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Incorporating Digital Tools to Facilitate Self-Directed Learning in Medical students and family medical residents

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Abstract

Digital technologies are transforming medical education by fostering self-directed learning (SDL). This prospective, quasi-experimental study examined the effects of a structured digital toolkit—comprising virtual-reality anatomy modules, AI-simulated clinical cases, and spaced-repetition quizzes—on SDL readiness, knowledge retention, and clinical performance among medical students and family medicine residents. Eighty participants (40 students, 40 residents) were quasi-randomized to intervention or control arms for 12 weeks. The intervention arm exhibited a significant increase in SDL readiness (+15%, $p < 0.001$), higher pass rates on objective structured clinical examinations (OSCE 85.2 ± 4.3 vs. 79.1 ± 5.1, $p = 0.002$), and superior knowledge test scores (+10%, $p < 0.01$). Engagement metrics correlated strongly with SDL readiness ($r = 0.68$, $p < 0.001$). Learner surveys indicated enhanced autonomy and satisfaction. Findings support the integration of blended digital tools to strengthen SDL and clinical competence. This model offers a validated, scalable framework for medical education.

Keywords: self-directed learning; digital tools; medical education; blended learning

Introduction

Self-directed learning (SDL) is essential in medical education, empowering practitioners to proactively identify learning needs, source knowledge, and evaluate outcomes. With the complexity of modern healthcare, SDL helps learners navigate expansive and evolving

information. However, traditional curricula often fail to sufficiently cultivate SDL skills in medical students and residents.1-4

In response, digital tools—ranging from virtual-reality (VR) modules to intelligent tutoring systems—have gained traction as enablers of personalized, interactive SDL. VR anatomy platforms immerse learners in 3D models, facilitating spatial understanding and engagement; AI-based clinical simulations offer adaptive feedback; and spaced-repetition quizzes reinforce knowledge over time using evidence-based memory techniques. Studies since 2022 have shown that these techniques enhance learner autonomy, retention, and clinical reasoning, although most research has focused on individual tools or single learner groups.5-7

Integration of multiple digital modalities into a coherent SDL ecosystem provides unique advantages: immersive experiences stimulate motivation; AI simulations simulate decision-making scenarios; quizzes reinforce memory. This synergy aligns with self-determination theory, which posits that competence, autonomy, and relatedness drive intrinsic motivation.8-9

Family medicine residents inhabit a high-paced, context-rich environment. Unlike medical students, they require SDL tools that align with clinical responsibilities and support lifelong learning habits. Yet, data on digital interventions tailored to residents remains sparse.10-11

Thus, this study investigated how a synergistic digital toolkit could enhance SDL readiness, knowledge retention, and clinical performance in both cohorts. It aimed to assess engagement-behavior correlations and learner perceptions. We hypothesized that a blended digital intervention would yield statistically and educationally significant gains over traditional methods. The work addresses current educational gaps and aligns with the digital transformation imperative in medical pedagogy.

Methodology

A quasi-experimental design was implemented at Children Hospital. The participants included 40 third-year medical students and 40 first-year family medicine residents, aged 22–35. Using Epi Info version 7, sample size was calculated assuming a 15% increase in SDL readiness ($\alpha = 0.05$, $\beta = 0.20$), necessitating 40 per arm to detect meaningful differences. Participants were stratified by

learner type and then assigned to intervention or control arm in equal numbers. Those with prior exposure to VR or AI-simulation platforms were excluded to avoid bias.

The blended digital toolkit consisted of three synchronized components: (1) a VR anatomy suite with interactive modules including self-assessment and immersive visualization; (2) AI-driven clinical cases tailored to virtual patient encounters, providing scaffolded feedback; (3) adaptive spaced-repetition quizzes delivered daily via mobile app to reinforce key knowledge. The control group followed the standard curriculum, including didactic lectures and textbook resources.

All participants completed the Self-Directed Learning Readiness Scale (SDLRS) at baseline and after 12 weeks. Knowledge retention was assessed via a validated 50-item multiple-choice examination, and clinical skills were evaluated through a standardized OSCE conducted by blinded assessors. During the intervention, backend systems captured engagement data: VR completion rates, quiz frequency, and simulation attempts per week. A final anonymized survey collected learner perceptions of autonomy, utility, and satisfaction using a 5-point Likert scale.

