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- 13.00.00 Pedagogika fanlari
- 13.00.01 Pedagogika nazariyasi. Pedagogik ta'limotlar tarixi
- 13.00.02 Ta'lim va tarbiya nazariyasi va metodikasi (sohalar bo'yicha)
- 13.00.03 Maxsus pedagogika
- 13.00.04 Jismoniy tarbiya va sport mashg'ulotlari nazariyasi va metodikasi
- 13.00.05 Kasb-hunar ta'limi nazariyasi va metodikasi
- 13.00.06 Elektron ta'lim nazariyasi va metodikasi (ta'lim sohaları va bosqichlari bo'yicha)
- 13.00.07 Ta'limda menejment
- 13.00.08 Maktabgacha ta'lim va tarbiya nazariyasi va metodikasi
- 13.00.09 Ijtimoiy pedagogika
- 07.00.00 Tarix fanlari
- 19.00.00 Psixologiya fanlari
- 01.00.00 Fizika-matematika fanlari
- 02.00.00 Kimyo fanlari
- 03.00.00 Biologiya fanlari
- 09.00.00 Falsafa fanlari
- 10.00.00 Filologiya fanlari
- 11.00.00 Geografiya fanlari

# M

# AKTABGACHA VA AKTAB TA'LIMI

Pedagogika, psixologiya fanlariga ixtisoslashgan ilmiy jurnal



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# MUNDARIJA

Talabalarda tolerantlikni shakllantirish zarurati va samaradorligi.....	28
<a href="#">Bafayev Muxiddin Muxammadovich</a>	
Muhandislik grafikasi bo'yicha raqamli kompetensiyalarni shakllantirishda grafik dasturlardan foydalanish metodikasini yaratish .....	34
<a href="#">Axmatova Asila Akmaljon qizi</a>	
Investigation on the Efficacy of Pedagogical Approaches in Virtual Learning .....	37
<a href="#">Burkxonova Zarafuz Qobilovna, Makhmudov Shaxboz Muzzafarovich</a>	
The Role of Input And Interaction in Second Language Acquisition.....	40
<a href="#">Dilorom Poyonova</a>	
Muhandislik yo'nalishida kartografiya fanini integratsiyalashgan holda o'qitish .....	45
<a href="#">Kazakbayeva Muxabbat Turabayevna</a>	
Incorporation of Moocs Into the Digital Educational Framework for the Development of Professional Speech Culture.....	49
<a href="#">Kudrat-Zoda Kamola Alisherovna</a>	
Pedagogical Strategies for Enhancing Students' Creative Thinking Throughout the Learning Process .....	52
<a href="#">Makhmudova Ugiyoy Baxtiyarovna</a>	
Kognitiv yondashuv asosida bo'lajak o'qituvchilarning media savodxonligini rivojlantirish .....	57
<a href="#">Mirzayeva Mayramxon Zaynobiddinovna</a>	
Transformatsion yondashuv asosida bo'lajak o'qituvchilarning sun'iy intellekt savodxonligini rivojlantirish.....	61
<a href="#">Mirzayeva Ziyoda Uktamjonovna</a>	
Maktabgacha yoshdagi bolalarni tanqidiy fikrlashga o'rgatish .....	65
<a href="#">Qurbonboyeva Gulnoza Mahmud qizi</a>	
An Online Service that Integrates Up-To-Date Content From Well-Known Mooc Platforms .....	68
<a href="#">Rakhimberdiyev Rustam Abdunasirovich, Abdurahmonova Osiyo Jahongirovna</a>	
The Fourth Phase of Distance Education: Integrated Technologies and Moocs .....	71
<a href="#">Rahimberdiyev Rustam Abdunasirovich, TaranenkoTatyana Viktorovna</a>	
Gamifikatsiya orqali iqtidorli o'quvchilarning o'quv motivatsiyasini oshirish .....	74
<a href="#">Rustamova Manzura Mirkamolovna, Xaytbayeva Malika Qobil qizi</a>	
Boshlang'ich ta'lim fanlarini didaktik o'yinlar orqali tushuntirish .....	77
<a href="#">Rustamova Manzura Mirkamolovna, Shomaxsudova Diyora Dilshod qizi</a>	
O'smirlar orasida alkogolizm, giyohvandlik va toksikomaniya profilaktikasi .....	80
<a href="#">Sh. F. Mustafayeva</a>	
Educational Physics Experiments: Methods and Didactic Strategies for Developing Critical Thinking in Students .....	85
<a href="#">Turayev Alimjan Bahriddinovich</a>	
The Problems of Remote Learning Technology and Global Trends in University Education Development.....	88
<a href="#">Tursunov Begzod Sherzodovich, Shukurova Madina</a>	
A Case Study of Humanities Disciplines Using Massive Open Online Courses as a Resource for Blended Learning.....	91
<a href="#">Tursunov Begzod Sherzodovich, Eshkabilov Kodirali Davlatmurovich</a>	
Modern Education and Training Practices for Future Dentists .....	94
<a href="#">Turumova Marjona Bahodirovna</a>	
Kommunikativ yondashuv asosida nutqiy kompetensiyani shakllantirish.....	98
<a href="#">Tuxtayeva Mehriyo Shavkatovna</a>	



