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Development and Adaptation of VR Solutions for Computer Science Education in Kazakhstan

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Abstract. *An analytical review of international virtual reality (VR) tools used in computer science education is presented, and assesses their applicability to school and university curricula in Kazakhstan is given. The study examines the main approaches to VR described in international literature from 2011 to 2024, including visualization of algorithms and data structures, VR-based programming environments, puzzle-based tools supporting computational thinking, and modeling of systems and network processes. These categories were compared with the content of the computer science curricula of primary, secondary, high school, and higher education in Kazakhstan. The results show that international VR solutions are consistent with key curricular topics such as algorithmizing, programming, data structures, logic, and systems. The study concludes that VR can be integrated into educational practices in Kazakhstan with minimal curriculum changes, while further analysis is needed to address practical implementation issues.*

Keywords: *virtual reality (VR), computer science, education, simulation, programming, visualization.*

Introduction

Virtual Reality (VR) is simultaneously a concept, a technological tool, and an interactive environment that provides the user with deep immersion into a computer-generated world [1]. To create this experience, specialized head-mounted displays (HMDs) such as the Oculus Rift or Meta Quest are used, along with controllers and motion-tracking sensors that capture the user's movements and en-

able interaction with virtual objects [2]. VR is becoming an increasingly influential tool in computer science education due to its ability to transform abstract and technically complex concepts into intuitive, interactive, and visually rich experiences. Computer science traditionally relies on symbolic, textual, and highly abstract representations, often making it difficult for beginners to understand key topics such as algorithms, data structures, or system behavior. VR offers a fundamentally different approach to learning, providing immersive environments in which students can dynamically observe computational processes and interact with 3D representations of data and program execution.

International research shows that VR increases engagement, develops abstract thinking, and improves understanding of complex concepts through its immersive experience [3]. In computer science, VR is used to visualize algorithms, provide 3D representations of data structures, model network processes, and create simulations to study computer architecture and operating systems. These approaches are reflected in recent empirical work: VR visualizations of algorithms and data structures [4], VR environments that combine coding with immediate 3D feedback [5], and VR puzzle/quest formats that support computational thinking [6].

While most methodological advances have come from the international research community, Kazakhstan has also begun integrating virtual reality into educational practice. Recent national studies demonstrate the positive impact of using virtual reality in computer science teaching, demonstrating increased engagement and improved conceptual understanding at the school and university levels [7]. These developments indicate that virtual reality technologies are gradually becoming part of the local educational landscape, contributing to a wider shift towards innovative digital learning. However, the use of VR directly in computer science teaching is still at an early stage, and analysis of how international solutions relate to Kazakhstani educational programs is still limited. In particular, the extent to which existing VR tools correspond to the content of the subject "Computer Science" in elementary, middle, and high school, as well as typical university courses in computer science, is not considered.

Thus, this study aims to identify which foreign VR solutions can be used for teaching computer science in Kazakhstan and to what extent they align with the content and requirements of national educational programs. The study therefore formulates a central research question:

Which foreign VR tools and approaches are suitable for teaching computer science in Kazakhstan, and how well do they fit the local educational context?

The scientific novelty of this work lies in its systematic comparison of international virtual reality solutions with the structure and subject content of Kazakhstan's computer science curricula at all levels of education. While previous research in Kazakhstan has focused primarily on the general potential of virtual reality in education, this article proposes a structured matrix linking specific virtual reality approaches to specific curricular topics.

Methodology

The study was conducted as an analytical review with elements of thematic comparison.

1. Analysis of international literature.

Articles from ACM, Springer, MDPI, Education Sciences, Computers & Education (2011-2024) were used. We selected papers containing descriptions of VR methods for teaching algorithms, data structures, programming, systems, networks, and computational thinking.

2. Identification of VR areas.

Through open coding, four main thematic groups of VR applications were identified:

- VR visualization of algorithms and data structures;
- VR programming environments;
- VR puzzles for computational thinking;
- VR simulations of system and network processes.

