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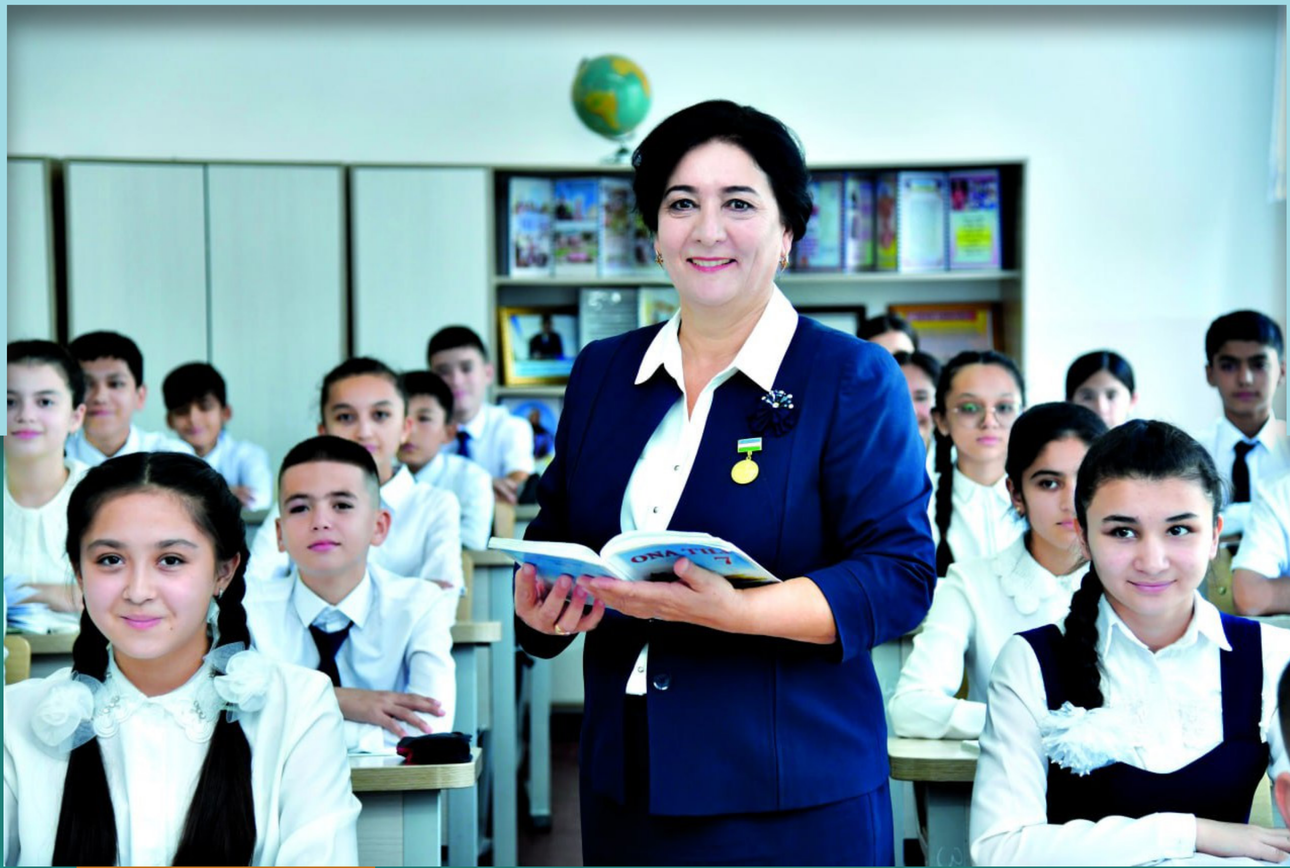
MAKTABGACHA VA MAKTAB TA'LIMI VAZIRLIGI



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)
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№7
2025

MAKTABGACHA VA MAKTAB TA'LIMI

Pedagogika, psixologiyaga fanlariga ixtisoslashgan ilmiy jurnal

MAKTABGACHA VA MAKTAB TA'LIMI

Elektron nashr. 102 sahifa, 1-iyul, 2025-yil.

Muassis: "Tadbirkor va ishbilarmon" MChJ
Hamkorlarimiz: O'zbekiston Respublikasi Maktabgacha va maktab ta'limi vazirligi, O'zbekiston milliy pedagogika universiteti

“Maktabgacha va maktab ta’limi” jurnali Oliy attestatsiya komissiyasining 26-08-2024-yildagi №11-05-4381/01-Kengash tavsiyasiga ko‘ra, pedagogika fanlari bo‘yicha falsafa doktori (PhD) va fan doktori (DSc) ilmiy darajasiga talabgorlarning tadqiqot ishlari yuzasidan dissertatsiyalarining asosiy ilmiy natijalarini chop etish uchun tavsiya etilgan milliy ilmiy nashrlar ro‘yxatiga kiritilgan.