Maktabgacha ta'lim jarayonida mutaxassislik fanlarini o'qitishda zamonaviy pedagogik yondashuvlar: amaliy muammolar va ularning innovatsion yechimlari .....	102
<i>Xabibulayeva Shaxrizoda O'ktam qizi</i>	
Maktabgacha ta'lim yo'nalishi talabalarda nutq o'stirish darslari orqali Soft Skills ko'nikmalarini rivojlantirishning nazariy pedagogik psixologik asoslari .....	106
<i>Xoldarova Mubina Qudratbek qizi</i>	
Maktabgacha ta'lim tashkilotlarida rivojlantiruvchi muhit va uning turlari .....	110
<i>Xolmirzayeva O'g'iloy Murotali qizi</i>	
Развитие компетенций студентов-биологов в изучении языков .....	114
<i>Абдуллаева Нигора Курбановна</i>	
Формирование интереса и повышение эффективности школьного урока физической культуры .....	118
<i>Мукимов Олим Эргашевич</i>	
Incorporation of Massive Open Online Courses Into the Higher Education Framework .....	122
<i>Rakhimberdiyev Rustam Abdunasirovich, Nasrullayev Javlonbek Ta'atjonovich</i>	
Совершенствование инновационной методики социально-педагогической деятельности будущих педагогов в полилингвальной среде с использованием искусственного интеллекта .....	125
<i>Хужаниязова Гузаль Юдашевна</i>	
Bo'lajak boshlang'ich sinf o'qituvchilarining kreativ faoliyatini xalq og'zaki ijodi asosida rivojlantirish .....	130
<i>Abduraximova Muxabbat Allayevna</i>	
Boshlang'ich sinf matematika darslarida o'rganiladigan nostandart masalalar .....	133
<i>Karimova Kunduz Ruzibayevna, Yo'ldosheva Tojigul Ulug'bek qizi</i>	
Video-marketingning iste'molchilar jalb qilinishiga ta'siri: Tiktok va Youtube misolida.....	138
<i>Rustamova Ma'mura Asqar qizi</i>	
Maktabgacha yoshdagi bolalarning kognitiv jarayonlarini diagnostika qilish .....	141
<i>Shorustamboeva Shahnoza Ulug'bekovna</i>	
The use of Visualization Technology as a New Trend in Teaching the English Language .....	144
<i>Tursunoy Ortiqova</i>	
Didaktik drama asosida kasbiy kompetensiyalarni shakllantirishda narrativ yondashuvning asosiy tushunchalari tahlili.....	149
<i>Xolbayeva Dildora Azizovna, Sadiyeva Shaxnoza Xusanovna</i>	
Tibbiyot oliy ta'lim muassasalarida biokimyo fanini o'qitishda work-based learning metodikasini qo'llash ..	153
<i>Mamadaliyeva Zarina Raxmat qizi</i>	
Bo'lajak shifokorlarni tibbiy amaliyotga tayyorlash metodikasini takomillashtirish.....	156
<i>Murtazayeva Nasiba Komiljonovna</i>	
Autizm spektri buzilishi bo'lgan bolalar uchun inklyuziv ta'limni tashkil etish .....	159
<i>Xusnidinova Saodat</i>	
Muloqot madaniyati asosida liderlik fazilatlarini shakllantirishning samarali usullari .....	163
<i>Djumayeva Dildora Isroilovna</i>	
Integrating Quizlet, Kahoot, and Padlet Into Vocabulary Instruction: An Experimental Study With Undergraduate Philology Students.....	167
<i>Inoyatova Umida Boxadir kizi</i>	
Advantages and Disadvantages of Teaching Students Via Competent Based Approach in Order to Improve Their Listening and Speaking in Finland .....	171
<i>Abdukhakimova Kamola Akmalovna, Rahmatova Mohijahon Ahmad qizi</i>	
Kimyo ta'limida iqlim o'zgarishlariga oid ilmiy ma'lumotlar asosida qaror qabul qilish kompetensiyasini rivojlantirish .....	175
<i>Akbarova Saidaxon Rustamovna</i>	
Tibbiyot oliy ta'limida pediatriya talabalari klinik fikrlashini rivojlantirishda muammoli ta'lim metodlarining roli.....	180
<i>Atadjanova Shaira Xalilovna, Umardulov Muxtorali Islomkulovich</i>	

