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DEVELOPMENT OF PREVENTIVE IMMUNE CULTURE AMONG MEDICAL UNIVERSITY STUDENTS IN THE CONTEXT OF DIGITAL MEDICAL EDUCATION

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Abstract

Statement of the problem. Contemporary medical education requires future physicians to acquire not only clinical knowledge and practical skills but also readiness for preventive activities, assessment of infectious risks, immunization and responsible use of reliable medical information in digital environments. Therefore, the development of preventive immune culture among medical students represents an important component of professional training.

Purpose of the article. The study aimed to provide a theoretical rationale and experimentally evaluate the effectiveness of a methodology for developing preventive immune culture among medical university students in the context of digital medical education within the discipline of Infectious Diseases.

Methodology. The study employed analysis of scientific and pedagogical literature, pedagogical observation, questionnaires, testing, written assessment, problem-based and clinical tasks, simulation-based learning and mathematical-statistical analysis. The pedagogical experiment was conducted in 2022–2025 at Andijan State Medical Institute, Samarkand State Medical University and Bukhara State Medical Institute. A total of 459 students participated in the study; experimental and control groups were formed for the intervention stage.

Research results. The Smart Immunity model was developed, comprising analytical-diagnostic, digital educational, digital monitoring-and-assessment, and preventive activity and health-promoting practice blocks. The methodology incorporated QR codes, electronic learning materials, virtual clinical cases, simulation scenarios, interactive video materials, mobile digital resources, problem-based learning and clinical cases. In the experimental group, the proportion of students demonstrating a high level of preventive immune culture increased from 9.6% to 19.4%, while the proportion demonstrating a medium level increased from 23.1% to 63.8%; the proportion with a low level decreased from 67.2% to 16.8%. Changes in the control group were substantially less pronounced. The mean final score was 4.08 in the experimental group and 3.49 in the control group, with an effectiveness coefficient of

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1.17. The observed differences were statistically confirmed.

Conclusions. The integrated use of digital technologies combined with competency-based, problem-based, clinical-situational and simulation-based learning contributes to the development of students' knowledge and practical readiness for preventive activities.

Author's contribution. The author developed the Smart Immunity conceptual model, diagnostic and assessment tools, and the methodology for integrating digital technologies into teaching the discipline Infectious Diseases.

Keywords: medical education, digital medical education, preventive immune culture, infectious diseases, digital technologies, Smart Immunity, simulation-based learning.

Statement of the Problem

Modern medical education is developing amid the simultaneous complication of epidemiological challenges and the accelerating digital transformation of the educational environment. The training of a future physician can no longer be limited to the transmission of theoretical knowledge about diseases, their mechanisms of development and methods of treatment. Professional medical practice requires the ability to prevent diseases, assess risk factors, provide preventive counseling, participate in immunoprophylaxis, critically evaluate medical information and use digital resources for professional interaction.

Prevention of infectious diseases occupies a special place in this system. Unlike many other pathological conditions, the spread of infections is directly associated with human behavior, the state of public health, sanitary and hygienic conditions, vaccination, epidemiological vigilance and the timeliness of preventive measures. Therefore, a future physician must possess not only knowledge of pathogens and mechanisms of pathogenesis but also a well-developed preventive orientation.

Within the dissertation research, preventive immune culture is considered an integrative construct that combines knowledge of the immune system and immunoprophylaxis, practical skills in preventive activity, a motivational and value-based attitude toward health preservation, the ability to analyze epidemiological risks, and readiness to use digital tools for obtaining and disseminating scientifically substantiated information.

The relevance of developing this quality is reinforced by the spread of digital medical information. A medical student continuously interacts with electronic educational resources, social networks, medical information systems, video materials, mobile applications and interactive platforms. Consequently, medical education should develop not only the ability to find information but also the ability to assess its reliability, compare different sources and use evidence-based information in professional practice.

