participants to the experimental and control groups, this design enables systematic comparison of changes between groups and supports the evaluation of intervention effects over time [36, 37]. Pretest measurements were used to establish participants' baseline levels, posttest measurements to evaluate the immediate effects of the intervention, and follow-up measurements to assess the extent to which these effects were sustained. Accordingly, changes in CMSE, OA, ATP and RSE were compared over time between the experimental and control groups.

A schematic overview of the randomized controlled experimental design and implementation process is presented in Fig. 1.

As shown in Fig. 1, the experimental procedure comprised the following stages: selecting pre-service teachers from four universities through simple random sampling, randomly assigning them to the experimental and control groups, administering the pretest measures, implementing the eight-week intervention, administering the posttest measures, and conducting the follow-up assessment.

Participants

The target population comprised 2,273 final-year pre-service teachers enrolled in the faculties of education at Dicle University, Firat University, İnönü University, and Kahramanmaraş Sütçü İmam University. Simple random sampling was used to select prospective participants from the target population. Ethical approval was obtained from the Social and Human Sciences Research Ethics Committee of Firat University (Session No: 2024/11; Decision No: 7; Date: May 30, 2024). The study, titled “Öğretmen Adaylarının Gerçeklik Şokunu Aşmaları İçin Dijital Asistan Destekli Bir Öğretimin Tasarımı ve Etkililiğinin İncelenmesi”, was reviewed and approved unanimously by the ethics committee. All procedures were conducted in accordance with the relevant institutional guidelines and ethical principles for research involving human participants. All participants were informed about the purpose and implementation procedures of the study, and informed consent was obtained before data collection.

Following receipt of the necessary institutional permissions, class lists of final-year pre-service teachers were obtained from the participating universities. The initial recruitment target was 400 participants, comprising 50 participants per study group at each university. To account for potential attrition during the study, 700 pre-service teachers were ultimately enrolled. Participants were randomly assigned to the experimental and control groups in a 1:1 ratio using random numbers generated in Microsoft Excel, resulting in 350 participants in each group.

Some participants in the experimental and control groups did not complete one or more of the pretest, posttest, or follow-up assessments. In addition, some participants in the experimental group withdrew before completing the eight-week intervention. Participants who did not complete all three assessments and, in the experimental group, those who did not complete the entire intervention were excluded from the final analyses. Accordingly, the final analyses were based on participants who completed all three measurement occasions and met the applicable intervention-completion criterion.

A total of 626 pre-service teachers completed the pretest assessment, including 294 participants in the experimental group and 332 in the control group. At posttest, the number of participants decreased to 559, comprising 271 participants in the experimental group and 288 in the control group. A total of 480 participants completed the follow-up assessment, including 248 participants in the experimental group group and 232 in the control group. Of these participants, 439 completed all three measurement occasions and met the analytical inclusion criteria; their data were included in the final analyses (experimental group: $n = 231$; control group: $n = 208$). The final analytical sample was 17.8% male ($n = 78$) and 82.2% female ($n = 361$). Of the participants, 27.8% attended Firat University ($n = 122$), 25.5% attended Kahramanmaraş Sütçü İmam University ($n = 112$), 23.7% attended İnönü University ($n = 104$), and 23.0% attended Dicle University ($n = 101$).

From pretest to posttest, the attrition rate was 7.8% ($n = 23$) in the experimental group and 13.3% ($n = 44$) in the control group. From pretest to follow-up, the corresponding attrition rates were 15.6% ($n = 46$) and 30.1% ($n = 100$), respectively. When completion of all three assessments and fulfillment of the analytical inclusion criteria were considered jointly, the reduction from the pretest sample to the final analytical sample was 21.4% ($n = 63$) in the experimental group and 37.3% ($n = 124$) in the control group. To assess potential attrition-related bias, baseline scores were compared between participants included in the final analyses ($n = 439$) and those who completed the pretest but were subsequently excluded ($n = 187$). No statistically significant differences were found in CMSE, $t = 1.12$, $p = .262$, $d = 0.10$; ATTP, $t = 1.34$, $p = .181$, $d = 0.12$; OA, $t = 0.46$, $p = .645$, $d = 0.04$; or RSE, $t = 1.83$, $p = .069$, $d = 0.16$. The small effect sizes, ranging from $d = 0.04$ to 0.16 , indicated that exclusion from the final analyses was not associated with substantial systematic differences in the baseline variables examined.

Data Collection Instruments

Four instruments were used to measure pre-service teachers' CMSE, ATTP, OA and RSE. Detailed information on each instrument is presented below.

Classroom Management Self-Efficacy Scale. Developed by Elçiçek et al. [38], the scale consists of 30 items across five dimensions. The items are rated on a 5-point Likert-type scale ranging from 1 (“highly inadequate”) to 5 (“highly adequate”). Total scores range from 30 to 150, with higher scores indicating stronger perceived self-efficacy in classroom management. In the present study, Cronbach's alpha coefficients for the overall scale were .919 at pretest, .932 at posttest, and .921 at follow-up.

Attitude Toward the Teaching Profession Scale. Developed by Gürhan [39], the scale consists of 27 items across three dimensions. The items are rated on a 5-point Likert-type scale ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). Total scores range from 27 to 135, with higher scores indicating more positive ATTP. In the present study, Cronbach’s alpha coefficients for the overall scale were .921 at pretest, .925 at posttest, and .930 at follow-up.

Occupational Anxiety Scale. Adapted by Saban et al. [5] based on the theoretical framework proposed by Borich [40], the scale consists of 45 items across three dimensions. The items are rated on a 5-point Likert-type scale ranging from 1 (“not anxious at all”) to 5 (“very anxious”). Total scores range from 45 to 225, with higher scores indicating greater occupational anxiety. In the present study, Cronbach’s alpha coefficients for the overall scale were .983 at pretest, .984 at posttest, and .985 at follow-up.

