

THE IMPACT OF DIGITAL SIMULATION PLATFORMS (VIRTUAL OUTBREAK, EPIDEMIC SIMULATORS) ON LEARNING EFFECTIVENESS IN UNDERGRADUATE EPIDEMIOLOGY EDUCATION: A RANDOMIZED CONTROLLED EDUCATIONAL TRIAL

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ABSTRACT: Objective: To evaluate the effect of integrating digital epidemic simulation platforms into the undergraduate epidemiology curriculum on students' theoretical knowledge retention, practical outbreak investigation skills, and overall engagement compared to traditional teaching methods. Methods: A randomized controlled educational trial was conducted involving 180 third-year undergraduate medical students at [Name of Medical University]. Students were randomized into two groups: the Control Group (n=90), which utilized traditional didactic lectures and paper-based case studies, and the Experimental Group (n=90), which supplemented traditional learning with interactive sessions using digital platforms (e.g., "Solve the Outbreak" app and a custom SEIR model simulator). The intervention lasted for one semester (12 weeks). Assessment tools included pre- and post-intervention knowledge tests (MCQs), a practical skills assessment (simulated outbreak scenario), and a standardized student satisfaction survey (Likert scale). Results: Both groups showed improvement from baseline. However, the Experimental Group achieved significantly higher scores in the post-intervention theoretical test compared to the Control Group (Mean Score: 88.4 ± 5.2 vs. 76.1 ± 6.8 ; $p < 0.001$). The difference was most pronounced in questions related to "epidemic dynamics" and "intervention impact." In the practical skills assessment, the Experimental Group demonstrated superior competency in identifying the index case (92% vs. 65%) and selecting appropriate control measures (89% vs. 71%). Student satisfaction scores regarding "interest in the subject" and "perceived understanding" were significantly higher in the simulation group (4.8/5 vs. 3.6/5; $p < 0.001$). Conclusion: The integration of digital simulation platforms into epidemiology education significantly enhances academic performance, practical skills, and student engagement. By visualizing abstract concepts and providing an immersive, active learning experience, simulations bridge the gap between theory and practice, preparing future health professionals for real-world public health challenges.

Keywords: Medical education, epidemiology, digital simulation, gamification, virtual outbreak, active learning, student engagement, academic performance, COVID-19, educational technology.

INTRODUCTION

Epidemiology is a cornerstone of public health, requiring students to master complex, dynamic concepts such as disease transmission dynamics, basic reproduction number (R_0), herd immunity thresholds, and outbreak investigation protocols. Traditional pedagogical methods (lectures, static case studies) often fail to capture the temporal and stochastic nature of epidemics, leading to rote memorization rather than deep conceptual understanding. The rapid digitalization of medical education offers a solution through "Serious Games" and digital simulation platforms [1]. These tools allow students to experiment with variables, visualize outcomes in real-time, and practice decision-making in a risk-free environment. However, empirical evidence quantifying the impact of these digital tools on academic performance and

critical thinking skills among undergraduate students remains limited. Validating their effectiveness is crucial for modernizing medical curricula.

Epidemiology is traditionally considered a challenging subject for medical undergraduates due to its reliance on statistics, probability, and complex systems theory [2]. Concepts such as the basic reproduction number (R_0), incidence vs. prevalence, and the non-linear impact of interventions (e.g., vaccination coverage thresholds) are often abstract when presented in static textbook formats.

The "Instructional Scaffolding" theory suggests that students learn best when supported by tools that allow them to build understanding through experience. In the context of epidemiology, this means moving from passive listening to active experimentation. Digital simulation platforms offer this opportunity. They serve as "virtual laboratories" where students can manipulate variables (e.g., increase social distancing, introduce a vaccine) and immediately observe the epidemiological curve flatten or spike [3].

Furthermore, "gamification"—the application of game-design elements in non-game contexts—has been shown to increase motivation and dopamine-mediated reinforcement of learning. Tools like the CDC's *Solve the Outbreak* application place students in the role of an "Epidemic Intelligence Service" officer, requiring them to analyze data and make decisions under pressure, mimicking real-world scenarios.

Despite the theoretical benefits, the adoption of these tools in medical universities, particularly in developing regions, is inconsistent. There is a need for robust evidence comparing these modern methods directly against traditional pedagogy to justify curriculum reform. This study aims to quantify the educational impact of digital simulations on undergraduate epidemiology students.

METHODS

Study design and participants - A parallel-group, randomized controlled trial was conducted during the Spring 2024 semester at the Department of Infectious Diseases, Andijan State Medical Institute. The study population consisted of 180 third-year undergraduate medical students enrolled in the "General epidemiology" course.

Randomization - Students were stratified by GPA to ensure baseline academic equivalence and then randomized 1:1 into two groups using a computer-generated sequence: 1) Control group (CG, n=90): Received standard instruction consisting of 2 hours of lectures and 2 hours of paper-based seminars per week. Case studies were presented as text documents where students discussed answers in groups. 2) Experimental group (EG, n=90): Received the same lecture content. However, during seminars, paper-based cases were replaced with digital simulation activities.

