Alternative Forms of Laboratory Teaching during the Lockdown Period Caused by the COVID-19 Pandemic

Stepan Major, Marie Hubálovská, and Roman Loskot

***Abstract*—This article deals with problematics of laboratory learning in the state of total lockdown of educational institutions which was caused by COVID-19 pandemic. Schools in the Czech Republic have been operating in a special regime for more than a year, when most students and pupils cannot directly participate in school teaching, which results in significant changes in the way teaching is organized. There is a significant application of various forms of e-learning and schools use the concept of blended learning, however, practical teaching in laboratories and workshops was particularly hard hit. When replacing student experimental work in laboratories, teaching with the help of virtual laboratories is the strongest. Due to the general irreplaceability of real physical experience of pupils, various combined forms of teaching are used, where only a part of pupils work in the school, so as to minimize the risk of spreading the infection, but these pupils take turns in laboratories. Furthermore, some teachers try to design students' home experiments, in the implementation of which the principles of design-based learning and project-based learning are strongly applied. In this article, substitute teaching of laboratories in subjects such as physics, chemistry or electrical engineering in schools is mapped and evaluated, special emphasis is placed on high schools with curriculum focused towards technics and engineering. It is in these schools that the approach to teaching known as design-based learning is very well applied and the students of some selected schools were able to work on home experiments. It was this form of substitute teaching that proved to be the most effective.**

***Index Terms*—Lockdown, laboratory class, STEM education, experimental learning, blended learning, e-learning, virtual laboratory.**

I. Introduction

This article analyzes the teaching of physical and technical laboratories during the pandemic caused by COVID-19, especially during the period of the long-term total lockdown, which forced radical changes in the teaching process and the transition to online teaching, e-learning etc. However, there are courses that focus on practical training. The activities in which students are trained are much harder to replace by online teaching than in the case of a more theoretically oriented subject. A typical example are courses or lessons that are based on the work of students in laboratories.

These laboratories often use measuring instruments and other materials that are not available for students at home, whether for economic or safety reasons or otherwise. Typical examples of this equipment used in physical and technical laboratories are materials testing machines such as tensile test machines. Taking into account the importance of practical experience in vocational training, it is generally not desirable to give up teaching in laboratories. This is why people working in education must look for suitable ways of organizing laboratory teaching in an optimal way also at the time of the total lockdown.

In the specific conditions resulting from the measures against the spread of the virus, two semesters of teaching at universities and two school semesters at secondary and primary schools have already taken place. While in the case of teaching theoretical subjects, teaching can be implemented using many forms of learning using various online platforms and other means.

During this period there was a significant improvement in quality and efficiency of the educational process. It should be added that compared to spring 2020 there was a significant improvement in the quality of online teaching and also the teachers used more and more modern methods in practice. However, a large part of teaching still has the nature of mere lectures or exercises in which the physical interaction of a student and a teacher was replaced by a contact using a webcam. In this case teachers are using MS Teams or Google class [1]-[3]. Communication via email is also common [1], [3]-[5]. In this case, in terms of other characteristics, it is practically a teaching using face-to-face classroom practices. It can be said that these lessons cannot be considered from the point of view of exact definition and from any of the known forms used in teaching based on information technologies described in the literature, such as Blended learning [6]-[16].

Teaching practical subjects in laboratories is much more complicated and it is difficult to replace in the lockdown period. At the beginning of the epidemic, when teachers assumed that schools would be closed only briefly pedagogical staff assumed schools opening after a maximum of a few weeks. In this period, it was assumed, that it is not necessary to devote special effort to the organization of teaching laboratories, because activities carried out in school laboratories and workshops that could not be carried out during short lockdown could be easily replaced after the end of the lockdown.

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Most of these teachers had the idea that after the reopening of schools they would replace the missed lessons with block teaching in laboratories, including teaching on Saturday and Sunday when teaching is not standard. This idea soon turned out to be nice. Some schools decided to replace the teaching of practical subjects during the summer holidays, while others stepped up and applied intensively virtual laboratories, whose form and concept often differ significantly. Some teachers implemented the full transition to virtual platforms, both commercial and those developed directly by the teacher for their own lessons (which was a common phenomenon at universities) [1], [3], [17]-[19].

These virtual laboratories often use animations of the studied phenomena, while the less advanced ones basically contain only film samples of individual experiments, while the more advanced ones are based on simulation programs. In this case, the experiment has the nature of animation of a certain event, in which the student can choose the input conditions of the experiment and the simulation program will show the result [17]-[23].

