The Impact of AI-Assisted Adaptive Training Approach on Radiation Safety Competence in Healthcare Workers

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Abstract

Aim: The aim of this study is to evaluate the effect of an artificial intelligence (AI)- based adaptive training model on the radiation safety competence (knowledge, attitude, and protective behavior) of healthcare professionals.

Method: The research was conducted in a quasi-experimental design with a pre-test–post-test control group. A total of 120 healthcare professionals working with radiation in a university hospital participated in the study. Participants were assigned to experimental (n=60) and control (n=60) groups using computer-assisted random number generation. The experimental group received an AI-assisted adaptive training program for four weeks. The system operated with a rule-based algorithm that dynamically adapted the difficulty level of the content according to predefined success thresholds based on participant performance. The same content was presented to the control group using a traditional classroom-based method. The Radiation Safety Knowledge Test, Attitude Scale, and Protective Behavior Assessment Form were used as data collection tools. Data were evaluated using dependent and independent samples t-test, ANCOVA, and multiple linear regression analyses. The adaptive system operated according to predefined rule-based performance thresholds. The system operated with rule-based adaptive decision logic based on predefined performance thresholds, instead of machine learning-based autonomous model training.

Results: After the intervention, a statistically significant increase was found in the knowledge, attitude, and protective behavior scores of the experimental group compared to the control group ($p<0.001$). ANCOVA results showed that the type of training had a significant and large effect size on the final test competency scores. A significant improvement was observed, especially in the protective behavior dimension.

Conclusion: The AI-assisted adaptive training model offers a promising approach to increasing the radiation safety competency of healthcare professionals. The findings suggest that performance-based adaptive content and individualized feedback can support sustainable behavioral change in radiation safety training. It is recommended that the generalizability of the model be evaluated with larger sample sizes and long-term studies.

Keywords: Radiation safety, artificial intelligence, healthcare professionals, adaptive training, quasi-experimental study.

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Yapay Zeka Destekli Uyarlanabilir Eğitim Yaklaşımının Sağlık Çalışanlarının Radyasyon Güvenliği Yeterliliğine Etkisi

Öz

Amaç: Bu çalışmanın amacı, yapay zeka (YZ) destekli uyarlanabilir eğitim modelinin sağlık profesyonellerinin radyasyon güvenliği yeterlilikleri (bilgi, tutum ve koruyucu davranış) üzerindeki etkisini değerlendirmektir.

Yöntem: Araştırma, ön test–son test kontrollü grup ile yarı deneysel bir tasarımda yürütülmüştür. Üniversite hastanesinde radyasyon ile çalışan toplam 120 sağlık profesyoneli çalışmaya katılmıştır. Katılımcılar bilgisayar destekli rastgele sayı üretimi ile deney (n=60) ve kontrol (n=60) gruplarına atanmıştır. Deney grubuna dört hafta boyunca YZ destekli uyarlanabilir eğitim programı uygulanmıştır. Sistem, katılımcı performansına dayalı önceden tanımlanmış başarı eşiklerine göre içeriğin zorluk düzeyini dinamik olarak uyarlayan kural tabanlı bir algoritma ile çalışmıştır. Kontrol grubuna aynı içerik, geleneksel sınıf tabanlı yöntemle sunulmuştur. Veri toplama araçları olarak Radyasyon Güvenliği Bilgi Testi, Tutum Ölçeği ve Koruyucu Davranış Değerlendirme Formu kullanılmıştır. Veriler bağımlı ve bağımsız örneklem t-testi, ANCOVA ve çoklu doğrusal regresyon analizleri ile değerlendirilmiştir. Uyarlanabilir sistem, önceden tanımlanmış kural tabanlı performans eşiklerine göre çalışmış olup, makine öğrenmesine dayalı özerk model eğitiminden ziyade kural tabanlı uyarlanabilir karar mantığı ile işletilmiştir.

Bulgular: Müdahale sonrası deney grubunun bilgi, tutum ve koruyucu davranış puanlarında kontrol grubuna göre istatistiksel olarak anlamlı bir artış gözlenmiştir ($p<0,001$). ANCOVA sonuçları, eğitim türünün final test yeterlilik puanları üzerinde anlamlı ve büyük etkisi olduğunu göstermiştir. Özellikle koruyucu davranış boyutunda önemli bir gelişme gözlenmiştir.

