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The new concept of laboratory support for educational institutions and scientific establishments

P. Kozub [a,*], S. Kozub [b], V. Lukianova [a], L. Borysova [c], D. Taraduda [c], T. Kachur [c]

[a] Department of Natural Science, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
[b] Department of Medical and Bioorganic Chemistry, Kharkiv National Medical University, Kharkiv, Ukraine
[c] Department of Logistics and Technical Support of Rescue Operations, National University of Civil Defence of Ukraine, Kharkiv, Ukraine
* Corresponding e-mail address: pkozub@pkozub.com
ORCID identifier: https://orcid.org/0000-0002-7162-027X (P.K.); https://orcid.org/0000-0002-5932-8129 (S.K.); https://orcid.org/0000-0001-9167-0058 (D.T.)

ABSTRACT

Purpose: To develop a new concept of laboratory support for learners at different levels of education to maintain a high education quality in conditions of limited opportunities, such as lockdown, lack of funding, etc.

Design/methodology/approach: To create a new concept, the practical experience of school teachers, educators of technical colleges and universities, research workers, as well as experience of scientists in the educational field published in open information' sources was taken into account. The development of a new concept was carried out from 2014 to 2016, and its implementation, introduction into the educational process, and possible ways to solve technical and organizational difficulties from 2016 to the present. In the last year, special attention was paid to distance learning.

Findings: The development and the first practical steps to implement the new concept of updating the laboratory support of educational institutions clearly demonstrate of its practical implementation' feasibility. Positive consequences from the implementation were identified as constant improvement of laboratory equipment, increase in the educators' level, transformation of virtual distance learning based on lectures and videos into real learning with "live" visual demonstration of physical, chemical, biological and other processes and experimental research. As a recommendation, should wish that at the state level to recommend the implementation of this approach and to propose some legal mechanisms to overcome identified problems.

Research limitations/implications: The present study was conducted for Ukrainian educational institutions with the involvement of foreign students from different countries studying in Ukraine.

Practical implications: The introduction of a new concept into the educational process in countries with a weak economy will improve the educational quality and reduce the cost of creating laboratory support.

Originality/value: Equipment should not only be a teaching tool, but also a teaching subject.

Keywords: Laboratory support, Education of engineers and scientists, Practical skills, Laboratory work, Demonstration, Research

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EDUCATION AND RESEARCH TRENDS IN MATERIALS SCIENCE AND ENGINEERING

1. Introduction

In the system of teaching technical, chemical, biological and many other disciplines in natural sciences, laboratory teaching and practical work are one of the important links in education [1-3], since the implementation of these works contributes to the best and longest assimilation of new material, as well as to the acquisition of practical skills necessary in professional activity. This is due to the fact that in professional activity and scientific research it is necessary to use real objects and processes, and also perform concrete actions (like modelling, experimental determination, design, the ability to write reasoned reports, etc. [4-6]), and the connection between abstract (theoretical) and real objects allows us to better memorize theory, understand, and use it in practice.

The opportunity to touch, see the reactions and transformations taking place, hear sounds, smell the smell etc. contributes to a better understanding of the environmental laws (for example, Pythagoras, Newton, Gay-Lusak, etc.) and their linkage with real physical processes.

In this study, learners (students) include those who acquire new knowledge. This concept applies not only to schoolchildren or students, but it also applies to young scientists, professionals who need to improve their qualifications, or those who acquire new qualifications, etc. Consequently, the problem of organizing and providing technical support for laboratory and practical work for engineering specialties in natural sciences should be considered in a broader aspect, namely, as a demonstration laboratory experiment at school, college or in the first years of the university, and as research laboratory equipment for performing graduate works or scientific dissertations. The main goal of laboratory teaching and practical works is to reflect certain physical, chemical, biological and other phenomena in things familiar to the observer, or to demonstrate to learners the features of new equipment.

To achieve the maximum demonstration effect, usually used special demonstration equipment or special laboratory equipment (Fig. 1).