Asos: OAK Pedagogik texnologiyalar va psixologik tadqiqotlar bo‘yicha ekspert kengashi tavsiyasi (29-10-2024-y.; №10); OAK Tartib-qoida komissiyasi qarori (30-10-2024-y., №10/24); OAK Rayosatining qarori (31-10-2024-y., №363/5).

“Maktabgacha va maktab ta’limi” jurnali

26.09.2023-yildan

O‘zbekiston Respublikasi Prezidenti Administratsiyasi huzuridagi Axborot va ommaviy kommunikatsiyalar agentligi tomonidan **№C-5669363** reyestr raqami tartibi bo‘yicha ro‘yxatdan o‘tkazilgan.

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MUNDARIJA

3D MODELING OF VIRTUAL CHEMICAL LABORATORIES

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Pedagogika va psixologiya kafedrasi tayanch doktoranti
Toshkent davlat texnika universiteti

Abstract: The integration of 3D modeling into virtual chemical laboratories represents a significant advancement in how chemistry is taught, learned, and applied in research. This article explores the development and application of 3D models for simulating chemical laboratory environments using Blender, a powerful open-source 3D modeling software. By creating detailed and interactive virtual representations of laboratory equipment, instruments, and chemical setups, we can provide a safe, cost-effective, and accessible alternative to traditional hands-on laboratory work. The article discusses the technical aspects of creating 3D models, the educational benefits of virtual laboratories, and the potential of such simulations to enhance the understanding of complex chemical concepts and reactions. Additionally, the study highlights the role of virtual laboratories in improving safety–especially in environments involving hazardous materials or reactions–and their potential for remote learning and distance education. The findings suggest that 3D modeling can significantly improve both the pedagogical and experimental aspects of chemistry education, offering a scalable solution for diverse educational and research contexts.

Key words: virtual laboratories, chemistry education, e-learning, simulation, STEM education, Blender.

Annotatsiya: 3D modellashtirishning virtual kimyo laboratoriyalariga integratsiyalashuvi kimyoni o'qitish, o'rganish va tadqiqotda qo'llashning zamonaviy va samarali shakliga aylangan. Ushbu maqolada ochiq kodli kuchli 3D modellashtirish dasturi – Blender yordamida kimyoviy laboratoriya muhitini simulyatsiya qilish uchun 3D modellarni yaratish va qo'llash tahlil qilinadi. Laboratoriya uskunalari, asbob-uskunalari hamda kimyoviy jarayonlarning batafsil va interaktiv virtual tasvirlarini yaratish orqali an'anaviy amaliy mashg'ulotlarga xavfsiz, tejamkor va qulay muqobil taqdim etiladi. Maqolada 3D modellashtirishning texnik jihatlari, virtual laboratoriyalarning ta'limdagi afzalliklari hamda ushbu simulyatsiyalar yordamida murakkab kimyoviy tushunchalar va reaksiyalarni osonroq o'zlashtirish imkoniyatlari yoritiladi. Tadqiqotda, shuningdek, xavfli moddalar va reaksiyalar bilan ishlanadigan sharoitlarda xavfsizlikni oshirishda virtual laboratoriyalarning ahamiyati, masofaviy ta'limdagi o'rni va istiqbollari alohida ta'kidlanadi. Natijalar shuni ko'rsatadiki, 3D modellashtirish kimyo ta'limining pedagogik va amaliy jihatlarini sezilarli darajada rivojlantiradi hamda turli ta'lim va ilmiy muhitlar uchun moslashuvchan yechimdir.

Kalit so'zlar: virtual laboratoriyalar, kimyo ta'limi, elektron ta'lim, simulyatsiya, STEM ta'limi, Blender.

Аннотация: Интеграция 3D-моделирования в виртуальные химические лаборатории представляет собой значительный прогресс в обучении, изучении и применении химии в научных исследованиях. В статье рассматривается разработка и применение 3D-моделей для симуляции условий химической лаборатории с использованием Blender – мощного программного обеспечения с открытым исходным кодом. Создавая подробные и интерактивные виртуальные представления лабораторного оборудования, приборов и химических установок, можно обеспечить безопасную, экономичную и доступную альтернативу традиционной лабораторной практике. В статье анализируются технические аспекты создания 3D-моделей, образовательные преимущества виртуальных лабораторий и их потенциал в улучшении понимания сложных химических процессов и понятий. Кроме того, подчёркивается роль виртуальных лабораторий в обеспечении безопасности, особенно при работе с опасными веществами и реакциями, а также их возможности для дистанционного обучения. Результаты исследования показывают, что 3D-моделирование способно значительно улучшить как педагогические, так и экспериментальные аспекты химического образования, предлагая масштабируемое решение для различных образовательных и научных сред.