Reality Shock Expectation Scale. Developed by Kim and Cho [41] and adapted into Turkish by Özdemir and Büyükgöze [42], the scale consists of nine items representing a single dimension. The items are rated on a 7-point Likert-type scale ranging from 1 (“not at all true”) to 7 (“completely true”). Total scores range from 9 to 63, with higher scores indicating stronger expectations of reality shock. In the present study, Cronbach’s alpha coefficients for the overall scale were .873 at pretest, .901 at posttest, and .895 at follow-up.

Intervention Program and Implementation Process

The intervention process was designed and implemented in accordance with the MC-AI-ELE model developed to reduce the challenges that pre-service teachers may encounter during the transition to the teaching profession. The intervention program and implementation process were structured based on the ADDIE instructional design model [43], and the analysis, design, development, implementation, and evaluation phases were conducted systematically. During the analysis phase, the needs of pre-service teachers were identified through a review of the literature [44] and findings obtained from semi-structured interviews conducted with 31 teachers who had been actively working in the profession for no more than 10 years [45]. During the design phase, learning objectives, content structure, and assessment processes were planned, whereas the development phase involved the creation of module content and the digital learning environment [46, 47]. In the implementation phase, the eight-week intervention process was conducted, and in the evaluation phase, the effectiveness of the system was examined through pretest, posttest, and follow-up measurements.

The MC-AI-ELE model was grounded in experiential learning theory [27], reflective learning theory [34], and social cognitive theory [35]. Within this framework, the intervention aimed to support pre-service teachers’ professional self-efficacy by enabling engagement with authentic professional experiences, participation in reflective thinking processes, and involvement in structured learning experiences.

During the analysis and development phases of the ADDIE model, module content was developed to address situations that pre-service teachers may encounter during their early professional experiences. Case-based simulations and an AI-supported digital assistant were developed, while mentoring support and self-assessment systems were integrated into the educational portal. Accordingly, the digital learning environment consisted of five integrated components: (1) a modular learning system, (2) an AI-supported digital assistant, (3) case-based simulations, (4) a self-assessment system, and (5) mentoring support.

The case-based simulations were designed to support the concrete experience and reflective observation stages of Kolb’s [27] experiential learning cycle by providing opportunities to engage with authentic professional situations. The AI-supported digital assistant aligned with Bandura’s [35] social cognitive theory, particularly regarding observational learning and self-efficacy development, by providing immediate feedback and instructional guidance. The self-assessment system and mentoring support were structured in accordance with Schön’s [34] reflective practitioner approach and aimed to encourage pre-service teachers to critically evaluate their own learning processes and develop their professional identities.

The system was developed as a web-based (<https://ogretmenadaylari.firat.edu.tr>) and mobile-compatible learning environment, enabling pre-service teachers to progress asynchronously at their own pace. In addition, role-based authorization mechanisms and cloud-based data infrastructure were integrated into the system. An overview of the system structure, user flow, and core components is presented in Fig. 2.

The instructional content used in the MC-AI-ELE system was organized into eight modules: (1) Turkish Education System, (2) Türkiye Century Education Model, (3) Regional Differences in Education, (4) Digital Transformation in Education, (5) Classroom Management, (6) Measurement and Evaluation in Education, (7) Occupational Anxiety, and (8) Crisis Management. Each module included structured content designed to address professional situations that pre-service teachers may encounter during their transition to the teaching profession. The modules incorporated AI-generated instructional videos, digital documents developed by the researchers, and interactive learning activities.

The digital assistant used in the study was designed as a domain-specific chatbot trained using content developed by the researchers. Throughout the MC-AI-ELE process, participants were able to ask questions to the digital assistant, receive explanations related to module content, and access supportive feedback regarding simulation-based situations. By analyzing participant queries, the digital assistant generated contextually relevant responses and guidance. Through this process, the intervention aimed to support pre-service teachers' problem-solving, pedagogical reasoning, and reflective thinking processes. In addition, through the "Ask Mentor" section integrated into the system, participants were able to communicate with expert mentors via messaging and receive individualized feedback throughout the intervention process. This structure was designed to enable pre-service teachers to benefit from both AI-supported immediate assistance and human-centered mentoring processes.

The case-based simulations were developed within a Unity-based application environment. Simulation-supported activities were implemented in the modules on Regional Differences in Education, Classroom Management, Occupational Anxiety, and Crisis Management. These modules were selected because they required participants to engage directly in decision-making, problem-solving, communication, and situational reasoning processes. In contrast, the remaining modules primarily focused on conceptual knowledge, theoretical content, and cognitive awareness; therefore, information-based digital materials and interactive learning resources were preferred for those modules. During the simulations, participants actively engaged in decision-making processes related to authentic professional situations and evaluated alternative approaches regarding how teachers should respond in specific contexts. Following each simulation activity, pre-service teachers were able to ask questions to the digital assistant, interact with the system, and receive immediate feedback related to the scenarios presented. This process was intended to promote practical awareness and strengthen pedagogical reasoning skills.

At the end of each module, participants' learning levels were evaluated through the "Self-Assessment" section. During this process, online assessments consisting of 20 randomly selected questions were administered using item pools developed by the researchers and reviewed by field experts for content validity. Participants were required to achieve a minimum score of 80% before proceeding to the next module. This mastery criterion was established in accordance with Bloom's mastery learning approach, aiming to support competency-based and progressive learning processes [48, 49].

Prior to the intervention, both online and face-to-face orientation sessions were conducted to support participants' adaptation to the system. During these sessions, participants were informed about the use of the digital assistant, the module structure, simulation-based learning environments, and the self-assessment system. In addition, instructional videos introducing the educational portal were prepared, and technical support was provided throughout the implementation process. These procedures aimed to increase participants' technical and pedagogical readiness for the intervention process.

