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**A SOFTWARE APPLICATION FOR THE STUDY OF LIGHT DISPERSION****ПРОГРАМНИЙ ЗАСТОСУНОК ДЛЯ ВИВЧЕННЯ ДИСПЕРСІЇ СВІТЛА****Tatarchuk T. V. / Татарчук Т.В.***s.t.s., as.prof. / к.т.н., доц.*

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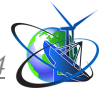
**Abstract.** *The paper examines the implementation of the practical part of the program in the discipline "physics" regarding the study of light dispersion in the conditions of online learning, specifically during the martial law in the regions close to the front line. A software application has been created based on a real experiment on the study of light dispersion. The application programming interface (API) of Windows Forms, which is part of the Microsoft .NET Framework in the integrated development environment (IDE) of Microsoft Visual Studio 2022, was chosen for it.*

**Keywords:** *software application, light dispersion, lens.*

**Introduction.**

Pecently, Ukraine has faced the problem of organizing full-time students' education and schoolchildren during martial law in the regions close to the front line. Most educational institutions in cities that are near the demarcation line and are subject to constant bombardment have switched to distance learning. In such conditions, the implementation of the practical part of the program, namely the performance of laboratory work, becomes a difficulty. Also, in modern conditions, the practical orientation of education acts as a means of deepening the theoretical knowledge of students of higher educational institutions, which contributes to the use of productive teaching methods. It is very difficult to include in the educational program all the knowledge, skills, and abilities that are necessary for a highly qualified specialist in his practice. This is given that the world is undergoing a very rapid development of technologies, updating of information. [1].

In the "Standard of higher education" [2] in the system of training future



engineers, for example, for fields of knowledge 13 “Mechanical engineering”, 14 “Electrical engineering” 17 “Electronics and telecommunications” 19 “Architecture and construction” for the first (undergraduate) level of higher education, the list of competencies of graduates of higher education institutions is defined. The educational program, in particular, in physics, should be aimed at ensuring general and special (professional) competences in the relevant specialty, which is determined by a certain standard of higher education.

According to the “Standard of Higher Education” in the conditions of educational activity of the participants of the educational process, the formation of general competencies takes place, namely: “skills in the use of information and communication technologies”, “ability to adapt and act in a new situation”. Understanding of theoretical, practical, experimental issues, for example, from the section “Optics” contributes to the formation of professional, subject competencies such as “the ability to solve typical engineering tasks in accordance with specialization”, “critical understanding of scientific facts, concepts, theories, principles, and methods necessary for professional activity”.

**Statement of the problem.** Mastery of the above-mentioned competences during the comprehension of educational material of a practical direction, for example, regarding the importance of physical knowledge for the creation, improvement, use of optical devices, optical fiber; the application of optics in the field of energy changes the ideas of scientists, engineers, users regarding its production, etc. There is no doubt in anyone's mind that an understanding of the above-mentioned questions is not possible without an awareness of physical knowledge.

One of the forms of organizing the educational process in the conditions of training future engineers in the discipline “physics” is a laboratory class. It is known that physical knowledge is confirmed in laboratory classes in the conditions of offline learning using laboratory equipment, and in remote conditions using software.

Scientists have prepared methodological recommendations for conducting a laboratory experiment, in particular, from the content module “Optics” for training future engineers in the aspect of the concentric-radial structure of the physics course.



The educational material of the physics course, for example, on the topic “Dispersion of light” is studied at different levels, namely: in the conditions of STEM education (grade 5), the basic course of physics (grade 9), high school (grade 11), the Small Academy of Sciences, university physics course (main and optional components according to specialty and level of higher education). At various stages of the educational process, the phenomenon of light dispersion is considered during the passage of a beam of white light through a three-sided prism, a converging lens. In the modern conditions of distance learning, there are certain difficulties in the implementation of the practical part of the program.