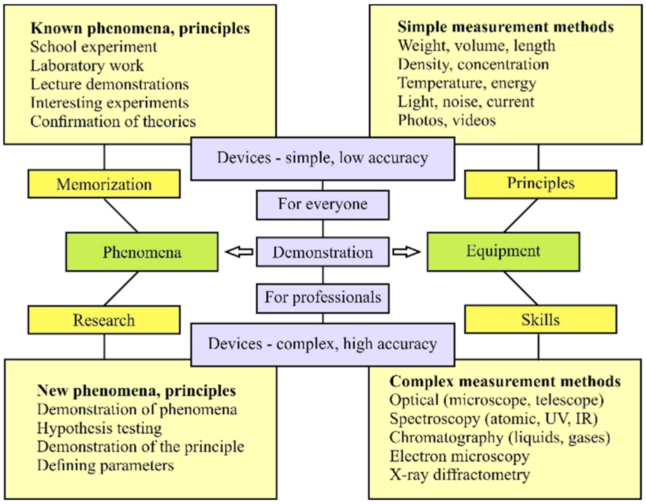

Fig. 1. Place of laboratory support in the education system

Thus, when teaching learners, it is necessary to have laboratory teaching aids, the quality of which is closely related to the level of education development. So, for example the equipment with laboratory instruments in schools of developed countries is much better than in schools of developing countries [7,8]. Similarly, laboratory equipment used in scientific institutions and technical universities of developed countries is not available for purchase by scientific institutions, colleges and universities in countries with weak economies, when there is a shortage or absence financing of educational institutions.

In addition to this, in recent years, distance learning has become increasingly relevant. This is due to the lack of opportunities (such as financial and time constraints, some physical limitations of a persons, etc.) to move between cities and countries in order to attend lectures, laboratory teaching and practical work. Distance learning has become especially relevant in the last year due to the spread of the aggressive Covid-19 virus and the introduction of a lockdown. However, distance education does not replace the need for learners to study laboratory practice.

Thus, the purpose of the study is to develop a new concept of laboratory support for learners at different levels of education to maintain a high education quality in conditions of limited opportunities, such as lockdown, lack of funding, etc.

2. Materials and methods

To create a new concept, the practical experience of school teachers who have different levels of funding, educators of technical colleges and universities, and research workers of research institutions was used. Namely:

- Were involved in training or research:
  - Schoolchildren – 33;
  - Students – 15;
  - PhD students – 7;
  - Associate professors – 4;
  - Professor – 1;
- Educators were involved who provided education:
  - School teachers – 18;
  - University educators – 8;
  - Scientists from research institutes – 4;
- The educational institutions' number that took part (from five cities of three countries):
  - Schools – 14;
  - Colleges – 7;
  - Universities – 9;
  - Research Institute – 3;
  - Commercial organizations (non-educational) – 2;
- Didn't want to take part in this experiment:
  - Schools – 2;
  - Universities – 1.

At the same time, based on open sources of information, the experience of scientists in the educational field was taken into account.

The development of a new concept of laboratory support was carried out from 2014 to 2016, and its implementation, introduction into the educational process, identification of technical and organizational difficulties and possible ways to solve them from 2016 to the present. At the same time, in the last year, special attention was paid to distance learning.

3. Results and discussion

3.1. Peculiarities of interaction between manufacturers of laboratory training aids and consumers

Equipping school and research laboratories requires funding and highly qualified laboratory workers (Fig. 2).