3. Comparison with Kazakhstani programs.

A comparison of VR curricula with Kazakhstan's educational documents was conducted:

- Primary school (digital literacy);
- General secondary school (informatics grades 5-11);
- High school specialization modules;
- Bachelor's CS programs in leading universities.

4. Assessment of adaptation conditions.

The following factors were considered: equipment availability, localization requirements, teacher readiness, availability of teaching materials, and infrastructure limitations.

Results and Discussion

An analysis of international studies has identified several consistent trends in the use of VR in computer science education, each varying in pedagogical potential, depth of visualization, and relevance to the topics taught in Kazakhstan. These trends form the basis for assessing the potential for adapting VR solutions to the national educational system.

First, a significant number of studies are devoted to the visualization of algorithms and data structures. VR environments allow for the display of the dynamics of stacks, queues, graphs, recursive functions, and sorting in

three-dimensional space [8]. Research shows that VR environments help students visualize abstract computer science concepts, which contributes to a deeper understanding of the material. For example, a systematic review by Radianti et al. [9] emphasizes that immersive VR environments allow students to observe processes and phenomena that are difficult to demonstrate with traditional teaching methods. This makes VR a particularly valuable technology for learning complex and abstract topics in computer science.

One of the most studied applications of VR in programming education is the use of environments where code execution is accompanied by immediate visual feedback. One such solution is the MYR platform, which integrates WebVR and programming fundamentals through the creation of 3D scenes using code [10]. The study notes that MYR allows students to simultaneously work with programming and create visual objects, increasing their engagement and interest in the subject.

Another trend is the use of VR games and puzzles to support computer science learning. A systematic review of VR in CS education noted that such games can positively impact the understanding of basic CS concepts and student engagement [11]. These formats increase motivation and interest, especially among beginning students.

Significant attention is also being paid to VR simulations, which help visualize processes inaccessible in traditional learning. According to Radianti et al. [9], VR simulations help students more quickly and deeply understand complex processes through immersive representations of interactions and system elements. The authors emphasize that such simulations are particularly useful in areas where real-world observation of processes is difficult. Based on a comparison of these areas with educational programs in Kazakhstan, the Table was compiled.

The analysis results confirm that VR has high potential for implementation in computer science education in Kazakhstan. Each VR approach supports specific educational objectives:

- Visualization facilitates the acquisition of abstract algorithms;
- VR programming makes learning code visual;
- VR puzzles develop logical and computational thinking;
- System simulators address the lack of experimental environments in OS and network training.

These approaches overlap with the content of domestic educational programs, confirming their feasibility without significant curriculum changes. Therefore, VR solutions can enhance existing computer science and informatics modules.

Adaptation Factors and Implementation Challenges

To assess the potential for international virtual reality solutions in Kazakhstan, several contextual factors must be considered. Virtual reality tools typically require sufficiently powerful computers or standard-alone headsets, and while large urban schools and universities meet these requirements, many rural institutions still lack the necessary equipment, making a phased implementation more realistic. Meanwhile, virtual reality devices in Kazakhstan are primarily used in pilot projects, and their limited availability means that large-scale integration will require planned procurement and maintenance. Since most educational virtual reality environments operate in English, effective use in primary and secondary schools also depends on localization into Kazakh and Russian. Teacher readiness is another key factor, as many computer science teachers have limited experience with immersive technologies, highlighting the need for targeted training and methodological support. Finally, issues

Applicability of international VR solutions to educational levels in Kazakhstan

VR Solution Type	Contents	Suitable for	Reason for Compliance
VR Algorithm Visualization	graphs, queues, sorting	High School, University	Corresponds to the topics "Algorithmization" and "Data Structures"
VR programming environments	code → visual scene	High school, university	Supports the teaching of Python, C++, and Java.
VR puzzles and games featuring	logic, quests, and sequences	Elementary and middle school	Develop computational thinking.
VR system simulators	operation systems, networks, and architecture	University	Completely consistent with CS disciplines

such as classroom space, stable internet access, and adherence to safety regulations must be considered. All these factors show that, despite strict adaptation to the curriculum, effective integration of virtual reality requires careful consideration of technical, organizational, and pedagogical conditions.

