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Intensive Training Model for Artillery Cadets Using 3D Simulators

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Abstract:

The article covers topical issues of organizing intensive training of artillery cadets in wartime based on the remote use of 3D simulators. In such an educational process, there is a need to coordinate dynamically the speed of developing detailed 3D models with the speed of information perception by cadets. The authors describe the process of information exchange in training system and they propose a mathematical model of information transmission. In addition, they offer a mathematical model of information perception by cadet and conduct a pedagogical experiment. Finally, they draw conclusions regarding the implementation of the developed models within the educational process. The results of the pedagogical experiment confirm theoretical formulations and make it possible to synchronize the speed of 3D models development with the speed of their study, considering the intensity of perception by cadets of a huge information volume within a short time.

Keywords:

3D modeling, cadet, intensive training, information exchange, perception of information, simulator, training system

1 Introduction

The epidemic of COVID-19 has caused a massive transition of educational institutions in the world to online learning with extensive use of simulation and interactive training courses. Another new trend in online education is 3D modeling, which provides much broader opportunities for students to develop knowledge and spatial thinking.

These trends also affect military education in Ukraine. In war conditions, the following features additionally influence them:

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- constant danger of enemy air and missile attacks on military institutions,
- impossibility to concentrate students in classes. Therefore, military education institutions prefer to use distance training, having theoretical lessons remotely,
- need to train a vast number of military personnel in a short time. In particular, for artillery, they train artillery commanders, logistic personnel, technical personnel, etc.,
- mixed levels of entrance knowledge and skills of learners: cadets of military institutes, mobilized personnel, volunteers, etc. In further consideration, we will call all of them – cadets,
- study of new types of weapons that are not in service with our own Armed Forces and have not been studied before,
- lack of training samples of weapons, and their detailed technical documentation.

All these features encourage the widespread use of 3D models combined into simulation training complexes (virtual 3D simulators), which is a new modern concept of military education [1].

2 Statement of Research Problem

The concept of intensive distance learning based on the use of virtual 3D simulators requires educational institutions to create enough computer 3D models of sufficient detail. Detail is the main characteristic of a 3D model, which determines the number of personnel and means for its creation. The more detailed the model, the more in-depth knowledge of a weapon's sample it can provide to the cadet. Although the development of detailed models requires a lot of work from a large team of personnel: designers, developers, programmers, etc., the number of such specialists is always limited. Moreover, the detail of the model is a limiting parameter for the learner, as it requires more effort to master and is limited by the physical capabilities of a person to perceive and memorize information.

Therefore, for an effective educational process under the specified conditions, there is a problem of dynamically coordinating the speed of creating detailed 3D models with the speed of information perception by cadets.

3 Overview of Related Works

Using 3D modeling in education is widely covered in scientific literature. Thus, publication [2] emphasizes the importance of familiarizing students with design skills during their 3D modeling training at the pre-university level. The article proposes an approach that uses the step-by-step differentiation of the structure of students' educational activities as the main psychological model for forming design skills. The authors describe the initial, basic, and professional stages of acquiring professional skills with tasks assigned to each stage.

In publication [3], the authors analyze the processes of visualized learning based on the presentation of graphic information visually and kinesthetically using information technologies. The authors of publication [4] present a framework for designing 3D cartoons, which are developed under the cognitive attributes of students and their practical skills using hand drawing and computer modeling. Publication [5] examines the impact of computer 3D modeling on the spatial abilities of teachers and students.

As a result, the authors found that 3D computer modeling provides additional opportunities for improving spatial abilities.

Publication [6] discusses the use of 3D modeling of parts in the educational process, which allows the student to get and perceive the internal construction of parts and devices. Publication [7] examines the didactic possibilities of 3D modeling tools for the personalization of learning and the conscious involvement of students in solving creative problems. The research problem defines the contradiction between the possibilities of 3D technologies to improve the quality of education by considering the individual characteristics of a person and the learning model used in educational organizations. The authors reveal the features of personalized training based on 3D modeling regarding a conscious choice of educational software, studying the theoretical foundations and tools of 3D modeling for solving creative structured tasks.

Despite the large number of publications devoted to the use of 3D modeling in the educational process, none of them addresses the questions posed at the beginning of the article. The authors of the considered publications focus their attention on various aspects of creating 3D models, proving that the use of 3D models can significantly improve the learning process. Nevertheless, the problem of building an effective system for the development and implementation of 3D modeling in changing dynamic conditions, when the educational process requires constant updating of the model base, remains unsolved.

In conditions of limited resources and time for developing models, it is important to achieve a balance between the training system, which generates visual 3D materials for learning, and the physical capabilities of cadets to perceive information. The training system must have time to prepare enough models or parts of models for their assimilation. Increasing the speed of developing 3D models will require additional involvement of personnel and resources and will lead to their inefficient use. Insufficient speed in developing 3D models will lead to inefficient use of cadets' capabilities.

Therefore, the purpose of this article is to create a model of intensive training for artillery cadets using 3D simulators.

In order to achieve this goal, it is necessary to solve the following research tasks:

- consider the process of information exchange in the training system,
- develop a mathematical model of information transfer in the training system,
- develop a mathematical model of information perception by cadet,
- conduct a pedagogical experiment and draw conclusions regarding the implementation of developed models in the educational process.