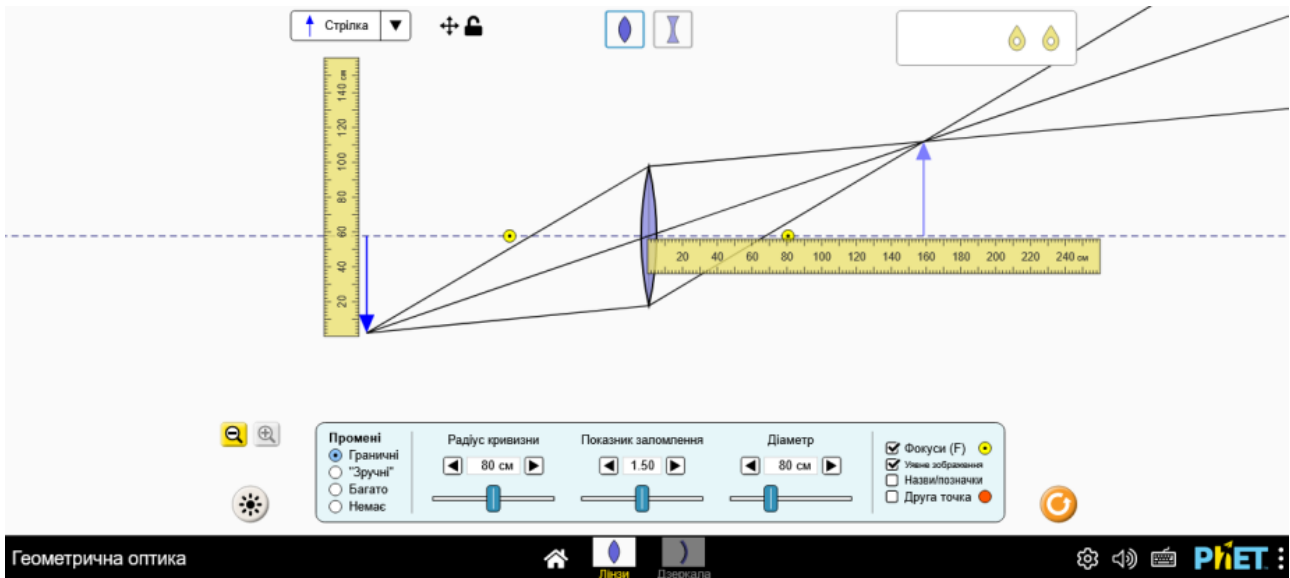
***The purpose of the study.*** Creation of a software application in accordance with a real experiment on the study of light dispersion for the implementation of the practical part of the program in the conditions of distance learning.

### **1. Analysis of recent research.**

There are different approaches to the study of light dispersion in the conditions of offline learning, namely: in higher education institutions during laboratory classes, light dispersion is studied [3,4]. In general educational institutions, frontal, demonstration experiments are conducted [5]; home experiment [6]; class [6], laboratory experiment [7].

In the conditions of distance learning, various applications / services are used [8-11], for example, PhET, phydemo.app and Zemax OpticStudio, but they do not always help to achieve the didactic goal. Let's consider them in more detail.

