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Interactive and Contact Education Technology for Laboratory Work With Haptic Gloves in a Virtual Environment

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Abstract

Interactive technologies identify the key positions of the education sector in the near future. The application of haptic interfaces and immersive approach in education dictated by the need to improve the efficiency of the educational process. The article describes the developed interactive and contact education technology of laboratory works with the use of haptic gloves in virtual environment (hereinafter – ICET), as well as the prototype of the haptic glove. The data demonstrating the high efficiency of educational material assimilation by students as compared to the traditional approach presented.

The aim of the article is to present and analyses the results of experimental research on the use of ICET by secondary school students during laboratory work in chemistry classes and on changes in the role of the teacher because of integrating immersive technologies into the educational process.

Based on the findings, the authors justify the necessity of using ICET in teaching sessions. The authors conclude that it is necessary to complement classical educational methods with immersive technologies in order to improve the quality of education in modern conditions.

The conducted research made it possible to obtain the results of practical experience in the implementation of training sessions in a virtual environment, taking into account the use of tactile devices for interaction with the simulation environment. Assessment of the level of residual knowledge of students shows the effectiveness of the integration of contact technologies with the virtual environment and proves the prospects for the development of tactile interfaces in education.

Keywords: interactive education, immersive technologies, haptic gloves, copy control, telescopic control, virtual reality, virtual reality education.

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1. Introduction
1.1. Relevance and analysis of existing technologies and research

Today, rapidly evolving digital technologies make it possible to create a living virtual (simulated by a computing system) environment. A wide range of specialised input/output devices - headphones, microphone, computer glasses, haptic gloves and suits, etc., enables user interaction with this environment.

One of the promising directions in the development of school education is the use of interactive technologies based on virtual reality (VR). This opens up opportunities in the creation and use of virtual laboratories for studying the world around us, forming skills and practicing skills for solving practical tasks, as well as for demonstrating their mastery and automated assessment (Uvarov, 2018). At the same time, virtual reality tools in the learning process should provide additional opportunities that traditional learning tools cannot provide. The relevance of the area under consideration according to (Issledovanie rynka..., 2022) supported by the following factors:

- The reduction in the price of technical equipment, over the past few years the prices of modern VR devices have managed to drop significantly, making them more affordable;
- The rapid growth of VR software, with several thousand different VR applications available today;
- The growth in VR investment – more than $ 2.5 billion a year;
- The number of major VR companies is increasing, with more than 300 on the European market, and giants such as Oculus, HTC, Sony, Microsoft, Samsung and many others have been introducing their technology into the field for some time now;
- The implementation of VR technology in the fields of education, energy, metallurgy, advertising, engineering, telecommunications, etc.

Among the existing educational VR projects in the Russian Federation, the following solutions are worth mentioning (15 VR- i..., 2020):

- MEL Chemistry VR, VR lessons on the main chemistry topics of a school course, developed by MEL Chemistry (MEL Chemistry VR, 2022);
- "Visualisation of Biological Objects" software from Visual Science, an educational product VR animation of viruses, a series of educational posters with augmented reality, and interactive applications (Visualisation of biological objects, 2022);
- An interactive military history museum by Digital Media Lab (Virtual Digital Media Lab, 2022);
- Interactive VR visualisations and educational games from Luden.io (Luden.io, 2022);
- A series of VR experiences in physics, stereometry and social studies from "PhisikonLab" LLC (Virtual'nye praktikumy, 2022);
- Atlas VR by Terra-Tech, a Russian virtual reality platform powered by remotely sensed data that allows the creation of digital copies of investment projects, historical, geographical, environmental and other processes and phenomena (TerraTekh, 2022).

This article discusses the possibility of introducing one of the immersive learning methods at the intersection of reality and the virtual world into the educational process of both general school and additional education, which meets the challenges of today's educational system. It is an interactive contact education technology (ICET) based on the mechanism of student's interaction with the virtual educational environment with their hands through the use of haptic (haptic) gloves (HG).

The use of haptic interfaces and virtual reality applications for educational purposes has been discussed since the first decade of the 21st century (Christodoulou et al., 2005; Barfield, 2009).

Current articles (Sanfilippo et al., 2022; Edwards et al., 2019) reflect the results of experimental studies. However, the performance of information perception in (13) is rather poorly described.

The authors (Petrenko et al., 2020; Petrenko et al., 2019) consider the use of haptic gloves and virtual environments as complete learning tools.

Articles (Xanthidou et al., 2022) have described research on the application of HG for chemistry lessons in a virtual environment. The results of such studies confirm the increased level of student engagement and motivation when using HG in the classroom, as well as the adequacy of the proposed immersive technology as a learning tool.

HGs are now widely used in cybernetics and robotics (Galofaro et al., 2022; Cieślik et al., 2022), especially in the development of copy control systems for robotic manipulators. Some

developers of immersive virtual reality devices offer tilted vibrating platforms as feedback (Zwoliński et al., 2022), but their use in the learning process is not yet possible due to insufficient development of hardware, methodology and software.

Existing HG analogues are shown in Figure 1: Peregrine Glove ST, Figure 1a (Peregrine Glove ST, 2022); Manus VR, Figure 1b (Manus VR, 2022); Plexus VR Glove, Figure 1c (Plexus VR Glove, 2022); CaptoGlove, Figure 1d (CaptoGlove, 2022); Avatar VR, Figure 1e (Avatar VR, 2); Noitom Hi5 VR Glove, Figure 1f (Noitom Hi5 VR Glove, 2022); Senso Glove Figure 1g, (Senso Glove, 2022); VRfree by Sensoryx, Figure 1h (VRfree by Sensoryx, 2022); VRgluv, Figure 1i (VRgluv, 2022).

Fig. 1. Haptic glove analogues for working in a virtual environment

Patent analogues of haptic gloves are also known, e.g. a haptic glove that functions as a computer mouse for virtual cursor movement and keystroke handling, described in patent US 6870526. The disadvantage of this device is that it is only designed to control the virtual cursor.

A device for generating control signals to manipulate virtual objects in a computer system according to gestures and positions of the operator's hand or other body part is described in patent US 7205979. A disadvantage of this device is its inability to operate without external sensors, making it difficult to operate the glove in some cases.

The closest analogue of the haptic glove under development is the device presented in US Patent US 9060385, Publ.: 16/06/2015. The prototype describes a virtual reality glove containing sensors located on the fingers of the glove and hand position sensors located on the phalanges of the fingers of the glove, with the sensors connected to a microprocessor. A disadvantage of the prototype and other known solutions, which use only sensors installed on the glove, is an accumulated error in determining the location of the user's hand, which makes it impossible to use such a system in practice without periodic calibration of the sensors. The frequency of calibration of the sensors depends on their accuracy, which affects the price of the product.

Based on an analysis of the methodological, software and hardware base for ICET, it was decided to develop a prototype of haptic gloves, virtual lessons and a methodological approach to their use in the educational process.

1.2. Purpose and objectives of the study
This article describes the prototyping of haptic gloves and virtual lessons to conduct research on their application in the educational process. The application of HG and virtual environment in

teaching is presented as a new form of interactive-contact laboratory work in a virtual environment.

The aim of the work is to create a prototype of an interactive-contact educational technology of laboratory works using HG in a virtual environment to conduct experimental research on the speed of learning of interactive-contact technology and the level of students' learning when using it in comparison with classical educational approaches on the example of the educational discipline of chemistry.

The work has the following objectives:
- Investigate the integration of immersive technologies into the educational process;
- Develop interactive and contact education technology;
- Conduct research into the speed of training level of educational technology and levels of learning in comparison with classical educational approaches.

2. Materials and methods
2.1. Integrating immersive technologies into the educational process

The dissemination of virtual reality technologies in Russian education is necessary and, above all, must meet the progressive trends of their global development.