Sonuç: YZ destekli uyarlanabilir eğitim modeli, sağlık profesyonellerinin radyasyon güvenliği yeterliliklerini artırmak için umut verici bir yaklaşım sunmaktadır. Bulgular, performansa dayalı uyarlanabilir içerik ve bireyselleştirilmiş geri bildirimin radyasyon güvenliği eğitiminde sürdürülebilir davranış değişikliğini destekleyebileceğini önermektedir. Modelin genellenebilirliğinin daha büyük örneklem büyüklükleri ve uzun süreli çalışmalarla değerlendirilmesi önerilmektedir.

Anahtar Sözcükler: Radyasyon güvenliği, yapay zeka, sağlık profesyonelleri, uyarlanabilir eğitim, yarı deneysel çalışma.

Introduction

Ionizing radiation has become an indispensable component of diagnostic and treatment processes in modern healthcare. The increasing use of technology, particularly in interventional radiology, cardiology, nuclear medicine, and radiotherapy applications, brings with it the risk of radiation exposure for healthcare workers. The International Atomic Energy Agency (IAEA, 2018) emphasizes that occupational exposure of healthcare personnel can be controlled through appropriate training and safety culture[1]. Similarly, the European Commission (2014) defines continuous and systematic radiation safety training as a mandatory requirement[2].

Radiation safety is not a concept limited solely to technical knowledge. It encompasses a multi-dimensional competency area including knowledge, attitudes, behaviors, and safety culture[3]. Literature reports that the radiation safety knowledge levels of healthcare workers are often insufficient, and in-service training is limited in creating behavioral change[4]. Traditional educational models are generally based on standardized presentations, failing to consider individual learning differences and offering adaptive content based on participant performance[5].

In recent years, artificial intelligence (AI)-based learning systems have offered innovative approaches in health education. Thanks to adaptive learning algorithms, machine learning-based performance analysis, and simulation-supported applications, the learning process can be personalized and real-time feedback can be provided[6]. AI-assisted models in health education are reported to have positive effects on knowledge acquisition and clinical decision-making skills[7,8]. However, experimental studies examining the effectiveness of AI-based educational models specifically in radiation safety are limited. Literature from 2023 onwards reports that AI-assisted adaptive learning systems in health education make significant contributions to clinical decision-making, procedural skill acquisition, and behavioral adjustment[9]. In particular, performance-based feedback and personalized content delivery are highlighted as increasing learning retention.

Measuring the effectiveness of educational interventions in the field of radiation safety should be evaluated not only by the increase in knowledge level but also by attitude change and the development of protective behaviors[10,11]. In this context, it is thought that AI-assisted educational models can support behavioral transformation through adaptive content presentation and simulation-based applications. However, research that demonstrates this assumption with experimental data is needed.

In this study, the effect of an AI-assisted adaptive training model on the radiation safety competency of healthcare professionals was investigated using a quasi-experimental design. The research is expected to contribute to the literature by providing scientific evidence for digital transformation approaches in radiation safety training and developing a model proposal for implementation.

Material and Methods

Research Design

This study is a quasi-experimental pre-test–post-test control group study conducted to evaluate the effect of an artificial intelligence (AI)-based adaptive training model on the radiation safety competence of healthcare professionals. Two parallel groups were included in the study: the experimental group (AI-assisted training) and the control group (traditional training). The intervention period was planned as four weeks.

In the study design, within-group and between-group changes were compared by performing pre- and post-intervention measurements.

Research Population and Sample

The research population consisted of healthcare personnel working with radiation in a university hospital (radiology technicians, interventional radiology nurses, operating room personnel, and nuclear medicine personnel).

The sample size was calculated using the G*Power 3.1 program. With a moderate effect size (d=0.50), a 95% confidence level, and an 80% power assumption, a minimum of 102 participants was required. Considering potential data loss, a total of 120 healthcare professionals were included in the study. Participants were divided into two groups using a simple random assignment method:

• Experimental group (n=60)

• Control group (n=60)

Inclusion criteria:

• Being a healthcare professional working with radiation for at least 1 year

• Voluntary participation

• Not having received radiation safety training in the last 6 months

Exclusion criteria:

• Not regularly attending the training process

• Missing pre-test or post-test data

Group assignment was performed by an independent researcher using a computer-assisted random number generation method. Assignment confidentiality was ensured using the sealed envelope method.