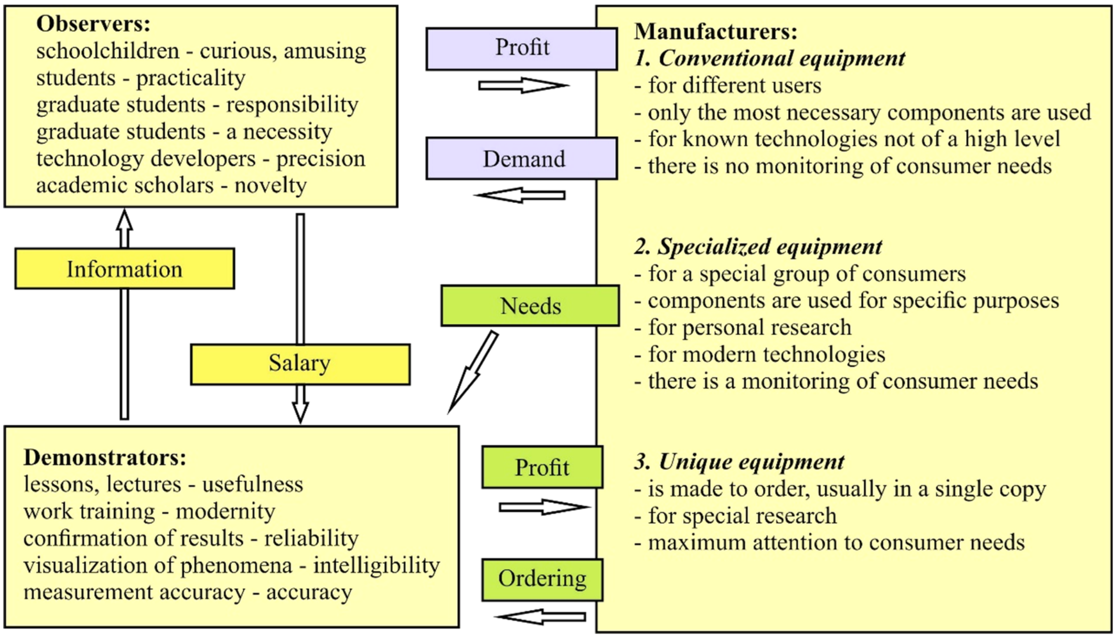

Fig. 2. Interaction between consumers and manufacturers of laboratory equipment in countries with weak economies

Figure 2 demonstrates that interactions between laboratory equipment manufacturers and consumers are commercial activities, while education is social (if we consider the education of citizens in general, without exclusively referring to commercial educational institutions).

The main goal of equipment manufacturers is to make a profit, and at the same time, the leaders and employees of these companies do not understand the specifics of the educational process well enough. At the same time, the performers of the educational process (teachers, scientists, lecturers and learning) are supported by public funds received from the activities of commercial organizations, and they have minimal knowledge of the technological or commercial features of creating new equipment and have little understanding of the commercial activities' specifics.

Thus, at the moment, when creating any laboratory equipment, in any educational or research institution, problems arise that, in principle, cannot be solved without changing the very concept of this part of the educational process.

From the point of view of the consumer, laboratory equipment must be constantly updated due to the constant development of technology and the level of teaching. It should match the ease of use of the student's developmental level. The variety of equipment should cover the needs at all levels of student development. The equipment should be accessible to the maximum number of learning and should be used for all possible forms of learning activity – demonstration, skill training, and research.

From the point of view of the equipment manufacturer, first of all, production should be profitable, and therefore the cost of this equipment should be as high as possible, the cost of production should be minimal, the duration of changes in updating the technological cycle and the numbers of product options are minimal.

Based on the foregoing, the modern concept of the laboratory base should provide for:

- Stationary (class, laboratory, organization),
- Service life not less than 5-10 years,
- Limited number of types of devices and manufacturers,
- Predominantly aesthetic appearance,
- Impossibility of modification during operation,
- Principle of work – collective.

For the study of complex natural processes (space, nano-biotechnology, medicine, geology and astronomy), this concept is justified. Demonstration of phenomena, research and training of specialists in these areas of education is impossible without sophisticated and high-precision equipment.

But for secondary school, vocational education, higher education, this approach does not fulfil its functions.

For this, it must be modified taking into account the current state of technology development and new teaching methods.