In the international literature, digital education for health professionals is considered an independent field of educational research. An analysis of 77 systematic reviews conducted by Car et al. demonstrated the broad use of various digital educational formats, virtual reality and online learning in the training of health professionals [Car et al., 2022]. At the same time, the authors point to the need for further accumulation of evidence

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on the effectiveness of digital education in low- and middle-income countries [Car et al., 2022].

Thus, the relevance of the study is determined by the need to provide a scientific rationale for organizing the educational process in such a way that digital technologies do not replace the content of medical education but instead become a means of developing preventive thinking, independence, practical skills and professional responsibility among students.

Purpose of the Article

The purpose of the article is to provide a theoretical rationale and experimentally verify the effectiveness of a methodology for developing preventive immune culture among medical university students in the context of digital medical education while studying the discipline Infectious Diseases.

Review of Scientific Literature on the Problem

The problem of digitalization of medical education is actively developing in contemporary pedagogy and medical education. International studies show that digital educational technologies can be used to develop knowledge, clinical skills, professional communication and decision-making ability.

Car et al. systematized the results of 77 reviews of digital education for health professionals and proposed a conceptual model that includes context, infrastructure, the educational process, learners, research activity and quality improvement [Car et al., 2022]. For the present problem, it is fundamentally important that the effectiveness of a digital technology depends not only on the technical tool itself but also on its pedagogical integration into the educational process.

The use of virtual patients is of considerable interest. Based on a systematic review, Plackett et al. showed that virtual patient educational tools are used to develop clinical reasoning among medical students [Plackett et al., 2022]. This finding is directly relevant to the teaching of infectious diseases, because clinical and epidemiological situations require sequential analysis of history, risk factors, symptoms, epidemiological links and preventive tactics.

A separate area of research concerns simulation-based learning. McInerney et al. systematized evidence on the effectiveness of simulation training for medical students and demonstrated its importance for developing practical professional outcomes [McInerney et al., 2022]. Alonso-Peña and Álvarez Álvarez also regard clinical simulation as an important area of modern medical education in their systematic review [Alonso-Peña, Álvarez Álvarez, 2023].

The potential of virtual reality in medical education is considered by Jallad and Işık, who summarized evidence on the use of VR simulation for developing medical skills [Jallad, Işık, 2022]. In the teaching of infectious diseases, such technologies make it possible to model situations involving patient isolation, use of personal protective equipment, epidemiological investigation and selection of preventive tactics.

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An important component of preventive training is the future physician's ability to discuss vaccination issues professionally. Kelekar et al. developed an educational intervention for medical students aimed at teaching counseling of patients who are hesitant about vaccination [Kelekar et al., 2022]. Their results show that vaccination-related issues can and should become an independent object of professional training for future physicians.

Digital transformation also affects assessment systems. In a systematic review, Chan et al. examined the use of virtual Objective Structured Clinical Examinations (OSCEs) in health professions education [Chan et al., 2023]. This direction corresponds to the task of improving diagnostics and monitoring of students' preventive competencies in a digital educational environment.

Professional and communication competencies are also becoming objects of simulation-based learning. Zhang et al. demonstrated the effectiveness of peer teaching in health professions education [Zhang et al., 2022], while studies of interprofessional simulation-based education indicate the possibility of developing teamwork and communication through modeled professional situations [Zhang et al., 2023].

Thus, contemporary international literature confirms the educational potential of digital, virtual and simulation technologies. At the same time, methods specifically focused on the comprehensive development of preventive immune culture among medical students remain insufficiently developed. Most studies address individual technologies or separate educational outcomes. This creates a need for an integrative model combining diagnostic, cognitive, practical, motivational-value and reflective components.

In domestic pedagogy and medical education, considerable attention is paid to the implementation of information and communication technologies, the competency-based approach and improvement of students' independent work. Begimkulov examines the scientific and pedagogical foundations for introducing information and communication technologies into higher pedagogical education [Begimkulov, 2007]. Works on digital pedagogy emphasize the need to use digital tools in accordance with didactic goals rather than merely as a technical supplement to traditional teaching [Mamatqulov, 2022].