4 Information Exchange in the Training System "Simulator–Cadet"

According to the statistics, 60 % of population are visual, 35 % are kinesthetic, and only 5 % are auditory [8]. Considering such a distribution, without a doubt, the main efforts in distance learning should be pointed specifically to the visual content. 3D graphics tools can supplement the visual environment with kinesthetic elements, thus expanding the number of people who can perceive information online.

Let us consider a virtual training system, which comprises two subsystems: simulator and cadet. Such a division is quite simplified since the simulator will be understood not only as technical means of visualizing 3D images but also as a group of designers, developers, and instructors (tutors) who fill these courses with information and manage it during the training of cadets.

The cadet subsystem is the second necessary element of the virtual training system which receives information from the simulator. Its main task is to perceive the received information to ensure the possibility of its further reproduction. The authors do not aim to investigate the psychological features of human perception – as a cognitive mental process that involves a person's reflection of objects and phenomena under the direct influence of the senses [9]. The authors use the concept of "perception" just to fix the fact of information exchange in the training system between the simulator and cadet.

4.1 Mathematical Model of Information Transfer in the Training System

As already mentioned, in the training system "simulator–cadet", specified subsystems can exchange information with each other. Each subsystem is characterized by some function *P*, which describes the efficiency of achieving the main goal of the training system (information transfer and perception by cadet) depending on the information available in both subsystems. Depending on the type of this function, a separate subsystem (simulator or cadet) is "interested" in transmitting, receiving, or saving information from another subsystem [10].

Let the simulator subsystem transmit information to the cadet subsystem. We can divide the volume of information at the disposal of subsystems into:

K_{Sim} – information volume in the simulator *Sim*,

J_{Sim} – information volume transferred from simulator *Sim* to cadet *Cad*,

K_{Cad} – information volume that cadet *Cad* has,

I_{Cad} – information volume perceived by cadet *Cad*.

An important research question is: what is information and how to measure information volume in the training system?

Within the framework of consideration, regarding the construction of a 3D training course with an optimal number of constituent elements, the information is defined as the elementary units that make up a sample of weapons, into which we can divide it using 3D graphics. The information volume (K_{Sim}, J_{Sim}, K_{Cad}, I_{Cad}) is the number of specified elements. Based on our experience of using 3D models for intensive training of artillery cadets, we found that the most optimal models for perception during one training day (6-8 hours of work with a 3D simulator) are 3D models that include from 25 to 30 graphic elements. Cadets easily perceive such an information volume, and after that, they can confidently reproduce received information after some time (e.g. the next day), and assemble a sample of weapons from individual elements. When trying to perceive a larger number of elements during a day, their efficiency of reproduction decreases because cadets forget a certain volume of information.

The efficiency of the simulator depends on the information in it and the information that was given to the cadet. However, the simulator cannot control the cadet's perception of information. Therefore, the evaluation of the simulator's performance can be presented as: $P_{\text{Sim}} = P_{\text{Sim}}(K_{\text{Sim}}, J_{\text{Sim}})$. Evaluation of cadet's performance will have the form: $P_{\text{Cad}} = P_{\text{Cad}}(K_{\text{Cad}}, I_{\text{Cad}})$. In a closed system, information volume $K_{\text{Sim}} + K_{\text{St}}$ does not change in time, so we can shorten one argument from the equations. Thus, the performance equations for *Sim* and *Cad* can be written as:

$$P_{\text{Sim}} = P_{\text{Sim}}\left(J_{\text{Sim}}\right), P_{\text{Cad}} = P_{\text{Cad}}\left(I_{\text{Cad}}\right) \tag{1}$$

The efficiency of the simulator depends on the information volume that it can generate and provide to the cadet. The efficiency of the cadet depends on the information volume that it can perceive and assimilate. We can understand the efficiency of the simulator as the probability that the simulator will generate an object comprising a number of elements J_{Sim} during the school day. The cadet's efficiency is the probability of the cadet's perception of an object with a number of elements I_{Cad} during the school day.

Let us also enter a value $L_{\mathrm{Sim}} = J_{\mathrm{Sim}} - I_{\mathrm{Cad}}$, which shows the information loss, as a part of the information that was transmitted by the simulator, but was not accepted by the cadet.

Fig. 1 shows the dependence of the cadet's performance on the volume of perceived information and the simulator's performance on the volume of information it can convey to the cadet. As we can see, because there are losses of information L_{Sim}, simulator's performance does not coincide with cadet's performance.