A practical example might look like this: the student chooses the speed and angle of the ball and the simulator will calculate the angle of the rebound, the trajectory of flight and the place where the ball would fall after the rebound. The results are visualized by a virtual laboratory in an illustrative form easily understandable to the student [23]-[26].

Some simulators are even more sophisticated and allow, for example, to assemble a virtual electrical circuit from various components (such as electrical resistors; wires; switches; various semiconductor components; appliances such as electric motors, light bulbs, diodes; and power supplies) with which the virtual laboratory works. After assembling circuit in simulator, the virtual laboratory allows to determine value of different electrical quantities on individual components, for example, the voltage across the resistors or the current flowing through the individual appliances. In the case of such a laboratory, for example, the student's task may be to perform control calculations of voltage and current on individual resistors using Kirchhoff's laws or to determine conductance. One of students ´goals can be comparison of current and voltage calculated by hand and the results given by virtual laboratory.

Although these resources are often very sophisticated, they are not able to fully replace students' laboratory work, especially in the case of higher forms of study such as technical oriented high schools, which place great emphasis on the practical part of teaching. All these sophisticated virtual laboratories cannot fully replace teaching at technical high schools or universities. This is the reason why some teachers have tried to implement experiments in their teaching, which students could carry out at home, using both commonly available tools and more sophisticated experiments with borrowed equipment.

The aim of this work was the implementation of research, which aimed to describing the procedures chosen by individual schools in dealing with the situation. Another goal was to assess the effectiveness of individual approaches to learning and its organization in the situation of general lockdown. This part of the research was carried out using questionnaires. When assessing the effectiveness of individual methods, it is then important to quantify the results. The quantitative part of the research then included interviews with individual teachers.

An important fact is that the authors themselves taught laboratory exercises in the field of technical measurements during the lockdown, which led them to introduce sets of laboratory work for students that can be done at home. Students' work in laboratories is closely related to the pedagogical concept known as Experimental-learning [27]-[31]. Teaching designed in this way then allows the use of other principles known from teaching methods such as Project-based learning PBL or Design-based learning DBL [32]-[37], but at the same time there are elements known from teaching based on the use of information technology such as blended learning [38], [39]. We will now briefly look at how these teaching methods are characterized or defined.

II. Experimental Learning

A. *Experimental Learning*

This learning method can be defined as learning through experience, and is more narrowly defined as "learning through reflection on doing" [27]-[29]. It is already clear from the title that experimental teaching could be combined with laboratory work of students, but experimental learning is in fact a much broader concept. Learning not only from humans but also from animals is in fact linked to experience. In this case experiments can be considered such as controlled experiences. But this is already too broad a view, and for our purposes it is more appropriate to return to a narrower but much more practical definition. The concept of Experimental learning is related to, but not synonymous with, other forms of active learning such as action learning, adventure learning, free-choice learning, cooperative learning, service-learning, and situated learning [28]-[31].

It needs to be explained here, that experimental learning is carried out outside of school and in school while experimental education is specifically linked directly from school activities. For experiential education to become efficient pedagogy, physical experience must be combined with reflection. The methodologies reflected in experiential education have evolved since the time of Hahn and Dewey. Experimental learning is based on set of general assumptions developer by trio of authors Walker, Boud and Cohen in the early 1990s [38], [40]. These assumptions are expressed here:

1) Experience is the foundation of, and the stimulus for learning;
2) Learners actively construct their own experience;
3) Learning is a holistic process;
4) Learning is socially and culturally constructed;
5) Learning is influenced by socio-emotional context in which it occurs.

Obviously, learning is far from just learning through school experiments, as it might seem to lay people. Assumption formulated by Cohen and its co-workers were outlined by Jenny Moon in 2004 using concepts of core connotations [27], [39]. Here we list core connotations in experimental learning developed by Moon [28], [39]:

1) The material for learning is usually direct experience.; It is not usually mediated or taught.;
2) There is often sense that experimental learning is preferred manner of learning, is better, more meaningful or empowering.;
3) There is usually reflection, either deliberately or non-deliberately, involved.;
4) There is usually some active phase of the learning: action, doing or experimentation. Experimental learning was described by circular mode. Various circular models have previously been used to describe the learning process.

However, one of them is very complex and that is why we will list it here. This circular model was shown by Colin Beard, see Fig. 1, see. [27], [39].