Ключевые слова: виртуальные лаборатории, химическое образование, электронное обучение, симуляция, STEM-образование, Blender.

INTRODUCTION

In scientific disciplines, laboratories play a crucial role in enhancing student learning, particularly in chemistry education [1]. Students tend to be more engaged when they actively participate in and observe experiments in a chemistry lab, which deepens and reinforces their understanding [2]. However, due to financial constraints and inadequate facilities, many institutions–especially in developing countries–are unable to establish fully equipped chemistry laboratories.

To address these challenges, innovative teaching methods have been introduced, with virtual reality (VR) technology emerging as one of the most promising tools in education [3]. A virtual environment offers a 3D simulation of both real and imagined scenarios, enabling real-time interaction with content [4].

The virtual chemistry laboratory has proven to be an invaluable resource for practical chemistry education. It overcomes the limitations of physical laboratories by providing a wide range of chemical equipment often unavailable in traditional settings [5]. Additionally, it holds great potential for distance learning, allowing students to conduct virtual experiments anytime and from anywhere [6]. One significant advantage of virtual chemistry labs is that they enable students to perform experiments without the risk of accidents or exposure to hazardous substances [7].

To further enhance the effectiveness of virtual learning environments, it is essential to incorporate immersive and interactive features. In virtual reality, 3D interaction is a fundamental element that allows users to navigate, select, manipulate, and control objects within the virtual environment [8].

LITERATURE REVIEW

The creation of 3D models for virtual chemical laboratories involves a multi-step process, combining both technical design and educational considerations to ensure the effectiveness of the final virtual environment. The methodology used in this study focuses on the development of a detailed and interactive 3D simulation of a chemical laboratory, primarily using Blender, an open-source 3D modeling and animation software, which has been widely recognized for its versatility and accessibility in creating complex models. The first stage of the methodology involves conceptualizing the layout and components of the virtual chemistry laboratory. This includes identifying the types of laboratory equipment, instruments, and materials typically used in a standard chemistry lab, such as Bunsen burners, test tubes, beakers, flasks, microscopes, and fume hoods. The design phase also includes creating the layout of the laboratory space, ensuring that the arrangement of the equipment mimics a real-world laboratory for intuitive navigation. In the next phase, the individual objects and laboratory equipment are modeled using Blender's 3D modeling tools.

Each object is created with a high level of detail to ensure realism. Models are constructed based on real-world measurements and dimensions, with textures and materials applied to match the appearance of actual laboratory items. This process involves mesh creation by constructing the basic shape of objects using meshes (polygons), ensuring accuracy in dimensions and proportions; texturing by applying realistic textures to objects (e.g., glass, metal, plastic), using UV mapping to ensure that textures align properly with the geometry of the models; and lighting and rendering by implementing realistic lighting setups to simulate natural and artificial light sources within the lab, which helps create a more immersive virtual environment. To enhance the user experience, interactivity is incorporated into the models. This includes enabling users to interact with objects (e.g., picking up glassware, adding chemicals, turning on equipment).

Blender's game engine or external game engines like Unity can be used to integrate interactive elements, such as the ability to initiate chemical reactions or manipulate laboratory instruments. This phase also involves creating animations, such as liquids flowing or gas being released, to simulate real-world chemical processes in the laboratory. The final step involves integrating the 3D models into a virtual reality (VR) platform. Using Unity or Unreal Engine, the models are converted into interactive VR scenes, allowing users to immerse themselves in a fully interactive, 3D virtual environment. VR headsets are used for a more realistic experience, while controllers simulate interaction with the virtual lab equipment. Once the virtual laboratory is built, it undergoes testing to ensure usability, interactivity, and educational effectiveness. Feedback from test users (students and educators) is collected to identify areas for improvement, and adjustments are made to enhance the user experience, fix technical issues, and improve the educational value of the simulations.