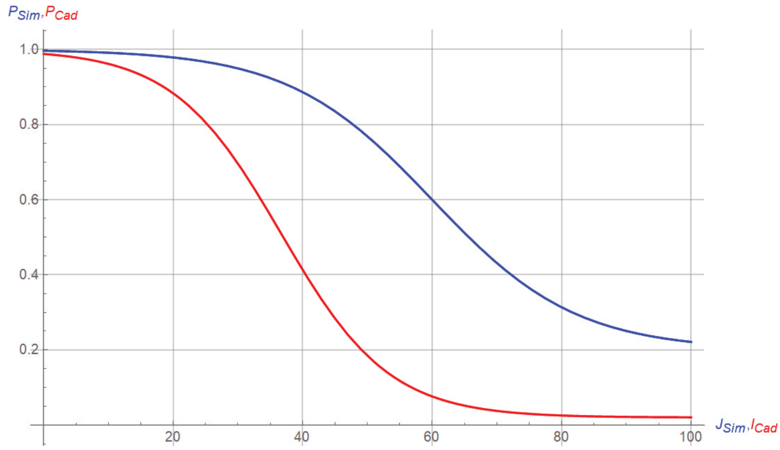

Fig. 1 Dependence of performance on the information volume

Also, the dependence of the simulator's performance is monotonic and decreases with the increase of information volume it can generate and provide to the cadet. Similarly, the cadet's performance decreases with an increase in the information volume received. The reason for this is the limitation of the cadet's physical abilities to perceive and memorize information. To ensure information balance, it is necessary that the simulator's performance is higher than the cadet's performance.

Change in value $P_i\left(i \in \{Sim, Cad\}\right)$ because of information exchange is the value of information [11]:

$$v_{\mathrm{Sim}} = \frac{\mathrm{d}P_{\mathrm{Sim}}}{\mathrm{d}J_{\mathrm{Sim}}},\ v_{\mathrm{Cad}} = \frac{\mathrm{d}P_{\mathrm{Cad}}}{\mathrm{d}I_{\mathrm{Cad}}} \tag{2}$$

Value v_i, $i \in \{Sim, Cad\}$ = corresponds to the degree of i-th subsystem motivation for information exchange. In the simplest case information flow $q_{\mathrm{Sim}}(v_{\mathrm{Sim}}, v_{\mathrm{Cad}})$ can be given as:

$$q_{\mathrm{Sim}}\left(v_{\mathrm{Sim}}, v_{\mathrm{Cad}}\right) = -\alpha\left(v_{\mathrm{Sim}} + v_{\mathrm{Cad}}\right) \tag{3}$$

where α is a dimensional coefficient of proportionality.

As shown in Fig. 2, information flow from simulator to cadet increases up to a certain value (in our case to J_{Sim}, $I_{\mathrm{Cad}} \approx 40$) and decreases further on.

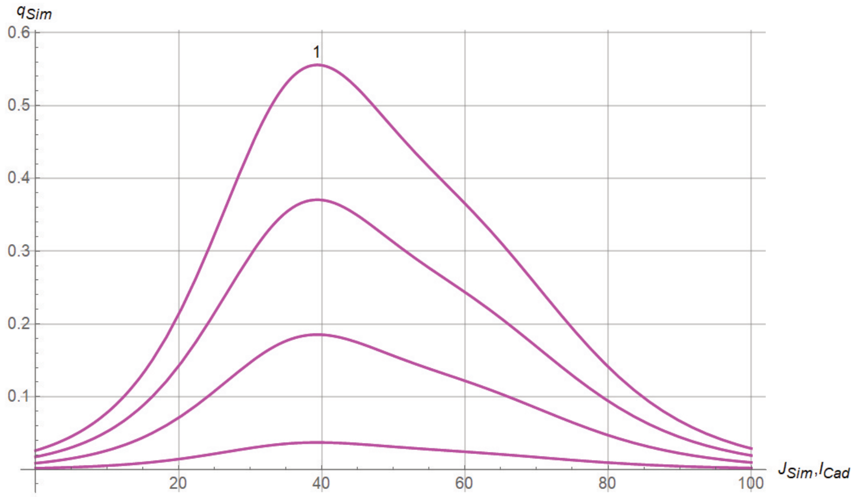

Fig. 2 Information flow q_{Sim} dependence from information volumes J_{Sim} and I_{Cad} at $\alpha = 1, 5\ 10, 15$ (for the case from Fig. 1*)*

This means that simulator can fill the system with new elements in an increasing number of up to 40 elements per day. The speed of filling the system with new elements exceeds the speed of their perception by cadet. After J_{Sim}, $I_{\mathrm{Cad}} \approx 40$ simulator can no longer provide a sufficient flow of elements. The information volume produced by the simulator during a training day is greater than cadet can perceive. Also, information flow q_{Sim} determines the change of unused information volume in the simulator:

$$\frac{\mathrm{d}J_{\mathrm{Sim}}}{\mathrm{d}t} = -\frac{\mathrm{d}K_{\mathrm{Sim}}}{\mathrm{d}t} = q_{\mathrm{Sim}}\left(v_{\mathrm{Sim}}, v_{\mathrm{Cad}}\right) \tag{4}$$

The intensity of information perception by the cadet will be $q_{\mathrm{Cad}} < q_{\mathrm{Sim}}(v_{\mathrm{Sim}}, v_{\mathrm{Cad}})$, because there is always a portion of the information that is not perceived by the cadet [12]. This portion of information grows as the information flow increases. In extreme cases, at $q_{\mathrm{Sim}} \to 0$ all the information that was transmitted by simulator can be perceived by cadet. In case when $q_{\mathrm{Sim}} \to \infty$, a portion of information perceived by the cadet, reduces to zero:

$$\left.\begin{aligned} q_{\mathrm{Cad}} &= p\left(q_{\mathrm{Sim}}\right) q_{\mathrm{Sim}} \\ \lim_{q_{\mathrm{Sim}} \to 0} p\left(q_{\mathrm{Sim}}\right) &= 1 \\ \lim_{q_{\mathrm{Sim}} \to \infty} p\left(q_{\mathrm{Sim}}\right) &= 0 \end{aligned}\right\} \tag{5}$$

