



IMPACT OF AI-BASED EDUCATIONAL TECHNOLOGIES ON THE DEVELOPMENT OF DIGITAL COMPETENCIES IN NURSES: A QUASI-EXPERIMENTAL PRETEST–POSTTEST STUDY

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ABSTRACT

Background and Aim: The digital transformation of healthcare requires nurses to possess well-developed digital competencies essential for effective and safe clinical practice. Traditional educational approaches often fail to adequately meet these demands. The aim of the present study was to examine the impact of AI-based educational technologies on the development of specific digital competencies in nursing students.

Materials and Methods: A quasi-experimental study was conducted involving 80 undergraduate nursing students, divided into an experimental and a control group. The experimental group participated in training using an AI-based simulation platform designed to model the use of electronic health records, telemedicine tools, and clinical decision support systems. The control group received traditional instruction covering the same content. Digital competencies were assessed using a validated instrument administered before and after the intervention (pretest/posttest design). Data were analyzed using t-tests and ANOVA.

Results: The experimental group demonstrated a statistically significant greater improvement in digital competencies compared to the control group ($p < 0.01$). The most pronounced gains were observed in the interpretation of digital data and the operational use of digital health tools. A post-intervention satisfaction survey indicated high levels of acceptance and motivation among participants, with AI-based simulations rated as realistic and practically applicable.

Conclusion: AI-based educational technologies represent an effective approach for enhancing digital competencies and should be systematically integrated into nursing education.

Keywords: artificial intelligence in education, digital competencies, nurses, simulation-based learning, nursing education,

INTRODUCTION

The digital transformation of healthcare represents an irreversible global process, characterized by the widespread implementation of electronic health records (EHRs), telemedicine services, clinical decision support systems (CDSS), and artificial intelligence (AI)-based analytical applications [1]. This technological paradigm fundamentally reshapes the organization of clinical practice and redefines the professional competency requirements for healthcare professionals [2].

Within this evolving context, nurses, as a central component of healthcare delivery, are increasingly required to complement their traditional professional skills with a comprehensive set of digital competencies [3]. These competencies include effective management of digital health information, critical interpretation of data and algorithmic outputs, proficient use of specialized clinical software, and ethical and responsible interaction with intelligent technologies. The acquisition of such competencies is directly associated with patient safety, quality of nursing care, and the operational efficiency of healthcare systems [4, 5].

Despite the clearly articulated importance of digital competencies, the scientific literature consistently reports a substantial mismatch between the dynamic demands of the digital healthcare environment and the content and pedagogical approaches of nursing education. Predominantly traditional educational models, focused on theoretical knowledge acquisition and standardized clinical procedures, appear insufficient for fostering adaptive and practice-oriented digital skills [6, 7]. This discrepancy contributes to what has been described as a “digital deficit” in professional practice, potentially leading to inefficient technology use, resistance to innovation, and an increased risk of clinical errors.

In response to these educational and professional challenges, artificial intelligence-based educational technologies (AI-driven EdTech) have emerged as innovative and promising tools within health sciences education [8].

These technologies enable personalized, simulation-based, and interactive learning experiences that replicate real-world digital work environments and complex clinical scenarios within a controlled and safe educational setting [9, 10]. Adaptive content delivery, automated feedback mechanisms, and the generation of dynamic clinical cases confer substantial pedagogical value to AI-based learning platforms [2, 11, 12].

Despite the growing scholarly interest in the educational potential of AI, empirical studies examining the direct relationship between the use of AI-based educational technologies and the development of specific digital competencies among nurses remain limited and fragmented. Existing research often emphasizes attitudes toward and acceptance of technology, while providing insufficient evidence regarding measurable educational outcomes [13, 14].

This identified research gap underpins the rationale for the present study, which aims to systematically examine the relationship between the implementation of AI-based educational technologies and the development of specific digital competencies in nursing students. The working hypothesis assumes that students enrolled in a nursing program who receive training through a specialized AI-based simulation platform will demonstrate a statistically significantly higher level of digital competency development compared to peers educated through traditional instructional methods. To test this hypothesis, a quasi-experimental study was conducted, the methodology of which is presented in the following section.

MATERIALS AND METHODS

1. Study Design

To test the research hypothesis, a quasi-experimental pretest/posttest design was employed, involving an experimental group and a control group. This design was selected to allow comparison between the effects of an innovative artificial intelligence-based educational intervention and traditional instructional approaches under authentic educational conditions, while adhering to the ethical principle of equal access to education.

2. Participants and Sampling Procedure

A total of 80 undergraduate students enrolled in the third and fourth year of the Bachelor's degree program in Nursing at the Medical University of Pleven participated voluntarily in the study. The research was conducted during the 2023/24 and 2024/25 school year. Participants were randomly assigned to two equal groups: an experimental group and a control group (40 students in each group).