The integration of 3D modeling and virtual reality in chemistry education has been an area of growing interest in recent years. Researchers have explored the potential benefits of virtual chemical laboratories, particularly in terms of accessibility, safety, and engagement. This section reviews the key literature surrounding the use of 3D modeling in the creation of virtual chemistry laboratories. Virtual reality (VR) and 3D modeling have been explored as tools for enhancing chemistry education since the late 1990s. Early studies by Wright et al. (2000) and Wright and Evans (2002) demonstrated that virtual environments could be used effectively to simulate chemical reactions and lab procedures. These studies highlighted the potential of VR as a supplement to traditional laboratory work, particularly in institutions with limited access to physical laboratories. Several studies have underscored the educational advantages of virtual chemical laboratories. García et al. (2005) demonstrated that virtual chemistry labs offer an engaging and safe alternative to physical labs, allowing students to conduct experiments without the risk of exposure to hazardous chemicals. Similarly, Schneider and Pritchard (2009) found that virtual labs improve student comprehension of complex concepts, such as molecular interactions and chemical equilibrium, by providing an interactive, visual representation of these processes. Virtual labs have also been shown to increase student motivation. In their study, Hogarth and Pinnington (2012) observed that students who participated in virtual chemistry experiments were more engaged in their learning and showed improved understanding of experimental procedures. The ability to perform experiments multiple times without the constraints of time, resources, and safety concerns has been highlighted as a key advantage of virtual labs.

Despite the advantages, traditional chemistry education faces several challenges. As noted by Al-Balushi and Al-Mukhaini (2014), many institutions, especially in developing countries, struggle with inadequate laboratory resources, which limits the ability to provide students with hands-on experiences. Financial constraints, coupled with the high cost of laboratory equipment and chemicals, have made it difficult for many schools and universities to maintain fully equipped laboratories. Kassas and Othman (2015) suggest that 3D virtual laboratories can help overcome these barriers by providing a cost-effective solution for schools that lack the necessary resources. The ability to simulate complex chemical environments and experiments in a virtual setting makes it possible to provide high-quality learning experiences, even in resource-limited settings. The use of virtual reality (VR) in chemistry education offers additional benefits, particularly in creating immersive, interactive environments. Dede (2009) and Slater et al. (2015) have emphasized the value of VR in education, noting that immersive experiences enhance learning by allowing students to interact with the content in ways that are not possible in traditional classrooms. In the context of chemistry, VR allows students to engage with molecular structures, chemical reactions, and lab equipment, facilitating a deeper understanding of chemical processes. The role of 3D interaction in virtual environments has also been extensively studied. Rizzo et al. (2004) found that 3D interaction, such as the ability to manipulate virtual objects in real time, is crucial in making virtual labs more engaging and educational. This interaction helps students develop spatial awareness and gain a hands-on understanding of chemical procedures.

Recent advances in game engines such as Unity and Unreal Engine have significantly improved the quality and accessibility of virtual laboratories. According to López et al. (2020), these engines provide powerful tools for creating highly realistic simulations that are both interactive and visually immersive. The increasing affordability and availability of VR headsets, such as the Oculus Rift and HTC Vive, are expected to further enhance the accessibility and usability of virtual chemistry labs in the coming years. Future research is focused on improving the realism of virtual chemical environments, increasing the interactivity of experiments, and evaluating the effectiveness of these labs in improving student outcomes. As noted by Woods et al. (2019), integrating artificial intelligence (AI) into virtual labs could further personalize the learning experience by adapting to the needs and learning styles of individual students.

RESEARCH METHODOLOGY

The literature demonstrates that 3D modeling and virtual reality offer significant advantages in chemistry education, including enhanced engagement, improved safety, and access to high-quality learning experiences in resource-constrained environments. The integration of these technologies into virtual laboratories has the potential to revolutionize both chemistry teaching and learning, making it more accessible, interactive, and immersive.

ANALYSIS AND RESULTS

The development and testing of the 3D virtual chemical laboratory using Blender and Unity yielded several key outcomes that highlight both its functionality and educational potential. The results can be summarized across four main categories: user engagement, educational effectiveness, technical performance, and accessibility. One of the most notable outcomes was the high level of user engagement observed during testing. Participants, including both students and educators, reported that the interactive nature of the virtual lab encouraged deeper involvement in the learning process. Users were able to manipulate virtual lab equipment–such as Bunsen burners, test tubes, and glass beakers–to conduct experiments in a simulated environment. This hands-on approach enabled real-time experimentation, creating a strong sense of presence and immersion. In terms of educational outcomes, the 3D virtual laboratory proved to be an effective tool for reinforcing theoretical concepts and enhancing practical skills.