We also have to consider $p(q_{\mathrm{Sim}})$ as the probability that the elementary information volume sent by the simulator will be perceived by the cadet:

$$p\left(q_{\mathrm{Sim}}\right) = \mathrm{e}^{-k \cdot q_{\mathrm{Sim}}\left(J_{\mathrm{Sim}}, I_{\mathrm{Cad}}\right)} \tag{6}$$

According to Eq. (5), the flow for cadet $q_{\mathrm{Cad}} = p(q_{\mathrm{Sim}})q_{\mathrm{Sim}}$ reaches a maximum within the same limits (J_{Sim}, $I_{\mathrm{Cad}} \approx 40$). At each moment of time, the value of p shows the efficiency of exchange, but the average value of p for the entire time process is not informative. To determine the efficiency of information exchange, we define the balance for the value:

$$L_{\text{Sim}} = J_{\text{Sim}} - I_{\text{Cad}} = \left[1 - p\left(q_{\text{Sim}}\right)\right] q_{\text{Sim}} \tag{7}$$

To determine the information volume J_{Sim}, when the maximum losses will be observed in the system, it is necessary to solve the task:

$$\frac{\mathrm{d}L_{\text{Sim}}}{\mathrm{d}J_{\text{Sim}}} = \left[1 - p\left(q_{\text{Sim}}\right)\right] q_{\text{Sim}} = 0 \tag{8}$$

For the case under consideration, the system will have maximum losses at $J_{\text{Sim}} = 39.4$ or any values of α. But, when optimizing the system, it will also be important to detect when the increase of L_{Sim} will make the system inefficient and further increase of J_{Sim} and I_{Cad} will be impractical. For this, we have to solve the task:

$$\frac{\mathrm{d}L_{\text{Sim}}}{\mathrm{d}J_{\text{Sim}}} = J_{\text{Sim}} - I_{\text{Cad}} = \left[1 - p\left(q_{\text{Sim}}\right)\right] q_{\text{Sim}} = \sigma \to \max \tag{9}$$

In our case, after $J_{\text{Sim}} = 29.2$ you should not try to increase the detail, since the efforts spent on developing the model will not be compensated by the speed of perception of such a large volume of information by cadet. Value σ is the rate of information loss because of the limited perception of information by the cadet. We can see that value σ and performance indicator p are monotonously connected. Let us express σ by p and we get:

$$\sigma = -\frac{1}{k}\left(1 - p\right)\ln p \tag{10}$$

The derivative of this function will have the form $\frac{\mathrm{d}\sigma}{\mathrm{d}p} = -\frac{1}{kp}\left[1 - p\left(1 + \ln p\right)\right]$. Because $p \in [0, 1]$, then $\ln p \leq 0$ and the expression in square brackets will always be positive. That is why $\mathrm{d}\sigma/\mathrm{d}p < 0$ at all possible values of p.

4.2 Mathematical Model of Information Perception by Cadet

A convenient model of the initial stage of information perception, postulated today in cognitive psychology, is shown in Fig. 3 [13]. Let us emphasize that this is only a model of simple visualization, and not a description of the structure and functioning of the human brain. Since the volume of sensory information that continuously enters cadet's neural network is astronomically large, the "higher level" cognitive systems select for further information processing only a part of the sensory information (block 7). This selection requires time to store information in the selection system. For example, the duration of visual (iconic) image storage (block 6) is approximately equal to 250 ms, and the duration of auditory (echoic) image storage is longer – from 250 ms to 4 s. The storage time in short-term memory (block 8) reaches 10-30 s, and in long-term memory, it is from several hours to days and months. Thus, we will be interested in the information transition from simulator to cadet's long-term memory (blocks 2-9).

Perception of external influences (stimuli) comprises two stages. The first stage is perception itself, an actual sensory impression. The second stage is reproduction, the ability to present what we memorized before it was erased. Thus, iconic and echoic storage allows the selection of essential information for further processing, limiting the bandwidth of cadet's information processing system.

