The Application of Tracker Video Analysis for Distance Learning of Physics

Ihor Chernetckiy [1], Iryna Slipukhina [2], Nataliia Kurylenko [3], Sergii Mieniailov [4] and Magdalyna Opachko [5]

[1,2] *National Center "Junior Academy of Sciences of Ukraine", Degtyarivska Street 38/44, 04119 Kyiv, Ukraine*
[3] *Kherson State University, University Street 27, 73000 Kherson, Ukraine*
[4] *National Aviation University, Lubomira Guzara Avenue 1, 03058 Kyiv, Ukraine*
[5] *State University "Uzhhorod National University", Narodna square, 3, 88000 Uzhhorod, Ukraine*

Abstract

Educational experiments, demonstrations, and laboratory works are the basis for the study of the natural sciences. The drastic restriction of lessons in a real physics laboratory in 2020 – 2021 clearly demonstrated their negative effect on the quality of education. In terms of distance and blended learning, video analysis of real experiments, processes, and phenomena is a real competitor to the corresponding digital models. The free software Tracker toolkit allows measuring physical quantities on the basis of video material, processing the received data, and comparing them with mathematical models. Tracker usage expands methods of obtaining and practical application of information, shows how to identify the actions of laws, and, therefore, forms the scientific competency of students. The general rules for creating educational videos suitable for analysis using Tracker are given in the article. There are demonstrated different approaches to creating instructions for laboratory works based on video analysis on the examples of labs such as measuring the acceleration of free fall (mechanics), determining the surface tension of a liquid (molecular physics), the study of the rotational motion of the Sun (astronomy). Reference videos, didactic recommendations, a collection of video problems, and instructions on non-traditional methods of educational experiment adapted for video analysis using Tracker have been created. They are posted in the section "Instrumental digital didactics" of the resource www.stemua.science of the National Center "Junior Academy of Sciences of Ukraine", which is popular among online users. Video analysis techniques are used for formal and non-formal education of pupils and students in the conditions of COVID-19; this has been verified during the training of educators and distance summer science school (2020).

Keywords

Video Analysis, Tracker, Instrumental Digital Didactics, Distance Learning, Didactics of Physics

1. Introduction

At this time, there is observed a significant activity of the pedagogical community in the direction of finding innovative forms, methods, and means of blended learning in the situation of existing and future threats (first of all COVID-19). Thoughts on the reliability of distance learning are discussed by T. Yeigh and D. Lynch [1]. M. Lieberman believes that the situation with distance learning may be a "new norm of education", which will necessity to be continued [2]. J. Hargis notes that for successful distance learning teachers have to properly integrate the learning material into the virtual environment

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EMAIL: manlabkiev@gmail.com; slipukhina2015@gmail.com; kurylenko.n.v1976@gmail.com; msm56msm@gmail.com; magdaopachko@gmail.com
ORCID: 0000-0001-9771-7830; 0000-0002-9253-8021; 0000-0002-1083-3247; 0000-0002-4871-311X; 0000-0003-0494-6883

following certain instructions [3]. Search for effective methods of the natural sciences teaching based on educational experiments, demonstrations, and laboratory works is especially important in this context. Their practical implementation (usually according to the offered instructions) consists of the following main stages, which are performed directly in the school laboratory (classroom):

- assembling the experimental installation;
- conducting an experiment;
- data collection;
- data processing and making conclusions (begins in the classroom and ends at home).

The organization of distance learning of physics at secondary schools (K-12) and institutions of higher education in the conditions of COVID-19 proved the difficulties of performance (which, in fact, was obvious) of the first three stages of laboratory works and experiments. The solution of this important problem in 2020 – 2021 for all natural sciences, as shown by a study of posts on the Internet and own practical experience, was carried out in three main ways.