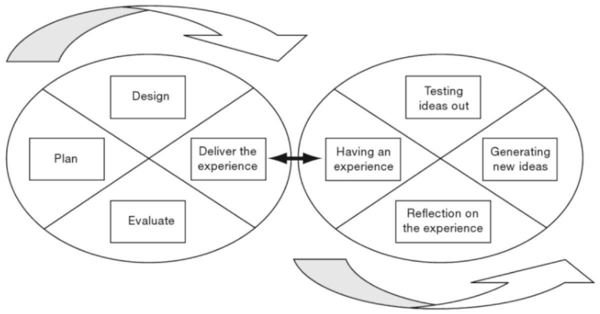

Fig. 1. Circular model of learning process proposed by Colin Beard, see [28].

B. Design-Based Learning and Project-Based Learning

Design-based education or Design-based learning (both names are common) can be described as an educational approach which has been mostly used in the context of secondary education to teach science curriculum [37], [41], [42]. This method was grounded in activating methods such as Learning by Design [41], [42], and Design-based Science [37], Design-based education has served to acquire problem-solving and analytical skills common to the science classes while having students to work in design assignments.

A search of the available literature shows the fact, that in the context of higher learning institutions there is visible connection between design-based learning and problem-based learning [43]-[49].

According to some authors, it can be said directly that, the design-based education is originated from problem-based learning or its principles are rooted in the educational principles of problem-based learning [37], [46], [47]. These educational principles are based on the special approach whose application helps development of inquiry skills and integrate theoretical knowledge by solving ill-defined problems [41], [42], [50]-[60]. One of typical characteristics of design-based learning is that this learning method makes emphasis on the planning process embedded in engineering assignments [43], [44], while applying knowledge of the specific engineering domain through the involvement of students in design activities of artifacts, systems or solutions.

1) Project-based learning

Project-based learning is an instructional methodology encouraging students to learn by applying knowledge and skills through an engaging experience [32]-[37], [61]-[68]. Project-based learning presents opportunities for deeper learning in-context and for the development of important skills tied to college and career readiness [32]-[37], [41], [69].

2) Design-based learning

Design-based learning can be described as a form of project-based learning in which students learn what they need to learn in a just-in-time fashion while trying to design something [41]-[50]. This approach was therefore gradually evolved from the original project teaching, with a number of authors addressing it [70]-[75] In the ideal situations students works in groups, students are working on one task for one or two months. This groups working on educational tasks can be understood as specific educational units for high school math, science, and technology classrooms. These students in learning units use engineering design processes as a foundational structure for the learning units. It is obvious that this structure improves the design outcomes and provides an organization of the science learning that happens inside the classroom. On other hand, it is often impossible to organize this course as one to two months lasting teaching units in schools. In reality, for organizational reasons, study blocks devoted to the work on task or solving problems are much smaller teaching units (most often from four to eight hours long) and this units, these units are repeated once week. The working time of the task is then one month or two. However, we need to add additional supports into the process to maximize learning in this classroom setting.

Concept of Design-based learning is closely related to the specific form of thinking so called Design thinking. Design thinking has a human-centered core [74], [75]. It encourages organizations to focus on the people they're creating for, which leads to better products, services, and internal processes. When you sit down to create a solution for a business need, the first question should always be what's the human need behind it?

In employing design thinking, you're pulling together what's desirable from a human point of view with what is technologically feasible and economically viable [74], [75]. It also allows those who aren't trained as designers to use creative tools to address a vast range of challenges. The process starts with taking action and understanding the right questions. It's about embracing simple mindset shifts and tackling problems from a new direction.

C. Blended Learning

The term blended learning includes a large number of methods that can effectively influence the educational process and which present to the user, respectively to learner or student the content of the course through a suitable software tool. This learning content is defined by curriculum of the study program [6]-[15], [38], [39].

So, we can say that learning contents is mastered by students using collaboration software. These instruments are mainly used by so-called Web-based courses, etc. This term for learning is also often used to describe a teaching / learning process that combines a number of activities, including face-to-face teaching within individual classes (in this case we use the phrase face-to-face classrooms as a technical term) [6]-[15]. We can also use another term so-called live e-learning. The last, but not insignificant, component of this teaching process is self-paced learning. Blended learning is also often characterized as distance learning supported by e-learning, the terminological boundary is not clearly defined for this term. In the case of high schools and secondary schools), the term blended learning is mostly associated with teaching (but also home preparation), which uses offline e-learning tools (ICT, etc.) - especially multimedia CD-ROMs (educational programs, encyclopedias, etc.).