3.2. The main characteristics of the traditional and new approach to the creation of laboratory support for educational institutions

The basis of the new concept of laboratory support should be the maximum possible participation of education' representatives in its creation.

Depending on the level of training of students and teachers, such participation may be different, but the basic principles for all links of the educational process can be defined as follows:

- Mobile nature (own workplace, home, remote research location),
- Service life no more than 1-2 years,
- Functionality and compliance with the level of education of students and teachers,
- The possibility of using unified modules from any manufacturer,
- The possibility of permanent and easy modification,
- Principle of operation – individual, remote, network (group or sequence).

The implementation of this approach radically changes the process of equipping educational institutions with laboratory tools, and even the learning process itself. First, the conversion time can be shortened by several years. Secondly, the new laboratory equipment will correspond to the level of technology development, that is, "keep pace with the times." Thirdly, the financial costs of retooling will be significantly reduced. Fourth, dependence on manufacturers will be eliminated. Fifth, the new laboratory equipment will take into account the latest educational trends such as the globalization of the educational process, the use of distance learning methods, etc. Sixth, the functionality of the equipment can gradually approach the functionality of professional laboratory equipment.

3.3. Basic principles of the new concept of laboratory support for educational institutions

The new concept of laboratory support for educational institutions provides for technical, organizational and methodological components (Fig. 3).

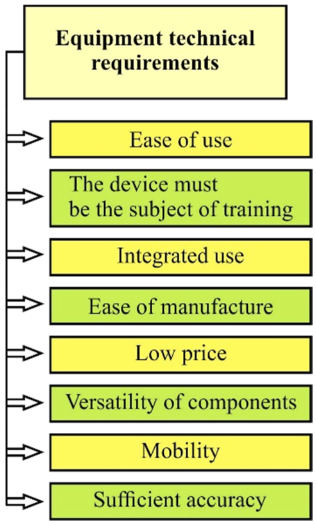

Fig. 3. The technical component of the new laboratory concept

Unlike the traditional approach, according to the new concept, students' laboratory support should not be one-time, but should be integrated into the different types of the educational process: demonstration, skills in working with equipment, use of equipment for research.

It should be clear and easy to use so that learning and teachers do not have a fear of breaking or misusing. The best option is the ability to use it without the participation of an educator and without prior long training.

Equipment should not only be a teaching tool, but also a teaching subject. This means that students, educators and researchers must take part in its creation in order to understand the laboratory devices' technical features and how they work.

The equipment should provide for its use for demonstration of educational material, for conducting research work, both in an educational institution and at home. This will develop students' skills in assessing the feasibility and relevance of creating new technologies.

The equipment should be designed for a short period of use (1-2 years), taking into account constant changes in the educational process, changes in technology and the peculiarities of its use (low level of user qualifications). This requirement prevents students and educators from fearing responsibility for the inevitable damage to equipment that may occur during work, and thus allows them to take more initiative in their use.

The equipment should be as simple as possible to manufacture, so that its creation can be entrusted to students, educators or researchers who usually do not have the skills to work with materials, complex devices, programs. As a result, it is possible to exclude manufacturers from the equipment manufacturing process, and the terms of its creation will be significantly reduced.

The equipment should be as cheap as possible in order to be able to constantly update it and make new samples. This provides an opportunity to experiment with various modifications of the laboratory equipment, constantly update it, create special options for research work and special cases of the demonstration work, duplicate instruments to increase the reliability or research' accuracy.

The equipment must be made of universal parts that are always available and can be replaced if necessary at any time if they fail. This will create a unified methodological base for the creation and use of equipment at the regional, national and, possibly, global (international) levels.

The equipment must be mobile to be able to use it both in distance learning conditions and for research work outside the laboratory. With this approach, unlike classical laboratory equipment, students can have an individual experience rather than being an observer in a group.

The measurement accuracy of the equipment should take into account the training level. This is important not only from the point of view of reducing the devices' cost, but from the point of view of acquiring skills in assessing the feasibility of the costs necessary to achieve a result.