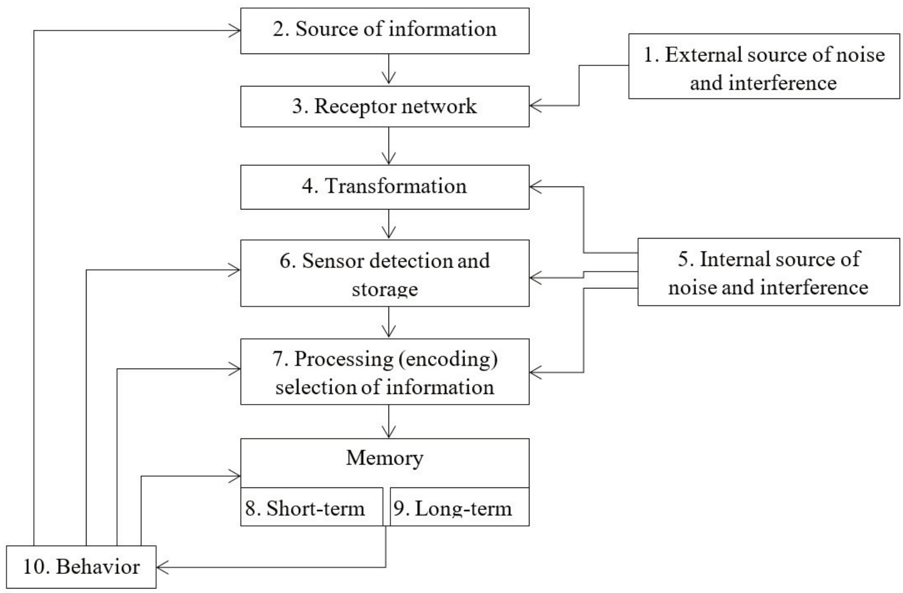

Fig. 3 Movement of information in the process of perception

Perception of external influences (stimuli) comprises two stages. The first stage is perception itself, an actual sensory impression. The second stage is reproduction, the ability to present what we memorized before it was erased. Thus, iconic and echoic storage allows the selection of essential information for further processing, limiting the bandwidth of cadet's information processing system.

The term "sensation" describes the primary process of receiving information, associating it with the reaction of the analyzers (eyes, ears, etc.) because of their influence on elementary types of stimulation (blocks 2 and 3). "Perception" means the next level of information processing, which involves higher cognitive mechanisms that interpret sensory information. Data interpretation depends on many complex cognitive factors, including prior knowledge about the world, the goals of observation, etc. Therefore, perception and interpretation may not coincide with the objective reality of the subject of observation. We should note that perception and information processing are affected by both external and internal noise: blocks 1 and 5.

We developed a mathematical model of memory from the representation of memory as an information process. Let us mark $I_{\mathrm{Cad}}(t)$ as a number of information units stored in cadet's memory at the moment of time t. As in the information transfer model for the training system, we will take as a unit of information some subjective and holistic entity that is a part of a sample of weapons, into which it can be divided using 3D graphics. Thus, we will have a mathematical model without reference to specific units of measurement of information. We use the following symbols in this model: R – the speed of information "arriving" to cadet; R_{Cad} – the speed of decrease of information volume in cadet's memory, determined by forgetting.

The information stored in cadet's memory will change in time:

$$\frac{\mathrm{d}I_{\mathrm{Cad}}}{\mathrm{d}t}=R-R_{\mathrm{Cad}} \tag{11}$$

Let us accept the hypothesis that forgetting information R_{Cad} is proportional to the difference between information that is present at time t and some of its final value I_∞, which is determined by the level of cadet's memory after a sufficiently long time

$$R_{\mathrm{Cad}}=\frac{\mu}{\tau}\left(I_{\mathrm{Cad}}-I_\infty\right) \tag{12}$$

where $0\le\mu\le 1$ is the dimensionless coefficient that depends on memory volume, individual characteristics, method of presenting information, etc.; τ – the time constant.

Therefore:

$$\frac{\mathrm{d}I_{\mathrm{Cad}}}{\mathrm{d}t}=R-\frac{\mu}{\tau}\left[I_{\mathrm{Cad}}(t)-I_\infty\right] \tag{13}$$

At R = const, μ = const, τ = const (do not depend on time) and initial conditions: $I=I_0$ at $t=0$ we will get the solution of this differential equation:

$$I_{\mathrm{Cad}}(t)=I_\infty+R\frac{\tau}{\mu}+\left(I_0-I_\infty-R\frac{\tau}{\mu}\right)\mathrm{e}^{-\mu T} \tag{14}$$

where $T=t/\tau$ is the dimensionless time normalized to τ.

Equation (14) makes it possible to predict the process of accumulation or decline of information in the cadet's memory depending on his/her psychophysiological properties, incoming information, and the level of its initial volume (Fig. 4).