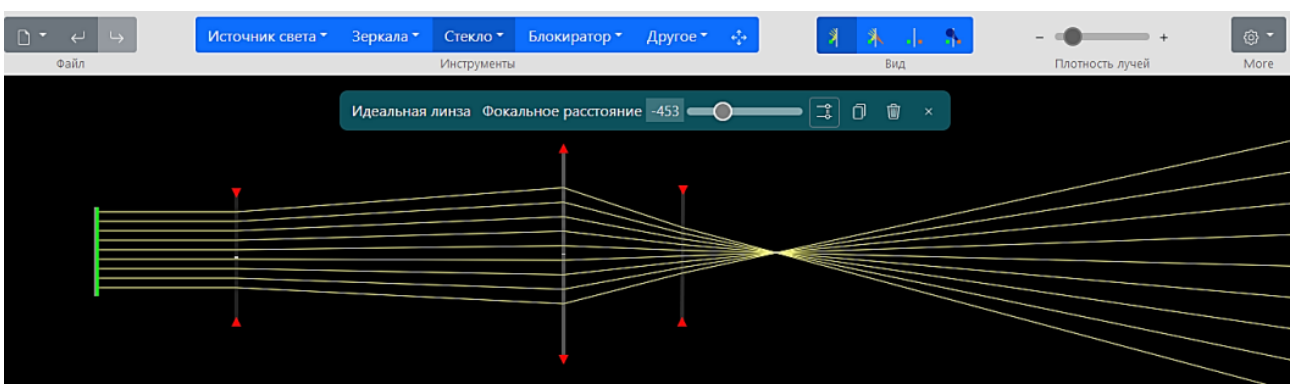
***PhET.*** Probably the most accessible of these applications/services is “PhET” (Fig. 1). Its main advantage is a convenient and understandable interface and the absence of platform dependence. There is a web version of the application/service, and versions of the application for Chromebook, Android, and IOS. Also, this application/service is almost completely free and Ukrainian and English localizations are available. Among the shortcomings of this service, it is necessary to note a rather serious limit in the permissible values for calculations, due to which it will be used mostly for educational purposes. It will be almost unnecessary for high school students or students of higher educational institutions.



**Figure 1 – An example of how the PhET application/service works [12]**

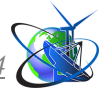
As can be seen from the figure, this simulation allows changing the geometric dimensions of the lens, its type and refractive index. In this case, the average value of the refractive index for white light is taken without taking into account dispersion. Subsequent paragraphs, however, are indented.

*phydemo.app*. Among the offered services/programs. “phydemo.app” (Fig. 2) is probably a self-combat, something in between. It, like PhET, is free and has a web version. Among its features, it has a wider functionality, and thanks to it, you can perform more complex tasks in optics, for example: the passage of beams at once through several lenses at different angles, or several light sources at once.



**Figure 2 – An example of the application/service phydemo.app [13]**

If we separate the shortcomings, then in this program/service, as in “PhET”,



research is limited by two-dimensional graphs, there is an opportunity to change the refractive index of the material, but the geometric dimensions of the steel.

The phenomenon of light dispersion is considered, usually, using a prism. Future engineers understand that lenses are used in modern optical devices. Due to the phenomenon of chromatic aberration, light rays of different wavelengths are focused at different distances from the optical center of the lens. The obtained results indicate the presence of normal dispersion in the lenses of the school set for optical experiments. Subsequent paragraphs, however, are indented.

**Zemax OpticStudio.** Zemax OpticStudio is one of the best software out there. It is used by many famous companies, such as: SONY, Roche Holding, Meta Platforms Technologies (Oculus), nLight, AOSense, Luminex, and others. Among all the programs/services listed above, Zemax OpticStudio has the widest functionality, allowing you to design optical circuits with high accuracy and any complexity. But, despite all its advantages, it has significant disadvantages, due to which it is mostly used by professionals. Firstly, this is the high cost of the program, you can see more details on the official website. Secondly, although convenient, the interface is complex and oversaturated for beginners. And thirdly, there are high technical requirements for the power of the computer, the amount of RAM, and the amount of free space on the drive.