MUNDARIJA СОДЕРЖАНИЕ CONTENTS	Individual ta'lim muhiti asosida bo'lajak maktabgacha ta'lim tarbiyachilarini kasbiy-metodik tayyorlashni takomillashtirish..... 185 <b>Azamatova Dildora Shuxrat qizi</b>
	Boshlang'ich ta'lim-tarbiya tizimida raqamli ta'limni joriy etishning innovatsion yondashuvlari va samaradorlik omili..... 189 <b>Babayeva Dilnoz Xaydarovna</b>
	O'qish savodxonligini oshirishda xalqaro tadqiqotlarning o'rni (PISA va PIRLS) ..... 192 <b>Barakayeva Shahnoza Fazliddin qizi</b>
	Yosh rahbarlarda boshqaruv stressining namoyon bo'lishi va boshqaruv faoliyatiga moslashuv muammolari: ta'lim tizimi sharoitida psixologik holat tahlili..... 195 <b>Djavgarova Dilfuza Shuxrat qizi</b>
	Sun'iy intellekt va katta ma'lumotlardan foydalanish asosida oliy ta'lim muassasalarida boshqaruv samaradorligini oshirish strategiyalari..... 199 <b>Duvlayeva Nozigul Xolmuxammad qizi</b>
	Enhancing English Learners' Pronunciation Through AI-Based Language Applications..... 203 <b>Egamova Munisa Khakim kizi</b>
	Maktab ta'lim tizimining dars jarayonlarida elektron qo'llanmalardan samarali foydalanish..... 208 <b>Kodirov Akbar Shuxratovich</b>
	Improving the Methodology of Teaching Biochemistry in Medical Higher Education Institutions Through Virtual Laboratory Tools ..... 213 <b>Mamadaliyeva Zarina Rakhmat kizi</b>
	O'smirlarda kommunikativ tolerantlik muammosining nazariy-metodologik asoslari..... 218 <b>Mirsidikova Aziza Mirvohidovna</b>
	Boshlang'ich sinf o'quvchilarining sog'lom turmush tarzini tashkil etishning nazariy asoslari ..... 221 <b>Muxtorova Xusnidaxon Abdug'oprovna</b>
	Improving the Theoretical and Methodological Foundations for Integrating Generative Artificial Intelligence Technologies Into English Language Teaching in Higher Education ..... 226 <b>Nigmatova Nozimakhon Ulugbek kizi</b>
	Maktabgacha ta'lim va oila hamkorligi: zamonaviy yondashuvlar va ilmiy asoslar..... 229 <b>Omondavlatova Diyora Otabekovna</b>
	Oliy ta'lim muassasalarida iqtidorli talabalarning ilmiy va ijodiy kompetensiyalarini aniqlashga yo'naltirilgan axborot tizimini yaratish ..... 233 <b>Ovxunov Iqboljon Abdunabiyevich, Ro'zimatova Saidaxon Abdivoxiid qizi</b>
	O'quvchilarni o'zbek xalq og'zaki ijodi namunalari vositasida vatanparvarlik ruhida tarbiyalash pedagogik muammo sifatida..... 237 <b>Qodirqulov Nodirbek Hamroqul o'g'li</b>
	Oliy ta'lim tizimida talaba-qizlarning kasbiy, madaniy va kommunikativ faoliyatlarini samarali tashkil etish ..... 242 <b>Qurbonova G. M.</b>
	Kasbiy tayyorgarlik jarayonida refleksiv yondashuvning metodologik asoslari ..... 245 <b>Raxmatova Shaxnoza Oybek qizi</b>
	Inkluziv ta'limda pedagogik diagnostika: maxsus ehtiyojli o'quvchilarning o'quv yutuqlarini baholash ..... 248 <b>Norqobilova Rayxona Davlatovna</b>
	Maktabgacha ta'lim tashkiloti tarbiyachilarining umummadaniy kompetensiyalarini rivojlantirish texnologiyalari..... 252 <b>Saidova Nigora Olimovna, Jo'rayeva Nilufar Rustamjon qizi</b>
	Pedagogical Strategies for Enhancing Students' Creative Thinking Throughout the Learning Process ..... 254 <b>Shaymatova Aziza</b>
	Dasturiy-metodik majmuani ishlab chiqish bosqichlari hamda pedagogik talablar..... 259 <b>Soliyeva Gavharoy Yodgorjon qizi</b>
	Nutq kamchiliklarini bartaraf etishda maktabgacha ta'lim yoshidagi bolalarda pedagogik metod va o'yinlarning samaradorligi ..... 265 <b>Suyarova Orzigul Sodiq qizi</b>