The introduction of immersive technologies based on immersion into an artificially simulated (virtual) reality into the educational process becomes a new challenge for the teacher. In today's reality, he or she must master the role of «an observer and an active participant in communication, using his or her experience and authority to orient the learner in the zone of learning meanings, to change the observable parameters of the learning environment» (Sergeev, 2010).

The authors (Dunleavy et al., 2009; Maliy et al., 2018; Voykunsky et al., 2008) focus on different psycho-pedagogical aspects of the use of immersive technologies in education.

Dunleavy, M., Dede, C., Mitchell, R. believe that the familiar «lecturer function is giving way to a guide role that enhances the psychological effect of group communication with the virtual world» (Dunleavy et al., 2009).

According to D.V. Malii, P.N. Medvedev, and M.G. Markova, immersive technologies will allow teachers to create conditions to increase students' motivation and develop their cognitive sphere (Maliy et al., 2018).

A number of 'old school' educators perceive virtual technology in education as an artificial world in which the pupil loses himself or herself and becomes steadily dependent on a fantasy environment. However, A.E. Voykunsky and G.Y. Menshikova prove that virtual reality does not cause inadequate thinking, does not reduce the level of reflection, does not carry a sense of bifurcation and loss of self as it, for example, occurs in the case of hypnosis or chemical influence on human (Voykunsky et al., 2008).

According to Microsoft Education, the use of virtual technologies attracts learners initially as entertaining and at the same time exploratory content. Compared to conventional learning activities, this format allows them to engage and retain their attention, which makes learning more productive (Preparing the Class of 2030; Preparing the Class of 20302022).

Thus, the effect of using immersive technology for educational purposes will be achieved if the following requirements are met:
- Designing components of a virtual environment that meet the requirements of educational standards;
- The need to create scenarios (guidelines) for interacting with visual interactive material;
- The need to create systems for modelling different educational practices for and with the learner to support processes for achieving learning outcomes;
- The need to develop a methodology for transferring selected elements of the school curriculum into virtual reality.

Interactive-contact educational technology enables a number of pedagogical tasks in the development of a digital learning environment (Figure 2), including control, gamification, personalisation of education and organisation of project-research work. For the learner, ICET is a means of achieving the necessary educational outcomes by increasing engagement, high speed of material assimilation, participation in team and project activities, activation of creativity and self-organisation.
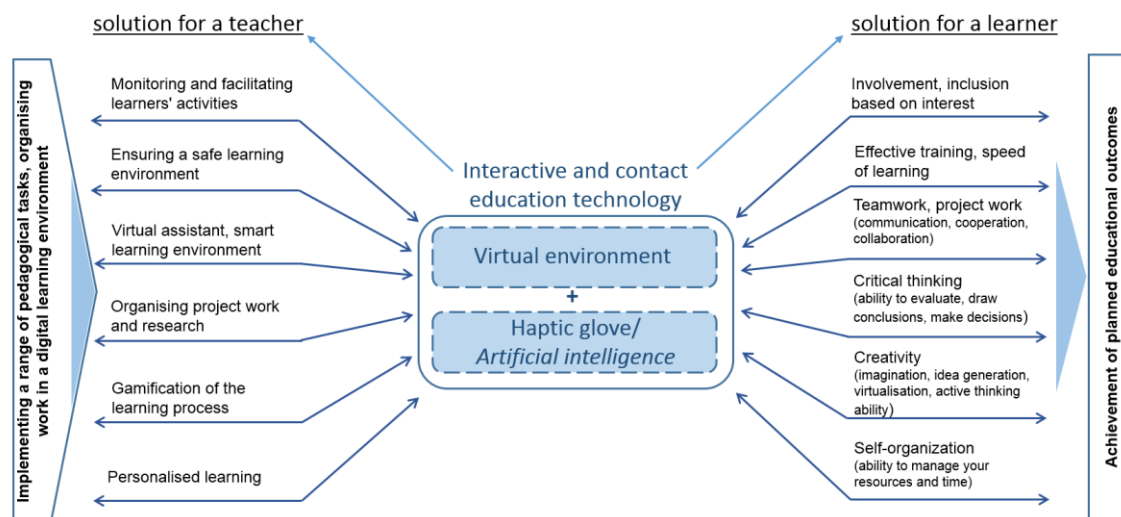
Fig. 2. Integration of interactive and contact-based learning technologies in the educational process

The teacher's main task is to stimulate the learning process as much as possible by providing students with guided autonomy, the so-called facilitation. Students learn how to acquire knowledge independently, which is also facilitated by a smart learning environment mechanism and built-in virtual assistants. It provides the opportunity to practice the necessary skills repeatedly without risk and with minimal loss of time, without excluding the function of indirect control by the teacher. This form of lesson enables learning by unobtrusively memorising the material while repeating the script.

ICET allows the safe conduct of complex experimental works, pre-project simulation activities of students. Thus, simulation in education (simulation) is an interactive method of developing skills and abilities, in which real processes are reproduced (modelled). The use of virtual technologies attracts students due to the possible entertainment component, but at the same time it allows the teacher to organize productive project-research activity, to implement the learning process with the gamification elements (Gerasimova et al., 2021).

Immersive learning 'adjusts' the education to each student, taking into account his or her usual pace of learning at a level that suits him or her. In doing so, the teacher can track the individual route of each student, which is the impetus for personalised learning.

The ultimate goal of interactive and contact-based education technology is for students to achieve the intended learning outcomes (Figure 2).

In a virtual environment, a person cannot be distracted by external stimuli. And game-like problem situations engage students in problem solving, thereby allowing them to focus on the material as much as possible and expand their cognitive experience. With the HG and the easy-to-understand interface of the accompanying software, much of the learning material can be made applicable in real life later on.

This article proves that when ICET components are integrated into the teaching and learning process, students' learning speed increases, which in turn demonstrates the effectiveness of the technology.

Immersive technologies in education are also expected to provide students with the skills required in today's digital society, including teamwork and project work (communication, cooperation, collaboration), critical thinking (ability to evaluate, draw conclusions, make decisions), creativity (imagination, idea generation, virtualisation, ability to think practically) and self-organisation (ability to manage one's resources and time).

2.2. Development of interactive and contact educational technology
2.2.1. Development of a prototype of an interactive and contact laboratory system

HG relates to an information input device for organising copy control of anthropomorphic manipulators, and can be used to acquire data on the position and orientation of the human hand,

as well as the orientation of the phalanges of its fingers. This information can then be used for real-time control of both robotic and virtual objects.

The technical result of the HG under development is the ability to transmit data about the position of the operator's hand and fingers to a computer or other device, while eliminating the accumulated measurement error of the glove-mounted sensors.

To achieve a technical result, HG 1 (Figure 3) contains sensors 2 located on the fingers of the glove, with the sensors connected to the control unit 6 and the control unit located on the back of the palm.

The sensors are gyroscopes and two light markers 4 mounted on rods 3 attached to the rear side, however the light markers are connected to the system board, which additionally contains a radio communication module for communication with a personal computer or other computing device via a radio link and a video camera is also connected to this device.
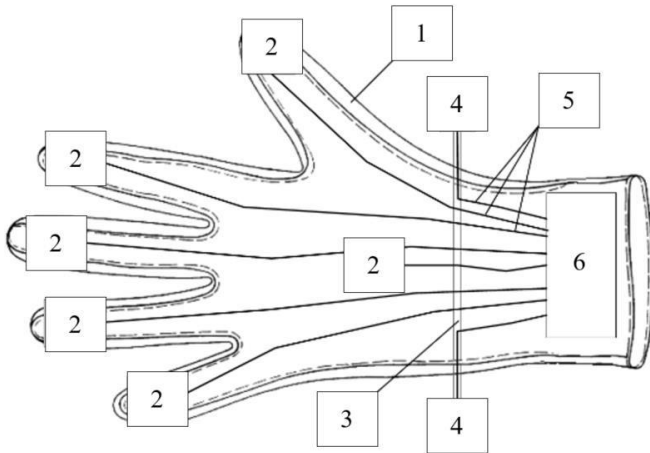

Fig. 3. Structure-algorithm diagram of the haptic glove

HG implements the following method of reading the position of a person's fingers and hand.