The most common and simplest approach to the organization of laboratory work is the use of software for computer simulation of experiments. Therefore, the first pieces of training of teachers in the situation of distance learning COVID 19 were aimed at these tools [4]. It should be noted that the use of modeling in the teaching of natural sciences and mathematics [5], especially for the organization of virtual laboratory work in physics, is popular at all levels of education [6, 7]. There are now many learning resources that offer a variety of interactive models suitable for conducting virtual experiments. Importantly, a significant number of such offers are free, for example, PhET Interactive Simulations [8], ComPADRE [9], VirtuLab [10], Tinkercad [11], and others.

Another approach is to create a video of the experiment in the laboratory during remote access of learners and send data to them. Such educational material, as a rule, shows the procedure of assembling an experimental setup, conducting an experiment, and measuring physics quantities. The obtained data are provided to learners for further processing and are distributed in various ways, most often this is done using the resources of educational institutions or on the YouTube channel [12].

An innovation of experiments arrangement in natural sciences is also m-learning based on the use of measuring elements of the smartphones as measuring devices [13, 14]. However, this method of learning also has limitations: the need for clear instructions, the difficulty of self-interpretation of graphic material, the need to switch between different units of measurement and more.

Long-term research suggests that an effective alternative to solving a wide range of educational difficulties in physics based on the observation of the real processes may be the use of video analysis [15], [16], [17]. The growing attention to the use of these tools in education at different levels is confirmed by statistics on the frequency of their use in scientific reports (Figure 1).

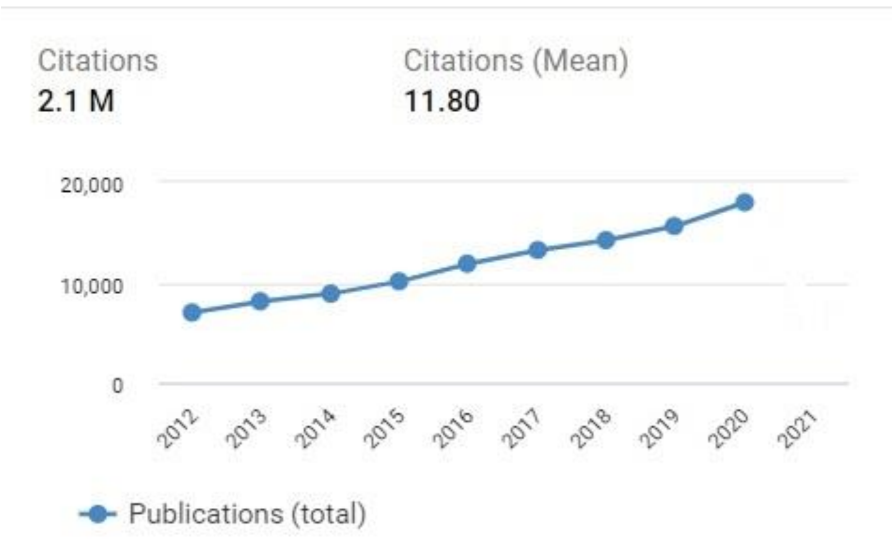

Figure 1: Data on the annual number of scientific publications for the keywords “education” + “video analysis”; (according to www.app.dimensions.ai)

2. Analysis of Related Research

The history of the use of video materials for scientific analysis began with the advent of photography as a technology. The study of E. Muybridge conducted in the late nineteenth century is one of the first in this context. His work on the problem of fixation and photographic display of various types of movement, such as animal movement, significantly contributed to the development of mechanics and biomechanics of athletics [18]. H. Edgerton, a pioneer of stroboscopic photography, became the famous successor of Muybridge in the twentieth century. The technology he initiated was later used to study a wide range of processes: from ballistics and synchronous motors to an atomic explosion during the first milliseconds [19].

Photo and video methods of data research are still widely used in all fields of science: biology uses the methods for microorganisms investigation; astronomy uses they for distant galaxies research with extraterrestrial telescopes; medicine uses they to obtain data on the features of the human body (microphotography, magnetic scanning, ultrasound, etc.); history uses they to analyze photo and video archives; criminology apply the methods to obtain photographic evidence.