In the first stage of the evaluation process, pretest measurements were administered online using electronic forms containing the study instruments. Following the pretest phase, the eight-week MC-AI-ELE intervention was implemented asynchronously with participants in the experimental group. Participants were instructed to complete the modules at their own pace. Throughout the intervention process, pre-service teachers were able to repeatedly access module content, rewatch instructional videos, receive support from the digital assistant, and communicate with mentors. In addition, participants' module progress, viewed videos, downloaded documents, and digital interaction processes were systematically logged through the system in order to monitor participation and learning progression. Participants in the control group continued with the existing instructional process and did not receive any intervention related to the MC-AI-ELE model.

Following the completion of the intervention process, posttest measurements were administered, and follow-up assessments were conducted 45 days later. The collected data were analyzed to evaluate the short- and medium-term effects of the MC-AI-ELE model.

Data Analysis

Before analyzing the pretest, posttest, and follow-up scores of the experimental and control groups, the assumptions underlying the parametric tests were examined. The normality assumption was evaluated by jointly considering skewness and kurtosis coefficients, Q–Q plots, and histograms. All analyses were conducted using IBM SPSS Statistics version 22. Information on the distributional characteristics of the data and the assumption checks is presented in Table 1.

Table 1
Distribution and assumption checks

Scale	Time	Skewness Range	Kurtosis Range	Levene's F; p	Mauchly's W; p	GG ϵ
CMSE	Pretest	[– 0.22; –0.11]	[0.11; 2.48]	0.02; 0.891	0.999; 0.725	0.999
	Posttest	[– 0.61; 0.12]	[0.27; 2.52]	0.15; 0.695	—	—
	Follow-up	[– 0.23; –0.21]	[1.24; 3.31]	0.57; 0.450	—	—
ATTP	Pretest	[– 0.57; –0.53]	[– 0.12; 0.15]	0.00; 0.957	0.993; 0.233	0.993
	Posttest	[– 0.27; 0.03]	[– 1.27; –0.76]	3.82; 0.051	—	—
	Follow-up	[– 0.32; –0.30]	[– 0.98; –0.63]	2.55; 0.111	—	—
OA	Pretest	[– 0.07; 0.09]	[– 0.25; 0.36]	0.48; 0.487	0.998; 0.633	0.998
	Posttest	[– 0.04; –0.04]	[– 0.08; 0.28]	3.10; 0.079	—	—
	Follow-up	[– 0.14; 0.01]	[– 0.13; 0.05]	0.05; 0.831	—	—
RSE	Pretest	[– 0.37; 0.30]	[– 0.11; 0.45]	0.44; 0.507	0.971; 0.001	0.971
	Posttest	[– 0.54; –0.05]	[0.28; 0.67]	1.70; 0.194	—	—
	Follow-up	[– 0.38; –0.08]	[0.27; 0.30]	1.62; 0.203	—	—
Note. The ranges for skewness and kurtosis indicate the lowest and highest cell values in the experimental and control groups. Since the Mauchly results are at the scale level, they are reported only once in the first row. GG = Greenhouse-Geisser.						

Across groups and measurement occasions, skewness coefficients ranged from – 0.608 to 0.299, whereas kurtosis coefficients ranged from – 1.265 to 3.311. According to George and Mallery [50], skewness and kurtosis values between – 2 and + 2 indicate that the assumption of normality is satisfied. The skewness values were close to zero, most kurtosis values remained within acceptable limits, and visual inspection of the Q–Q plots and histograms showed that the observations were largely distributed around the theoretical normal distribution line. Collectively, these findings indicated no substantial departures from normality that would preclude the use of parametric analyses. Considering these findings alongside the sample size and the robustness of mixed ANOVA to moderate deviations from normality, the data were considered to have adequate distributional properties for parametric analysis [51].

The assumption of homogeneity of variance was examined using Levene's test for each dependent variable at each measurement occasion. The *F* values obtained from Levene's tests ranged from 0.003 to 3.821, with *p* values ranging from .051 to .957. The nonsignificant results across all tests (*p* > .05) indicated that the variances of the experimental and control groups were homogeneous at the pretest, posttest, and follow-up measurements. The sphericity assumption for the repeated measures was assessed using Mauchly's test. Standard degrees of freedom were used for variables that satisfied the sphericity assumption, whereas the Greenhouse–Geisser correction was applied to RSE, the only variable for which this assumption was violated [52, 53].

To control the potential inflation of the familywise Type I error rate arising from the simultaneous testing of multiple dependent variables, the Holm sequential correction was applied to the *p* values obtained for the group × time interactions across the four

dependent variables. This method is a stepwise procedure that controls the error rate in multiple testing while retaining relatively high statistical power [54].

A 2×3 mixed-design analysis of variance was conducted to determine whether pre-service teachers' CMSE, ATTP, OA, and RSE scores differed as a function of the group $\times$ time interaction. Mixed-design ANOVA enables comparisons of changes over time between groups in experimental designs that include at least one between-subjects factor and one within-subjects factor [55]. Group (experimental and control) was specified as the between-subjects factor, and measurement time (pretest, posttest, and follow-up) was specified as the within-subjects factor. For each dependent variable, the main effects of group and time and the group $\times$ time interaction effect were examined. Holm-adjusted pairwise comparisons were conducted to identify the sources of statistically significant effects. The results were reported using the F statistic, degrees of freedom, p value, and partial eta squared (η^2) as the effect-size measure. In addition, the Aligned Rank Transform (ART) procedure was performed to assess the robustness of the group $\times$ time interaction findings to deviations from normality, with pseudo- η^2 reported as the effect-size measure [56, 57].

Results

This section reports the descriptive statistics, mixed-design ANOVA results, and ART findings from the robustness analysis, respectively. The means and standard deviations of the experimental and control groups' pretest, posttest, and follow-up scores are presented in Table 2.