Gyroscope set 2 defines the orientation of the attached parts of the human hand as quaternions $q_0' - q_5'$, where the quaternion q_0' corresponds to the measured orientation of the human palm, the quaternions $q_1' - q_5'$ correspond to the measured orientation of the human finger phalanges.

Control unit 6 reads the results of the gyroscope set 2 via the appropriate information channel. The control unit 6 then transmits the combined measurement results of the gyroscope set 2 to the personal computer 7 via the appropriate information channel.

The video camera 8 continuously captures the hand of the person with the visual markers 4 attached and transmits the results as an image stream to the personal computer 7.

The personal computer 7 collects and processes data from the control unit 6 and the video camera 8 to determine the position of the human palm as a three-dimensional vector p0, orientation of a human palm in the form of a quaternion q0 and orientation of the human phalanges in the form of quaternions $q_1 - q_5$.

A quaternion is a hypercomplex number (a vector of four components) that allows you to describe the rotation of figures/points in space:

$$q = (w, x, y, z), \tag{1}$$

where w – component indirectly corresponding to the angle of rotation; (x, y, z) – vector indirectly corresponding to the axis of rotation.

Suppose we need to rotate a figure about an axis (vector) v at an angle of α. Then the components of the corresponding quaternion can be calculated by the formulas:

$$w = \cos\frac{\alpha}{2}, \tag{2}$$

$$(x, y, z) = v * \frac{\sin\alpha}{2}. \tag{3}$$

Example. Suppose we need to rotate by 90° along the axis Oy a segment that starts at the origin and runs along the axis Ox. In Figure 4, the coordinate axes are marked with black lines, the start position of the segment is marked with a red line, the end position is marked with a green

line, the motion path is marked with a dotted orange line, the rotation axis is marked with a dotted blue line.
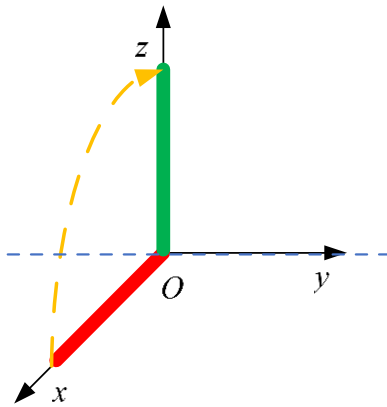

Fig. 4. Example of a rotation task

The axis of rotation coincides with the axis of Oy therefore $v = (0,1,0)$. The angle of rotation $\alpha = 90°$. According to formulae 2 and 3 we find the quaternion describing the rotation:

$$q = \left(\cos\frac{90°}{2}, 0, \sin\frac{90°}{2}, 0\right). \tag{4}$$

If two consecutive rotations described by quaternions are required q_1, q_2, it is necessary to perform a rotation according to the quaternion corresponding to their vector product:

$$q = q_1 \times q_2. \tag{5}$$

For HG, quaternions are used in the following instances.

1. To rotate the virtual hand. At the initial moment of time the operator's hand must be pointed according to the initial position of the virtual hand (palm parallel to the ground, i.e. horizontally, fingers pointing diagonally away and to the left). After switching on the HG, the gyroscope mounted on the back of the palm gives out some initial ($t = 0$) a non-zero quaternion $q_h^{(0)}$. Non-zero because the axes of the gyroscope have some unknown orientation. In this virtual environment, we need to obtain a «zero» (non-zero) rotation.

Subsequent measurements in the virtual environment do not use the absolute value of the quaternion $q_h^{(i)}, i = 1,2,...$, produced by the gyroscope when measured at t-time, but the relative value. The relative value $\Delta q_h^{(i)}$ is calculated by correcting for the quaternion $q_h^{(0)}$ at the initial position of the operator's hand:

$$q_h^{(0)} \times \Delta q_h^{(i)} = q_h^{(i)}, \tag{6}$$

$$\Delta q_h^{(i)} = \left(q_h^{(0)}\right)^{-1} \times q_h^{(i)}. \tag{7}$$

Expression (7) is obtained by multiplying both parts of equation (6) by $\left(q_h^{(0)}\right)^{-1}$.

2. For bending virtual fingers. This situation is complicated by the fact that the finger is a sequential kinematic chain (Figure 5a) for which only the palm quaternions are known q_h and the last (third) phalanx q_{f3}.

3. A primitive version of finger flexion can be realised as follows (Figure 5b). Flexion in all joints except the first joint is ignored. In this case, the quaternion $\Delta q_{f3}^{(i)}$ of the rotation in the joint between the palm and the finger at t-th moment can be found similarly to formula (7):

4.
$$\Delta q_{f3}^{(i)} = \left(q_h^{(i)}\right)^{-1} \times q_{f3}^{(i)}. \tag{8}$$

5. Note that in formula (8) the value of the quaternions at 0-th instant of time.

6. This «straight finger» option can be used as an intermediate implementation of finger bending.

7. A better option is to calculate quaternions of relative rotation $\Delta q_{f1}, \Delta q_{f2}, \Delta q_{f3}$ in all joints of the finger. The condition must be fulfilled for consecutive rotation (finger flexion):

8.
$$q_{f3}^{(i)} = q_h^{(i)} \times \Delta q_{f1}^{(i)} \times \Delta q_{f2}^{(i)} \times \Delta q_{f3}^{(i)}. \tag{9}$$

9. Equation (9) has many roots. To solve it, the following calculation is proposed. Let:

10.
$$\Delta q_{f1}^{(i)} \times \Delta q_{f2}^{(i)} \times \Delta q_{f3}^{(i)} = \Delta q^{(i)}. \tag{10}$$

11. Then:

12.
$$q_{f3}^{(i)} = q_h^{(i)} \times \Delta q^{(i)}, \tag{11}$$

13.
$$\Delta q^{(i)} = \left(q_h^{(i)}\right)^{-1} \times q_{f3}^{(i)}. \tag{12}$$

14. Let:

15.
$$\Delta q_{f2}^{(i)} = \sqrt{\Delta q^{(i)}}, \tag{13}$$

16. Then:

17.
$$\Delta q_{f1}^{(i)} = \Delta q_{f3}^{(i)} = \sqrt{\sqrt{\Delta q^{(i)}}}. \tag{14}$$

18. Thus, the desired $\Delta q_{f1}, \Delta q_{f2}, \Delta q_{f3}$ can be found by successive calculations of expressions (12) to (14).
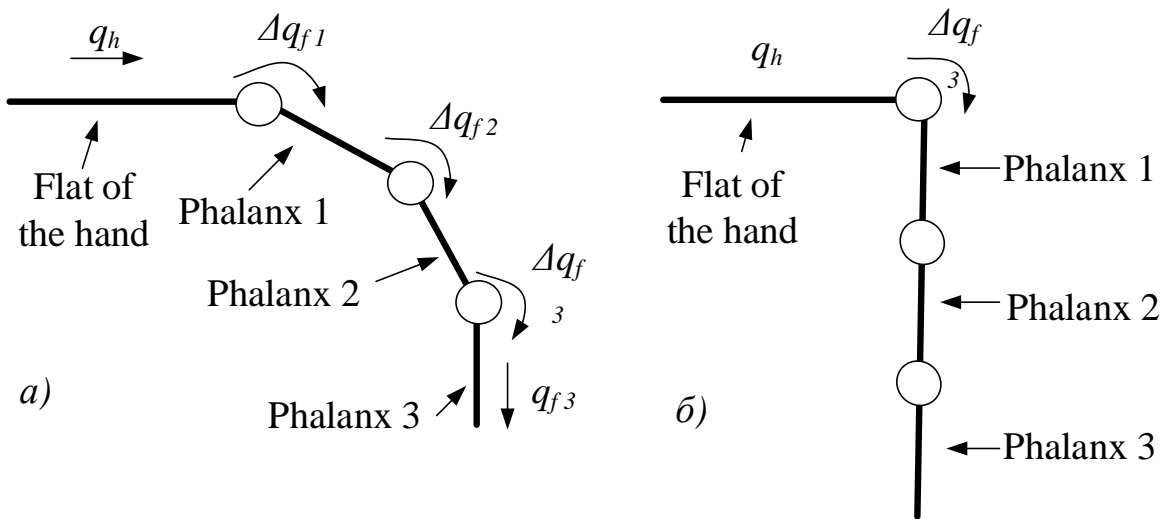