III. METHOD AND EXPERIMENT

A. Formulation of Hypothesis and Research Questions

In this paragraph, we will focus on the formulation of the hypothesis and the precise specification of the research objectives. We will first proceed to the formulation of the hypothesis. Advanced virtual laboratories are mostly based on simulation programs. In this case, student approaches to the virtual laboratory, similarly to a computer game. Only more reluctant or older students perceive virtual laboratory as a set of simulation tools based on mathematics and physics that allow you to predict the results of experiments. However, this does not matter according to some teachers, because students are often enthusiastic about the game and will understand other principles as further work is done. In the case of a virtual laboratory dedicated to optics, for example, a student can change the angle of incidence of light rays on a mirror and the program will show the angle of reflection in the simulation, i.e. where the ray is reflected. Similarly, for example, the elongation of a spring or the bending of a beam can be monitored in a virtual laboratory. Another program will help to explain the relationship between the increase in temperature and pressure in an isochoric process, i.e. the student sets the value of the temperature in the vessel and a fictitious pressure gauge shows him the appropriate value.

In this case, the student could subsequently verify the result of the simulation using a simple calculation using the equation of state of the gas to verify and draw in the notebook diagrams expressing the dependence between the quantities pressure p, temperature T and volume of vessel V.

Critics of this approach point out that while the simulation is excellent and realistic, students tend to best remember the experiments they will actually try. This critique is based on the idea that students perceive working with a simulator as a game. Although students remember the course of the experiment, they perceive it differently than the experiment carried out physically. Based on this consideration, it can be assumed that students who complete real laboratories will show a higher level of knowledge. However, the use of virtual laboratories is supported not only by the current specific situation, where schools are often closed for a long time, but also by the financial cost.

If each student has to complete precisely performed laboratories, teaching becomes very expensive. The optimal choice seems to be a suitable combination of all approaches together. At present, due to the lockdown, it is possible to implement teaching not only by means of experiments in virtual laboratories, but also by means of experiments that can be carried out by students with the help of tools commonly available in households or with the help of school-borrowed aids. Thus, it is possible to compare teaching based on purely virtual experiments with combined teaching, in which students also share the results of experiments. In this case, better understanding and higher motivation can be expected. During regular classes outside the lockdown period, students perceive working on a computer very positively, as a pleasant and attractive change compared to, for example, interpretation. However, somewhat different situation occurs at present state, when most teaching is carried out online in the current situation, where students are already spending computer lessons all year round, it is very tiring to unpleasant for them, and on the contrary, they perceive physical experimentation at home as a pleasant and activating change.

Questions and points of the hypothesis:

1) How are laboratories organized: a) they are not replaced; b) replaced in blocks at the time of holidays i.e., at the time of lower danger COVID-19.; c) teaching is carried out using virtual laboratories; d) combined form of laboratory teaching?
2) Is teaching implemented only with the help of virtual laboratories as effective as classical teaching? We assume that it is probably less effective.
3) The combined form of teaching laboratories will enable better mastery of the curriculum and will be more fun for students.

B. Implementation of Research and Experimental Teaching

Within the project, practical and research-theoretical solutions were solved. The research part was devoted to the collection of data on the teaching of laboratories at secondary schools (primary schools and universities were also partially included in the research). In the research part, the main goal was to evaluate the data collected in schools in order to describe and quantify the methods by which teachers replace practical teaching in the laboratory. Given that the preliminary investigation has already shown that the combined form is used the least by schools. This fact makes the combined teaching carried out by the staff and students of the Department of Technical Subjects who implemented this project more important.

Combined teaching of laboratories includes the following elements:

1) teaching in a virtual laboratory;
2) teaching based on students' home experiments;
3) substitute teaching in blocks.

Students complete most of the measured measurements in a virtual laboratory, which is due to the availability of technical means. However, some tasks can be physically performed at home by students using simple, commonly available aids. Experiments with a mathematical pendulum can be a typical representative of such problems. In fact, the work on such a home experiment is built on the same principles as applied in project-based learning and design-based learning. We will describe such a sample student laboratory work in the following paragraph. We will now look at the organizational framework of teaching in a combined form.