Table 2
Means and standard deviations of the pretest, posttest, and follow-up scores for the experimental and control groups

Scale	Group	Pretest M (SD)	Posttest M (SD)	Follow-up M (SD)
CMSE	Experimental	3.65 (0.50)	3.78 (0.56)	3.70 (0.48)
	Control	3.68 (0.46)	3.63 (0.50)	3.67 (0.49)
ATTP	Experimental	3.97 (0.61)	3.91 (0.65)	3.89 (0.62)
	Control	4.00 (0.60)	3.75 (0.69)	3.91 (0.68)
OA	Experimental	2.91 (0.85)	2.68 (0.87)	2.81 (0.87)
	Control	2.83 (0.85)	2.88 (0.81)	2.97 (0.88)
RSE	Experimental	4.46 (1.11)	4.37 (1.18)	4.43 (1.16)
	Control	4.50 (1.01)	4.43 (1.04)	4.55 (1.05)
Note. CMSE = Classroom Management Self-Efficacy; ATTP = Attitude Toward the Teaching Profession; OA = Occupational Anxiety; RSE = Reality Shock Expectation.				

Table 2 presents the means and standard deviations for the experimental and control groups at the pretest, posttest, and follow-up measurements. In the experimental group, the mean CMSE score increased from pretest to posttest (from 3.65 to 3.78) and subsequently decreased to 3.70 at follow-up. In the control group, the corresponding mean scores were 3.68 at pretest, 3.63 at posttest, and 3.67 at follow-up. The mean ATTP scores in the experimental group gradually decreased across the three measurement occasions, from 3.97 to 3.91 and then to 3.89. In the control group, the mean ATTP score decreased from 4.00 at pretest to 3.75 at posttest and subsequently increased to 3.91 at follow-up. For OA, the mean score in the experimental group decreased from 2.91 at pretest to 2.68 at posttest and increased to 2.81 at follow-up. In contrast, the mean OA score in the control group increased from 2.83 at pretest to 2.88 at posttest and then to 2.97 at follow-up. The mean RSE score in the experimental group decreased from 4.46 at pretest to 4.37 at posttest and increased to 4.43 at follow-up. Similarly, the mean RSE score in the control group decreased from 4.50 at pretest to 4.43 at posttest and subsequently increased to 4.55 at follow-up. These descriptive findings indicate that the patterns of change varied across variables and groups. A 2×3 mixed-design ANOVA was conducted to determine whether these changes were statistically significant as a function of group and time. Each

dependent variable was analyzed separately in terms of the main effects of group and time and the group $\times$ time interaction, and the results are presented in Table 3.

Table 3
Results of a 2 $\times$ 3 mixed-design ANOVA for scale mean scores

Scale	Effect	<i>F</i>	<i>p</i>	ηp^2	Holm <i>p</i>
CMSE	Group	1.72	0.190	—	—
	Time	1.43	0.240	—	—
	Group $\times$ Time	5.58	0.004*	0.013	0.016*
ATTP	Group	0.55	0.459	—	—
	Time	9.00	< .001*	—	—
	Group $\times$ Time	4.37	0.013*	0.010	0.026*
OA	Group	2.26	0.134	—	—
	Time	3.42	0.033*	—	—
	Group $\times$ Time	4.98	0.007*	0.011	0.021*
RSE	Group	0.88	0.348	—	—
	Time	1.24	0.288	—	—
	Group $\times$ Time	0.21	0.806	0.000	0.806
Note. Greenhouse-Geisser-corrected values are presented for the RSE's time and group $\times$ time effects. The Holm <i>p</i> -value indicates only the group $\times$ time correction across scales. * <i>p</i> < .05.					

As shown in Table 3, the group $\times$ time interaction was statistically significant for CMSE, $F = 5.58$, $p = .004$, $\eta p^2 = .013$, Holm-adjusted $p = .016$; ATTP, $F = 4.37$, $p = .013$, $\eta p^2 = .010$, Holm-adjusted $p = .026$; and OA, $F = 4.98$, $p = .007$, $\eta p^2 = .011$, Holm-adjusted $p = .021$. In contrast, the group $\times$ time interaction was not significant for RSE, $F = 0.21$, $p = .806$, $\eta p^2 = .000$. Post hoc pairwise comparisons were conducted to examine the patterns underlying the significant interactions.

For CMSE, the experimental group demonstrated a significant increase from pretest to posttest (mean difference = -0.14 , Holm-adjusted $p = .004$, Cohen's $d = -0.216$), followed by a nonsignificant decrease from posttest to follow-up (mean difference = -0.05 , Holm-adjusted $p = .197$, Cohen's $d = -0.085$). For ATTP, significant changes were observed in the control group. The control group's scores decreased significantly from pretest to posttest (mean difference = 0.25 , Holm-adjusted $p < .001$, Cohen's $d = 0.337$) and increased significantly from posttest to follow-up (mean difference = -0.15 , Holm-adjusted $p = .013$, Cohen's $d = -0.191$). In the experimental group, the decrease from pretest to posttest was not significant (mean difference = 0.06 , Holm-adjusted $p = .377$, Cohen's $d = 0.087$), nor was the change from posttest to follow-up (mean difference = 0.02 , Holm-adjusted $p = .676$, Cohen's $d = 0.028$).

For OA, the experimental group's scores decreased significantly from pretest to posttest (mean difference = 0.22 , Holm-adjusted $p = .003$, Cohen's $d = 0.221$). However, the change from posttest to follow-up was not statistically significant (mean difference = -0.13 , Holm-adjusted $p = .096$, Cohen's $d = -0.131$). For RSE, the experimental group showed a nonsignificant decrease from pretest to posttest (mean difference = 0.09 , Holm-adjusted $p = 1.000$, Cohen's $d = 0.062$). Although the scores subsequently increased from posttest to follow-up, this change was also not significant (mean difference = -0.06 , Holm-adjusted $p = 1.000$, Cohen's $d = -0.048$).

The results of the ART analysis conducted to assess the robustness of the mixed-design ANOVA findings are presented in Table 4.