Fig. 5. Calculating quaternions for finger bending

The following is a variation of a calculation methodology that can be used on a personal computer 7 to convert the measured values of the orientation of human hand parts and the image flow obtained by the video camera 8 into the calculated position and orientation of the human hand, and the calculated orientation of the phalanges of his fingers.

Let the following input data be known. The measured orientations of human hand parts as quaternions $q_0' - q_5'$ where q_0' corresponds to the measured palm orientation and $q_1' - q_5'$ corresponds to the orientations of some phalanges of his fingers, images of the operator's hand with light markers fixed on them.

The purpose of the calculation is to determine the position p0 and orientation q0 of the human hand as well as the orientation $q_1 - q_5$ phalanges of his fingers.

The following mathematical calculations can be used for the calculation.

The axes of a gyroscope performing a quaternion measurement $q_i', i = \overline{0;5}$ can have an arbitrary orientation. Therefore, in order to calibrate the axes, a person must bring his hand to some position corresponding to «zero» orientation of the palm. Let's denote it by $q_i'^{(0)}$ where «(0)» in upper index means some zero moment. In this case the orientation $q_i^{(t)}$ at all further moments of time t can be calculated by formula:

$$q_i^{(t)} = q_i'^{(t)} * \left[q_i'^{(0)}\right]^{-1}. \tag{15}$$

Let the video camera be at the origin of the Cartesian coordinate system $Oxyz$. Let's point the axis Oz against the camera's line of sight, the axis Ox horizontally to the right, axis Oy vertically upwards.

The purpose of the calculation is to determine the position p_0 of the hand, which can be described as the midpoint between two light markers. Let by digital processing of images obtained

from video camera 5, the apparent coordinates of the light markers can be obtained u и v on a two-dimensional image plane.

In this case, the relationship between the real position of the centre of the palm $p_0 = (x_0, y_0, z_0)$ and the apparent coordinates u, v can be described by the following equations:

$$p_0 = \frac{p_1 + p_2}{2}, \tag{16}$$

$$Cu_1 = \sin \alpha_1, \tag{17}$$

$$Cu_2 = \sin \alpha_2, \tag{18}$$

$$Cv_1 = \sin \beta_1, \tag{19}$$

$$Cv_2 = \sin \beta_2, \tag{20}$$

$$\frac{x_1}{z_1} = \sin \alpha_1, \tag{21}$$

$$\frac{x_2}{z_1} = \sin \alpha_2, \tag{22}$$

$$\frac{y_1}{z_1} = \sin \beta_1, \tag{23}$$

$$\frac{y_2}{z_1} = \sin \beta_2, \tag{24}$$

$$(x_1 - x_2)^2 + (y_1 - y_2)^2 = d_{xy}^2, \tag{25}$$

$$z_1 - z_2 = d_z, \tag{26}$$

where $p_1 = (x_1, y_1, z_1), p_2 = (x_2, y_2, z_2)$ – positions of the light markers; C – is the calibration factor, which can be selected by experiment; u_1, v_1 and u_2, v_2 – the visible coordinates of the first and second light marker in the flat image; $\alpha_1, \alpha_2, \beta_1, \beta_2$ – the angles which form the planes passing through the light markers with the optical axis of the video camera 5; d_{xy} – the length of the projection on the plane xy segment d, which connects the light markers; d_z – the length of the projection on the axis z segment d connecting the light markers.

The projections of a segment d can be calculated by measuring its length and the quaternion q_0 which describes its rotation in space.

By solving the above system of equations as well as by experimentally determining the coefficient of C, the position of palm centre can be calculated p_0, which confirms the feasibility of the proposed device.

Figure 6 shows the HG laboratory prototype designed according to the required input data.

Fig. 6. Photograph of a laboratory sample of haptic gloves

In order to make them easy to use, a prototype Flex-glove has been developed (Figure 7).

The proposed prototype is ergonomic and easy to use. Although the Flex sensors show less accuracy in operator hand positioning, the current accuracy, combined with the software shell, is sufficient for controlling objects in a virtual environment.

Fig. 7. Photograph of the haptic glove prototype

2.2.2. Developing an environment for interactive and contact lessons

The software environment of the virtual lesson is written in Unity. At the moment 6 experiments for laboratory works on chemistry of the 9th grade on studying the influence of the conditions of a chemical reaction on its speed have been developed. At the beginning of the lesson, brief theoretical information and safety precautions for working with hydrochloric acid and an alcoholic torch are given.

The general interface of the room is shown in Figure 8, where 8a is the start menu, where the arrows allow you to select the experience, its name is written in the centre, there is a button to go to the experience and a key to turn off. Figure 8b shows the experience menu, where clicking on the green question displays explanations of the experience, the objects can be moved by the operator's hands, at the end of the experience it is necessary to pull the lever, which will return the operator to the start menu. Figure 8c shows an example of a chemical reaction and its formula.
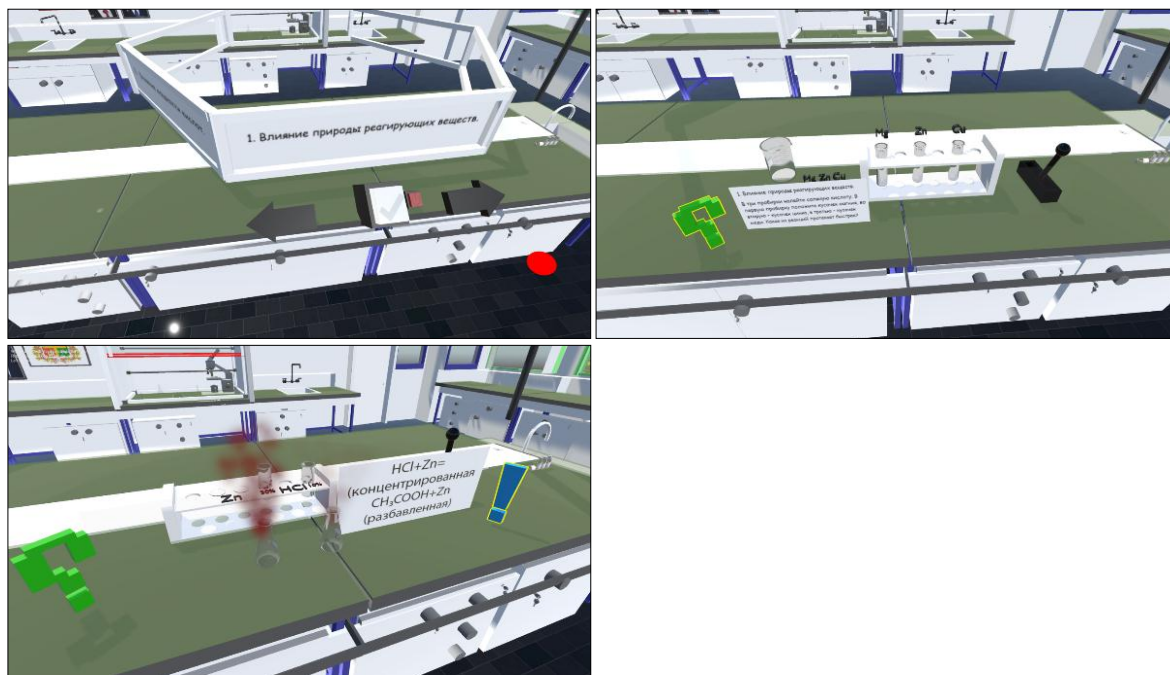