Conclusions

The review showed that international VR solutions for computer science education are thematically aligned with the content of Kazakhstan's educational programs and can be adapted for school and university levels.

Thus, the applicability of VR solutions to Kazakhstan's programs was assessed. VR visualization, VR programming, VR puzzle games, and VR system simulators are highly relevant to the topics taught in middle and high schools, and in universities in Kazakhstan, and can be integrated into the educational process.

A general analysis of international VR solutions shows that existing developments cover a wide range of computer science topics, from teaching programming basics to studying complex systems. This diversity allows for the integration of VR technologies into the educational process at various levels, from primary school to university programs. At the same time, adapting VR in Kazakhstan requires consideration of pedagogical resources, available technical infrastructure, and the content of current curricula.

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Қазақстанда компьютерлік ғылымдар білім беруіне арналған VR шешімдерін дамыту және бейімдеу

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Аңдатпа. *Информатика білімінде қолданылатын халықаралық виртуалды шындық (VR) құралдарына аналитикалық шолу жасалады және олардың Қазақстандағы мектеп және университет оқу бағдарламаларына қолданылуы бағаланады. Зерттеуде 2011 жылдан 2024 жылға дейінгі халықаралық әдебиеттерде сипатталған VR-ға негізгі тәсілдер, соның ішінде алгоритмдер мен деректер құрылымдарын визуализациялау, VR негізіндегі бағдарламалау орталары, есептеу ойлауын қолдайтын жұмбақ негізіндегі құралдар және жүйелер мен желілік процестерді модельдеу қарастырылады. Бұл санаттар Қазақстандағы бастауыш, орта, жоғары және жоғары білім берудің информатика оқу бағдарламаларының мазмұнымен салыстырылды. Нәтижелер халықаралық VR шешімдерінің алгоритмдеу, бағдарламалау, деректер құрылымдары, логика және жүйелер сияқты негізгі оқу бағдарламасының тақырыптарымен сәйкес келетінін көрсетеді. Зерттеу VR-ды Қазақстандағы білім беру тәжірибесіне оқу бағдарламасындағы минималды өзгерістермен біріктіруге болады, ал практикалық енгізу мәселелерін шешу үшін қосымша талдау қажет деп қорытындыланады.*

Кілт сөздер: *виртуалды шындық (VR), информатика, білім беру, модельдеу, бағдарламалау, визуализация.*

Развитие и адаптация VR-решений для обучения компьютерным наукам в Казахстане

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Аннотация. *Представлен аналитический обзор международных инструментов виртуальной реальности (VR), используемых в образовании в области информатики, и дана оценка их применимости к школьным и университетским программам Казахстана. В исследовании рассматриваются основные подходы к VR, описанные в международной литературе за 2011-2024 годы, включая визуализацию алгоритмов и структур данных, среды программирования на основе VR, инструменты, основанные на головоломках, поддерживающих вычислительное мышление, и моделирование системных и сетевых процессов. Эти категории были сопоставлены с содержанием учебных программ начального, среднего, старшего и высшего образования Казахстана по информатике. Результаты показывают, что международные решения в области VR согласуются с ключевыми учебными темами, такими как алгоритмизация, программирование, структуры данных, логика и системы. В исследовании сделан вывод о том, что VR может быть интегрирована в образовательную практику Казахстана с минимальными изменениями учебной программы, в то время как для решения проблем практического внедрения необходим дополнительный анализ.*

Ключевые слова: *виртуальная реальность (VR), информатика, образование, моделирование, программирование, визуализация.*

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