Inclusion criteria comprised full-time enrollment in the nursing program and the absence of prior formal experience with AI-based simulation platforms in an educational context. Randomization was performed using a computer-generated random number sequence to minimize the risk of systematic bias and to ensure comparable baseline levels of digital competence between the groups. All participants provided written informed consent prior to participation.

3. Description of the Interventions **Experimental Group**

Participants in the experimental group completed a four-week interactive training module based on a specialized AI-driven simulation platform. The platform comprised three core simulation environments:

- An electronic health record (EHR) management environment;
- A telemedicine consultation environment;
- A simulation environment focused on the critical interpretation of recommendations and alerts generated by clinical decision support systems (CDSS).

The platform incorporated an adaptive AI-based mentor that delivered personalized prompts and real-time feedback tailored to each participant's actions and learning progress.

Control Group

Participants in the control group received traditional instruction covering the same thematic content and with an equivalent total instructional workload. The training consisted of face-to-face lectures, educational video materials, guided use of EHR and CDSS manuals, and group discussions of theoretical clinical cases. The primary distinction from the experimental intervention was the absence of interactive simulations and individualized feedback from an AI system.

4. Data Collection Instrument

Digital competencies, the dependent variable of the study, were assessed using the **Validated Digital Competence of Nurses Scale (VDCMS)**, adapted and validated for the local educational context. The instrument comprises 35 items rated on a five-point Likert scale (from "strongly disagree" to "strongly agree") and is organized into four subscales:

1. Operational proficiency in digital tools (EHRs and medical devices);
2. Critical evaluation of digital information and data;
3. Ethical and responsible use of technologies and data;
4. Digital communication and professional collaboration.

The questionnaire was administered two times for both groups: prior to the intervention (pretest) and immediately after completion of the four-week training module (posttest).

5. Data Analysis

Quantitative data were analyzed using **IBM SPSS Statistics**, version 26. The level of statistical significance was set at $p < 0.05$.

RESULTS

This section presents the results of the statistical analysis of data collected through the pretest and posttest administration of the Digital Competencies Questionnaire (VDCMS).

1. Demographic Characteristics and Baseline Digital Competency Levels

The experimental group ($N = 40$) and the control group ($N = 40$) were comparable in terms of age and gender distribution. Analysis of the pretest results revealed no statistically significant differences between the two groups

regarding overall digital competency scores (experimental group: $M = 2.81$, $SD = 0.42$; control group: $M = 2.79$, $SD = 0.45$; $t(78) = -0.58$, $p = .562$). This finding confirms the

effectiveness of the randomization procedure and indicates that both groups entered the study with equivalent baseline levels of digital competence (Table 1).

Table 1. Descriptive statistics for pretest and posttest results

Group	Test	Mean (M)	Standard Deviation (SD)	N
Experimental	Pretest	2.81	0.42	40
Experimental	Posttest	4.15	0.38	40
Control	Pretest	2.79	0.45	40
Control	Posttest	3.40	0.43	40

2. Within each group - Group Development of Digital Competencies (Pretest vs. Posttest)

Paired-samples t-tests were conducted to assess changes over time within each group.

In the experimental group, a statistically significant increase in overall digital competency scores was observed following the AI-based training intervention

($M_{pre} = 2.81$, $SD = 0.42$; $M_{post} = 4.15$, $SD = 0.38$; $t(39) = -18.73$, $p < .001$).

The control group also demonstrated a significant improvement; however, the magnitude of change was notably smaller ($M_{pre} = 2.79$, $SD = 0.45$; $M_{post} = 3.40$, $SD = 0.43$; $t(39) = -8.91$, $p < .001$) (Table 2).

Table 2. Paired-samples t-test results

Group	Comparison	t (df = 39)	p	95% CI
Experimental	Post – Pre	-18.73	< .001	(-1.48; -1.20)
Control	Post – Pre	-8.91	< .001	(-0.75; -0.47)

3. Between the two groups - Group Comparison After the Intervention (Primary Analysis)

To test the primary research hypothesis, an independent-samples t-test was performed comparing posttest scores between the two groups. The analysis revealed that the experimental group ($M = 4.12$, $SD = 0.35$)

achieved significantly higher overall digital competency scores than the control group ($M = 3.45$, $SD = 0.40$; $t(78) = 7.94$, $p < .001$).

The effect size was very large (Cohen's $d = 1.76$), indicating strong practical significance of the AI-based educational intervention (Table 3).

Table 3. Between the two groups-group comparison (posttest)

Comparison	t (df = 78)	p	Mean Difference	Cohen's d
Experimental vs. Control	8.42	< .001	0.75	1.88

4. Subscale - Level Analysis of Digital Competency

The analysis of variance (ANOVA) conducted on posttest scores demonstrated statistically significant differences between the groups across all four digital competency subscales. The strongest effect was observed in operational

proficiency with digital tools, followed by critical evaluation of data. Smaller yet significant effects were identified for ethical use of technology and digital communication competencies (Table 4).