Fig. 8. a) Start menu, b) Chemical experiment menu, c) Chemical reaction example

Experiment 1 of the effect of the nature of chemicals is shown in Figure 9a. Pour hydrochloric acid into three test tubes: put a piece of magnesium into the first test tube, a piece of zinc into the second test tube and a piece of copper into the third test tube. Analyse which of the reactions proceeds faster.
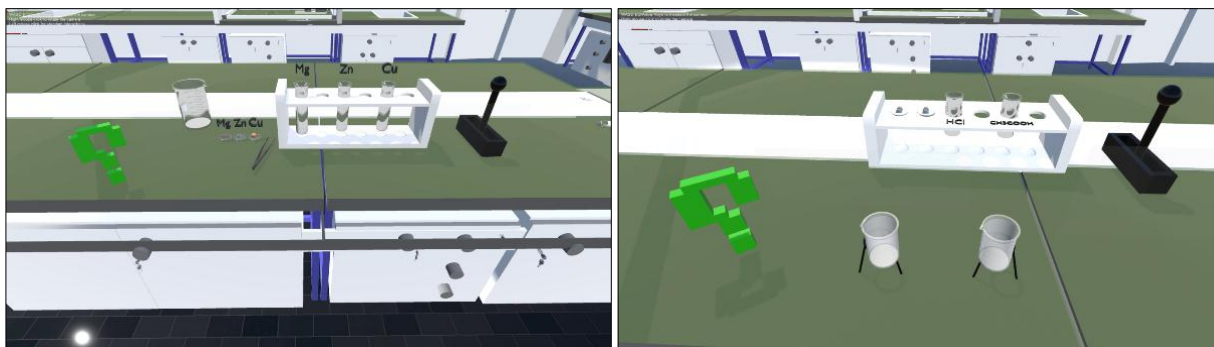
Fig. 9. a) Experiment 1 – effect of nature of chemicals. b) Experiment 2 – effect of acid power

Experiment 2 of the effect of the power of acids is shown in Figure 9b. Pour hydrochloric acid into one test tube and the same amount of acetic acid into another test tube. Put two zinc pellets into each test tube. Determine which reaction proceeds faster.

Experiment 3 of the effect of the concentration of reacting substances is shown in Figure 10a. One zinc pellet each should be placed in two test tubes. Pour 1 ml of 30 % hydrochloric acid into one tube and 1 ml of 10 % hydrochloric acid into the other tube. Analyse in which test tube the reaction is more intense.
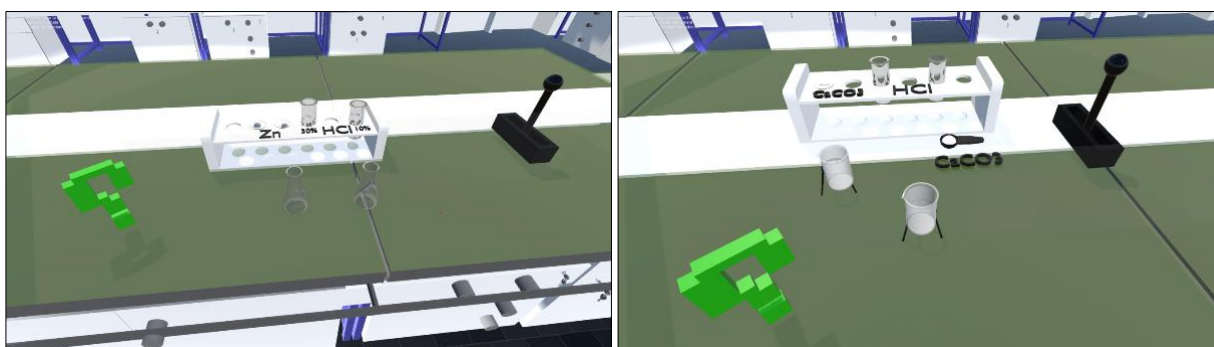
Fig. 10. a) Experiment 3 – effect of concentration of reactants, b) Experiment 4 – Influence of the contact surface of the reactants

Experiment 4 on the effect of the reagent contact surface is shown in Figure 10b. Place a piece of chalk in one test tube and put some chalk powder in the other test tube. Pour 1.5 ml of hydrochloric acid of equal concentration into each tube. Analyse if there is a difference in the rate of gas release.

Experiment 5 of the effect of temperature is shown in Figure 11a. Put one zinc pellet each into two test tubes. Pour 1 ml of hydrochloric acid of equal concentration into each test tube. Put one test tube in a beaker of hot water. Compare the intensity of the release of hydrogen bubbles in the test tubes and infer the effect of temperature on the rate of the chemical reaction.
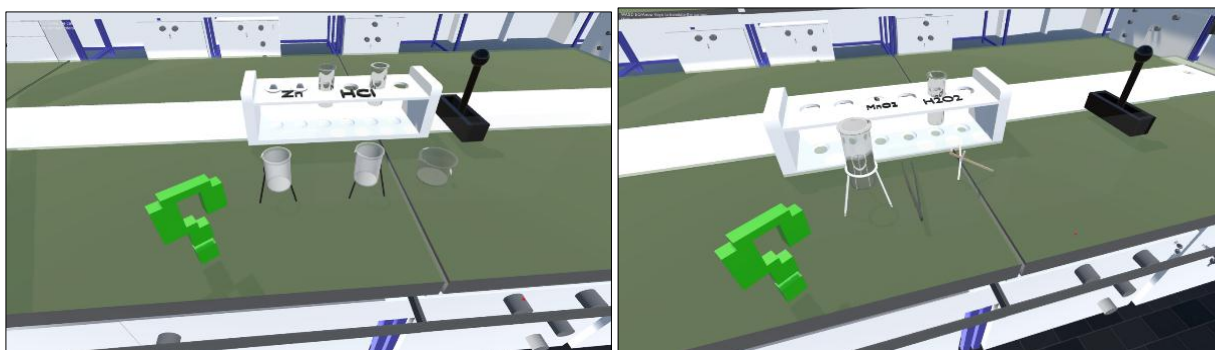
Fig. 11. a) Experiment 5 - effect of temperature, b) Experiment 6 – effect of gas on combustion

Experiment 6 on the effect of gas on combustion is shown in Figure 11b. Pour 1 ml of hydrogen peroxide into test-tube 1 and introduce a smoldering kindling torch without touching the liquid. Record the observation. Then add a few crystals of MnO2 to the hydrogen peroxide and add the spud again. Analyse the result (Figure 12).

After completing the experiments, there is an opportunity to review the reactions in order to record the results in a notebook.