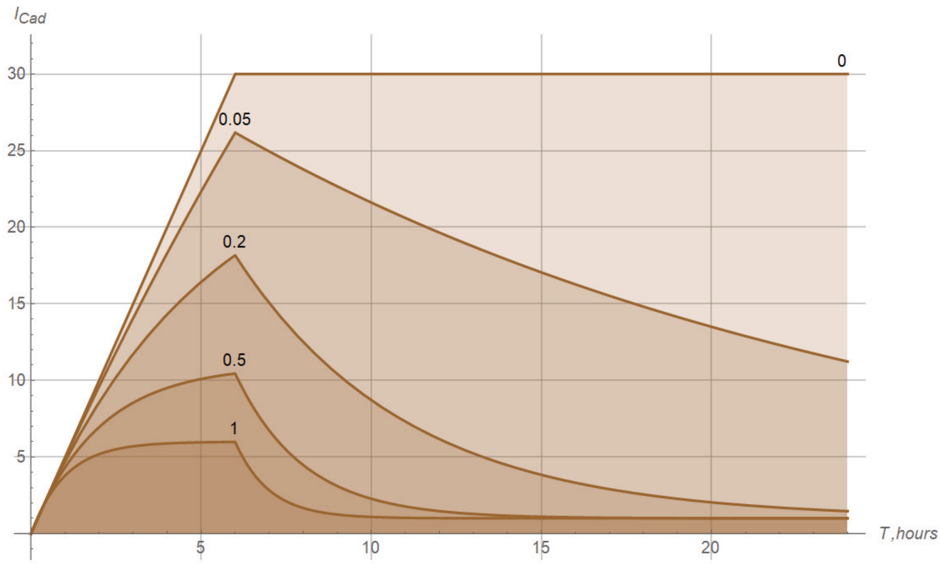

Fig. 4 Dynamics of the information volumes changes in memory during the day for different values of μ

5 Virtual Simulation Complex

According to the experience of combat operations, the efficiency of firing depends on the technical preparation of the gun and ammunition that implies the ability of a crew:

- to set firing data,
- to assemble shells and fuzes,
- to measure the wear of the barrel for corrections of the projectile's initial speed.

To conduct the experiment within the mentioned framework, we created a unified specialized class "Virtual Simulation Complex" with three virtual simulators: 1) "Sighting devices"; 2) "Ammunition"; 3) "Fire support means" [1, 14].

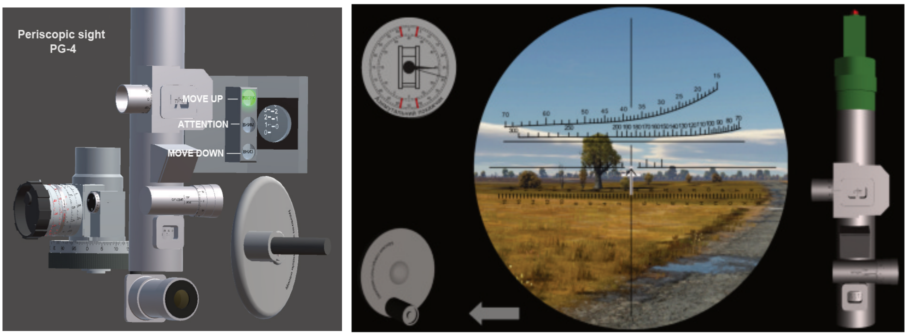

Fig. 5 Simulator of PG-2, PG-4 sights for self-propelled guns

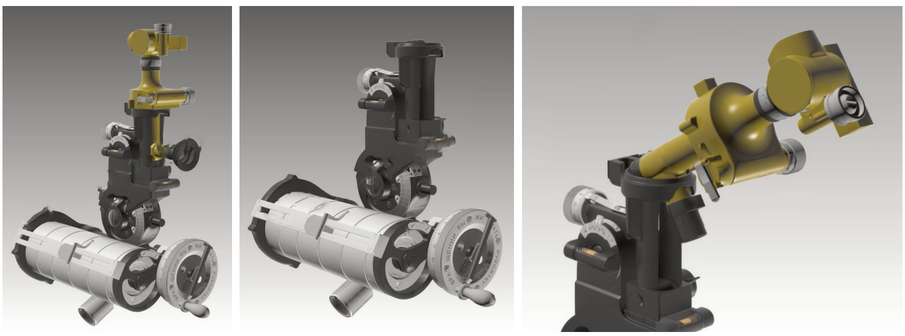

Fig. 6 Simulator of C-71-40, D-726-45 sights for towed guns

Fig. 7 Simulator of MPM-44M sight for mortars

1. For the development of cadets' skills in the correct use of sighting, we created virtual simulators of sighting devices for self-propelled and towed artillery, and mortar weapons. The main sights for self-propelled artillery are PG-2, PG-4 (Fig. 5), for towed guns – C-71-40, D-726-45 (Fig. 6), and for mortars – MPM-44M (Fig. 7).

2. The computer 3D simulator "Ammunition" allows cadets to practice preparing ammunition for firing and safety measures of military personnel during combat firing. Fragments of virtual simulator "Ammunition" are shown in Fig. 8. The task comprises separate operations, namely (from left to right): Charge Assembling, Setting Fuse, Setting Fuse on delay and ricochet, etc.

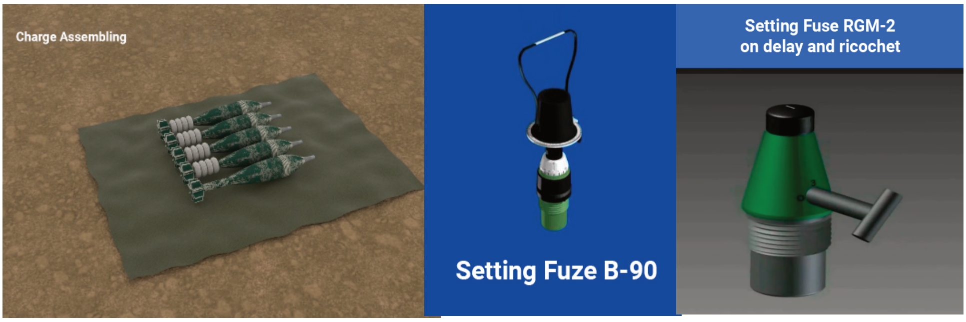

Fig. 8 Virtual simulator "Ammunition"

3. The computer 3D simulator "Firing Support" allows cadets to simulate measuring the length of the barrel chamber, which changes its dimensions during firing, which causes a decrease of initial speed of the projectile. We offered a model of the laser measuring device for chamber length (PZK-L) patented by authors (Pat. No. 118415 dated August 10, 2017). The general appearance of the PZK-L device in the assembled state and its components are shown in Figs 9 and 10, respectively.