At present, it is difficult to overestimate the role and importance of video analysis in experimental physics and related STEM disciplines. Digital technologies allow learners to quickly and efficiently record the dependence of the relative position of objects on time and study the process without interfering with its progress. This, in particular, allows to not intervening when observing the progress of a physics phenomenon. Elements of photography and video are used by researchers and engineers to study a wide range of phenomena and experiments: from filming mechanical movements, such as studying the motion of a body in a wind tunnel, to fixing the tracks of elementary particles.

Video analysis for educational purposes has been widely used since the beginning of the XXI century. Combining a full-scale experiment and digital processing of its data, video analysis helps to compare abstract physics concepts with real phenomena and processes “in life”; it can be effectively used in various innovative teaching methods for the development of critical thinking [17]. But, first of all, as noted by A. Artiningsih and S. Nurohman, the use of video analysis during physics study significantly increase the formation of research skills of students [20].

In the era of wide use of various gadgets, especially smartphones, participants of the educational process can create videos of phenomena and processes or use a huge number of available online resources – video aggregators for educational research, such as “The LivePhoto Physics Project” [21].

A variety of free or commercial programs can be the software for analytical processing of video material: Coach Logic [22], Physics ToolKit [23], Data Point [24] and others. At this time, all well-known manufacturers of training equipment, such as Vernier (Logger Pro) [25], Pasco [26] or Phywe [27], offer software for video analysis.

However, in our opinion, Tracker, the system of video file analysis and physical modeling, remains the most successful in terms of perfection and accessibility. It is free, multiplatform (compatible with Windows, IoS, Linux), and open source product that is constantly updated and improved (now available version 5.1.5) [28]. This soft with significant capabilities is integrated with a network of Web-resources and is small in size. The Tracker toolkit, namely the functionality of its Data Tool and Data Builder analysis modules, can be combined with video of the experiment and allows capturing and processing its data.

The greatest didactic value of Tracker, which explains its popularity among teachers, is the presence of a system of analysis of tabular data with the approximation of the results to a mathematical model of the process [29]. This is important, for example, to eliminate some common misconceptions through the comparison of own mental hypotheses and mathematical models from the video of the real process [30]. Other benefits are the import of a large number of video file types, open source code, and the ability for users to add their own developments to the Tracker library.

Tracker significant didactic effectiveness has been noted in many pedagogical studies around the world. Objects that can be studied on the basis of this software product can be quite various: from the study of kinematic, dynamic characteristics, and physics laws of motion [31, 32, 33] using laboratory equipment, transport tools and robots [34, 35] to the study of optical phenomena, such as spectral analysis [36]. Tracker has also been proven to be effective in developing flexible skills of students [17]. Learning to work with Tracker is one of the components of teacher training [37].

However, the effective use of moving image analysis technology during the teaching of STEM disciplines requires at least three conditions: the accessibility to high quality video; skills of using analytical tools of special programs; knowledge of the methodology of processing an array of experimental data regardless of methods of obtain them.

3. The Purpose of the Article

Distance learning of physics and other STEM disciplines on the basis of video analysis requires the development of a significant number of didactic materials for different topics of physics in accordance with existing curricula and for individual levels of data processing skills of learners. Therefore, the purpose of the article is to highlight the practical experience of creating and using teaching methods for scholars (K-12) and students based on Tracker Video Analysis, which have demonstrated the effectiveness during formal and non-formal education in conditions of COVID-19 and are an important part of the instrumental digital didactics.