Although participants were randomly assigned to the experimental and control groups, this study was classified as quasi-experimental because participants were recruited using convenience sampling from a single university hospital rather than being randomly selected from the target population. Therefore, randomization was applied only at the group allocation stage.

Data Collection Tools

Radiation Safety Knowledge Test: This is a 25-item multiple-choice test developed by the researchers based on the literature on radiation safety and occupational safety training (IAEA, 2018; European Commission, 2014). Each correct answer is worth 1 point, and an incorrect answer is worth 0 points. The total score ranges from 0 to 25. In the pilot application, the KR-20 reliability coefficient was calculated as 0.84. The content validity of the knowledge test was evaluated by taking into account the opinions of five academics specializing in radiation safety and medical education. The Content Validity Index (CVI) was calculated as 0.89. The test was piloted on 20 healthcare professionals, and its final version was determined by examining the item discrimination indices.

Radiation Safety Attitude Scale: The Radiation Safety Attitude Scale used in this study was developed by the researchers based on the literature on radiation safety and occupational safety training (IAEA, 2018; European Commission, 2014). It consists of 20 items on a 5-point Likert scale (1 = strongly disagree – 5 = strongly agree). The total scale score ranges from 20 to 100. In this study, the Cronbach alpha coefficient was found to be 0.88. As a result of the exploratory factor analysis, it was determined that the scale has a unidimensional structure and explains 61% of the total variance. The Kaiser-Meyer-Olkin (KMO) value was found to be 0.86, and the Bartlett sphericity test was significant ($p<0.001$).

Protective Behavior Assessment Form. The Protective Behavior Assessment Form was developed by the researchers based on international radiation safety guidelines and the ALARA principle (IAEA, 2018). This is a 12-item observational assessment form including personal dosimeter use, lead apron preferences, distance optimization, and compliance with radiation protection practices. Behaviors are coded as 0 (inappropriate) and 1 (appropriate).

Intervention Process

Experimental Group: AI- Assisted Training Model

The experimental group was given an AI-assisted adaptive training program consisting of a total of 8 modules, with two sessions per week for four weeks. The training model consists of the following components:

- Adaptive content guidance based on prior knowledge
- Scenario-based radiation exposure simulations
- Real-time performance analysis
- Personalized feedback reports
- Gamified dose management module

The system automatically adjusted the content difficulty level according to participant performance.

Technical Structure of the Artificial Intelligence System

The system used in this study does not include a machine learning-based predictive model. Instead, a rule-based adaptive decision algorithm is used that dynamically updates the content difficulty level based on participant performance thresholds. In the literature, such systems are defined as rule-based adaptive learning systems evaluated within the scope of symbolic artificial intelligence. Although the system does not perform autonomous data training, it provides performance-based real-time content adaptation and personalized feedback generation.

Control Group: Traditional Training

The control group received standard radiation safety training in a classroom setting with presentations and visual materials over the same period. The training content covered legislation, dose limits, and the use of protective equipment.

Data Collection

The pre-test was administered before the intervention, and the post-test was administered one week after the intervention was completed. The data collection process lasted approximately six weeks. Evaluators who conducted behavioral observations were not blind to group assignment. This may create a risk of observer bias. However, observations were performed using standardized checklists, and evaluation criteria were predefined. The evaluators conducting the behavioral observations received training on standardized evaluation criteria prior to the observations. The observation form items were structured with detailed operational descriptions. Inter-rater agreement was analyzed using Cohen's Kappa coefficient and found to be 0.82. This value indicates a high level of observer agreement.

Ethical Statement

The ethics committee approval was obtained from the Clinical Research Ethics Committee of Istanbul Okan University (Date: 05/02/2025, No: 2025-185). Administrative permission to conduct the study was also obtained from the management of the university hospital where the data were collected prior to the commencement of the study. The purpose of the study was explained to the participants, and their written consent was obtained. Data were collected anonymously and used only for scientific purposes.

Data Analysis

Data were analyzed using SPSS 26.0 software.

• Normality distribution was assessed using the Shapiro–Wilk test.

• Dependent samples t-test was used for within-group comparisons.

• Independent samples t-test was applied for between-group comparisons.

• ANCOVA analysis was performed for post-test results, controlling for pre-test scores as a covariance variable.

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• Effect size was calculated using Cohen's d coefficient.