Organizational framework of combined learning:

1) All students complete their laboratory task in a virtual laboratory. This goal will be achieved in the standard teaching units through online classes every week.
2) All students have a certain percentage (between 20% and 30% of all tasks to meet during the course) of laboratory tasks designed so that they can complete them at home using items of daily use or even items borrowed from school.
3) The last part of the course is occupied by experiments carried out in spare lessons. For hygienic reasons, it is not possible for all pupils to take part, but only one specific part. In this way, a quarter to a third of students work in the school laboratory, and the rest of the students receive a film or at least photographic recording of their work in the laboratory, along with the documentation of the experiment and the data obtained. The work is organized in such a way that individual pairs or triplets always send the result of their work to 4 to 9 students. During the next experiment carried out in the laboratories, a new group will then be selected, so that the students will gradually change and all complete one task in the laboratory.

Experimental teaching was organized by three members of the research team and students of teaching and selected teachers. This teaching was carried out at eight workplaces. The teaching consisted of the already described block of full-time teaching of laboratories and was combined with virtual and home laboratories, and in the next paragraph we will describe several briefly several tasks on which students worked.

C. Experiments as Student Home Projects

The motion of a mathematical pendulum is well described by a simple equation that allows to calculate the gravitational acceleration, if we know the length of the suspension and we are able to measure the oscillation time. The aids that students need are a string, a weight and a cell phone. Today, all students have smartphones that allow you to measure the oscillation time or the time of ten oscillations. Using this value and the length of the string, students can determine gravitational acceleration. Because the formulas that students use only apply to small swings, the student must take a picture of a small weight on the string at the moment of its maximum distance from the equilibrium position.

They then measure this deviation and use it as proof that these were so-called small oscillations. Another task is to make a film recording of the pendulum damping. Students record with a camera in a mobile phone (they can also use a larger number of images), from the recording they determine the dependence of the size of the maximum deviation on time. Another task of students is to monitor the effect of the weight of the string on the calculated magnitude of gravitational acceleration. Students will find that for heavier suspension, the calculated gravitational acceleration values are different from the table value. In this way, students can reveal the effect of the moment of inertia on the motion of a rotating body. As we can see with very simple household tools, students can carry out interesting experiments in physics and mechanics. Experiments in hydromechanics designed to teach Archimedes' law can be considered in a similar way.

For older or more experienced students who are also engaged in programming, it is possible to design many experiments that combine knowledge from the field of information technology, physics, electronics and other fields. An example of such an interdisciplinary experiment is the measurement of moisture and water absorption. For students, it is possible to purchase microcomputers-control units working on the basis of Arduino together with appropriate sensors. The price of one humidity sensor is between 1-2 EUR. In a special case, the author of this paper and his students used the XKC-Y25-V sensor designed for the Arduino platform, which was specially developed to support the teaching of programming and robotics.

Scripts usable for controlling such a sensor, ie. the control part of the program, students can find on the sensor manufacturer's website and can copy it into their control program. In this case, students can mount several sensors one behind the other on a ruler or rod. The distance between the individual sensors is precisely determined. After connecting the sensors to a circuit with a computer, students can receive information about humidity in several places on the pole. They stretch a strip of fabric along the bar. Then the students place the rod with the lower end in a pot of water. The water soaks into the strip of fabric and rises towards the dry end. Sensors detect humidity and students can plot a graph between humidity and distance to reveal that it is an exponential dependence or better, that the process can be described by exponential function.

Another very interesting experiment for students belongs to the theory of electromagnetism. Students get acquainted with the importance of power lines for the description of the electromagnetic field. This home experiment combines the student's independent work with the student's work with a simulator in a virtual laboratory. The calculation of magnetic fields is generally very complex and unmanageable for the student, due to the advanced mathematical apparatus which is needed to solve the problem.

However, the virtual laboratory allows to perform calculations of magnetic fields of variously arranged magnets (cylindrical, prismatic and horseshoe shape). Students then solve this task, which aims to compare the results of the simulation and the experiment. During the experiment, students place magnets under a thin but rigid plastic plate. The position of these magnets is precisely defined by a square grid. This plate is coated with a thin layer of oil so that steel sawdust can float on this layer.

Floating iron filings form shapes - lines on the surface of the plate, their orientation corresponds to the direction of the local vector of the magnetic intensity of the field formed by the magnets under the plate.

These and other tasks fit well into the support so called STEM education. Here we will briefly explain the concept of STEM, which is a common abbreviation for four closely connected areas of study: science, technology, engineering and mathematics. These fields of study are often associated due to the similarities that they share both in theory and practice.