Table 4
Group × Time interaction results in the ART analysis

Scale	<i>F</i>	<i>p</i>	Pseudo η^2	Holm <i>p</i>
CMSE	8.35	< .001*	0.019	0.001*
ATTP	4.71	0.009*	0.011	0.019*
OA	5.16	0.006*	0.012	0.018*
RSE	0.36	0.689	0.001	0.689
Note. * <i>p</i> < .05.				

The ART analysis results presented in Table 4 revealed a pattern that was generally consistent with the mixed-design ANOVA findings. The group × time interaction was statistically significant for CMSE, $F = 8.35$, Holm-adjusted $p < .001$, pseudo- $\eta^2 = .019$; ATTP, $F = 4.71$, Holm-adjusted $p = .019$, pseudo- $\eta^2 = .011$; and OA, $F = 5.16$, Holm-adjusted $p = .018$, pseudo- $\eta^2 = .012$. In contrast, the group × time interaction was not significant for RSE, $F = 0.36$, Holm-adjusted $p = .689$, pseudo- $\eta^2 = .001$. These results indicate that the group × time interaction findings obtained from the primary analyses were largely replicated using an alternative analytical approach, providing additional evidence for the robustness of the results.

Discussion

This study examined the effects of the eight-week MC-AI-ELE intervention on pre-service teachers' CMSE, OA, ATTP, and RSE. The findings showed significant changes in CMSE and OA between the pretest and posttest, although these changes were not maintained at follow-up. No significant change in ATTP was observed in the experimental group, whereas significant changes occurred in the control group. Furthermore, neither group demonstrated a significant change in RSE.

A significant change in CMSE favoring the experimental group was observed from pretest to posttest; however, this change was not maintained at follow-up. According to self-efficacy theory, mastery experiences, observational learning, social persuasion, and physiological and emotional states play important roles in the development of individuals' efficacy beliefs [58]. Research involving pre-service and early-career teachers has also shown that supportive practices such as modeling, feedback, and reflection can contribute to the development of self-efficacy [59]. In particular, recent findings have further supported the role of reflective activities in enhancing teacher self-efficacy [60]. From this perspective, the "Self-Evaluation" component of the intervention may have supported reflective learning by enabling pre-service teachers to review the decisions they made during case-based simulations and reflect on their own approaches. In addition to this reflective process, the post-intervention increase observed in the experimental group may have been associated with opportunities to make decisions and solve problems in realistic professional situations, as well as with feedback provided by the AI-supported digital assistant and expert mentors. However, the failure to maintain this improvement at follow-up may be attributable to the discontinuation of structured support and feedback after the intervention and to the limited opportunities available for participants to continue engaging in similar experiences that could reinforce their efficacy beliefs. This finding suggests that sustained improvement in CMSE may require repeated opportunities for practice, feedback, and reflection that reinforce efficacy beliefs rather than a one-time intervention.

Another finding was that OA decreased significantly from pretest to posttest in the experimental group, although this reduction was not maintained at follow-up. Pre-service teachers' occupational anxiety has been associated with classroom management, perceived inadequacy, and uncertainty arising from actual teaching experiences [61, 62]. The reduction observed in this study may have resulted from opportunities to make decisions, solve problems, and evaluate alternative solutions through case-based simulations reflecting authentic professional challenges, such as regional differences, classroom management, occupational anxiety, and crisis management. Indeed, realistic and structured learning experiences have been shown to support pre-service teachers' preparation for professional situations [63]. The explanations and guidance provided by the AI-supported digital assistant throughout the intervention may also have helped participants evaluate the problems they encountered and perceive uncertainty as more manageable. However, the absence of a sustained effect at follow-up may be related to the discontinuation of structured practice and support after the intervention and the lack of similar professional experiences through which the

initial gains could be reinforced. Evidence indicating that the absence of continued practice and support after an intervention may contribute to the weakening of short-term gains over time also supports this interpretation [64]. Accordingly, structured experiences may be beneficial in reducing OA in the short term, but similar experiences may need to be repeated throughout teacher education to sustain these gains.

Regarding ATTP, scores decreased from pretest to posttest in both the experimental and control groups. At follow-up, the decline continued in the experimental group, whereas the control group's scores increased relative to the posttest. ATTP may be influenced not only by experiences related to performing teaching duties but also by factors such as the social status of the profession, working conditions, career expectations, and individual motivation. They may therefore be associated with multiple psychosocial constructs [65, 66]. Consequently, an eight-week intervention may not be sufficient to produce short-term changes in ATTP, which may not be directly altered by professional training provided during teacher education. Previous studies have similarly reported that short-term professional training received by pre-service teachers does not produce significant changes in their ATTP [67, 68]. This finding suggests that ATTP may be only moderately responsive to short-term educational interventions or interventions focusing on specific professional skills. Nevertheless, the modest decline in the experimental group's ATTP scores from pretest through follow-up indicates that the intervention did not produce the anticipated positive change in attitudes toward teaching. The marked decrease observed in the control group at posttest and its partial reversal at follow-up suggest that attitudes may have been influenced by academic, professional, or contextual conditions specific to the measurement period. Because these factors were not directly measured in the present study, this pattern should not be interpreted as an intervention effect.

Another important finding was the nonsignificant group $\times$ time interaction for RSE. Reality shock arises not merely from prior awareness of the difficulties associated with teaching but from the discrepancy between the expectations developed during teacher education and the actual working conditions encountered after entering the profession [9, 69]. RSE may therefore represent a context-sensitive construct that responds only modestly to short-term structured learning and feedback and is primarily reshaped within authentic school contexts, where the full responsibilities of the teaching role are assumed. Although pre-service teachers spend time in schools as part of their teaching practicum, these experiences are generally limited in duration, occur under mentor supervision, and do not require them to assume the full range of teachers' institutional responsibilities. Reality shock, by contrast, becomes particularly salient when teachers must independently manage a classroom, assume responsibility for the consequences of instructional decisions, and simultaneously contend with workload, time pressure, parent and administrator expectations, and the organizational conditions of the school [9, 10]. Although the case-based simulations used in this study enabled participants to become familiar with such situations and consider possible solutions, they may not have fully reproduced the emotional, relational, and institutional pressures generated by sustained interactions with actual students and other school stakeholders. The absence of a significant change may therefore reflect not so much a limitation of the intervention itself as the relative resistance of RSE to change before the actual transition into the profession.