• The significance level was accepted as $p<0.05$.

The percentage improvement for each outcome variable was calculated using the formula: ((post-test score – pre-test score) / pre-test score) × 100.

Results

Demographic Characteristics of Participants

A total of 120 healthcare professionals participated in the study. The demographic characteristics of the experimental and control groups are presented in Table 1.

Table 1. Distribution of participants' demographic characteristics by groups

Variable	Experiment (n=60)	Control (n=60)	Total (n=120)	p
Age (Mean±SD)	32,8±5,6	33,4±6,1	33,1±5,8	0,58
Gender				
Female	36 (%60)	34 (%56,7)	70 (%58,3)	0,64
Male	24 (%40)	26 (%43,3)	50 (%41,7)	
Occupation				
Radiology Technician	21 (%35)	21 (%35)	42 (%35)	0,71
Nurse	17 (%28,3)	17 (%28,3)	34 (%28,3)	
Operating Room Staff	13 (%21,7)	14 (%23,3)	27 (%22,5)	
Nuclear Medicine	9 (%15)	8 (%13,4)	17 (%14,2)	

No statistically significant differences were found between the groups in terms of age, gender, and occupational distribution ($p>0.05$). This indicates that the groups were initially homogeneous.

Pre-Test Comparisons

No significant differences were found between the knowledge, attitude, and behavior scores of the groups before the intervention ($p>0.05$). This finding indicates that the initial levels were similar and that the effect of the intervention can be evaluated more effectively.

Effect on Knowledge Level

The pre-test–post-test knowledge scores of the experimental and control groups are given in Table 2.

Table 2. Pre-test–post-test comparison of knowledge scores

Group	Pretest (Mean±SD)	Posttest (Mean±SD)	t	p	Cohen's d
Experiment	63,1±8,2	88,7±5,9	-20,14	<0,001	1,92
Control	63,8±7,7	77,9±7,4	-9,62	<0,001	1,05

An increase of 40.6% was observed in the knowledge score in the experimental group. The increase in the control group remained at 22.1%. In the post-test comparison between the groups, the knowledge score of the experimental group was significantly higher ($t=8.34$; $p<0.001$). The effect size ($d=1.38$) is very high.

When the pre-test scores were controlled in the ANCOVA analysis, the effect of the training model on the knowledge score was found to be significant ($F=72.51$; $p<0.001$; $\eta^2=0.38$). This value indicates a large effect size.

Effect on Attitude

Table 3. Pre-test–post-test comparison of attitude scores

Group	Pretest (Mean±SD)	Posttest (Mean±SD)	t	p	Cohen's d
Experiment	72,1±6,4	91,2±4,9	-17,83	<0,001	1,74
Control	71,4±6,9	80,8±6,7	-8,41	<0,001	0,93

The increase in attitude scores in the experimental group was 26.5%. ANCOVA results showed a significant difference between groups ($F=44.36$; $p<0.001$; $\eta^2=0.27$).

Effect on Protective Behavior

Table 4. Comparison of protective behavior scores

Group	Pretest (Mean±SD)	Posttest (Mean±SD)	Increase (%)	p	Cohen's d
Experiment	6,9±1,8	11,2±0,9	62,30%	<0,001	2,01
Control	6,7±1,9	8,5±1,6	26,80%	<0,001	0,89

The effect size in the behavioral dimension (d=2.01) is very high. This result shows that AI-assisted simulation-based training has a strong effect on behavioral change. No clustering at maximum value was observed in the final test score distribution. This indicates that the high effect size obtained is not due to a ceiling effect.

Multiple Regression Analysis Results

A multiple linear regression analysis was applied to determine the variables predicting the total competency score in the radiation safety final test. In the model, the independent variables included training type (0=Traditional, 1=AI-assisted), age, gender (0=Male, 1=Female), and professional experience duration (years). Assumptions were tested before the regression analysis.

- No multicollinearity problem was found (VIF values ranged from 1.08–1.34).
- The Durbin–Watson coefficient was calculated as 1.91, and no autocorrelation was determined.
- It was determined that the residuals showed a normal distribution.

The model was found to be statistically significant ($F(4,115)=21.04$; $p<0.001$) and explains 42% of the variance in the dependent variable ($R^2=0.42$; Adjusted $R^2=0.40$).