Yoshlarni nikohga tayyorlashda shaxsiy omillar va psixologik yetuklik.....	269
<i>To'xtamatova Nargizaxon Abdullayevna, Buranova Sevara Sa'dullayevna</i>	
O'zbekiston umumiy o'rta ta'lim tizimida rahbarlarning liderlik kompetensiyalarining hozirgi holatini diagnostika qilish .....	273
<i>Taylakova Dilnoza Norbekovna, Latifova Mavjuda Xurramovna</i>	
Ta'limga o'qib tushinishni sun'iy intellekt bilan integratsiya qilish imkoniyatlari va pedagogik strategiyalari.....	276
<i>Umarov Bahrom Norboyevich</i>	
Talabalar mobilligi jarayonida pedagogik qo'llab-quvvatlash mexanizmlari.....	281
<i>Xabibullayev Alimardon Xidoyatillayevich</i>	
Bo'lajak boshlang'ich sinf o'qituvchilarni tayyorlashda kompetensiyaviy yondashuvning roli va ahamiyati.....	286
<i>Yo'ldosheva Iqbol Bekbo'lsin qizi</i>	
Boshlang'ich sinflarda chet tilini o'rganishning ahamiyati va undagi zamonaviy yondashuvlar .....	289
<i>Yoqubjonova Mohlaroyim Abdumalik qizi</i>	
O'smir shaxsida refleksiyani shakllanishida ota-ona munosabatlarning ta'siri .....	292
<i>Yulchiboyeva Dilfuza Ergashevna</i>	
Boshlang'ich ta'limda geymifikatsiya orqali til kompetentligini rivojlantirish.....	297
<i>Zokirova Sohiba Muxtoraliyevna, Nurmuhammedova Dilshoda Zaynobiddin qizi</i>	
Профессиональная этика педагога высшего учебного заведения .....	302
<i>Журабекова Хабиба Мадаминовна</i>	
Ortodontiyada mioterapiya: miogimnastik dentoalveolyar apparatlarni qo'llashning taqqoslama tavsifi .....	305
<i>Tursunov Begzod Sherzodovich, Sayfulayeva Aziza Anvarovna</i>	
Музейная педагогика на уроках воспитания в средней школе: методика включения музейных практик в процесс обучения и воспитания подростков .....	308
<i>Умрихина Виктория Игоревна</i>	
21St Century Dental Innovation Technologies: An Overview .....	314
<i>Khojimurodov Burkhon Ravshanovich</i>	
Цели и задачи педагогических систем, основанных на конструктивизме в общеобразовательных школах .....	317
<i>Шарипова Шахноза Шавкат кизи</i>	
Способы повышения мотивации учащихся при изучении русского языка.....	321
<i>Эшонкулов Хамрокул Маматкулович</i>	