4. Method

Open data sources (Scopus, Web of Science, Google Scholar, and Research Gate) were used to classify current research on the use of video analysis in teaching physics and other natural sciences; combinations of keywords “education”, “video analysis”, “Tracker”, “distance learning”, “physics”, etc. were used. Data on site traffic www.stemua.science are obtained on the basis of www.cloudflare.com. Methods of video analysis using for teaching physics and STEM disciplines were created in collaboration with the Department of educational and thematic knowledge systems of the National Center “Junior Academy of Sciences of Ukraine” (NC JASU) and discussed with teachers during professional pieces of training. Qualitative testing of the proposed method of teaching physics took place in 2020 - 2021 and was aimed at the preliminary implementation of the created video materials of the physics experiments and detection of didactic peculiarities of their use. Educational tasks based on video analysis were used by the authors during distance learning of students of secondary schools (K-12) and higher education institutions (formal education), as well as at a distance summer scientific school organized by NC JASU in June 2020 (non-formal education), in which more than 100 young people from different regions of Ukraine took part.

5. Results and Discussion

Long-term practice of methodical video material creating for effective organization of teaching on the basis of Tracker (as well as other similar programs) requires compliance with certain conditions during the process of recording. We have clarified the rules for creating videos suitable for their further analysis, in particular, for building a mathematical model:

- a gadget with high-quality optics to record video should be used;
- frequency of shooting is selected in accordance with the type of phenomenon that is planned to be recorded (from 30 frames per second to 1000);
- the device must be motionless and the experimental setup must be completely in the frame during recording;
- the object must move in a plane perpendicular to the recording device;
- the moving object should contrast with the background.

A number of videos of experiments for laboratory works in mechanics, molecular physics, optics, atomic and nuclear physics have been created in the STEM laboratory of MANLab NC JASU, which are posted in the sections “Instrumental digital didactics” of the resource www.stemua.science [37]. This activity was aimed at developing appropriate methods of distance learning of physics and consisted of the following main tasks:

- provide the maximum number of the laboratory works with reference videos suitable for the use of Tracker (or other similar software products);
- create detailed instructions for data collection and analysis for each laboratory work;

- create “unconventional” methods of conducting the experiment adapted for the use of Tracker;
- create didactic material for the formation of video tasks.

Note that while studying mechanical phenomenon by means of the process record, a certain algorithms are used to determine keyframes, shooting frequency, single segment, position of the coordinate system, tracking the position of objects on each frame manually or automatically, selecting parameters for research, analysis of graphical or tabular representation of experimental data, construction of a mathematical model corresponding to the studied phenomenon, and selection of appropriate coefficients to match the behavior of the model in the recorded experiment.

Let us consider a few examples of the main didactic approaches to application of video analysis based on Tracker that were used by us for creating instructions for laboratory work on the school course of physics (K-12); they can also be successfully used for teaching junior students of higher education institutions.

One of the important laboratory experiments for mechanics study is to determine the acceleration of free fall. However, as we know, the study of this fundamental concept since the time of Galileo causes some difficulties: a body motion under the action of gravity occurs in a certain environment (mostly in the air). Therefore, the motion only closely corresponds to the conditions of free fall of bodies. The method proposed by us allows determining the acceleration of the fall of various objects, comparing the obtained values with the standard one, and making conclusions about the existing influence of the environment. In the context of the application of software for video analysis, the task of this lab is divided into two main stages:

- conducting an experiment with different bodies and creating videos of their fall;
- determination of the numerical value of the acceleration of falling bodies and comparison with the standard value of the acceleration of free fall.

In order to create reference videos, our method considers the processes of a tennis ball, a ping-pong ball, and a rubber “jumper” ball falling. Their movement against the background of a delineated surface or ruler is recorded by a digital camera or camcorder installed in accordance with the abovementioned rules. The next stages of the work are carried out using analytical tools Tracker [28]. Figure 2 shows the program window for the laboratory work. Tracker tools plot markers of body positions on the board background in consecutive frames; created automatically tabular and graphical data x(t) are shown on the right.