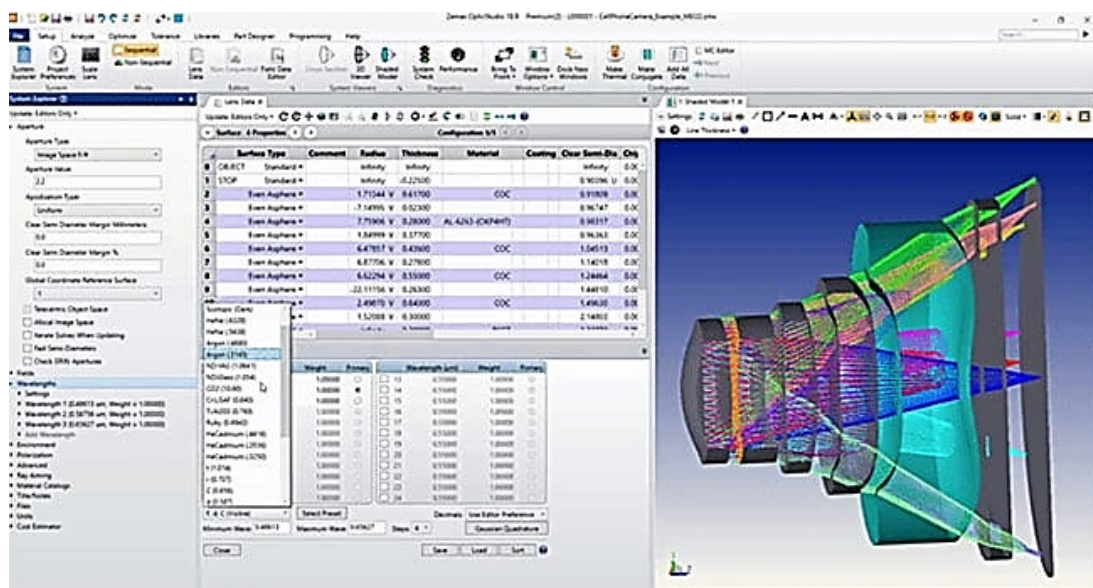


Figure 3 – An example of the Zemax OpticStudio application/service [14]



Thus, based on the analysis of the above applications, the advantages of our application are as follows:

- free, unlike Zemax OpticStudio;
- does not require special installation or Internet access (portable);
- takes into account the dispersion of light in various materials, unlike PhET and phydemo.app;
- easier visualization and construction of light rays;
- allows you to change the refractive index of the external environment;
- it is possible to take into account the experimental error in calculations.

The disadvantages of our simulation at the moment:

- narrow specialization (calculating only focal lengths and constructing rays), in the future it is planned to have the opposite effect and expand the functionality;
- at the moment the interface is in Ukrainian, but it is planned to add English;
- at the moment there is a limitation on glass brands, it is planned to add manual introduction of the refractive index of the lens;
- the number of wavelengths for which the calculation is carried out is limited, but this is due to the limitations of DSTU, which was used.

## 2. Algorithm for creating a software application for the study of light dispersion.

To create a software application for studying the phenomenon of dispersion, we used data from DSTU 13659-78 [15] (Table 1) for the visible part of the spectrum (lines h, F', F, e, D, C', r).

**Table 1. Refractive index depending on the wavelength for some brands of glass**

Stamp\ $\lambda$ , $\mu\text{m}$	h	F'	F	e	D	C'	r
	0,4046	0,48	0,4861	0,546	0,5893	0,6438	0,7065
LK3	1.49900	1.49264	1.49226	1.48911	1.48740	1.48566	1.48407
F6	1.63164	1.61540	1.61445	1.60701	1.60310	1.59928	1.59596

For example, we took the values of the refractive indices of the medium for different wavelengths for the following glass brands: LK3, K8, BK13, TK13, STK3,



TF5, TF10, KF6, TBF4, F6. We decided to use converging and dispersing lenses as an object of observation. In the application menu, the user can choose the type of lens himself. In addition, we also take into account that the refractive index of the external environment can also change.

The main formula used in calculating the focal length of a lens is of the form. 1

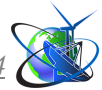
$$\frac{1}{F} = \left( \frac{n_{gl}}{n_{en}} - 1 \right) \cdot \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \quad (1)$$

## 2.1 Creation of interactive elements

To create the application, we chose the Windows Forms application programming interface (API), which is part of the Microsoft .NET Framework. The whole process took place in the Microsoft Visual Studio 2022 integrated development environment (IDE) [16,17]. We started the process of creating the application with the markup and formatting of the graphical interface elements. For the calculation, we are to select: the type of lens, the brand of glass, the colors of the rays and the radius of curvature of the lens. We also added a toggle to account for error. (Fig. 4). For convenience, the selector for this type of lens and brand of glass is located in the menu, which will make the application more concise and convenient. Also added some properties to the elements for correct display depending on the size of the window.