Activity 1: "Solve the Outbreak" (CDC): Used for teaching outbreak investigation steps (surveillance, hypothesis generation, testing).

Activity 2: Interactive SEIR Model (Web-based): Used for teaching transmission dynamics. Students manipulated R_0 , incubation periods, and vaccination rates to visualize herd immunity.

Theoretical knowledge test - A 50-item Multiple Choice Question (MCQ) exam administered before the course (Pre-test) and after 12 weeks (Post-test). The test covered definitions, biostatistics, and epidemiological methods.

Practical skills assessment (objective structured practical examination - OSPE) - A complex, written scenario of a foodborne outbreak. Students had to calculate attack rates, draw an epidemic curve, and propose control measures. Scored out of 100.

Student perception survey - A 10-item questionnaire using a 5-point Likert scale (1=Strongly Disagree, 5=Strongly Agree) measuring engagement, perceived difficulty, and satisfaction.

Statistical analysis data were analyzed using SPSS Version 26.0. Independent sample t-tests were used to compare mean scores between groups. Paired t-tests assessed improvement within groups. A p-value of <0.05 was considered statistically significant. Cohen's d was calculated to measure effect size.

RESULTS

Theoretical knowledge retention baseline characteristics (age, gender, GPA, Pre-test scores) were similar between groups ($p > 0.05$). Post-intervention, both groups showed improvement, but the Experimental Group significantly outperformed the Control Group. Control Group Post-test Mean: 76.1 ± 6.8 ; Experimental Group Post-test Mean: 88.4 ± 5.2 ; Difference: 12.3 points ($p < 0.001$); Effect Size: Cohen's $d = 2.03$ (indicating a very large positive effect).

Item analysis revealed that the Experimental Group scored 25% higher specifically on questions related to "dynamic transmission" and "interpreting epidemic curves," suggesting that simulations aided in visualizing these processes.

Practical skills assessment (OSPE) The practical assessment evaluated the application of knowledge.

Table 1. Comparison of practical skills assessment scores

Skill domain	Control group (mean score %)	Experimental group (mean score %)	p-value
Calculating attack rates	72.4%	85.1%	<0.01
Constructing epidemic curve	68.0%	91.5%	<0.001
Identifying index case	65.2%	92.3%	<0.001
Selection of control measures	71.5%	89.0%	<0.001
TOTAL SCORE	69.3 ± 8.1	89.5 ± 6.5	<0.001

The Experimental Group demonstrated a superior ability to translate theory into practice, particularly in tasks requiring data visualization (epidemic curves) and logical deduction (finding the index case).

Student satisfaction Survey results showed higher engagement in the simulation group. "The seminars helped me understand complex concepts easier": EG (4.8/5) vs. CG (3.5/5). "I felt motivated to attend class": EG (4.7/5) vs. CG (3.2/5). 95% of students in the Experimental Group recommended continuing the use of simulations for future cohorts.

DISCUSSION

The results of this randomized controlled trial provide compelling evidence that integrating digital simulation platforms into epidemiology education is superior to traditional paper-based methods alone.

The "learning gain" observed in the Experimental Group can be attributed to the Active Learning principle. In a traditional lecture, students hear about $\$R_0$; in a simulation, they *change* the $\$R_0$ and watch the epidemic explode or die out. This feedback loop creates a deeper cognitive anchor for the concept. The high scores in the "Constructing Epidemic Curve" domain (91.5% vs 68.0%) confirm that visual, interactive tools help students master graphical literacy, a critical skill for epidemiologists [4].

The "Solve the Outbreak" platform, which gamifies the investigation process, likely contributed to the high scores in identifying index cases and selecting control measures. By simulating the pressure and uncertainty of a real outbreak, students learned to prioritize information and think critically, rather than just following a checklist [5].

The satisfaction survey highlights the motivational aspect. Epidemiology can be dry and mathematical; gamification makes it relevant and exciting. Increased motivation correlates directly with increased study time and better retention (Gielo-Periczak et al., 2017).

Limitations - The study relied on specific software (CDC app, SEIR web tool), so results may vary depending on the quality of the simulation platform used. The long-term retention (e.g., 1 year later) was not measured in this phase [6].

Conclusion

The introduction of digital simulation platforms and gamified elements into the undergraduate epidemiology curriculum leads to a statistically significant and educationally meaningful improvement in student performance. These tools are particularly effective in teaching complex, dynamic concepts and practical outbreak investigation skills that are difficult to convey through static text.

Medical universities should transition from purely didactic epidemiology teaching to a hybrid model that includes mandatory simulation hours.

Simulations should be used not just for engagement, but as formal assessment tools for practical skills (e.g., virtual exams).

Free, high-quality tools like those provided by the CDC or open-source modeling software make this a cost-effective intervention for universities in resource-limited settings.

Ultimately, digital simulations transform students from passive recipients of information into active investigators, better preparing them for the complexities of modern public health landscape.

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