3.4. Technical methods for implementing a new concept

At first glance, the combination of all these requirements seems impossible, but an analysis of the capabilities of modern electronic devices and their development trends allows us to assert that this is not only realistic, but also possible in the shortest possible time (Fig. 4).

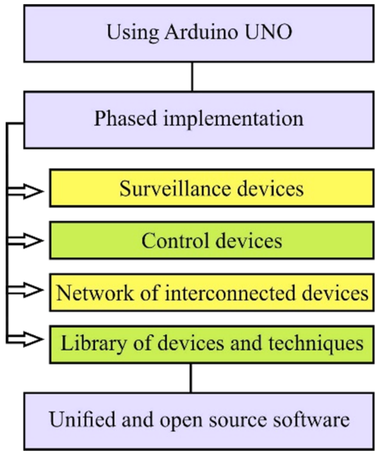

Fig. 4. Technical ways to support the proposed approach to upgrading laboratory equipment

As a basis for laboratory equipment, it is advisable to use microcontrollers in combination with a set of sensors, actuators and elements for output and data transmission.

Depending on the requirements for equipment (for a school laboratory, or laboratory work at a university, or scientific research in research institutions), devices for specific conditions, the number of sensors and actuators, their safety and reliability, etc. may differ. However, from an economic point of view, while ensuring a good level of educational development, the most expedient is the use of Atmel AVR microcontrollers [9-11], which satisfy most of the above requirements for the new concept of laboratory support. In addition, even a beginner can study the Atmel AVR Design Guide [9]; the microcontroller is able to interact with the designed final equipment and is a complete design environment for developing and debugging microcode [11]; it is capable of execute any number of tasks in a multithreaded fashion and is able to switch between different tasks using a forward scheduling algorithm with the flexibility of blocking a task and giving it a longer execution time depending on the priority level [10]. These microcontrollers are cheap, have a large number of additional parts, sensors and actuators, all of their clones are the most compatible, the largest number of tutorials and application programs have been developed for them [9-11]. New additional parts are constantly being created for these controllers. Moreover, the devices created on their basis can be quickly modified into more professional versions. It is advisable to use the Arduino UNO board as a base module, since this board has the entire set of basic functions and the largest number of additional modular boards, which makes it possible to create a laboratory equipment system without additional manufacturing of special boards, eliminates the need for soldering parts and manufacturing cases. In addition, if it is necessary to create more powerful versions of devices on this basis, Leonardo, Mega can be used, and to create less powerful versions – Mini or Nano.

Depending on the amount of funds, the level of students' involvement, educators and researchers, the implementation of the new concept of laboratory support is possible and expedient in several stages.

At the first stage, it is advisable to create only recording devices, consisting of four parts – the main board, the information storage board, the display board and the corresponding sensors. Such a complete set in the shortest possible time will make it possible to create a complex of electronic laboratory instruments for school laboratories. On the positive side, 38 sensors are offered in the basic set, which provide almost all possible methods for monitoring physical and chemical parameters. At this stage, it is advisable to attract schools to create laboratory instruments not only for the school laboratory, but also for higher educational institutions. This will facilitate the establishment of their cooperation and in the future can become a very effective mechanism in career guidance work.

At the second stage, the use of additional unified actuator boards (not necessarily all at the same time) will make it possible to create muffle furnaces, dryers, centrifuges, mixers, electrolysers, illuminators and heaters, and other means of a modern chemical, physical and biological laboratory, which are necessary for educational laboratories. The use of communication modular cards based on Wi-Fi, Bluetooth and radio communication will allow these two systems of mechanisms to be linked into a single system, resulting in the integration of a system of laboratory instruments that can synchronously measure dozens of different parameters independently of each other, store them and, if necessary, transfer them to single repository.