IV. Results and Data Collection

The study team collected data on high schools in the Czech

Republic. Questionnaires were sent to teachers at 80 technical oriented high schools and 25 universally oriented high schools (called gymnasiums). Furthermore, eighty primary schools participated in the questionnaire survey. Only the eighth and ninth grades were monitored in primary schools. The researchers also contacted teachers and students at four universities, although in this sector it was only a matter of obtaining additional information. The questionnaires contained questions concerning the method of teaching and the use of time allowance for individual activities. Due to the relatively small scope of this work, the individual questions used in the questionnaire will not be presented here. The scope and methods of compensatory teaching are described and analyzed in the following paragraph

A. Compensatory Teaching and Its Composition

This paragraph is devout to description of composition and time development of compensatory learning from quantitative point of perspective. In this section, we have focused on the selection of several subjects that are typically taught in laboratories. These subjects are representants of universal science curriculum: Physics, Chemistry and Biology. However, there is no teaching of biology at technical secondary schools. These schools have special curriculum based on specific educational goals. In the case of technical high schools teaching subjects such as mechanics, mechanical engineering and mechanical technology, electrotechnics, electrical engineering and electronics were monitored. For all these subjects, a large rate of laboratory work performed by students is typical.

TABLE I: TECHNICAL HIGH SCHOOL (STUDENTS AGED 15 TO 19 YEARS, CURRICULUM BASED MECHANICAL OR ELECTRICAL ENGINEERING). SPRING 2020

Subject Method of compensation	Phy	Ch	Me	Ele	NS
VL	9	0	7	10	11
CL	2	8	10	11	21
CTL	7	0	4	13	13
CTHE	0	0	0	1	1
NM	-	-	-	-	34

The results of the survey are evident from Table I to IX. The reader can also deduce individual questions from this table. The table contains many abbreviations, meaning of these abbreviations will be explained in the following text.

TABLE II: TECHNICAL HIGH SCHOOL (STUDENTS AGED 15 TO 19 YEARS, CURRICULUM BASED MECHANICAL OR ELECTRICAL ENGINEERING). AUTUMN 2020

Subject Method of compensation	Phy	Ch	Me	Ele	NS
VL	15	3	7	14	23
CL	0	2	10	11	15
CTL	7	8	4	13	21
CTHE	3	0	6	6	6
NM					15

The abbreviations used in the table are listed here: Phy - Physics, Ch – Chemistry or Chemical Technology, Me-Mechanics, mechanical engineering and mechanical technology, Ele-Electrotechnics and electrical engineering, Bio-Biology, VL- Virtual labs, CL- Compensatory lessons during days off and holidays, CTL- Combined teaching of laboratory work (this course includes the following elements: 1) teaching in a virtual laboratory; 2) compensatory laboratory teaching in day blocks in school); CTHE- Combined teaching supplemented by home experiments (It has the same structure as the previous one, but in addition, home experiments are included), NM- No compensation for missed laboratory classes, NS-the number of schools using the given method for at least one subject. Last abbreviation used in Tables – NMS has meaning-no measurable results.

TABLE III: TECHNICAL HIGH SCHOOL (STUDENTS AGED 15 TO 19 YEARS, CURRICULUM BASED MECHANICAL OR ELECTRICAL ENGINEERING). WINTER 2021

Subject Method of compensation	Phy	Ch	Me	Ele	NS
VL	23	3	7	15	24
CL	0	2	10	10	14
CTL	7	8	4	14	22
CTHE	3	0	6	6	6
NM					14

The method of teaching was recorded separately for each semester, thus obtained tables for spring 2020 and autumn 2020, the third table in the series always follows the beginning of 2021 (which is labeled winter 2021).

TABLE IV: HIGH SCHOOL WITH A GENERAL EDUCATION FOCUS (STUDENTS AGED 15 TO 19 YEARS, NO SPECIAL CURRICULUM). SPRING 2020

Subject Method of compensation	Phy	Ch	Bio	NS
VL	3	2	0	3
CL	0	2	0	2
CTL	0	0	0	0
CTHE	0	0	0	0
NM				20

TABLE V: HIGH SCHOOL WITH A GENERAL EDUCATION FOCUS (STUDENTS AGED 15 TO 19 YEARS, NO SPECIAL CURRICULUM). AUTUMN 2020

Subject Method of compensation	Phy	Ch	Bio	NS
VL	3	4	2	5
CL	0	1	0	1
CTL	0	1	0	1
CTHE	1	0	0	1
NM				17

TABLE VI: HIGH SCHOOL WITH A GENERAL EDUCATION FOCUS (STUDENTS AGED 15 TO 19 YEARS, NO SPECIAL CURRICULUM). WINTER 2021

Subject Method of compensation	Phy	Ch	Bio	NS
VL	5	5	2	5
CL	0	0	0	0
CTL	0	2	0	2
CTHE	1	0	0	1
NM				19