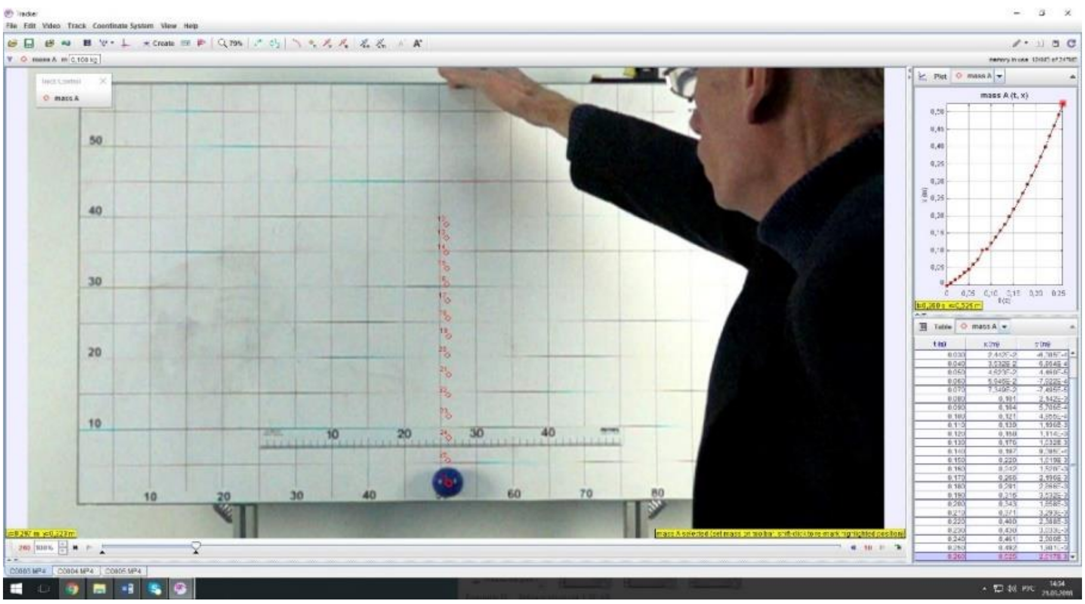

Figure 2: Look of Tracker window

An interesting continuation of this work is the determination of the acceleration of free fall on the Moon. To do this, we can use a video of astronauts conducting the Galileo experiment, which is available on the NASA website and is freely downloadable [38].

Note: despite the fact that a significant amount of educational research using Tracker is related to mechanics, its tools are suitable for labs performing in other topics of physics. An example is a laboratory study to measure the surface tension of a liquid by the method of air bubble formation at a given temperature at a small depth (Rebinder method) [39]. The condition for the formation of an air bubble is the creation of excessive pressure in it. According to the dependence of the Laplace pressure model under the curved surface, its maximum value inside a bubble will be at the bubble minimum diameter that is at the moment of the bubble formation at the end of the capillary [40]. The installation for a surface tension measuring consists of a vessel with the investigated liquid, a glass tube (capillary), a water aspirator, a glass connector, a crane, silicone tubes, and a water manometer (Figure 3).

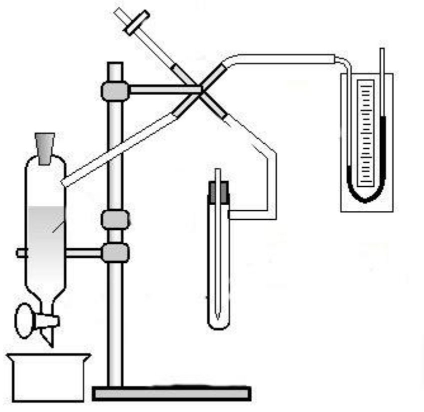

Figure 3: The installation for measuring the liquid surface tension by the method of bubble formation at a given temperature

When the crane is open, water begins to flow out of the vessel. The volume of air above the water in the vessel increases; thus, the pressure in the vessel decreases. At a certain pressure above the surface of the liquid an air bubble is pressed out into the liquid from the end of the capillary tube. The tube diameter is known or determined by a digital microscope. The pressure arising under the action of surface tension forces is equal to the pressure difference measured by the manometer. Based on the created video recording of the experiment, Tracker instruments determine the extra pressure at the time of separation of the bubble on the scale of the liquid manometer and calculate the surface tension of the liquid (Figure 4).