The examples in Figs 9 and 10 show a complex object that can be disassembled or assembled in the study process. Cadets are provided with instructions for use. Component parts of the PZK-L device are marked: 1 – knurled nut; 2 – measuring ring; 3 – barbell; 4 – thrust ring; 5 – guide disk; 6 – mine for the measuring device; 7 – guide disk retainer; 8 – flange; 9 – tube; 10 – tube handle; 11 – portable laser range finder; 12 – rod extensions; 13 – sender; 14 – sender knocker; 15 – sender stops; 16 – sender handle.

Fig. 9 Common view of the PZK-L laser device in the assembled state

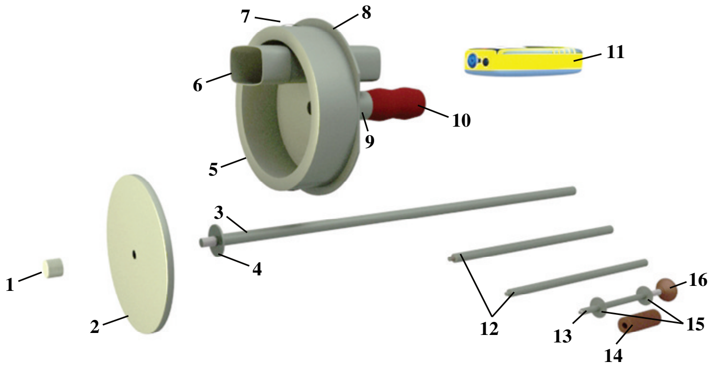

Fig. 10 Main construction of the PZK-L laser device

Software of the simulators provides the ability for cadets to perform tasks independently or under the instructor's supervision/observation. In addition, we lay time standards for implementing relevant operations down. At the end of the test, cadet can see the score and his/her errors on the monitor. Such a simulator not only enables the cadets to acquire primary skills, but it also raises their awareness of the physical essence of aiming, which increases the efficiency of studying weapons samples.

6 Methodology of the Experiment

Based on the above mathematical models, we developed the methodology of experimental work.

A group of 30 cadets was offered to study the construction and various aspects of the use of artillery weapons and ammunition based on the developed 3D models:

- checking sighting devices and installing settings for firings,
- assembling shells and equipment of blasters,
- measuring the wear of the bore and determining corrections for changes in the initial speed of the projectile.

The time unit of training was one school day, during which we allocated 6 hours of time to direct work with the virtual 3D simulator. To determine the perception of 3D objects, we used models that included a different number of elementary units. Totally five types of 3D objects were studied:

- "Single Object". The number of elementary units in such an object does not exceed 50. The object is complete and represents one sample of weapons or a device. The study of such an object does not require the use of additional tools.
- "Group object. Simple topology". Such an object comprises several subsystems that can function and be studied separately. Subsystems are connected to each other in a simple way. The total number of elementary units in such an object does not exceed 80.
- "Group object. Complex topology". A static object consists of several subsystems that form an object of complex topology: subsystems can be fully or partially nested within each other. The total number of elementary units in such an object is over 100.
- "Complex object from single and group objects of complex topology". An object capable of dynamically changing its topology and architecture. Constituent

subsystems of such an object can be connected or disconnected from other subsystems in the process of application. The total number of elementary units in such an object is over 100.

- "Complex object of complex topology using additional tools". These are the most difficult-to-study objects with a dynamically changing topology and architecture, for the perception of which it is necessary to use other (virtual) tools. The total number of elementary units in such an object is over 100.

The study of weapons samples and the order of their use in mastering the 3D course are completely independent. For the study, we offered the cadets a set of 3D models that give the opportunity to disassemble or assemble a sample, watch video instruction, listen to basic information on the procedure and features of the sample's application, and practice kinesthetic skills in disassembling and assembling an object. Tools of the 3D model are used to disassemble the object into separate components (elements) and assemble a complete object from individual elements. A description, which includes the name of the element, its functional purpose, the material from which it makes the element, geometric dimensions, mass, order of application, etc. accompanies images of elementary units and blocks.

Checking the quality of information perception was carried out the day after the direct work with the 3D simulator (approximately 24 hours after the start of studying the object). The next day, the cadet had to complete the following tasks:

- disassemble or assemble an object from individual elements,
- demonstrate the correct use of the object,
- answer additional questions about the use of the object.

We conducted the experiment in 5 training days, during which cadets practiced tasks of increasing complexity:

- day 1 – "Single Object",
- day 2 – "Group object. Simple topology",
- day 3 – "Group object. Complex topology",
- day 4 – "Complex object from single and group objects of complex topology",
- day 5 – "Complex object of complex topology using additional tools".