Pre- and post-assessment surveys administered to students revealed a significant improvement in their understanding of key chemical topics such as chemical reactions, titration techniques, and molecular structure visualization. Prior to the virtual lab sessions, students generally demonstrated only a moderate understanding of laboratory safety protocols, the structure of common lab equipment, and basic chemical principles. Following the sessions, there was a marked improvement in students' ability to identify laboratory equipment, explain chemical processes, and perform virtual experiments. Notably, average post-assessment scores increased by 35% compared to pre-assessment results. The most significant improvements were observed in complex topics like molecular bonding and reaction analysis, where 3D visualization allowed students to observe molecular interactions in ways that traditional textbooks could not provide. From a technical perspective, the virtual laboratory demonstrated strong performance in terms of system functionality, interaction responsiveness, and visual fidelity. Blender and Unity were effectively integrated to create realistic 3D models and immersive VR simulations. The models featured high levels of detail, allowing accurate representation of lab tools and environments. However, a few technical challenges were encountered. Frame rate drops occurred during intensive interactions involving multiple animated objects, particularly when simulating multi-step chemical processes. Compatibility testing with various VR headsets–including Oculus Rift and HTC Vive–showed mostly smooth performance, although older headsets occasionally experienced reduced quality and responsiveness. Despite these issues, the virtual lab was considered technically successful. Approximately 90% of users reported no significant technical problems, and the majority appreciated the system's interactive feedback, which provided step-by-step guidance during virtual experiments. A further advantage of the virtual lab was its accessibility for remote learning. The ability to perform simulations from any location with an internet connection proved invaluable for students unable to attend in-person classes or those in areas with limited access to physical labs.

During testing, 75% of students indicated that they found the option to experiment outside of scheduled class times particularly helpful for reinforcing their understanding. Students valued asynchronous access to the lab, which enabled them to revisit complex topics and learn at their own pace. Table 1 provides a summary of student feedback regarding accessibility and learning outcomes.

Table 1: **Summarizes the feedback on the accessibility of the virtual laboratory**

Feature	Percentage of Students Reporting Positive Feedback
Ability to access remotely	87%
Convenience of self-paced learning	75%
Usefulness for reinforcing concepts	82%

The virtual laboratory environment demonstrated a significant improvement in safety compared to traditional chemistry labs. During testing, users were able to perform hazardous experiments–such as those involving flammable or corrosive chemicals–without the risk of injury or exposure to toxic substances. This enhanced safety feature was particularly emphasized by educators, who noted that virtual labs could serve as an effective tool for introducing students to essential laboratory safety protocols before engaging in real-world experiments. The findings from this study indicate that 3D modeling and virtual reality technologies have strong potential to transform chemistry education. The interactive and immersive nature of the virtual laboratory fosters deeper engagement, enhances educational outcomes, and offers a flexible platform for remote learning. Although technical challenges persist–particularly concerning system performance and VR device compatibility–the overall success of the virtual lab in improving both learning effectiveness and safety underscores its promise as a valuable educational tool for the future of chemistry instruction.

CONCLUSION

The development of 3D virtual chemical laboratories has demonstrated considerable promise in transforming the way chemistry is taught and learned. By utilizing advanced tools such as Blender for 3D modeling and Unity for virtual reality integration, this study has shown that virtual labs can effectively simulate real-world chemical environments, providing a safe, interactive, and engaging learning experience for students. The results from user testing highlighted the positive impact of virtual chemistry labs on student engagement, learning outcomes, and the ability to perform experiments in a risk-free setting.

The ability to simulate complex chemical reactions and laboratory procedures, including those involving hazardous substances, offers a significant advantage in terms of both safety and accessibility. Students can explore, experiment, and repeat procedures without the constraints of time, resources, or safety concerns–leading to deeper understanding and improved retention of key concepts. Furthermore, the asynchronous nature of virtual laboratories makes them an ideal tool for remote learning, particularly in areas where access to physical labs may be limited or restricted.

While technical challenges such as frame rate performance and compatibility with older VR headsets were encountered, the overall functionality and effectiveness of the virtual laboratory were well received by both students and educators. Future developments could focus on improving these technical aspects, enhancing the realism of the simulations, and expanding the range of chemical experiments available in the virtual environment.

In conclusion, 3D modeling and virtual reality represent a transformative approach to chemistry education, offering innovative solutions to the challenges posed by traditional laboratory settings. The virtual chemical laboratory not only supports hands-on learning but also opens new avenues for distance education, making it a powerful tool in modernizing chemistry education. As technology continues to advance, the potential for virtual labs to complement–and eventually supplement–physical laboratory experiences will only increase, making science education more accessible, engaging, and effective for students worldwide.

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Mas’ul muharrir: Ramzidin Ashurov
Ingliz tili muharriri: Murod Xoliyorov
Musahhih: Alibek Zokirov
Sahifalovchi va dizayner: Iskandar Islomov

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