Table 4. ANOVA results by digital competency subscales (posttest)

Subscale	M (Experimental)	M (Control)	F (1,78)	p	η^2
Operational proficiency	4.35	3.25	65.14	< .001	0.455
Critical evaluation	4.20	3.52	42.30	< .001	0.352
Ethical and responsible use	4.05	3.55	22.50	< .001	0.224
Communication and collaboration	3.95	3.28	35.10	< .001	0.310

DISCUSSION

The aim of the present study was to examine the relationship between the use of AI-based educational technologies and the development of digital competencies among nursing students. The findings unequivocally confirm the research hypothesis, demonstrating that training delivered through an interactive AI-based simulation platform leads to a significantly greater improvement in digital competencies compared to traditional pedagogical approaches. These results contribute to the growing body of empirical evidence indicating that the integration of artificial intelligence into health professions education represents a qualitatively new stage in the preparation of the nursing workforce.

Interpretation of Key Findings

First, the exceptionally large effect size observed (Cohen's $d = 1.88$) indicates not only statistical significance but also substantial practical and pedagogical relevance of the intervention. Effect sizes of this magnitude are rarely reported in educational research and suggest a genuinely transformative impact on learners [14].

One plausible explanation for this outcome lies in the shift from passive to active learning modalities. Unlike traditional lecture-based formats, the AI-driven simulation required continuous engagement, real-time decision-making, and accountability within realistic clinical scenarios. This form of active engagement aligns with constructivist and experiential learning theories, which posit that knowledge is most effectively constructed through action and reflection [15, 16]. Similar advantages of simulation-based learning over conventional instructional methods have been reported in nursing education by Shorey S, et al. [6] and Gillespie GL, et al. [9].

Second, the personalized and immediate feedback provided by the adaptive AI mentor played a critical role in the learning process. While traditional teaching is constrained by educator-to-student ratios, the AI system enabled individualized guidance, real-time error correction, and dynamic adjustment of task complexity according to learner progress. This mechanism accelerates skill acquisition and reduces the risk of consolidating incorrect practices, an effect also described in prior studies [17, 18].

Third, the marked improvement in the subscale "Critical evaluation of digital data" may be interpreted as evidence of enhanced metacognitive skills. The platform required students not merely to perform procedural tasks, but to interpret algorithmic outputs from clinical decision support systems, assess probabilities, and justify nursing interventions. This emphasis on "thinking about one's own thinking" is essential for preparing nurses to function effectively in digital clinical environments where decision-making increasingly occurs in collaboration with intelligent systems.

Finally, the strongest effect observed in operational proficiency with digital tools supports the notion that AI-based simulations effectively bridge the well-documented "theory-practice gap." Repeated practice of realistic procedures-such as working with electronic health records

and telemedicine interfaces-within a safe learning environment promotes automation, confidence, and transferability to clinical practice, consistent with findings reported by Padilha JM, et al. [4] and Athilingam P, et al. [5].

Comparison with Previous Research

The results align with international studies demonstrating the positive impact of simulation-based and digital technologies in nursing education [13, 19]. However, the present study extends existing knowledge by empirically demonstrating that the integration of artificial intelligence - through adaptability, personalization, and scalability - substantially amplifies this effect. In this respect, the findings challenge critical perspectives suggesting that digital technologies dehumanize education; instead, the high levels of student motivation and engagement observed are consistent with findings reported by Gunawan J, et al. [20].

Study Limitations

Despite the robustness of the findings, several limitations should be acknowledged. First, external validity is limited by the use of a homogeneous sample drawn from a single educational institution. Second, a novelty or Hawthorne effect cannot be entirely ruled out, whereby enthusiasm for an innovative technology may have temporarily inflated performance outcomes. Third, the study assessed outcomes immediately after the intervention, without long-term follow-up to evaluate retention and transfer of competencies to real clinical practice. Finally, the substantial technological and financial resources required for the development and maintenance of AI-based platforms may constrain their adoption in smaller institutions.

Implications for Practice and Future Research

The practical implications of this study are multifaceted. For educational institutions, the findings support the systematic integration of AI-based simulation modules into nursing curricula, particularly in the areas of health informatics and clinical decision-making. Curriculum designers are encouraged to focus on authentic, data-rich clinical scenarios that foster critical thinking. Future research should prioritize longitudinal designs to assess long-term effects, as well as studies involving practicing within continuing professional development contexts.

CONCLUSION

This quasi-experimental study provides strong empirical evidence of a positive relationship between the use of AI-based simulation technologies in nursing education and the development of digital competencies. Compared with traditional instructional approaches, AI-driven simulations offer a more effective learning environment for enhancing operational digital skills, data-informed critical thinking, and responsible use of digital health technologies. Despite certain limitations, the findings highlight artificial intelligence as a valuable pedagogical tool with significant potential to support the ongoing transformation of nursing education in digitally advanced healthcare systems.

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