TABLE VII: GRAMMAR SCHOOL (STUDY YEAR EIGHT OR NINE, PUPILS AGED 13 TO 14 YEARS). SPRING 2020

Subject Method of compensation	Phy	Ch	Bio	NS
VL	4	6	0	8
CL	0	0	0	0
CTL	0	0	0	0
CTHE	0	0	0	0
NM				72

TABLE VIII: GRAMMAR SCHOOL (STUDY YEAR EIGHT OR NINE, PUPILS AGED 13 TO 14 YEARS). AUTUMN 2020

Subject Method of compensation	Phy	Ch	Bio	NS
VL	23	19	3	32
CL	0	0	0	0
CTL	3	3	0	3
CTHE	2	0	5	7
NM				38

TABLE IX: GRAMMAR SCHOOL (STUDY YEAR EIGHT OR NINE, PUPILS AGED 13 TO 14 YEARS). WINTER 2021

Subject Method of compensation	Phy	Ch	Bio	NS
VL	25	24	3	35
CL	0	0	0	0
CTL	3	3	0	3
CTHE	2	0	0	2
NM				40

B. *Effectiveness of Compensatory Laboratory Classes*

The fundamental problem of evaluating any teaching is to determine its effectiveness. The effectiveness of teaching could be measured using a didactic test of knowledge and competencies. Effectiveness was measured by scoring in a test ranging from 0 to 60. These tests were developed to determine skills and knowledge of students in the area different subjects such as physics.

TABLE X: RESULTS OF TESTING THE EFFECTIVENESS OF TEACHING. TECHNICAL HIGH SCHOOL (STUDENTS AGED 15 TO 19 YEARS, CURRICULUM BASED MECHANICAL OR ELECTRICAL ENGINEERING)

Subject Method of compensation	Phy	Ch	Me	Ele
VL	35	27	35	39
CL	17	34	30	33
CTL	36	35	35	43
CTHE	46	-	37	40
NM	29	12	31	27

In Tables X-XII, we then present an evaluation of the effectiveness of the teaching process from the perspective of students and teachers. This table also shows the results of testing students in subjects that students completed using laboratory work.

TABLE XI: RESULTS OF TESTING THE EFFECTIVENESS OF TEACHING HIGH SCHOOL WITH A GENERAL EDUCATION FOCUS (STUDENTS AGED 15 TO 19 YEARS, NO SPECIAL CURRICULUM)

Subject Method of compensation	Phy	Ch	Bio
VL	36	38	NMS
CL	23	36	NMS
CTL	31	27	NMS
CTHE	42	-	NMS
NM	21	19	NMS

TABLE XII: RESULTS OF TESTING THE EFFECTIVENESS OF TEACHING GRAMMAR SCHOOL (STUDY YEAR EIGHT OR NINE, PUPILS AGED 13 TO 14 YEARS)

Subject Method of compensation	Phy	Ch	Bio
VL	36	36	NMS
CL	-	-	NMS
CTL	28	41	NMS
CTHE	32	-	NMS
NM	26	17	NMS

Another topic studied is the way in which pupils and students perceive teaching and its organization. Due to limited space, we will present in one table. Pupils and students rated the teaching on a scale from 1 to 10, with 10 indicating a positive evaluation. Results of this evaluation are shown in Tables XIII. The following abbreviations were used in this table: THS - technically oriented high school; GM-Grammar school, HS-High school with a general study plan.

TABLE XIII: EVALUATION OF THE QUALITY OF TEACHING BY STUDENTS THEMSELVES

Subject Method of compensation	THS	HS	HM
VL	9	8	9
CL	3	2	-
CTL	9	8	10
CTHE	7	8	7
NM	4	6	3

Questionnaire sets were also prepared for teachers. In the case of teachers, it was studied what methods they use in their own words in teaching, or what principles they have decided to apply in the planning and preparation of alternative teaching at the time of school closure. Results of this research are shown in Tables XIV-XVI. In this case, the number given in the table corresponds to the weighting factor assigned to the method.