The advantage of using HG is to practice your reagent handling skills.
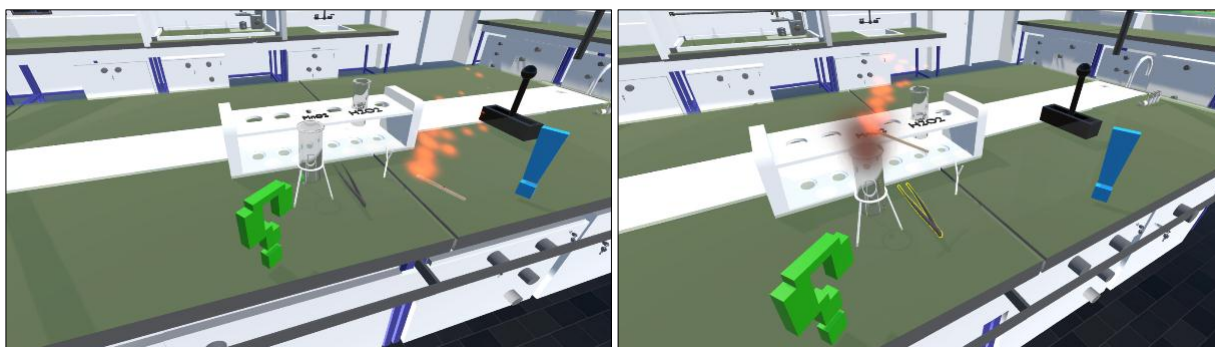
Fig. 12. Chemical reaction of gas effect on combustion

In the context of interactive work in a virtual environment, the learner is able to acquire the knowledge, skills and attitudes to perform chemistry laboratory work.

2.2.3. Technical implementation algorithm for an interactive and contact classroom system

The server part is written in Python 3.8 for the Jupyter Notebook runtime. The server part performs the following functions:

- Collection of measurement results from HG sensors;
- Capture and process a video stream from a webcam;
- Calculation of the position and orientation of the palm and fingers of the human hand;
- Sending data to a Unity-based simulation environment.
- A generalised algorithm for the server part is shown in Figure 13.

Consider the steps of the algorithm:

- Variable initialisation. Variables to be initialised include settings for webcam exposure, window size, IP address and port of the remote host, etc.

- Read user settings. This step reads settings such as the maximum and minimum values of light filters applied when processing images from the webcam. These settings are individual for each workstation, so they are stored in an external file.

- Initialise the webcam. The webcam is checked and connected to an available webcam, and the exposure, frequency and resolution are set.

- Running the data stream to the simulation environment. The server part is implemented as a multi-threaded application for asynchronous data collection from the HG, webcam, data processing and transfer of processing results to the simulation environment.

```
                          ┌─────────────┐
                          │    Start    │
                          └──────┬──────┘
                                 ▼
   1  ┌──────────────────────────────────────────────────┐
      │             Variable initialization               │
      └──────────────────────┬───────────────────────────┘
                             ▼
   2  ╱──────────────────────────────────────────────────╱
     ╱                Read user settings                 ╱
    ╱───────────────────────┬──────────────────────────╱
                            ▼
   3  ┌──────────────────────────────────────────────────┐
      │              Webcam initialization                │
      └──────────────────────┬───────────────────────────┘
                             ▼
   4  ┌──────────────────────────────────────────────────┐
      │    Starting a data stream in a simulation environment │
      └──────────────────────┬───────────────────────────┘
                             ▼
   5  ┌──────────────────────────────────────────────────┐
      │ Starting the flow of collecting the results of polling sensors of the haptic glove │
      └──────────────────────┬───────────────────────────┘
                             ▼
   6                      ◇ To finish work? ◇ ── Yes ──►
                             │ No
                             ▼
   8  ┌──────────────────────────────────────────────────┐
      │          Getting an image from a webcam           │
      └──────────────────────┬───────────────────────────┘
                             ▼
   9  ┌──────────────────────────────────────────────────┐
      │ Applying light filters, calculating the coordinates of the centers of light spots │
      └──────────────────────┬───────────────────────────┘
                             ▼
  10  ┌──────────────────────────────────────────────────┐
      │ Obtaining measurement results from haptic glove sensors │
      └──────────────────────┬───────────────────────────┘
                             ▼
  11  ┌──────────────────────────────────────────────────┐
      │            Glove Position Calculation             │
      └──────────────────────┬───────────────────────────┘
                             ▼
  12  ┌──────────────────────────────────────────────────┐
      │        Visualization of calculation results        │
      └──────────────────────┬───────────────────────────┘
                             ▼
  13  ┌──────────────────────────────────────────────────┐
      │ Sending calculation results to the simulation environment │
      └──────────────────────────────────────────────────┘
                             ▼
   7  ┌──────────────────────────────────────────────────┐
      │    Terminate all threads, release resources used   │
      └──────────────────────┬───────────────────────────┘
                             ▼
                          ┌─────────────┐
                          │     End     │
                          └─────────────┘
```
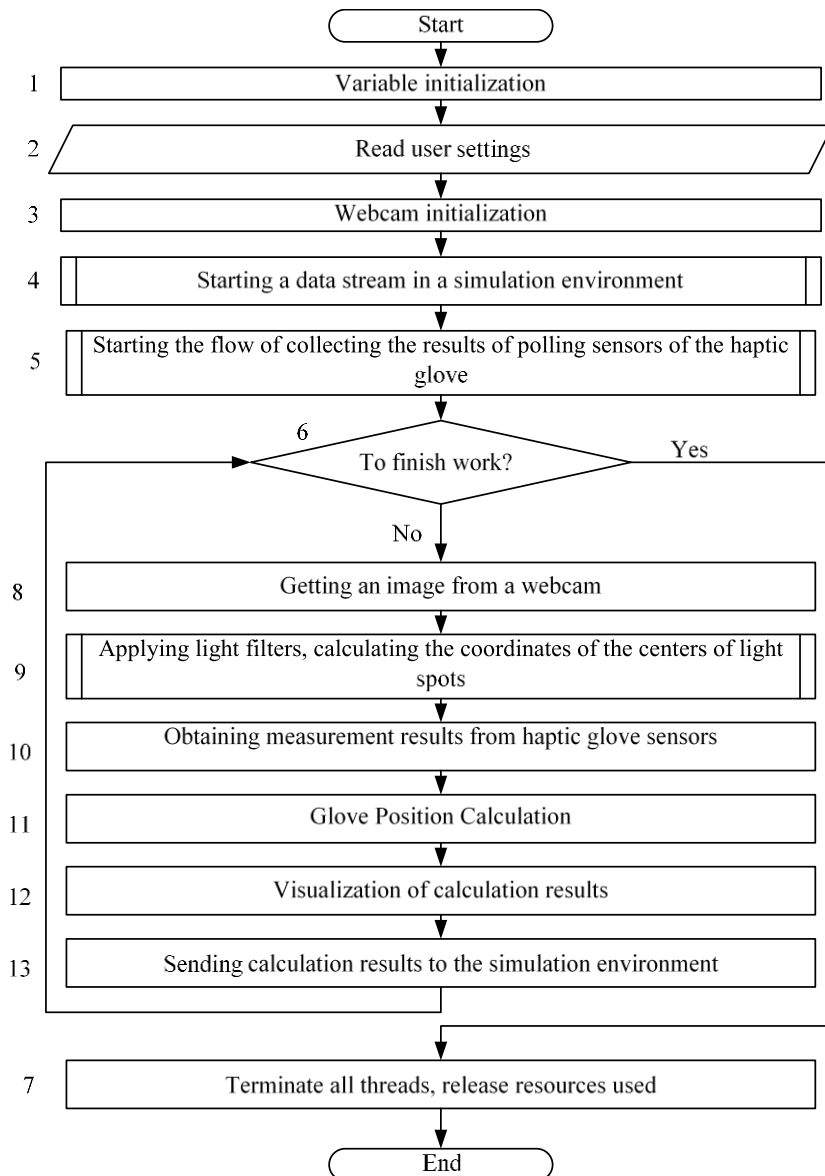
Fig. 13. Algorithm of the server part

1. Start the HG sensor measurement collection stream.

2. If the user signals the end of the work, step 7 is performed. If the work continues, step 8 is performed.

3. Completion of all threads, releasing the resources used. Completed threads include main thread, data transfer thread to simulation environment, HG sensor acquisition thread. Resources in use include webcams and network connection socket.