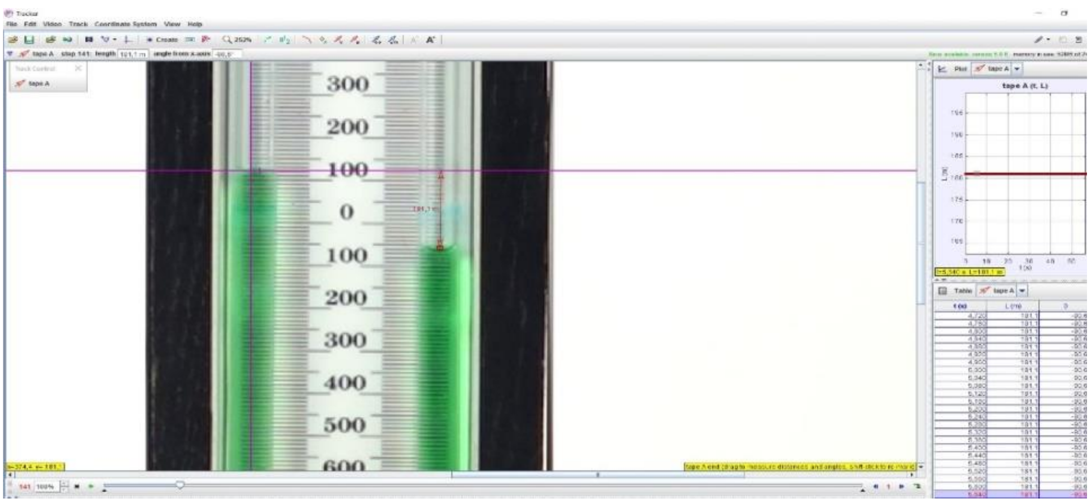

Figure 4: Tracker program window when measuring the surface tension of liquid by the method of bubble formation at a given temperature

Another interesting example of the use of video analysis is the study of the rotational motion of the Sun based on video recording of the motion of the photosphere gas, which is studied by the motion of formations on the surface of this star. The main object of identification is a sunspot. A video image of its surface obtained by the SOHO Space Observatory can be used for analysis [41]. With the help of Tracker tools we can determine, for example, the speed of the photosphere and the period of rotation of the Sun at different latitudes. A detailed description of the work with the video lecture can be found at http://surl.li/tegv.

The approbation of our laboratory works and video tasks was carried out during distance and blended learning in formal and non-formal schooling as well as during educational activities for students and teachers from different regions of Ukraine. One of the important and popular forms of teaching talented youth is summer science schools. Such a school under the patronages of NC JASU in June 2020 was carried out distantly and was devoted to the study of processes in mechanical systems. Participants of the school were offered to perform four laboratory works. The labs “Study of oscillations of the filament pendulum” and “Study of oscillations of the spring pendulum” were performed according to traditional methods, supplemented by the use of video analysis. Two other laboratory experiments are included in the curriculum of the profile level in physics (K-12). The task of “Study of the oscillations of the physical pendulum” is to determine the distance between the center of mass and the point of suspension at which the period of oscillation of the pendulum will be minimal. Fulfillment of “Study of the phenomenon of mechanical resonance” is proposed using a new methodological approach based on the study of the oscillations of a steel ruler with neodymium magnets; video recording was at a frequency of 500 frames/s, which made it possible to accurately determine the frequency of oscillations and their amplitude. The methods of carrying out of the works are described in detail and step by step in the section “Instrumental digital didactics” of the virtual STEM laboratory MANLAb [37].