Further steps to improve such laboratories can be carried out by creating local servers for accumulating experimental data and remotely controlling laboratory instruments based on microcomputers such as Raspberry, creating a unified software environment for instruments, developing guidelines for the creation and use of laboratory instruments, creating their library (for example, for exchange , alternating or sharing).

Instruments should be gradually created, while increasing their complexity, since the basic principle of developing new laboratory instruments provides for the direct involvement of participants in the educational process who do not yet have experience in programming and using microcontrollers. After some time after acquiring the necessary experience, they will pass it on to the next generations of students.

The software of the devices should be so simple that it can be used and modified by students in computer science lessons, and teachers and researchers on their own without additional knowledge of programming languages.

To fulfil this requirement, each of the memory cards in each laboratory instrument must contain a complete set of information for using the setup, code modification and internal program of the microprocessor. The main program (sketch) should have a unified modular structure that can be easily modified with minimal programming knowledge. The format of information output and input should be uniform and generally acceptable.

3.5. Organizational features of the concept implementation

The organizational features of the implementation of the new concept are to attract students of the middle and senior grades of general education schools, which can perform a relatively simple, but important part of the work – assembly, launch and testing of devices (Fig. 5). This will contribute to a faster re-equipment of the chemical, physical and biological laboratories of many educational institutions; in addition, many schoolchildren will be involved in this process during the combined time from classes, which excludes the possibility of their idleness or communication with negative personalities.

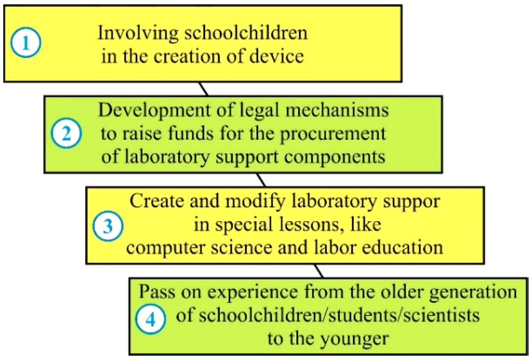

Fig. 5. Key organizational points required to implement the concept

At the same time, in order to attract all schoolchildren, it is advisable to assemble, launch and test devices in computer science or labour education lessons, which will facilitate the production of more such devices over several sessions.

In this case, the purchase of the necessary parts can be carried out both for individual funds (at the expense of parents) and for sponsorship or funds of the school, regional or state educational authorities. Depending on the complexity and purpose, laboratory equipment can be created by each student for personal use and without returning laboratory equipment to school; for use in a school laboratory; for use in several schools, or universities, or scientific institutions.

This approach allows you to start creating a new laboratory base without wasting time on tenders and other similar procedures.

The process of reprogramming microcontrollers is possible and advisable to carry out on the basis of schools directly at the lessons of computer science. When creating simple laboratory instruments, middle school students can cope with this, and to create more complex programs, from the point of view of the educational process, it is advisable to involve high school students.

3.6. Use of laboratory equipment

According to the new concept of laboratory equipment, each device must be used for different types of work.

Each device should be used as a teaching tool, that is, as a laboratory device for demonstrating certain processes or for acquiring skills in working with equipment, as well as a tool for vocational training and computer science lessons for middle and high school students. At the same time, as students master the material, each device should undergo a step-by-step transformation from a simple level to a more complex one. As a result, with the participation of students, the equipment can be improved even to the level of a specialized laboratory installation for performing specific tasks, which implies a special set of sensors, actuators, modes, etc.

To increase the speed and efficiency of improving laboratory equipment, it is advisable to hold competitions among students with the help of young scientists for the most interesting solutions using microcontrollers of practical importance.

If there are several units of laboratory equipment located in different places (at home, in an educational institution, in a scientific institution), it is interesting from a practical point of view to organize them into local networks. To create such networks, it is advisable to attract senior students specializing in the creation of distributed, remote, network laboratories. This approach makes it possible to use laboratory equipment in rural areas, under quarantine conditions, for distance learning for students with disabilities in another city or country.