4. Obtaining an image from a webcam.

5. Application of light filters, calculation of coordinates of light spot centres. Based on the userdefined settings, the image from the webcam is digitally processed to identify the light markers and calculate the apparent two-dimensional coordinates of their centres. These variables are used in step 11.

6. Obtaining HG sensor polling results. These results are obtained from the corresponding HG sensor polling result acquisition thread being executed in parallel by using shared variables.

7. Calculation of the glove position. Based on the survey results from step 10 and the calculation results from step 9, calculate the Cartesian coordinates of HG.

8. Visualisation of the calculation results.

9. Sending calculation results to the simulation environment. Calculation results are sent via UDP to the Unity based simulation environment.

A video of the ICET prototype is available over the link (Video of prototype work, 2022).

2.2.4. Teacher and learner interaction in a virtual laboratory environment

Integration of interactive and contact education technologies in the educational process is shown in Figure 2, according to this we will consider options for teacher-student interaction in a virtual laboratory (VL) environment using the example of a chemistry laboratory.

The VL-trainee interaction implies organisation of independent work (self-training, self-testing) of the trainees in the virtual laboratory as a simulation environment. In this case the individual pace of lessons is ensured in accordance with the learner's capabilities and abilities, the need for selfeducation is formed. If necessary, the learner can seek advice from a teacher or «virtual assistant».

The teacher-learner interaction can be used when working with a group of learners who are geographically located in the same or different classrooms, as well as remotely from each other and from the teacher, which makes it possible to organise online learning. It can be applied during the explanation of new material, demonstration experiment with the purpose of forming stable cognitive interests on the discussed problem and activation of the students' activity. The teacher works with all students simultaneously: discussing questions and tasks, analysing, comparing, summarising the results of judgements, instructing, setting up a student experiment.

Trainee-LL-trainee interaction involves the organisation of group (team) work by the trainees. A special case of this interaction is learner-trainee-LL-trainee interaction – the work of learners in pairs. The teacher is the organiser and coordinator (facilitator) of learners' face-to-face or online work.

Based on the ICET design produced, we will conduct pilot studies of the speed of training level of educational technology and the level of learning compared with classical educational approaches.

3. Results
3.1. Assessing the speed of learning of ICET technology

A test group of 3 teachers aged 35, 42 and 53 and 18 pupils of the 9th grade of a comprehensive school was selected for the study. Photographs of the work with the test groups are shown in Figure 14.

To investigate the speed of technology acquisition, the time required for a student to complete two experiments in a laboratory work without errors was measured (Table 1, Figure 15).

In Table 1, column 1 shows the sequence numbers of performers, column 2 shows the number of attempts, and column 3 shows the time spent by the performer on mastering the material from the start of the experiments, including time to correct mistakes made. It should be taken into account that some participants of the test group, having made a mistake in the course of work, started the attempt all over again.

Column 4 shows the execution time of the 6 laboratory works, including learning the requirements of the laboratory work (green question in the simulation) and recording in the notebook the final formulas for each experiment. Column 5 shows the time of the laboratory work consisting of 6 experiments (converted to minutes and seconds for convenience).

Fig. 14. Photograph of work with test groups

Table 1. Results of a study on learning speed using ICET

User	Number of attempts	Training time, sec	Time of laboratory work, sec	Time of laboratory work, (min, sec)
Learner 1	3	117	631	10,19
Learner 2	2	86	761	12,25
Learner 3	2	57	592	9,31
Learner 4	4	192	843	14,02
Learner 5	3	106	666	11,04
Learner 6	2	92	777	12,34
Learner 7	1	42	677	11,10
Learner 8	2	65	647	10,28
Learner 9	4	142	597	9,34
Learner 10	3	101	643	10,26
Learner 11	2	96	799	13,11
Learner 12	5	207	726	12,04
Learner 13	3	125	700	11,24
Learner 14	2	76	665	11,03
Learner 15	3	94	633	10,20
Learner 16	4	133	628	10,17
Learner 17	2	77	640	10,24
Learner 18	3	98	632	10,19
Average by learner	2,78	105,89	680,98	11,02

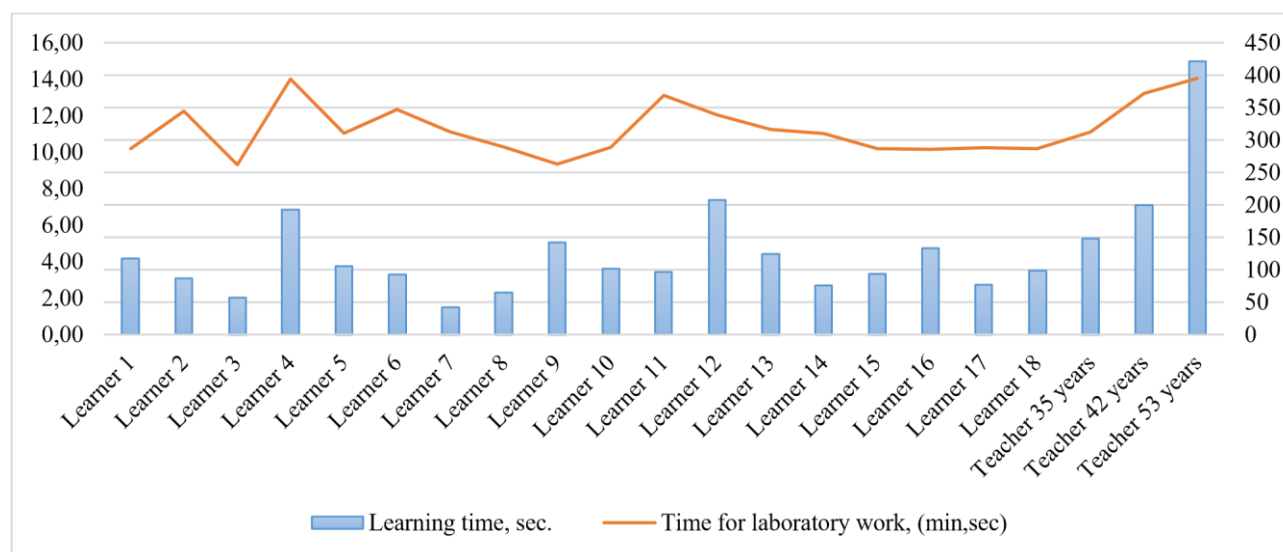|				
Teacher 35 years	4	148	678	11,11
Teacher 42 years	4	199	818	13,23
Teacher 53 years	8	421	849	14,05
Average by teacher	5,33	256,00	781,71	12,48

Fig. 15. Results of a study on the speed of learning and time to complete interactive and contact laboratory activities

The results of the study show that the pupil's habituation to steering via HG (proprioception) varies from 1 to 5 minutes. The average result was just under 2 minutes. At the same time, it took the pupils between 9.5 and 15 minutes to complete all the experiments of the laboratory work. The full cycle of laboratory work, taking into account learning the technology, learning how to perform the experiment and recording the results of chemical reactions was about 20 minutes.

The results of teachers' mastering of technology are mixed, the average speed of mastering is about 4-5 minutes, with an average of about 13 minutes spent on laboratory works. It is worth noting that due to the small sample of teachers the results may not be objective, however, on such a small sample it is noticeable that depending on the age of a teacher the time of mastering the technology increases proportionally.

3.2. Assessment of the learning level compared to classical approaches to education

Another test group of 15 Year 9 pupils was selected to assess learning levels. Pupils were divided into 3 test groups of 5 pupils each. Pupils in the first group performed laboratory work using real reagents. The second group watched the video tutorial of the laboratory work. The third group used the ICET.

After completing the work, each group member was given a quiz consisting of 10 random questions on the laboratory work done. The total question bank was 30 questions. The test was administered 3 times. On the day of the laboratory work, 3 days after the laboratory work, and one week after the laboratory work.