The problem of clinical training also presupposes integration of theoretical content with practice-oriented methods. Harden and Laidlaw emphasize the need for medical teachers to develop the ability to design the educational process with a focus on professional outcomes [Harden, Laidlaw, 2020]. Epstein and Hundert associate physicians' professional competence with the integration of knowledge, skills, values and the ability to apply them in a specific professional situation [Epstein, Hundert, 2002].

Thus, the analysis of scientific literature indicates that the theoretical prerequisites for applying digital technologies, simulation-based learning and the competency-based approach have been sufficiently developed. However, the problem of comprehensively forming preventive immune culture among future physicians within the discipline Infectious Diseases requires further methodological development and experimental verification.

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Research Methodology

The study was based on systemic, competency-based, activity-based, constructivist and digital approaches to the organization of professional medical education. In accordance with the study objective, preventive immune culture was considered a result of the integration of cognitive, motivational-value, practical-activity and reflective components.

The study used historical, sociological, pedagogical, clinical, laboratory, written, analytical and mathematical-statistical methods. The diagnostic toolkit included questionnaires, testing, written control tasks, problem situations, clinical cases, simulation tasks and elements of an Objective Structured Clinical Examination.

The pedagogical experiment was conducted in 2022–2025 at Andijan State Medical Institute, Samarkand State Medical University and Bukhara State Medical Institute. A total of 459 students participated in the study. For the experimental stage, an experimental group of 229 students and a control group of 230 students were formed.

The experiment included diagnostic, formative and final stages. At the diagnostic stage, the baseline level of students' knowledge and practical readiness was determined. The formative stage involved systematic use of the developed methodology. At the final stage, repeated diagnostic assessment was conducted and the results were compared.

The conceptual basis of the formative stage was the Smart Immunity model. Its structure includes four interconnected blocks: analytical-diagnostic; digital educational; digital monitoring-and-assessment; and preventive activity and health-promoting practices.

The analytical-diagnostic block was aimed at determining the baseline level of preventive immune culture. At this stage, students' knowledge of immunity, vaccination, routes of infection transmission, sanitary and hygienic measures, and preventive algorithms was assessed.

The digital educational block included electronic learning materials, video materials, QR codes, virtual clinical situations, interactive tasks, mobile resources and simulation scenarios. Their content was linked to specific topics within the discipline Infectious Diseases.

The digital monitoring-and-assessment block provided ongoing and final assessment. Online testing, electronic assignments, checklists, analysis of clinical situations and reflective tasks were used.

The fourth block was focused on transferring acquired knowledge and skills into preventive activity. Students were offered tasks related to the selection of preventive measures, analysis of epidemiological risk, preparation of vaccination recommendations, assessment of the reliability of digital information and development of preventive messages.

Chi-square (χ^2) and Fisher criteria were used for statistical processing. Baseline comparability of the groups was assessed on the basis of the diagnostic-stage results. At a significance level of $p = 0.05$, critical values specified by the research methodology were applied.

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Research Results

The baseline results indicated that the experimental and control groups were comparable. At the first stage, the mean indicator was 3.40 points in the experimental group and 3.42 points in the control group. The effectiveness coefficient was 0.99. At the second stage, the mean values were 3.49 and 3.51 points, respectively, and at the third stage they were 3.59 and 3.61 points. Thus, before implementation of the formative methodology, no statistically significant advantage of the experimental group was identified.

After implementation of the developed methodology, the indicators of the experimental group changed substantially.

Table 1

Level	Experimental group before the experiment	Experimental group after the experiment
High	9.6%	19.4%
Medium	23.1%	63.8%
Low	67.2%	16.8%

Note: data are presented based on the materials of the pedagogical experiment.

As shown in Table 1, the proportion of students with a high level in the experimental group doubled, increasing from 9.6% to 19.4%. A more substantial change was observed for the medium level: its proportion increased from 23.1% to 63.8%. At the same time, the proportion of students with a low level decreased from 67.2% to 16.8%.