**Figure 4 – The application interface and an example of the menu**



## 2.2 Creating a graphics field

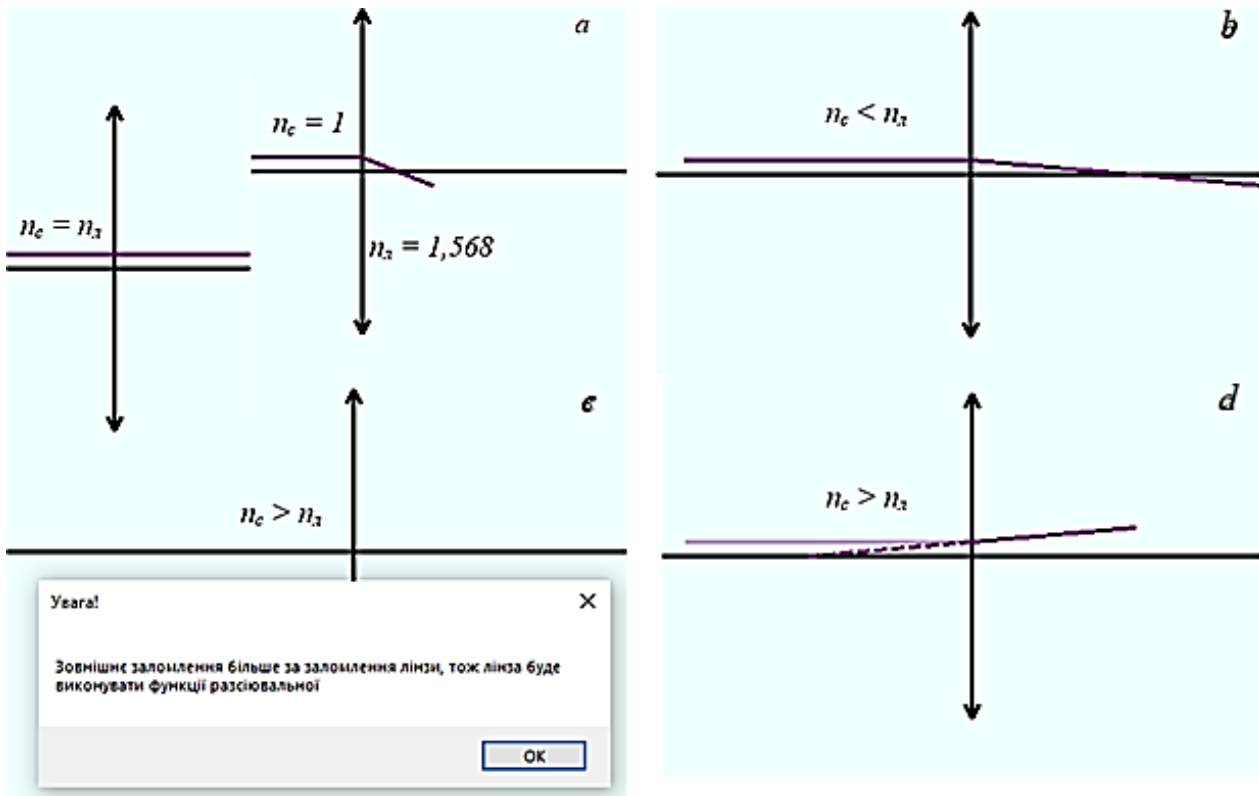
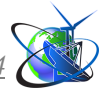
To create the graphics frame, the System.Drawing namespace was used to create a graphical representation of the rectangle, which is then displayed on the screen using the CreateGraphics() method. So when you click the build button in the free space, a rectangle is created with black faces and a light blue background for more contrast. For this, a new Graphics object named GraphField was created, in this object a rectangle was created and, using a pen and a brush, gave it color. Also added is the axis of the optical center, and the graphic designation of the lens with a vertical line and arrows at the ends. These arrows are represented by two Point arrays, which are then used to create two Polygon objects using the DrawPolygon method of the GraphField object. Also, for convenience, the middleX and middleY variables that mark the center of the rectangle have been added.