Baseline characteristics across groups (age, gender, prior academic performance) were compared with chi-square and ANOVA tests to ensure homogeneity. Intervention effects were analyzed with repeated-measures ANOVA; post-hoc Bonferroni corrections identified differences between subgroups. Correlation analysis (Pearson's r) assessed the relationship between engagement metrics and SDLRS score improvement. Multivariate linear regression adjusted for demographic covariates. A p-value < 0.05 was considered significant. Ethical approval was granted by the institution's review board, and verbal informed consent was obtained in accordance with local regulations.

Results

Table 1. Baseline Characteristics

Group	n	Age (years)	Gender (M/F)	Baseline SDLRS (mean ± SD)	p-value
Students – Intervention	20	23.5 ± 2.1	10/10	62.3 ± 7.2	0.78

Group	**n**	**Age (years)**	**Gender (M/F)**	**Baseline SDLRS (mean ± SD)**	**p-value**
Students – Control	20	23.8 ± 2.4	11/9	63.1 ± 6.9	
Residents – Intervention	20	29.1 ± 3.5	9/11	61.8 ± 7.0	
Residents – Control	20	28.9 ± 3.3	8/12	62.5 ± 6.8	

All baseline characteristics were statistically comparable between intervention and control groups ($p > 0.7$).

Table 2. Post-Intervention Outcomes

Measure	**Intervention**	**Control**	**p-value**
SDLRS score ↑	+15.2 ± 4.1	+3.5 ± 3.8	<0.001
Knowledge test (%)	88.5 ± 3.9	80.2 ± 4.2	<0.001
OSCE score (%)	85.2 ± 4.3	79.1 ± 5.1	0.002

Table 3. Engagement Metrics & Correlation with SDLRS

Metric	**Intervention mean ± SD**	**Pearson r vs SDLRS (p)**
VR module completion (%)	92 ± 8	0.68 (<0.001)
Quiz attempts per week	4.5 ± 1.2	0.55 (0.001)
AI simulation sessions	3.1 ± 0.9	0.60 (<0.001)

Tables demonstrate significant improvement in SDL readiness, knowledge, and clinical performance in the intervention arm. Engagement metrics strongly correlate with SDL gains.

Discussion

The integration of virtual reality, AI-driven simulations, and spaced-repetition quizzes substantially improved SDL readiness, knowledge retention, and clinical competence among both medical students and family medicine residents. The 15% increase in SDLRS scores surpasses

effect sizes reported in similar recent randomized trials, highlighting the impact of a multi-modal digital strategy.13-14

Post-intervention knowledge test and OSCE gains (10% and 6% respectively) corroborate findings from recent meta-analyses emphasizing active learning and periodic reinforcement. Notably, residents benefitted equally, underscoring the toolkit's adaptability across learner levels. Engagement-behavior correlation affirms that active participation drives learning gains—supporting principles outlined in self-determination theory.15-17

Learner surveys reported enhanced autonomy, confidence, and satisfaction—consistent with contemporary literature endorsing digital autonomy as a motivational factor. The holistic design of the toolkit, combining immersion, adaptive challenge, and sustained reinforcement, created an environment conducive to deep learning.18-19

Although the study design did not include longitudinal follow-up, the near-daily engagement embedded by the tools suggests durable habits may be forming. Limitations include institutional homogeneity and absence of cost-effectiveness analysis. Nevertheless, the absence of adverse reactions or technical difficulties indicates feasibility.20

Future work should explore expansion to interdisciplinary specialties, evaluate longitudinal retention, and cost–benefit analysis. Leveraging telemetry for individualized feedback or gamification may further enhance engagement and learning outcomes.

In conclusion, this integrative digital approach offers a robust, scalable platform for SDL enhancement. The findings support adopting such blended modalities as standard curricular supplements in medical education.

Conclusion

A blended suite of digital learning tools significantly enhances self-directed learning readiness, clinical competence, and knowledge retention among medical students and family medicine residents. This model bridges a critical educational gap and offers a scalable, validated strategy for modern curricula. Future studies should evaluate long-term retention and broader application across specialties.

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