During the experiment, we investigated the number of cadets who correctly completed the task and could reproduce the object (sample of weapons) from the initial set of components, demonstrated the correct use of the object, and correctly answered additional questions.

According to the results of the experiment, we calculated probabilities of correct actions and answers as frequency of the event: $p = n_x/N_x$, where n_x is the number of correctly completed tasks; N_x – the total number of tasks.

7 Experimental Results and Discussion

We calculated the possibilities of correct reproduction of the objects and averaged them by performing types of experiments and the number of perceived elements. For all conditions of the experiment, we got the dependence of the probabilities of correct reproduction on the number of elements and the complexity of the studied object. The average probabilities of correct reproduction by a group of cadets P_{correct} under different experimental conditions are listed in Tab. 1.

Let us analyze the results. As we can see from Tab. 1, the correct reproduction of the construction or the order of application of the sample of weapons is ensured with a greater probability with simple single objects with a small (n < 50) number of elementary units. Here, for a sample comprising 25 elementary units, correct reproduction on the next day is ensured with a probability of 0.8, and when the number of elements increases to 40, the probability decreases to 0.48.

In more complex cases, for example, for a group object with complex topology, with the same 25 constituent elements, the probability of correct reproduction $P_{correct}$ is 0.78, and when the number of further elements increased to 100, it decreases to 0.07. This makes the intensification of studying complex samples, and therefore the rapid development of 3D models, impractical because of the impossibility of perception by cadets of a big volume of information within a short time.

The study of complex objects with a complex topology, which requires the use of additional tools, demonstrates an extremely limited efficiency. If with a few forming elements ($n < 20$), the object is still perceived effectively enough (the probability of correct reproduction is 0.81), then a small increase in the number of elements (for example, up to 30) leads to a decrease in the probability to 0.55 and less. Thus, we can conclude that, for the study of complex objects in high detail, it is necessary to count on a larger amount of time.

Tab. 1 Probability of correct object reproduction ($P_{correct}$)

Type of experiment	**The number of perceived elements**											
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**	**60**	**80**	**100**
1. Single Object ($n < 50$)	0.99	0.97	0.94	0.89	0.80	0.68	0.59	0.48	–	–	–	–
2. Group object. A simple topology ($n < 80$)	0.98	0.95	0.93	0.88	0.79	0.66	0.55	0.44	0.26	0.20	–	–
3. Group object. Complex topology ($n > 100$)	–	0.93	0.92	0.86	0.78	0.69	0.52	0.40	0.24	0.17	0.11	0.07
4. Complex object from single and group objects of complex topology	–	–	0.90	0.84	0.75	0.63	0.48	0.36	0.17	0.10	0.05	0.02
5. Complex object of complex topology using additional tools	–	–	0.87	0.81	0.73	0.55	0.42	0.27	0.10	0.06	0.03	0.01

8 Conclusions

The global trend of modern education is the transition from traditional face-to-face teaching to teaching online, with the support of technologies using 3D modeling. For military education, this provides serious advantages, as it allows training to be carried out even during the war, without gathering a big number of cadets in one place for a long time and transferring the study of theoretical foundations to distance education.

Intensive training of cadets based on the use of virtual 3D simulators implies the need for the educational institution to create enough computer 3D models of various levels of detail in a short time. Using models with high detail provides the cadet with deeper knowledge. But it requires more time for perception and a huge amount of work from a large team of employees: designers, developers, programmers, and other personnel. Therefore, for the organization of efficient learning in specified conditions, there is a problem of dynamically coordinating the speed of developing detailed models with the speed of information perception by cadets.

Model of the information transfer in the training system "simulator-cadet" can be described by an exponential dependence, where the efficiency of both the simulator and cadet decreases with the increase of the information volume that the simulator can generate and provide to the cadet. The efficiency of the simulator means the probability that the simulator subsystem will generate an object or a group of objects comprising a given number of elements during the school day. The cadet's efficiency is the probability of the cadet's perception of an object with a given number of elements during the training day. The information volume generated by the simulator should always be more than the volume perceived by the cadet, as there is always the information that is transmitted but not perceived by the cadet.

The model of information perception by the cadet takes into account forgetting and therefore requires that the rate of information inflow to the cadet (the number of information units per unit of time) is greater than the rate of decrease in the information volume in the cadet's memory because of forgetting. This approach makes it possible to predict the process of accumulation or decline of information in the cadet's memory depending on his/her psychophysiological properties, incoming information, and its initial volume.

Results of the pedagogical experiment confirm the theoretical dependences and show that the correct reproduction of the construction or order of use of the sample of weapons is ensured with greater probability with simple single objects within a few elementary units. In more complex cases, for example, for a group object with a complex topology or a complex object that requires the use of additional tools, the probability of correct reproduction is lower, and with a further increase in the number of elements, it approaches zero. This makes the intensification of studying complex samples, and therefore the rapid development of 3D models, impractical because of the impossibility of the cadets' perception of a big volume of information within a short time.

The developed model, which was used during the experiment, is primarily intended for the theoretical training of gun commanders and platoon leaders, who must possess elementary skills in the use and maintenance of artillery weapons, including during combat.

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