In the control group, the changes were considerably less pronounced. The proportion of students with a high level increased only from 9.6% to 10.3%, the medium level from 23.6% to 24.2%, while a low level remained characteristic of the majority of students.

The obtained results indicate that traditional mastery of educational material alone does not ensure a pronounced improvement in preventive immune culture. More substantial changes were observed when digital tools were combined with problem-based, clinical and simulation methods.

The questionnaire results are of particular interest. In response to the question “What is preventive immune culture?”, the number of positive responses in the experimental group increased from 95 to 123 students, while the number of negative responses decreased from 66 to 23 students.

For the question concerning the use of digital technologies to promote prevention of infectious diseases, the number of positive responses in the experimental group increased from 74 to 115 students. This indicates an increased ability among students to use digital

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resources not only to obtain educational information but also to solve professional preventive tasks.

Positive dynamics were also identified in understanding the role of personal hygiene and public sanitation. The number of positive responses increased from 59 to 91 students. When analyzing a practical situation related to identification of a suspected case of infectious disease, the number of positive responses increased from 10 to 48 students, while the number of negative responses decreased from 130 to 41 students.

Table 2

Diagnostic indicator	Before the experiment	After the experiment
Understanding of the concept of preventive immune culture, positive responses	95	123
Understanding of the importance of immunoprophylaxis, positive responses	75	102
Knowledge of the possibilities of digital technologies in infection prevention, positive responses	74	115
Understanding of the importance of hygiene and sanitation, positive responses	59	91
Readiness to determine preventive tactics when an infectious disease is suspected, positive responses	10	48

Changes affected not only the cognitive component. In the analysis of practice-oriented tasks, students in the experimental group demonstrated a more consistent sequence of actions: identification of epidemiological risk, selection of a preventive measure, justification of the decision, use of a digital source and formulation of a recommendation.

The results of the final assessment also demonstrated differences between the groups.

Table 3

Level	Experimental group	Control group
High	26.0%	11.8%
Good	54.5%	27.6%
Medium	19.5%	60.5%

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In the experimental group, 80.5% of students demonstrated a high or good result, whereas the corresponding proportion in the control group was 39.4%. At the same time, the proportion of students with a medium result was 19.5% in the experimental group and 60.5% in the control group.

The mean values of the final indicators are presented in Table 4.

Table 4

Indicator	Experimental group	Control group
Stage I	4.03	3.47
Stage II	4.07	3.48
Stage III	4.14	3.51
Mean value	4.08	3.49
Effectiveness coefficient	1.17	—

The difference between the mean values was 0.59 points in favor of the experimental group. The mean effectiveness coefficient was 1.17.

Statistical analysis confirmed the identified differences. In the final analysis, χ^2 values were 24.12, 26.08 and 25.42 at the individual stages, with a total value of 74.72 against a critical value of 7.81. The obtained values exceeded the critical value, which made it possible to reject the null hypothesis within the adopted statistical model.

Additional verification using Fisher's criterion showed a similar trend. At the beginning of the experiment, the empirical values did not exceed the critical value of 1.67. After completion of the formative stage, values for a number of indicators reached 4.46, 9.25 and 6.12, respectively. This indicates statistically significant changes in the indicators of the experimental group.

Discussion of the Results

The obtained results allow preventive immune culture to be regarded as a complex outcome of medical and pedagogical training. Importantly, the changes in indicators occurred not only in the reproduction of knowledge but also in practice-oriented tasks.

The results are consistent with contemporary studies of digital medical education. Car et al. note that digital education for health professionals constitutes a broad field that includes online education, virtual reality, mobile technologies and other digital formats [Car et al., 2022]. At the same time, the authors emphasize the need for further study of the effectiveness of digital education in different educational and socioeconomic contexts.