## 2.3 Extraction of data from the interface

A RayCollor array was created to store the data of 7 RGB values of colors (purple, blue, cian, green, yellow, orange, red) witch uses for calculations of the selected rays. When choosing the color of the beam, the value of the corresponding part of the array is used for passing to the method of ray output to the graph.

The RayRefraction array was created to store the refractive index value corresponding to the glass brand. When a glass grade is selected, its corresponding refractive values are passed to the basicRayCalc function for calculation.

The direction of the rays after refraction in the lens depends on the optical properties of the environment. If the refractive index of the external environment is lower than the refractive index of the lens material, the type of lens does not change. If the refractive index of the external medium is greater than the refractive index of the lens material, then the type of lens changes to the opposite: a converging lens becomes a diffusing lens and vice versa. By default, it is assumed that the external environment is air (Fig. 6a). If the external environment is not air, then our application takes this feature into account (Fig. 6 b-d).



**Figure 5 – An example of application operation taking into account the refractive index of the external environment:**

**a –  $n_c = 1, n_l = 1,568$ ; б –  $n_c \neq 1, n_c < n_l$ ; в,г –  $n_c \neq 1, n_c > n_l$**

### 2.4 Error

Since the application can build several graphs at once, we decided that it would be appropriate if for each of them its own random error was created. For this, a new Random Inaccuracy array was created, which will contain data about the error or its absence.

To find out whether to take the error into account or not, we used two methods. The first one checks whether the switch is on, if the check is passed, the calculation is performed and the error value is set for each element of the Random Inaccuracy array. Since the error did not occur, the Random class was used to create a variable with a random value between 1 and 1.2. In the second method, it is checked whether the error switch is turned off, if the check is passed, then the value 1 is given to all elements of the Random-Inaccuracy array. Thus, when taking into account the error, a random error of 0% to 20% is added to the result, otherwise a 0% error is added.



## 2.5 Calculation of the focal length and the image of rays on the graph

In order for the application to display multiple rays at once, the positionRayCalc function is used to allow multiple rays to be displayed at the same time. Thanks to this function rays do not overlap each other. To construct the graph, the beam is divided into 2 parts, before and after refraction in the lens. In the first case, the application draws a straight line to the lens. The second case, from the point of intersection of the beam with the lens to the focus, which is determined by formula 1, after which it continues to build in the same direction for a certain distance. In both cases, the CreateGraphics() method is used, and the pen is the same color as the ray.

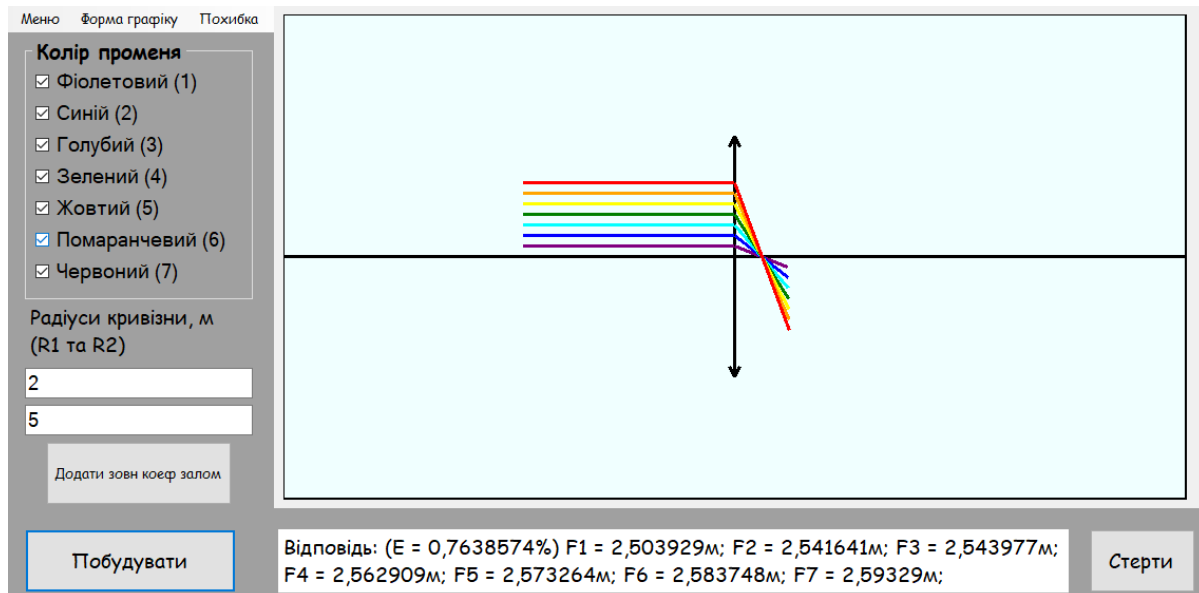
To calculate the focal length, formula 1 is used, which is adapted to the variables used in the code. Instead of the refractive index  $n$ , the corresponding parts of the RayReflection array and user-specified radii of curvature are used.