Reference videos were created for each of the laboratory works. The tasks consisted of two main stages: determination of certain physics quantities (period, frequency, amplitude, etc.) based on video analysis and comparison of experimental and theoretical data. Each participant's report contains tables with experimental data, graphs built in Excel, and creative tasks using Tracker. In addition, participants were invited to perform a creative task related to their own project and its implementation using Tracker tools. An important motivating factor is that the authors have the opportunity to publish their work on the resource http://stemua.science in the sections “Methods” or “Research work”. An example of such a development is “Determination of spring stiffness using mathematical pendulums” [37].

The quality of carrying out each stage was evaluated separately: the maximum score for one work is 5 points and additional points for the creative task; obtained by the student data were compared with previously calculated ones using the same video. The accuracy of calculation and execution of all tasks designated in the work was considered. Special attention was paid to the analysis and understanding of graphic material.

The event took place distantly; more than 100 students of secondary schools were registered to participate in the summer scientific school, 78 of whom successfully completed the laboratory practice. Based on the total assessments, conclusions were made about mastering the proposed methods by the participants and their distribution in accordance with the accomplishment of the work (Figure 5).

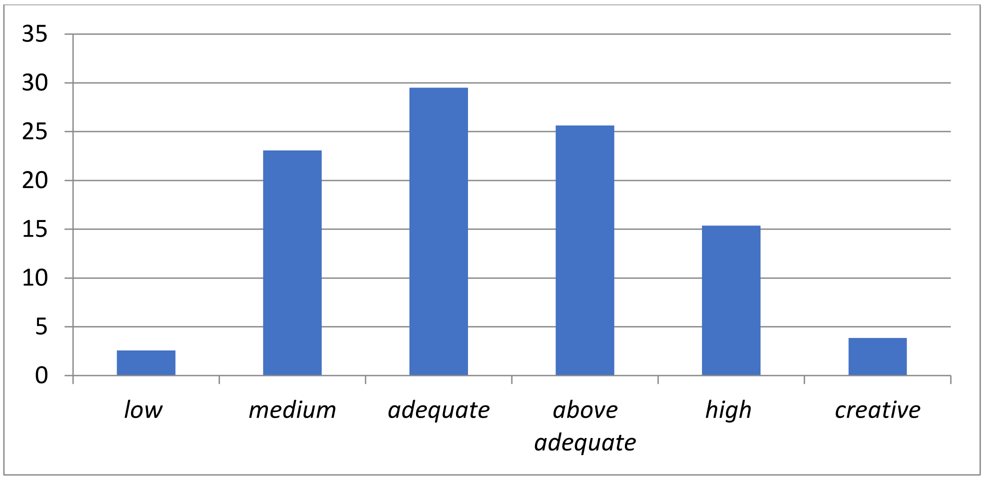

Figure 5: Distribution of participants according to the ability to use Tracker: horizontally - the level of mastery of video analysis; vertically - number of persons, %

An important conclusion is that a significant number of scholars of secondary schools are able and willing to use practical and analytical tools of video analysis to study physical phenomena using detailed instructions. However, only 3% of participants were able to demonstrate their skills at a creative level.

Methodical work on the creation of didactic materials based on video analysis was started in the STEM laboratory of NC JASU in 2006 and continues to this day. More than 35 different methods of performing laboratory work with the use of tools for video analysis have been created and tested in formal and non-formal education, secondary (K-12) and higher school; the reference video recordings and video lectures have been created. A study of statistics using www.cloudflare.com showed a significant interest of the world community of educators in the methods of video analysis created and tested by us; they are now available at www.stemua.science in free access (Figure 6).