In our study, digital technology was not considered an independent object of learning. A QR code, electronic module, virtual case or mobile resource was included

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within a specific didactic sequence. The student had to obtain information, interpret it, apply it to solve a specific situation and justify the decision. This sequence makes it possible to connect digital competence with professional competence.

The obtained results also correspond to research on virtual patients. Plackett et al. showed that virtual educational tools can be used to improve clinical reasoning [Plackett et al., 2022]. In the present study, a virtual clinical situation was used primarily to develop clinical and epidemiological reasoning: the student had to establish the relationship between symptoms, epidemiological history and preventive actions.

The simulation component of the methodology played a substantial role. McInerney et al. note the educational potential of simulation-based learning for medical students [McInerney et al., 2022]. In our study, simulation tasks brought the learning situation closer to professional practice while maintaining controlled educational conditions.

The preventive orientation of the methodology distinguishes it from approaches focused predominantly on developing clinical treatment skills. The central focus was on solving problems related to preventing the spread of infection, vaccination, sanitary and hygienic measures, risk assessment and professional communication.

Preparing students for communication on vaccination issues is of particular importance. The study by Kelekar et al. demonstrated the possibility of purposefully developing counseling skills among medical students for patients who are hesitant about vaccination [Kelekar et al., 2022]. In our methodology, this direction was expanded by incorporating the digital information environment: students were asked not only to formulate a preventive recommendation but also to evaluate the reliability of the information used to substantiate it.

The assessment system is also of fundamental importance. The development of preventive immune culture cannot be adequately evaluated by testing alone. A test primarily reflects cognitive outcomes. Therefore, the study combined test assignments, clinical situations, practical tasks, questionnaires and elements of simulation-based assessment.

This approach corresponds to current developments in digital assessment. Chan et al. show that the virtual OSCE is becoming one of the directions in the transformation of professional competency assessment in health professions education [Chan et al., 2023].

The results of the study suggest that the greatest pedagogical effect arises from combining several components: a diagnostic procedure, digital educational content, a problem situation, independent decision-making, practical action and reflective assessment. Consequently, the effectiveness of Smart Immunity is determined not by a single digital tool but by the systemic organization of the educational process.

Author's Contribution

The author defined the conceptual basis for developing preventive immune culture among medical university students in the context of digital medical education; developed the Smart Immunity model and its structural-functional components; determined criteria and diagnostic tools for assessing preventive immune culture; developed a methodology

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for integrating digital educational resources, problem-based learning, clinical cases and simulation tasks into teaching the discipline Infectious Diseases; organized and analyzed the results of the pedagogical experiment; performed mathematical-statistical processing of the obtained data; and formulated the conclusions of the study.

Conclusion

The conducted study showed that the development of preventive immune culture among medical university students requires a specially organized pedagogical system integrating the content of the discipline Infectious Diseases, the preventive orientation of professional training and the possibilities of the digital educational environment.

The developed Smart Immunity model ensures interconnection among diagnostics, learning, practical activity, monitoring and reflection. Its application made it possible to substantially change the structure of educational outcomes among students in the experimental group.

The most pronounced dynamics were observed in the experimental group: the proportion of students with a high level of preventive immune culture increased from 9.6% to 19.4%, the proportion with a medium level increased from 23.1% to 63.8%, while the proportion with a low level decreased from 67.2% to 16.8%.

The mean final indicator in the experimental group was 4.08 points compared with 3.49 points in the control group, while the mean effectiveness coefficient reached 1.17. Statistical processing using the χ^2 and Fisher criteria confirmed the significance of the identified differences.

The principal result of the study is the substantiation that digital transformation of medical education acquires pedagogical value when it is meaningfully integrated with competency-based, problem-based, clinical and simulation-based learning. Under these conditions, digital technologies become a tool for developing not only information literacy in future physicians but also preventive thinking, the ability to make substantiated decisions and readiness for professional preventive activity.

The author's contribution consists in the development and experimental verification of the Smart Immunity model, diagnostic and assessment tools, and a methodology for integrating digital technologies into teaching the discipline Infectious Diseases.

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