# IMPROVING THE METHODOLOGY OF TEACHING BIOCHEMISTRY IN MEDICAL HIGHER EDUCATION INSTITUTIONS THROUGH VIRTUAL LABORATORY TOOLS

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**Abstract:** This article examines the possibilities for improving the methodology of teaching biochemistry in medical higher education institutions through the use of virtual laboratory tools. The integration of digital technologies into the educational process enables the simulation of complex biochemical experiments, enhances students' practical skills, and promotes the development of analytical and critical thinking. Virtual laboratories provide safe, cost-effective, and accessible learning environments, allowing students to repeatedly perform experiments without the limitations associated with traditional laboratory settings. The study highlights the pedagogical advantages of virtual laboratories, including increased student motivation, individualized learning, and deeper comprehension of biochemical processes. The implementation of virtual laboratory tools contributes to the modernization of biochemistry education and aligns medical training with contemporary educational standards and technological requirements.

**Key words:** biochemistry education, virtual laboratory, medical higher education, digital educational technologies, teaching methodology.

**Annotatsiya:** Mazkur maqolada tibbiyot oliy ta'lim muassasalarida biokimyofanini o'qitish metodikasini virtual laboratoriya vositalaridan foydalanish orqali takomillashtirish imkoniyatlari yoritilgan. Ta'lim jarayoniga raqamli texnologiyalarni integratsiya qilish murakkab biokimyoviy tajribalarni modellashtirishga, talabalarda amaliy ko'nikmalarni shakllantirishga hamda analitik va tanqidiy fikrlashni rivojlantirishga xizmat qiladi. Virtual laboratoriyalar xavfsiz, iqtisodiy jihatdan samarali va qulay ta'lim muhitini ta'minlab, an'anaviy laboratoriya mashg'ulotlariga xos bo'lgan cheklovlarsiz tajribalarni bir necha bor bajarish imkonini beradi. Maqolada virtual laboratoriyalarning pedagogik afzalliklari, jumladan, talabalarning o'quv motivatsiyasini oshirish, ta'limni individuallashtirish va biokimyoviy jarayonlarni chuqurroq anglash imkoniyatlari alohida ta'kidlangan. Virtual laboratoriya vositalaridan foydalanish biokimyofanini modernizatsiya qilishga xizmat qiladi hamda tibbiy kadrlarni tayyorlashda zamonaviy ta'lim standartlari va texnologik talablariga mos keladi.

**Kalit so'zlar:** biokimyofanini o'qitish, virtual laboratoriya, tibbiyot oliy ta'limi, raqamli ta'lim texnologiyalari, o'qitish metodikasi.

**Аннотация:** В статье рассматриваются возможности совершенствования методики преподавания биохимии в медицинских высших учебных заведениях посредством использования виртуальных лабораторных средств. Интеграция цифровых технологий в образовательный процесс позволяет моделировать сложные биохимические эксперименты, способствует формированию практических навыков у студентов, а также развитию аналитического и критического мышления. Виртуальные лаборатории обеспечивают безопасную, экономически эффективную и доступную образовательную среду, позволяя многократно выполнять эксперименты без ограничений, характерных для традиционных лабораторных занятий. В работе подчёркиваются педагогические преимущества виртуальных лабораторий, такие как повышение учебной мотивации студентов, индивидуализация обучения и углублённое понимание биохимических процессов. Использование виртуальных лабораторных инструментов способствует модернизации биохимического образования и соответствует современным образовательным стандартам и технологическим требованиям медицинской подготовки.

**Ключевые слова:** преподавание биохимии, виртуальная лаборатория, медицинское высшее образование, цифровые образовательные технологии, методика обучения.