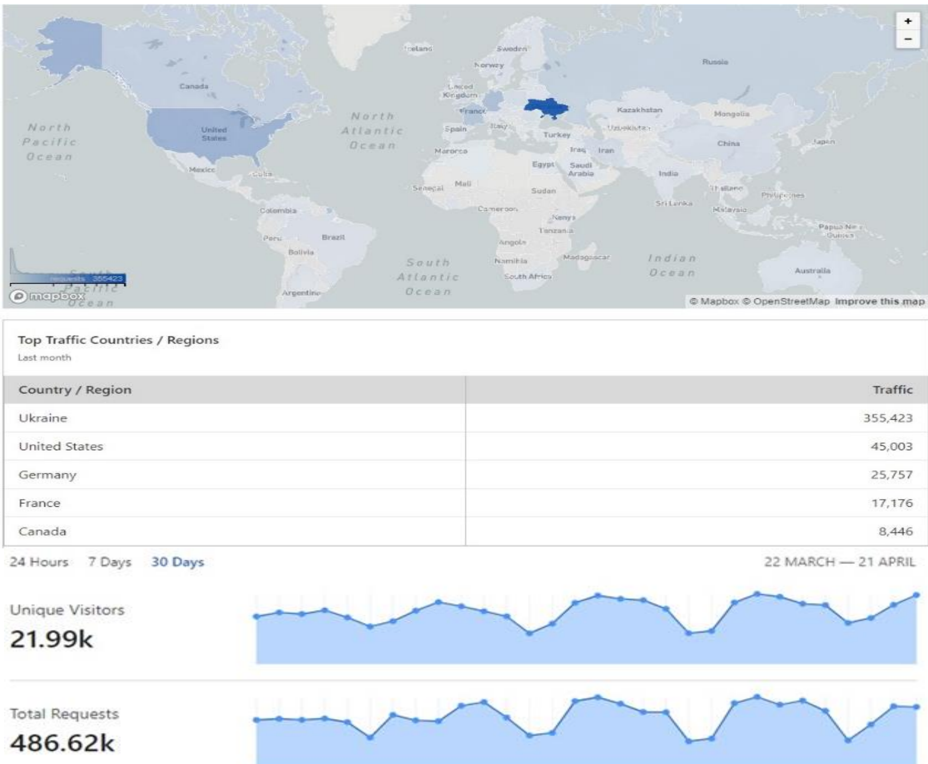

Figure 6: Web Traffic www.stemua.science Requests by Country (above) and the number of visits for March-April 2021 (below); (according to www.cloudflare.com)

6. Conclusions

The result of the work is the adaptation of the software product Tracker for distance and blended learning. The examples of video analysis using Tracker described in the article have been widely used through the activities of NC JASU. The creation of the manual “Instrumental digital didactics” [42] is an important result of the current period of this study and an attempt to systematize the existing pedagogical experience. This publication demonstrates the basic technical requirements and methodological approaches in the context of the application of video analysis for distance and blended learning of physics and other natural sciences. A collection of video tasks using the Tracker was created during the research. A high recording frequency was used to measure more accurately the position of bodies; consequently, a high-quality video archive was created. It is posted in the section “Additional materials” [37]. It should be noted that the Tracker resource [28] contains data on educational studies suitable for carrying out entry-level projects.

The method of video analysis was used as a supplement to the basic educational process in physics at general secondary schools as well as for teacher training courses. Qualitative approbation of this method was carried out on the basis of the National Aviation University, Kherson State University, and Uzhhorod National University. It should be noted that performing the tasks of video analysis using Tracker encouraged students to create similar videos on their own. This is confirmed by the active participation of students of Kherson State University in the competition for the best video experiment and video puzzle. This competition is a part of the “Science Week”. Videos edited by students can be used as a means of career guidance or during their internship, etc.

Further pedagogical investigations in the context of the study are aimed at improving the methodology of physics study with an emphasis on achieving a creative level of application of the tools for video analysis. As a result, a student mastered the Tracker algorithm should be able to make own research or use materials available in the library.

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