In Türkiye, prospective teachers must take a centralized teacher appointment examination and rank within the available appointment quotas. In 2026, 369,038 candidates took the teacher appointment examination [70]. The large number of candidates, coupled with the limited appointment quotas determined according to staffing needs, reflects the intense competition and employment uncertainty surrounding entry into the teaching profession [71]. These conditions constitute an important contextual factor that may shape pre-service teachers' attitudes toward the profession and their expectations of actual school life. In such a context, participants may have viewed school realities as part of a distant and hypothetical future rather than as an immediate and certain professional experience. Because this explanation was not directly examined in the present study, it should be regarded not as a causal conclusion but as a contextual interpretation to be tested in future research using variables such as appointment expectations, employment uncertainty, and perceived likelihood of appointment. Longitudinal investigations of RSE across the transition from teacher candidacy to entry into the profession, together with the integration of simulation-based interventions with extended school experience and early-career mentoring, may provide more informative findings.

Considered collectively, the findings demonstrate the potential of a multi-component, AI-supported learning environment to strengthen pre-service teachers' preparation for the profession while also showing that intervention effects vary according to the nature of the outcome and the timing of measurement. The short-term changes observed in constructs more directly associated with practice, feedback, and problem-solving experiences, particularly CMSE and OA, underscore the importance of providing structured preparation environments in which pre-service teachers can encounter professional problems, reflect on the consequences of their decisions, and receive support when needed. In contrast, the limited changes in constructs more strongly embedded in social, institutional, environmental, and professional contexts, such as ATTP and RSE, indicate that short-term digital or simulation-based interventions alone may not transform the full range of perceptions and expectations associated with teaching. The principal contribution of this study is therefore to demonstrate that the developed portal functions not merely as a medium for delivering instructional content but as an integrated preparation model that combines modular learning content, simulations reflecting authentic professional situations, modular assessment processes, an AI-supported digital assistant, and mentoring support to help bridge the gap between theoretical knowledge and professional practice. Nevertheless, the weakening of some gains at follow-up indicates that pre-service teachers' professional development should be supported through continuous practice, feedback, and school-based experiences. Accordingly, teacher education should not be limited to courses designed solely to impart knowledge and skills; rather, it should be organized within a holistic structure that integrates digital learning environments with teaching practice and early-career support, enabling prospective teachers to engage with professional realities gradually and continuously.

Limitations and Future Research.

The findings of this study should be interpreted in light of several limitations. First, some participants initially randomized to the experimental and control groups did not participate in one or more of the pretest, posttest, or follow-up measurements, and some participants in the experimental group did not complete the eight-week intervention. Consequently, the analyses were conducted using data from participants who completed all three measurements and fulfilled the intervention requirements. The absence of significant baseline differences between participants who were included in and excluded from the final analyses, together with the small effect sizes, provided no evidence of substantial systematic attrition in the variables examined. Nevertheless, the possibility of selection bias cannot be entirely excluded because attrition rates differed between the experimental and control groups and complete-case analyses may have partially weakened the balance initially achieved through randomization. Future studies may support stronger causal inferences by employing strategies to improve participant retention, systematically documenting reasons for attrition, and, where possible, applying intention-to-treat analyses and appropriate missing-data methods.

Second, the intervention lasted eight weeks, and the follow-up measurement was conducted approximately 45 days after its completion. Although this period allowed the short- and medium-term effects of the intervention to be examined, it was insufficient to determine whether the gains were maintained over the longer term. Indeed, the failure to maintain the posttest changes in CMSE and OA at follow-up highlights the need for longer-term evidence regarding the sustainability of the intervention effects. Future studies could use longer follow-up intervals, such as six months and one year, and assess participants' development after they enter the profession to determine the intervention's enduring effects on the transition to teaching.

Third, although the asynchronous delivery of the intervention provided participants with flexibility in terms of time and learning pace, the duration of system use, frequency of access to the content, repetition of simulations, number of questions submitted to the digital assistant, and extent of engagement with mentoring support may have varied across participants. Although system interactions were recorded, these data were not analyzed in the present study as indicators of intervention dosage or quality of engagement. Therefore, participants assigned to the same intervention group cannot be assumed to have engaged with the learning environment to an equal extent. Future research could link system logs and learning analytics with outcome variables to identify the patterns of use associated with stronger gains.

Fourth, MC-AI-ELE was a multi-component intervention integrating modular content, case-based simulations, an AI-supported digital assistant, modular assessment, and mentoring. Although the research design was suitable for evaluating the overall effect of the intervention, it did not permit identification of the specific component, or interaction among components,

responsible for the observed changes. The findings should therefore not be interpreted as evidence of the independent effect of the digital assistant or any other individual component. Future research could employ factorial designs, multi-arm experimental studies, or component analyses to compare the independent and combined effects of simulations, the digital assistant, and human mentoring. Qualitative and quantitative analyses of the questions submitted to the digital assistant, the responses it generated, and patterns of human–AI interaction could also help clarify the mechanisms through which the intervention produces its effects.

Fifth, the study findings were based on scores obtained from self-report measures. Although self-report instruments are useful for assessing participants' perceptions, attitudes, and expectations, they may be affected by social desirability, response tendencies, and participants' limited ability to evaluate their own competencies accurately. Therefore, the extent to which the observed increase in CMSE and decrease in OA translated into actual classroom behavior and teaching performance could not be directly determined. Future studies could supplement self-report measures with classroom observations, performance-based tasks, simulation performance, teaching-practicum evaluations, system-use data, and qualitative interviews, thereby enabling intervention effects to be corroborated across multiple data sources.