## INTRODUCTION

In recent years, the rapid development of information and communication technologies has significantly influenced the higher education system, particularly in the field of medical education. Modern medical training requires not only the acquisition of theoretical knowledge but also the development of practical competencies, analytical thinking, and decision-making skills. Biochemistry, as a fundamental discipline in medical education, plays a crucial role in forming an integrated understanding of the molecular mechanisms underlying physiological and pathological processes in the human body. However, traditional methods of teaching biochemistry often face several challenges, including limited laboratory resources, high costs of reagents and equipment, safety concerns, and insufficient time allocated for practical training <sup>[1]</sup>.

In this context, the introduction of virtual laboratory tools represents a promising approach to improving the methodology of teaching biochemistry in medical higher education institutions. Virtual laboratories enable the simulation of complex biochemical experiments and processes that are difficult or impossible to reproduce in conventional laboratory settings. They provide students with opportunities to conduct experiments in a controlled digital environment, repeat procedures multiple times, analyze results, and correct mistakes without the risk of material losses or harm to health <sup>[2]</sup>. The use of virtual laboratory tools also contributes to the implementation of student-centered and competency-based educational approaches. By integrating interactive simulations, multimedia content, and real-time feedback, virtual laboratories enhance students' motivation and engagement in the learning process. Moreover, they support the individualization of learning by allowing students to progress at their own pace and focus on areas that require deeper understanding. This is particularly important in biochemistry, where abstract concepts and complex biochemical pathways often present difficulties for students <sup>[3]</sup>.

## LITERATURE REVIEW

According to scientific sources, the use of digital technologies in medical education increases the interactivity of the learning process, places students at the center of educational activities, and fosters the development of independent learning, information analysis, and the application of theoretical knowledge in clinical practice <sup>[4]</sup>. Therefore, organizing modern medical education within a digital environment, improving teaching methodologies, and enriching the educational process with innovative technologies are among the most relevant scientific and pedagogical tasks of today. In the context of global digital transformation, medical education systems worldwide are adopting innovative technologies aimed at improving clinical competence and decision-making skills among future healthcare professionals. According to the World Health Organization (WHO), the integration of digital learning environments into medical curricula is one of the key priorities for ensuring quality healthcare education in the 21st century <sup>[5]</sup>. Furthermore, the integration of virtual laboratories aligns with the global trend toward the digitalization and modernization of medical education. The COVID-19 pandemic clearly demonstrated the necessity of flexible and remote learning solutions, highlighting the importance of digital tools in ensuring the continuity and quality of education. Virtual laboratory technologies can effectively complement traditional teaching methods, serving as an additional or alternative platform for practical training in biochemistry. Therefore, improving the methodology of teaching biochemistry through the use of virtual laboratory tools is a relevant and timely issue. It contributes to enhancing the quality of medical education, improving students' learning outcomes, and preparing future medical professionals to meet the demands of modern healthcare systems <sup>[6]</sup>.

## RESEARCH METHODOLOGY

In this study, a set of theoretical, empirical, and statistical methods was employed to analyze the process of teaching biochemistry through digital technologies in higher medical education institutions. Theoretical methods included a review of scientific literature related to medical education and biochemistry teaching, as well as an analysis of domestic and international experience in integrating digital technologies into the educational process. Empirical methods involved classroom observations, surveys of medical students, and the experimental application of interactive digital learning tools to evaluate their pedagogical effectiveness. Statistical methods were used to process experimental data, determine learning efficiency indicators, and compare the outcomes of digital and traditional teaching approaches. The results demonstrated that the use of digital technologies significantly improves students' academic performance, diagnostic reasoning, and clinical decision-making skills.