3.7. The results of the practical implementation of the new concept

The practical implementation of the proposed concept became possible after practical work with schoolchildren and teachers, students and educators of higher educational institutions, representatives of commercial organizations and charitable foundations since 2016.

Over the years, schoolchildren, without the direct intervention of adults, have created devices (Fig. 6):

- Spectrometer (UV, red, green, blue, IR),
- Photocolorimeter,
- Digital microscope,
- For monitoring the microclimate of the room (temperature, humidity, light, CO_2, noise),
  for determining
- Of gas concentrations (CO, CO_2, H_2, C_2H_5OH),
- Of light intensity, thermometer, and humidity sensor,
- Of temperature, humidity and carbon dioxide level,
- Of magnetic field,
- Of noise level,
- Of thermal conductivity of materials.

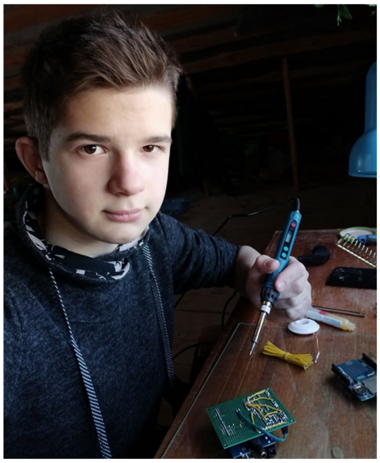

Fig. 6. Schoolboy as a performer/constructor/designer of new laboratory equipment

All devices, in addition to being used in school lessons, were used for scientific research by schoolchildren, students, associate professors.

Practical testing in real conditions of the working capacity of the created laboratory equipment made it possible to formulate technical requirements for individual components of the equipment, approaches to its assembly, use and improvement.

During their operation, schoolchildren completed 12 scientific works, of which 6 works received prizes on the cone of scientific works of the Minor Academy of Sciences of Ukraine. Was completed and successfully defended 2 theses and 3 research projects.

According to the reviews of school teachers and university educators, the most interesting works from the point of view of the educational process were highlighted, which were devoted to:

- Study of changes in the microclimate in classrooms,
- Study of the effect of artificial lighting on plants (Fig. 7),
- Study of the kinetics of photosynthesis and respiration by plants,
- Research of fermentation processes,
- Development of light-absorbing coatings,
- Development of coatings for air conditioning,
- Studies of the composition of combustion products of various materials,
- Study of daily changes in the spectrum of solar radiation,
- Creation of photocatalytic water purification systems.

Cooperation of higher educational institutions with schoolchildren and teachers contributed to the development of a unified approach to the creation of new laboratory software, which was presented in the form of a unified technical task with clear recommendations that are understandable even for a student.

Fig. 7. An example of using the device in biology lessons

The constant change in the cast of performers turned out to be the most difficult moment in the implementation of the new concept. Therefore, it became necessary to develop a method of transferring skills from high school students or graduates to younger generations.

This experience was formalized and formed the basis for the next scientific work, which is planned for submission to the competition of the Small Academy of Sciences of Ukraine this year.

To implement the work on the creation of a network of laboratory instruments, two school scientific works have been completed and negotiations are underway to attract students and teachers of higher educational institutions as the main consultants and developers of the architecture of this network.

3.8. Discussion and proposals for the development of a new concept

It should be noted that the obtained practical results on the implementation of the a new concept of laboratory support can be considered only as a technical feasibility of implementation, since during this time it was revealed that the main ones are precisely organizational problems.

For example, some school leaders qualified the work on the creation of laboratory instruments as the labour of minors and equated such activities not with educational activities, but with illegal ones. In this regard, they refused to participate in the process of implementing the new concept and to organize training for schoolchildren in the creation of laboratory instruments as part of the computer science and labour education lessons.

Further, funds from the school fund are not planned for the purchase of some components for creating devices, and many parents refused to purchase the necessary components for personal funds. Also, there was a problem of accounting and writing off broken devices and components.