Sixth, the study measured pre-service teachers' expectations of reality shock rather than the reality shock actually experienced after entering the profession. Because the participants had not yet assumed the full responsibilities of the teaching role, the findings should not be generalized to actual experiences of reality shock. Future longitudinal research following pre-service teachers from the period before graduation through their first years in the profession could clarify the relationship between anticipated reality shock and the reality shock experienced after entering teaching.

Finally, the sample consisted of final-year pre-service teachers enrolled in faculties of education at four public universities in Türkiye. Although the universities represented different regional contexts and thereby contributed to sample diversity, the findings cannot be directly generalized to other year levels, teaching specializations, institution types, or education systems. Future research using more balanced samples drawn from different teaching specializations, year levels, university types, and cultural contexts could help determine the participant groups and conditions under which the intervention is most effective.

Conclusion

This study examined the effects of an eight-week multi-component AI-supported experiential learning intervention on pre-service teachers' CMSE, OA, ATTP, and RSE. Following the intervention, the experimental group demonstrated an increase in CMSE and a decrease in OA; however, these changes were not maintained at follow-up. These findings suggest that integrating AI-supported applications with case-based simulations, problem-solving activities, feedback, modular assessment, and reflective processes may strengthen pre-service teachers' perceptions of professional competence and reduce their occupational anxiety in the short term.

Nevertheless, the intervention did not produce effects of the same direction or magnitude across all the variables examined. No significant intervention effect was found for RSE. Although a significant group $\times$ time interaction was identified for ATTP, the experimental group did not demonstrate a significant improvement in the expected direction. These differing results suggest that outcomes more directly associated with practice and feedback processes, such as CMSE and OA, may be more responsive to structured learning interventions. In contrast, changes in constructs influenced by broader social, institutional, and professional contexts, such as ATTP and RSE, may require longer-term interventions and authentic school experiences.

The present study is important in that it conceptualized AI not merely as a stand-alone technology for delivering information but as part of an integrated teacher education environment incorporating modular content, case-based simulations, a digital assistant, modular assessment, and mentoring. The findings indicate that such environments have the potential to support the transition between teacher education and the actual demands of the profession. However, short-term digital interventions alone should not be expected to produce enduring and comprehensive professional transformation. Integrating AI-supported experiential learning environments with teaching practice, authentic school experiences, and sustained early-career mentoring may help pre-service teachers enter the profession feeling better prepared and more adequately supported.

Declarations

Data Availability Statement

The datasets generated and analysed during the current study are not publicly available because they contain information obtained from human participants and are subject to ethical and confidentiality restrictions. De-identified data may be made available by the corresponding author upon reasonable request, subject to approval by the relevant ethics committee and compliance with applicable data protection requirements.

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Author Contributions

S.K. conceived, supervised, and coordinated the study and finalized the manuscript. M.AL. A.K., and S.P. contributed to the study design and implementation of the experimental training process. M.Y. contributed to the methodology, statistical analyses, and interpretation of the findings. M.I. and M.AY. developed the AI-supported digital assistant. M.E.Ç. developed the simulation-based applications. Y.S. designed and implemented the technical infrastructure and web-based learning platform. E.A. contributed to writing the Introduction, and Y.D. contributed to writing the Discussion. All authors reviewed and revised the manuscript, approved its final version, and agreed to be accountable for their respective contributions.

Competing Interests

The authors declare no competing interests.

Declaration of Artificial Intelligence Use

During the preparation of this manuscript, the authors used a generative artificial intelligence tool solely to support English-language editing, including improvements in grammar, clarity, and readability. The tool was not used to generate research data, conduct statistical analyses, interpret the findings, formulate scientific conclusions, or produce references. All AI-assisted content was critically reviewed, verified, and revised by the authors, who take full responsibility for the accuracy, integrity, and originality of the manuscript.