Also, to avoid "runtime exeption", we added a condition to check the denominator for 0. The code describing the calculation of the beam path after refraction in the lens:

```
double Value = 1/(((RayRefraction / EnvironmentRefraction)-1)*(1/R1+1/R2));
if (Value == 0)
{
    MessageBox.Show("Неможливо розрахувати", "Помилка!");
    return 0;
}
return Value;
```

## 2.6 Displaying the results of the focal length calculation on the screen

A new array named FocalSolutionSTR was created to display the answer. After the calculation, the results of the focal length of the corresponding rays are entered into this array. If the ray is not selected for the calculation, then an empty value is entered into the array in the sector corresponding to it. In the end, the text in the field with the answer changes to the values of the sequentially listed array sectors using a loop. In fig. 7 presents the overall result of the application.



**Figure 6 – An example of the general operation of the application**

### 2.7 Prospects for further research.

At the moment, this application has been tested among both students and schoolchildren. The guys noted the convenience of the interface, the functionality of the application corresponds to the tasks set. It allows users to run applications from Windows 7 and higher, but they asked to add the ability to run the application on Linux.

It is also planned in the future to conduct a comparative analysis of the results of the simulation and a real experiment by analogy with the work [18].

### Conclusions.

1. The educational and methodological support for the study of the phenomenon of light dispersion using printed media and applications / services such as PhET, phydemo.app and Zemax OpticStudio was analyzed.

2. In order to implement the practical part of the program in distance learning conditions, a software application was created in accordance with the actual experiment on the study of light dispersion.

3. To create a software application, the Windows Forms application programming interface (API), which is part of the Microsoft .NET Framework in the Microsoft Visual Studio 2022 integrated development environment (IDE), was chosen.

4. During the creation of a software application for the study of the phenomenon of light dispersion, the following was taken into account:



- arbitrary choice of the brand of glass from which the lens is made,
- arbitrary choice of the radius of curvature of the lens,
- change in the refractive index of the medium,
- the obtained result takes into account the measurement error;
- a new RandomInaccuracy array was created, which will contain data about the error or its absence.

5. Students and schoolchildren note that this application is easy to use and its functionality corresponds to the assigned tasks.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article

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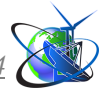
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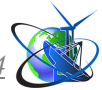
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***Анотація.** У статті розглядається реалізація практичної частини програми з дисципліни «фізика» щодо дослідження розсіювання світла в умовах онлайн-навчання, зокрема під час воєнного стану в районах, близьких до лінії фронту. Програмний додаток створено на основі реального експерименту з дослідження розсіювання світла. Для нього обрано інтерфейс прикладного програмування (API) Windows Forms, що є частиною Microsoft .NET Framework в інтегрованому середовищі розробки (IDE) Microsoft Visual Studio 2022.*

***Ключові слова:** програмний додаток, дисперсія світла, лінза.*

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