Implementation of the new concept also revealed some of its shortcomings and limitations, which are as follows:

1) Accuracy of results. The proposed approach is especially good for most screening studies, since it is most important for schoolchildren and junior students to understand directly the research process and natural phenomena. For this category of learners, the high accuracy of the results obtained is not key at the training stage. Also at the stage of dissertation research to demonstrate processes and identify certain phenomena, this approach is also relevant. However, if the dissertation research of the identified phenomena requires high-precision results, then it is certainly necessary to use professional high-quality equipment.
2) Using Arduino UNO board. The capabilities of this board are limited by the number of sensors. So, there are only 5-7 sensor connections for one installation. At the same time, in the modern market, only about 8 types of sensors have a fairly low (affordable for a low-income buyer) cost. Other types, as a rule, are quite expensive and the question arises about the expediency of their acquisition for some tasks.
3) The prefabricated design of the equipment does not allow operating it under stressful conditions, such as high or low temperatures, strong vibrations, in aggressive environments, etc. But at the same time, such conditions are unacceptable in an educational institution and, as a rule, such conditions are absent in the educational process.

However, despite these difficulties, the most significant advantages of this concept are improving the education level in secondary schools and higher educational institutions, as well as attracting foreign students to study due to the availability of remote laboratory work in many engineering subjects.

One of the ways to solve organizational problems can be the creation of a library of laboratory support with instructions for its design. To begin with, three basic configurations can be offered:

1. Ready laboratory instrument:
   - Ready device;
   - Instructions for the use of the device/devices and work;
   - Video (audio) instructions for the work/work cycle;
   - Journal of Research;
   - Test questions of research.
2. Remote laboratory/scientific work:
   - Personal set of components;
   - Instructions for assembling the device/devices;
   - Instructions for the use of the device/devices and work;
   - Video (audio) instructions for the work/work cycle;
   - Journal of Research;
   - Questions about research done.
3. Laboratory/scientific setup:
   - List of components (the student receives it independently);
   - Instructions for assembling the device/devices;
   - Instructions for the use of the device/devices and work;
   - Video (audio) instructions for the work/work cycle;
   - Research journal;
   - Questions about research done.

The use of such libraries is analogous to the use of traditional libraries for school textbooks, teaching aids, scientific literature, etc. After completing the research, the schoolchild/student/researcher returns the laboratory equipment to the library, just like it returns a tutorial. However, depending on the wishes of users, such equipment can be left for personal use on an ongoing basis for a certain amount, which guarantees the possibility of further updating the collection of such a library.

It should be noted that this approach has shown its effectiveness and is currently used by some schoolchild, students, educators, researchers for their scientific activities. However, it has not yet become widespread. It would be advisable at the state level to recommend the implementation of this approach and to propose some legal mechanisms to overcome the above problems.

4. Conclusions

In accordance with the results obtained, the authors conclude that the development and the first practical steps to implement the new concept of updating the laboratory support of educational institutions clearly demonstrate of its practical implementation' feasibility in the educational process. At the same time, positive consequences from the implementation were identified, namely:

- Students have visual, accessible and useful material for school lessons in labour education and computer science, undergraduate diplomas and postgraduate research;
- There is a constant renewal and improvement of laboratory equipment;
- There is an increase in the educators' level in accordance with modern achievements of technology and technology for teaching;

- There is a more responsible attitude of students towards laboratory equipment, since it is created with their own hands and is more understandable and accessible to use, which does not cause fear and mistakes in its use;
- There is a transformation of virtual distance learning based on lectures and videos into real learning with "live" visual demonstration of physical, chemical, biological and other processes and experimental research.

As a recommendation, should wish that at the state level to recommend the implementation of this approach and to propose some legal mechanisms to overcome problems associated with the procurement of components and the preparation of training programs for schoolchildren in labour education and computer science lessons, taking into account the present concept of laboratory support for educational institutions.

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