Virtual and mixed reality in the study of the geometry of the crystal lattice

P V Zakharov¹, R S Vdovin¹, A V Markidonov², A S Kochkin³ and A S Vdovin¹

¹Shukshin Altai State University for Humanities and Pedagogy, 53 Vladimir Korolenko St., 659333, Biysk, Russia
²Novokuznetsk Branch-Institute of Kemerovo State University, 23 Tsiolkovsky St., 654041, Novokuznetsk, Russia
³Altai State University, 61 Lenin Ave., 656049 Barnaul, Russia

E-mail: zakharovpvl@rambler.ru

Abstract. The article considers the possibility of using virtual and mixed reality in studying the geometry of the crystal lattice in the framework of the course of solid state physics. The application of mixed and virtual reality technologies in the study of various branches of physics is receiving more and more attention. Virtual reality headsets were used in practical and laboratory classes, where students had to create crystal structures and carry out modeling of various processes. When studying complex spatial objects of crystallography, virtual reality technology allowed students to familiarize themselves with the object of study in more detail, understand the structure of crystals and, accordingly, complete the task in a timely manner. At the same time, the prolonged use of virtual reality headsets led to rapid fatigue of students.

1. Introduction

The introduction of new information and communication technologies in the educational process is an integral element of the development of the education system. Today it is difficult to imagine a cycle of classes in any discipline without the use of modern technology. New technologies are of particular relevance in the study of the disciplines of the natural science cycle. Where visualization of complex processes is required. Often the possibility of conducting field experiments in physics, chemistry, biology, etc. difficult due to safety requirements and the cost of their implementation. In this case, computer technology comes to the rescue. Until recently, photo and video materials, computer modeling and computer experiments were massively applied and applied. The active development of modern computer technology allows reproducing natural phenomena and processes with greater reliability. One such technology is virtual reality (VR), as well as related augmented and mixed reality technologies.

Using virtual reality, it is possible to carry out complex educational experiments and experiments [1], which helps to expand the capabilities of students by increasing interactivity and promotes a useful understanding of learning [2-4]. This technology was used in various complex fields [5, 6] and is very useful for providing learning processes, while some authors [7, 8] note that it contributes to better cohesion and cooperation between students. Survey works began in the context of education on the use of virtual reality. The most active research is in the field of medicine. So the authors of the review [9] analyzed a number of studies and came to the conclusion that most of them showed the presence of increased attention retention and motivation among students when using VR.
The application of mixed and virtual reality technologies in the study of various branches of physics is receiving more and more attention. For example, the work [10] discusses the use of mixed reality for real-time visualization of a three-dimensional magnetic field, where it is possible to visualize magnetic flux lines in real time and simulate the distribution of magnetic flux lines in space. In [11], the authors developed an application that facilitates learning the principles of the secondary structure of the protein, the simplicity and limitations of the presented model is a force in the learning context that provokes questions and, therefore, a deeper understanding of the object of study [11].

A number of works emphasize the effectiveness of VR technology in combination with other teaching methods. In particular, special emphasis is placed on gaming technology. This trend is understandable. Virtual reality allows you to easily create game situations, thereby increasing interest in the learning process. So in [12], the authors emphasize that gamification allows students to motivate through the use of game design elements. Also, during the experiments they obtained very specific results, indicating the rapid adaptation of students to a virtual laboratory. In addition, there was a decrease in incorrect answers by 50%, and correct answers increased by 14%. It is emphasized that the virtual laboratory does not replace the teacher, but is an addition to the educational process [12]. The author of [13] addresses the issue of gamification and virtual reality, where it is concluded that the creation of virtual worlds allows us to explain complex and abstract concepts, and also contribute to student motivation.

In this article, we will consider the possibility of using mixed reality technology in studying the theme of the geometry of the crystal lattice in the course of solid state physics by students of the third year of study. At the same time, the form of conducting the classes was classic.

2. Methods and Approaches
As the environment of virtual, augmented and mixed reality, we used equipment and basic classvr software [14], which allows us to control the operation of each headset and at the same time provide an individual approach to each student. In figure 1 shows the content management interface and VR headsets.

![Figure 1. VR content and headset management system: (a) content management; (b) headset management.](image_url)
The basic set of materials of the portal is limited and cannot fully provide studies of the course of solid state physics, since mainly focused on the school curriculum. Therefore, to study the topic of crystallography, crystal models were developed (see Figure 2 (a) – (d)), which allow using mixed-reality technology to get acquainted with the three-dimensional structure of crystals, with the types of planes and the concepts of Miller indices. In figure 2 (e), (f) show the structures available in the portal catalog, which were also used for demonstration to students.

Figure 2. Examples of three-dimensional crystal models: (a) Graphene, (b) Diamond, (c) CuAu, (d) NaCl, (e) C70 fullerene, (f) Carbon nanotube.

VR headsets were used in practical and laboratory classes, where students had to create crystal structures and model various processes in them using the molecular dynamics method.

3. The results and the discussions
Studying the theme of the geometry of the crystal lattice requires developed spatial thinking. Often, projections of crystals on a plane and three-dimensional images of crystals were used. This approach caused difficulties for students to understand the assignment and, as a consequence, the inability to complete it on time.
The combination of the classical form of employment and technology of mixed reality made it possible to ensure control of students' results, as well as the fulfillment of basic tasks on the subject under discussion. Student attendance increased by 30% in the classroom, if previously reported on the use of headsets in practical and laboratory work. At the same time, the percentage of completed tasks in the prescribed period increased by 14%. This is primarily due to the fact that students much more quickly understood the volumetric structure of crystal lattices, which facilitated their subsequent construction for a molecular dynamics code. In the future, students visualized their models using Ovito and compared with models through VR headsets.

During the work, 3D crystal models with various structures and stoichiometric compositions were developed for demonstration through virtual reality headsets. Particular attention was paid to modern structures, including nano-objects based on carbon allotropium. This important area in materials science affects both the theoretical aspects of crystallography and plays an important practical role in science and technology.

We also see the promising application of these technologies in solving scientific problems. When introducing condensed matter into scientific activity in the field of physics, students face complex tasks related to visualization of complex objects of the microworld, for example, soliton-type waves, in particular, discrete breathers [16, 17]. The use of VR technology can simplify this process in the initial stages and will allow you to more quickly learn the basics of scientific work in this direction. This issue will also be the subject of our further research.

4. Conclusion
Based on the results of the study, a number of conclusions can be drawn. First of all, it is worth noting the increased interest of students in the study of the discipline and their more active attendance of classes at which the use of VR headsets was announced. When studying complex spatial objects of crystallography, virtual reality technology allowed students to familiarize themselves with the object of study in more detail, understand the structure of crystals and, accordingly, complete the task in a timely manner. At the same time, the prolonged use of virtual reality headsets led to rapid fatigue of students.

Summing up, we can say that the use of VR in the course of solid state physics can increase students' interest, activate their work and provide a deeper assimilation of the material. It is worth noting that to determine the volume of use of VR content and its concretization over a wide range of topics in solid state physics, a longer and more detailed study is required, which will be the subject of our further research.

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