The results of testing the study groups in the scoring system are presented in Table 2 and Figure 16.

Table 2. Assessment of learning levels of test groups of grade 9 pupils (points)

User	Learning tool	Test 1 day	Test day 3	Test day 7
Learner 1	Laboratory experience	8	6	5
19. Learner 2	20. Laboratory experience	21. 10	22. 9	23. 8
Learner 3	Laboratory experience	9	8	6

| Learner 4	Laboratory experience	8	8	6
Learner 5	Laboratory experience	10	8	7
Average score	Laboratory experience	9,00	7,80	6,40
Learner 6	View video lesson	9	6	5
Learner 7	View video lesson	7	5	4
Learner 8	View video lesson	9	9	8
Learner 9	View video lesson	8	7	6
Learner 10	View video lesson	8	6	4
Average score	View video lesson	8,20	6,60	5,40
Learner 11	Interactive contact work	9	8	7
Learner 12	Interactive contact work	8	7	6
Learner 13	Interactive contact work	10	9	8
Learner 14	Interactive contact work	9	8	8
Learner 15	Interactive contact work	8	7	6
Average score	Interactive contact work	8,80	7,80	7,00
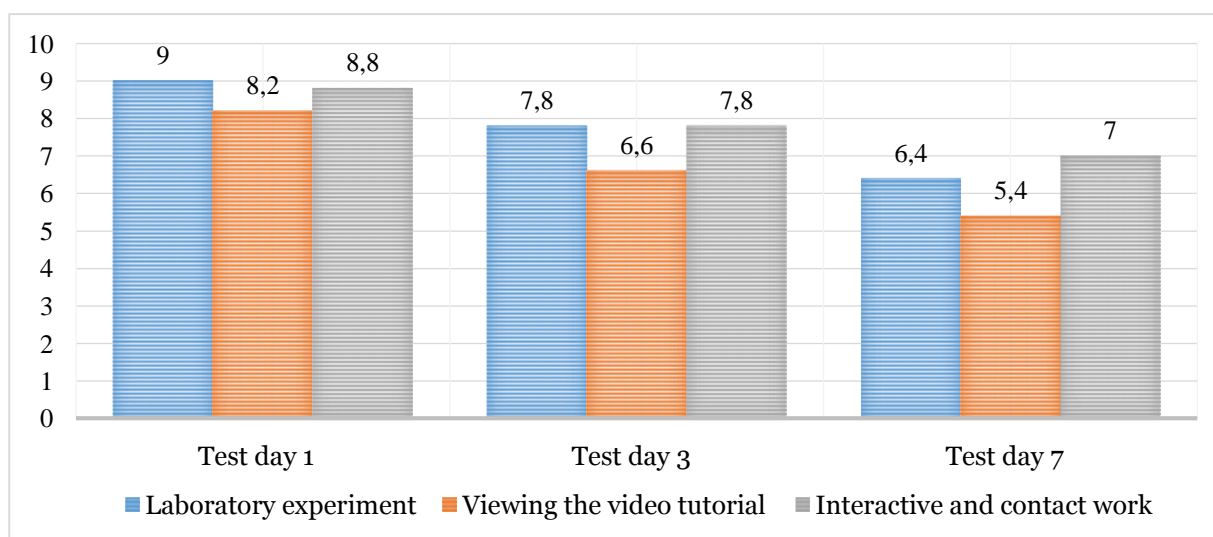
Fig. 16. Comparison of average learning assessment results of test groups of grade 9 students

According to the results, on the day of the laboratory work, the level of absorption of the participants in the first and third groups was almost identical (8.8 points versus 9 for the classical laboratory work with reagents).

However, 7 days after the laboratory work, participants in the third group had a slightly higher level of residual knowledge than students who had used the classical laboratory work method.

The results obtained explained by the high involvement of the student in the educational process and the interest in new technology.

From the results of the study, it is noticeable that group viewing of video lessons is an inefficient way of learning based on the data of Figure 16. Perhaps students are not interested in the passive format of watching videos of school experiments.

Thus, based on the results of the learning assessment, it can be concluded that ICET has been successfully implemented in the classroom.

4. Discussion

The results of the conducted research show that the use of ICET in the main general education school can affect the quality of education by increasing the involvement of students and the level of residual knowledge.

In (Sahin et al., 2019), a study was made of the relationship between the performance of students in astronomy lessons in the traditional format and in the AR format. According to the results of the study, it was found that students in the AR-learning group had a higher level of academic achievement and a positive attitude towards the course than students in the traditional learning group. In the work, this considered as evidence of the positive effect of AR technology (Chang et al., 2021). There was a significant difference in performance between AR and the traditional group, with students who attended science classes using AR technology scoring higher on the Science Achievement Test than those who studied traditionally. Similar results also obtained in other well-known works (Cai et al., 2014; Abdusselam, 2014).

Regarding other works, I would like to note the shortcomings resulting from personal experience in conducting classes with the developed technology. The first barrier to the use of new technologies in education was the difficulty in the process of entering and controlling a group in a virtual environment, primarily associated with moderating a large flow of processes. A similar problem considered in (Nasser et al., 2020). However, in (Fransson et al., 2020), the emphasis placed on the fact that the development of technologies will make it possible to overcome this barrier in the near future due to the development of discipline in conducting classes of this kind.

An important factor is the need to organize work for teachers to pass the necessary advanced training courses in the field of immersive technologies in order to prevent a shortage of qualified personnel to carry out educational activities using VR.

The use of ICET broadens the range of possible practical elements in the lesson structure. The time is optimised for students and teachers while maintaining compliance of the subject work programmes with the requirements of the federal state educational standard.

Thus, the structure of a lesson using ICET involves a 40-minute lesson with the following allocation of time:
- 5 minutes – preparing the workplace,
- 5-10 minutes – explanation of the practical work by the teacher,
- 20 minutes – direct performance of the work using ICET,
- 5-10 minutes – discuss the results of the work and tidy up the workplace.

The following applications of ICET should be highlighted:
- Development and implementation in the digital learning environment (DLE) ecosystem in accordance with the national policy on digital transformation of education;
- Online learning, interactive, supplementary education, online olympiad movements;
- The implementation of educational programmes and hands-on training sessions in various disciplines by experienced teachers in small schools and schools in remote areas.

5. Conclusion

This article describes the development of ICET. The article describes the development of an HG prototype and virtual lessons for conducting research on the application of immersive technologies in the educational process.

This article conducts experimental research on the speed of mastering ICET and the level of student learning when it is applied in comparison with classical educational approaches to chemistry lessons.

According to the results of a study on the speed at which pupils learn ICET technology, getting used to the controls via HGs averages just under 2 minutes. It took pupils between 9.5 and 15 minutes to complete the 6 experiments of the laboratory work. A complete laboratory work cycle, including learning the technology, learning how to perform the experiment and recording the results of chemical reactions, was around 20 minutes.

The learning assessment results show a positive score on the first day of testing, 8.8 versus 9 for the classical laboratory work with reagents.

However, 7 days after the laboratory work, the level of residual knowledge is not significantly higher than in classical laboratory work methods.

It is worth noting that classical laboratory work with reagents should be present in the educational process. However, research shows that the use of immersive technology has its advantages in the form of the possibility of diversity of forms of classes, increasing the level of involvement in the educational process while maintaining a high level of residual knowledge.

In the future, large-scale studies are planned, with more lessons both available in the curriculum and expanded with new reagents. It is planned to increase the test groups of students to

1,000. In addition, it is planned to conduct a study to identify the dependence of the speed of mastering the technology on the age of both pupils and teachers.

The development of a module for remote teacher access to virtual student laboratories during interactive and contact labs is planned in order to remotely monitor the progress of the student's work.

6. Acknowledgments

7. Conflict of interest

The authors declare no conflict of interest.

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