Table 5. Variables predicting radiation safety post-test competency score

Variable	**B**	**SH**	**β**	**t**	**p**
Fixed	54,27	3,84	—	14,13	<0,001
Education Type	8,96	1,12	0,61	7,98	<0,001
Professional Experience	0,18	0,09	0,14	1,99	0,049
Age	0,07	0,11	0,05	0,64	0,52
Gender	0,84	0,96	0,06	0,87	0,38

According to the analysis results, the type of training is the strongest and most significant predictor of the total competency score ($\beta=0.61$; $p<0.001$). Participants who received AI-assisted training had an average of 8.96 points higher final test competency scores compared to those who received traditional training.

The duration of professional experience is a weak but significant predictor ($\beta=0.14$; $p=0.049$). It was determined that age and gender variables did not significantly contribute to the model ($p>0.05$).

When the standardized coefficients are examined, it is seen that the effect of the type of training is significantly higher than all other variables. No clustering was observed at the maximum values in the final test scores. This indicates that the high effect size obtained is not due to the ceiling effect.

Discussion

The findings showed that the rule-based AI-assisted adaptive training model had a significant positive impact on the radiation safety knowledge and application skills of healthcare professionals. This result is consistent with previous literature highlighting the supportive role of educational technologies in clinical training processes. In particular, adaptive learning approaches have been reported in previous systematic reviews to increase learning outcomes by providing personalized content based on learners' performance[8]. These reviews have shown that adaptive digital learning models have a moderate to high impact on cognitive gain and learning retention compared to traditional in-service training programs. Current meta-analytic findings show that adaptive digital learning models for healthcare professionals have a higher behavioral transfer effect compared to traditional training[9].

In recent years, research examining the contribution of AI-assisted training approaches to the skill development of healthcare professionals has increased. For example, Woolf (2021) stated that systems providing performance-based feedback in health education increased learning motivation and application competence[6]. Similarly, findings indicating that simulation-based training has positive effects on the clinical practice performance of healthcare professionals are widely reported in the literature[11]. In this context, the high effect sizes observed in our current study suggest that the combined use of rule-based adaptive artificial intelligence and simulation-based learning may have strengthened behavioral outcomes.

International studies on radiation safety have reported that while improvements in healthcare professionals' knowledge levels based on traditional training have been observed, the sustainability of behavioral change remains limited[3,10]. These studies show that training interventions aimed solely at increasing knowledge in the field of radiation safety struggle to change behavioral practices. In our study, however, the significant increases observed in behavioral competencies in addition to knowledge acquisition point to the potential of adaptive learning systems to support both cognitive and behavioral outcomes simultaneously. The high effect size obtained in the behavioral dimension ($d>2.00$) may be related to the intensive and short-term application of the intervention. Furthermore, because only short-term measurements were taken, long-term behavioral sustainability was not evaluated. Therefore, the persistence of the effect should be tested with future long-term follow-up studies. However, the study has some limitations, such as its design, population structure, and short-term measurements. The fact that the research was conducted in a single center and that observers were not blinded to group assignment should be considered in terms of the generalizability of the findings and the objectivity of the evaluation.

In addition, the digital literacy levels of the participants were not controlled for, and this should be examined as a variable affecting the benefit obtained from digital education systems. The high effect sizes, especially in behavioral change, may be due to the intensive nature of the intervention and the novelty effect (Hawthorne effect); therefore, it is important to evaluate the findings with long-term follow-up.

Overall, this study provides significant evidence supporting the feasibility and effectiveness of using rule-based adaptive artificial intelligence applications in the development of radiation safety education programs. Supporting future studies with multi-center and long-term follow-up designs will more clearly reveal the sustainable effects of these training models.

Conclusion And Recommendations

This study demonstrated that a rule-based, AI-assisted adaptive training model significantly increased the radiation safety competence of healthcare professionals in terms of knowledge, attitudes, and protective behaviors. The strong effect, particularly in the behavioral dimension, suggests that simulation-based and performance-based feedback-incorporated adaptive training approaches can be effective in developing a safety culture.

The findings indicate that radiation safety training should not be limited to traditional knowledge transfer-based models, and that integrating individualized digital learning approaches into training processes could be beneficial. However, multi-center and follow-up studies are needed to evaluate the applicability and long-term effects of the model in different institutions.

In conclusion, AI-assisted adaptive training systems offer a viable and promising approach to improving the radiation safety competencies of healthcare professionals.

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