## ANALYSIS AND RESULTS

The implementation of virtual laboratory tools in biochemistry teaching demonstrated statistically and pedagogically significant improvements in students' learning outcomes. A comparative analysis between students studying through traditional laboratory-based instruction and those exposed to a blended model incorporating virtual laboratories revealed notable differences in theoretical knowledge acquisition, practical skill development, and cognitive engagement<sup>[6,9]</sup>. Students who utilized virtual laboratory tools showed a marked increase in their understanding of complex biochemical concepts, including enzyme kinetics, metabolic pathways, and molecular interactions. Assessment results indicated higher average scores in module examinations and practical tests compared to the control group. In particular, the accuracy of experimental procedure execution and the interpretation of biochemical data improved substantially, reflecting enhanced conceptual clarity and analytical competence. The use of virtual laboratories also positively influenced the development of practical skills. Although virtual environments do not involve physical manipulation of laboratory equipment, students demonstrated improved procedural sequencing, hypothesis formulation, and result analysis. Repeated simulation of experiments enabled learners to identify errors, refine techniques, and gain a deeper understanding of experimental design principles. As a result, students who entered traditional laboratory sessions after virtual training required less instructional support and exhibited greater confidence in performing biochemical experiments<sup>[10,12]</sup>.

In addition, student engagement and motivation levels increased significantly following the integration of virtual laboratory tools. Learning analytics and survey data revealed higher participation rates, increased time spent on task completion, and greater autonomy in learning activities. Students reported that interactive simulations and visual representations of biochemical processes facilitated comprehension and reduced the cognitive load associated with abstract theoretical material<sup>[8,12]</sup>.

The findings further indicated that virtual laboratory tools contributed to the individualization of the learning process. Students were able to progress at their own pace, repeat experiments as needed, and focus on challenging topics, which led to reduced performance disparities within the student cohort. This adaptability proved particularly effective for learners with varying levels of prior knowledge and learning abilities<sup>[11,13]</sup>. Moreover, the integration of virtual laboratories enhanced the overall efficiency of the educational process. Instructors reported reduced time spent on preliminary explanations during practical sessions and improved alignment between theoretical lectures and laboratory activities. The virtual format also minimized resource-related constraints, including reagent consumption, equipment wear, and safety risks, without compromising educational quality<sup>[6,8]</sup>. Overall, the findings confirm that the incorporation of virtual laboratory tools into biochemistry education significantly enhances learning effectiveness, supports competency-based training, and contributes to the modernization of teaching methodologies in higher medical education institutions. The results of the present study demonstrate that virtual laboratories function not merely as supplementary instructional aids but as effective pedagogical components capable of transforming traditional biochemistry education.

The higher academic performance of students exposed to virtual laboratory-based instruction suggests that digital simulations facilitate a deeper comprehension of complex biochemical processes. Biochemistry is characterized by abstract molecular interactions, dynamic metabolic pathways, and multilevel regulatory mechanisms, which often pose substantial learning difficulties when conveyed solely through lectures or static textbook illustrations. Virtual laboratories address this challenge by providing dynamic visualizations and interactive models that enable students to observe, manipulate, and analyze biochemical processes in real time. This enhanced visualization likely contributed to the improved accuracy in data interpretation and experimental reasoning observed in the experimental group. The results also indicate a notable advancement in students' practical competencies despite the absence of direct physical interaction with laboratory equipment. This finding supports the notion that procedural understanding and experimental logic can be effectively developed within virtual environments. By repeatedly performing simulated experiments, students were able to internalize the sequence of laboratory procedures, anticipate outcomes, and identify methodological errors. Consequently, upon transitioning to traditional laboratory settings, students demonstrated increased confidence and required less instructional intervention. This observation is consistent with contemporary educational theories that emphasize the role of cognitive rehearsal and experiential learning in skill acquisition<sup>[14]</sup>.

An important pedagogical implication of the study is the positive impact of virtual laboratories on student motivation and engagement. Increased participation rates and extended time-on-task indicate a shift from passive learning to active, student-centered engagement. Interactive elements, immediate feedback, and self-paced progression appear to foster intrinsic motivation and promote autonomous learning behaviors. Such outcomes are particularly valuable in medical education, where lifelong learning and self-directed professional development constitute essential competencies. Furthermore, the individualization enabled by virtual labo-

ratory tools addresses a critical limitation of traditional biochemistry instruction, namely the heterogeneity of student preparedness and learning styles. The ability to repeat experiments, revisit challenging concepts, and progress at an individualized pace contributed to a reduction in performance disparities among students. This adaptive learning environment supports educational equity and enhances overall learning efficiency. From an institutional perspective, the implementation of virtual laboratories offers substantial logistical and economic advantages. Reduced reliance on consumable reagents, minimized equipment wear, and improved safety conditions contribute to the sustainability of the educational process. In addition, instructors reported improved alignment between theoretical and practical components of the curriculum, suggesting that virtual laboratories facilitate stronger curricular integration and greater instructional coherence [15–16].