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Figures

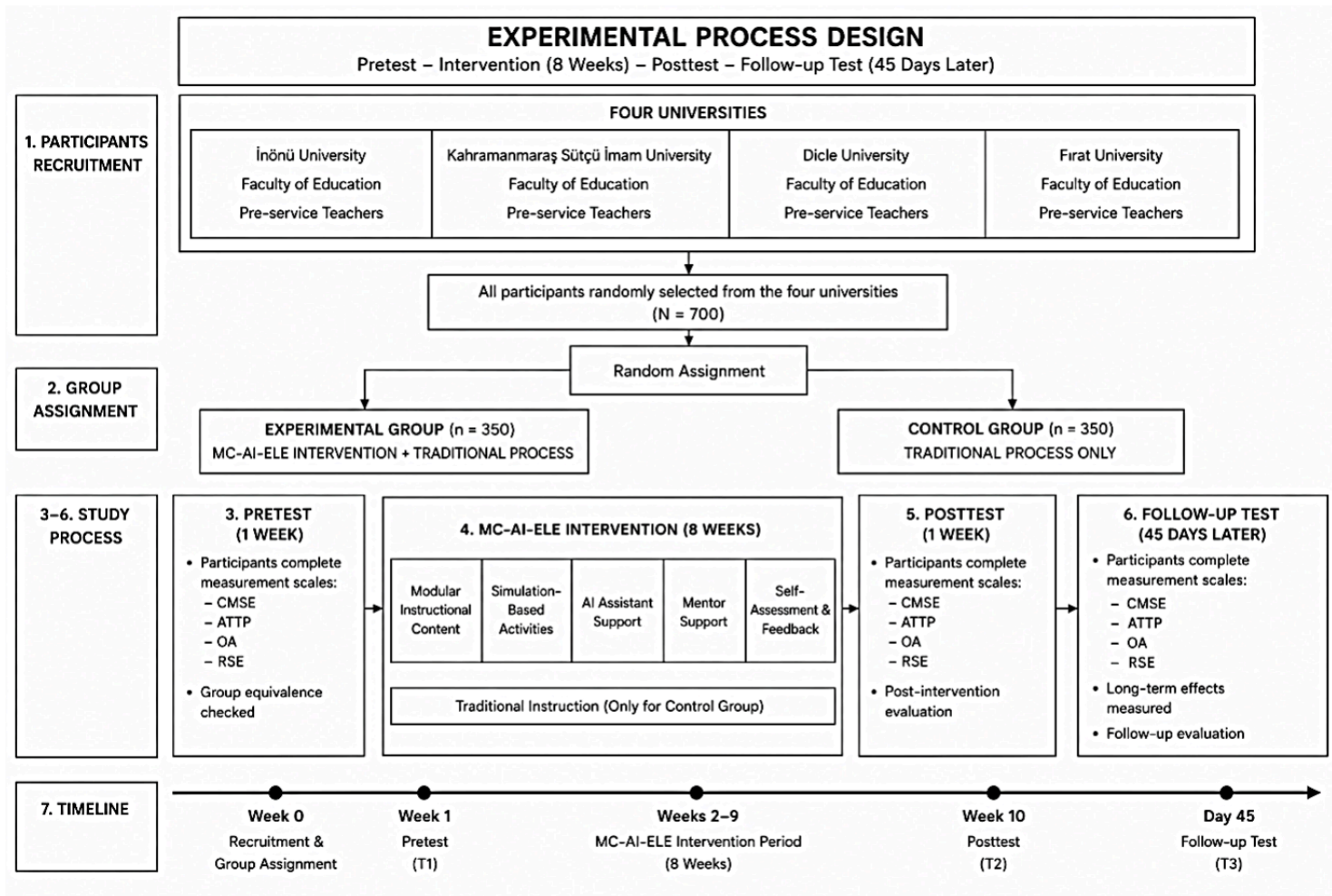


Figure 1

Pretest–Posttest–Follow-up Experimental Design

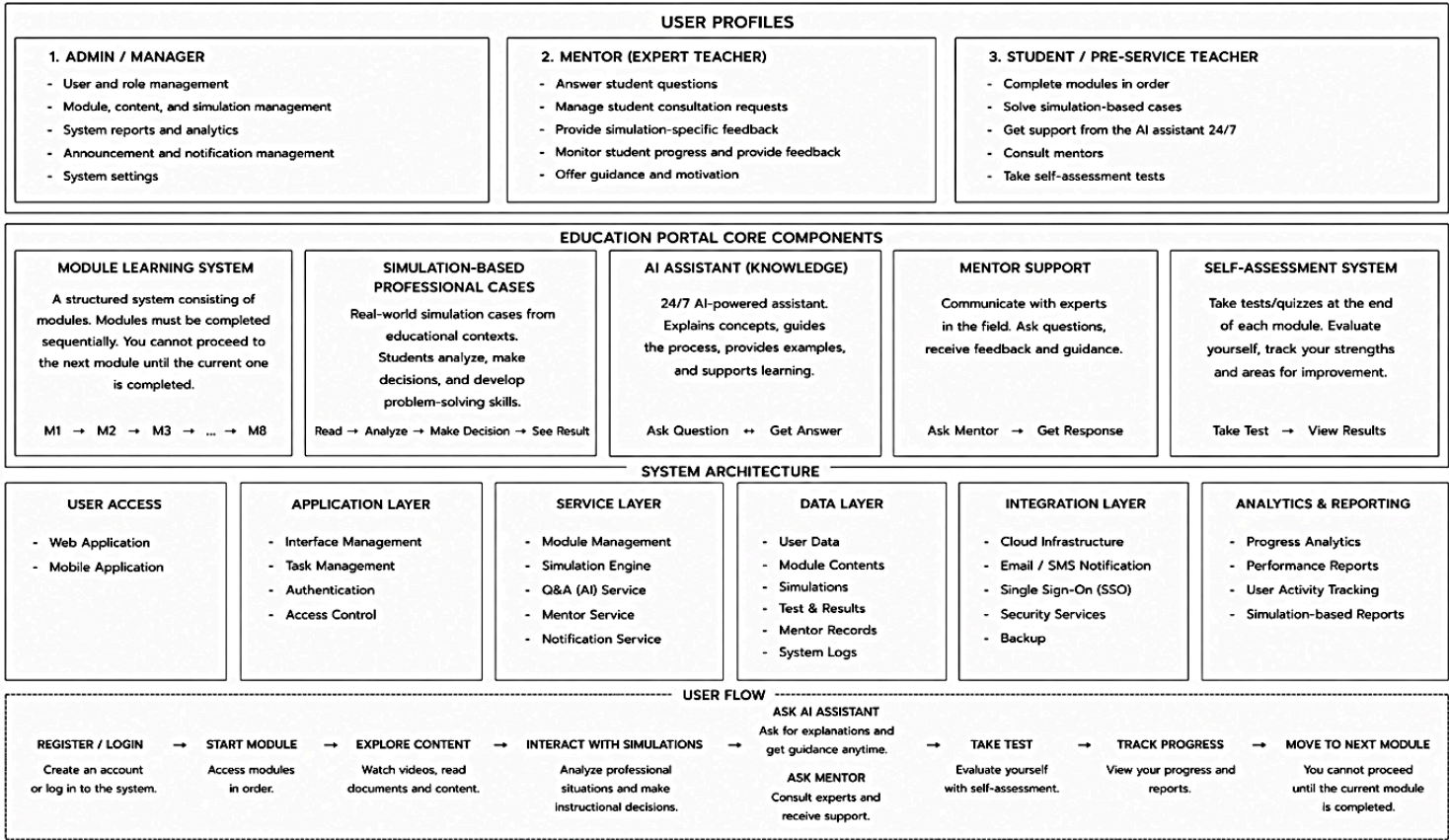


Figure 2

MC-AI-ELE Portal: System Architecture, Core Components, and User Flow

Supplementary Files

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