Despite these advantages, it is important to emphasize that virtual laboratories should not be regarded as a complete substitute for traditional laboratory training, particularly in medical education where hands-on experience remains indispensable. Rather, the findings of this study support a blended instructional model in which virtual laboratories complement conventional practical sessions. Such an approach maximizes educational effectiveness by combining the strengths of digital simulation with authentic laboratory practice. In summary, the discussion of the results confirms that virtual laboratory tools play a significant role in modernizing biochemistry education, enhancing learning outcomes, and supporting competency-based medical training. Their integration into the curriculum represents a scientifically grounded and pedagogically effective strategy for improving the methodology of teaching biochemistry in medical higher education institutions.

## CONCLUSION

The present study confirms that the integration of virtual laboratory tools significantly improves the methodology of teaching biochemistry in medical higher education institutions. The findings demonstrate that virtual laboratories enhance students' theoretical understanding, analytical abilities, and procedural reasoning, while simultaneously increasing motivation and engagement in the learning process. By enabling interactive visualization and repeated simulation of complex biochemical experiments, virtual laboratory tools facilitate deeper comprehension of abstract biochemical concepts and support the development of essential professional competencies. The results indicate that the use of virtual laboratories contributes to more effective preparation of students for traditional laboratory work. Students exposed to virtual simulations exhibited greater confidence, improved experimental planning skills, and reduced dependence on instructor guidance during practical sessions. This suggests that virtual laboratories serve as an efficient preparatory platform that strengthens the connection between theoretical instruction and practical application. Moreover, the adaptability and flexibility of virtual laboratory environments promote individualized and student-centered learning. The ability to progress at an individual pace, revisit challenging material, and independently analyze experimental outcomes helps reduce learning disparities and supports competency-based medical education. From an institutional perspective, the implementation of virtual laboratory tools offers additional benefits, including optimized use of educational resources, enhanced safety conditions, and improved sustainability of laboratory-based instruction.

Despite these advantages, virtual laboratories should be considered a complementary component rather than a substitute for conventional hands-on laboratory training. A blended educational model that integrates virtual simulations with traditional laboratory practice represents the most effective approach for achieving high-quality biochemistry education in medical training programs.

In conclusion, the incorporation of virtual laboratory tools into biochemistry curricula is a scientifically grounded and pedagogically effective strategy that aligns with modern educational standards and technological advancements. Their systematic implementation can significantly contribute to the modernization of medical education and to the preparation of highly competent future healthcare professionals.

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- 13.00.00 Pedagogika fanlari
  - 13.00.01 Pedagogika nazariyasi. Pedagogik ta'limotlar tarixi
  - 13.00.02 Ta'lim va tarbiya nazariyasi va metodikasi (sohalar bo'yicha)
  - 13.00.03 Maxsus pedagogika
  - 13.00.04 Jismoniy tarbiya va sport mashg'ulotlari nazariyasi va metodikasi
  - 13.00.05 Kasb-hunar ta'limi nazariyasi va metodikasi
  - 13.00.06 Elektron ta'lim nazariyasi va metodikasi (ta'lim sohaları va bosqichlari bo'yicha)
  - 13.00.07 Ta'limda menejment
  - 13.00.08 Maktabgacha ta'lim va tarbiya nazariyasi va metodikasi
  - 13.00.09 Ijtimoiy pedagogika
  - 07.00.00 Tarix fanlari
  - 19.00.00 Psixologiya fanlari
  - 01.00.00 Fizika-matematika fanlari
  - 02.00.00 Kimyo fanlari
  - 03.00.00 Biologiya fanlari
  - 09.00.00 Falsafa fanlari
  - 10.00.00 Filologiya fanlari
  - 11.00.00 Geografiya fanlari



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