TABLE XIV: LEARNING APPROACHES USED BY TEACHERS IN SUBSTITUTE TEACHING — TECHNICAL HIGH SCHOOL

Subject Method of compensation	DBL	PBL	EL	BL	EE
VL	4	8	9	6	4
CL	2	4	10	1	0
CTL	4	8	10	2	2
CTHE	9	8	9	8	3
NM	1	2	3	1	9

The questionnaires were formulated in such a way that teachers could state three approaches to teaching, the principles of which they try to apply in teaching. This approach was chosen because experience shows that a combination of methods and approaches is used in teaching rather than one pure approach that would be fully in line with the definition known from the literature.

TABLE XV: LEARNING APPROACHES USED BY TEACHERS IN SUBSTITUTE TEACHING — HIGH SCHOOL WITH A GENERAL EDUCATION FOCUS

Subject Method of compensation	DBL	PBL	EL	BL	EE
VL	5	7	7	5	8
CL	0	0	10	7	0
CTL	3	7	8	2	2
CTHE	8	10	10	8	4
NM	0	3	5	5	8

There are several new abbreviations in these new tables, which have not yet appeared in the text, so we will list them here: DBL Design-based learning, PBL Problem-based learning, EL-Experimental learning, BL Blended learning and EE which is used here to denote e-learning. If the teacher chooses three approaches at once, he should choose one dominant one in the questionnaire, whose principles he considers to be the most important and most effective in teaching. The table is designed so that it should be used to determine the correlation between the chosen method of teaching substitution and the approach to teaching that the teacher tries to apply in his work with pupils and students.

TABLE XVI: LEARNING APPROACHES USED BY TEACHERS IN SUBSTITUTE TEACHING — GRAMMAR SCHOOL

Subject Method of compensation	DBL	PBL	EL	BL	EE
VL	2	6	5	6	7
CL	-	-	-	-	-
CTL	2	6	8	2	2
CTHE	3	8	6	7	4
NM	0	3	1	3	9

V. DISCUSSION

This research sought to determine which approach was best. Due to the fact that laboratory work in biology was practically not carried out at all, this subject was excluded from the effectiveness test. The relatively poor results of students in the group "CL- Compensatory lessons during days off and holidays" can probably be attributed to unsystematic work, when students work rather suddenly and thus there is not enough consolidation of studies. This group is characterized by the largest difference between the best and lowest results.

This fact suggests that, expecting teachers to catch up with a neglected subject in a substitute term, they may have organized other online instruction at a lower level than teachers conducting instruction in groups with virtual labs or a combined form. In general, the worst results for all subjects and types of schools correspond to classes in which teachers did not attempt to replace laboratories in any of the ways discussed here (this is the group which is in the table described as NM-No compensation for missed laboratory classes). This probably indicates a generally lower interest in teachers and school management in providing quality teaching. In these schools, teachers can be characterized by a high incidence of occupational burnout among teachers. In general, the data in the tables indicate that the highest efficiency was achieved in secondary schools in the group "CTHE-Combined teaching supplemented by home experiments ". These groups show a high level of motivation of teachers and students. The studied group "substitute teaching on holidays" in the subject of physics is very small and the average achieved score cannot be considered telling.

An interesting picture is provided by discussions with teachers on the topic of teaching methods. Teachers and schools that use laboratories more in teaching are more interested in applying the principles of "Project-based learning" and "Design-based learning", especially the group using blended learning enriched with home experiments, these home experiments can be considered as the most significant application of the principles of "Project-based learning" and "Design-based learning". In the case of chemistry, the smallest difference can be observed between the group "Substitute teaching on holidays" and the group "Combined teaching". It should be added that the chemistry-oriented fields of secondary schools represented only 11% of the analyzed fields of study. The rest of the technical high schools were evenly divided between the specializations of "mechanical engineering" and electrotechnics.

Another topic discussed here is how the pupils and students perceive recent and unusual form of teaching. These results were shown in Table XIII. Pupils and students rated the teaching on a scale from 1 to 10, with 10 indicating a positive evaluation.

Next, you need to look at the approaches that teachers apply from their own point of view. It has been repeatedly shown that older teachers in particular have a problem with basic terminology, for example they consider assigning tasks to be calculated as form of problem-based learning. If we look at Tables XIV, XV and XVI, we immediately notice that schools in which no greater effort has been made to replace practical teaching in laboratories, only e-learning is used as a substitute for lockdown. As interviews with teachers from these schools have shown, teachers in these schools perceive e-learning only as sending assignments by email and lecturing via a webcam.

Teachers who have devised home experiments for students, which have the nature of student projects and are based on the principles known from Design-based learning, apply not only its principles in teaching, but also make extensive use of Blended learning. The highest motivation and knowledge of modern teaching methods can probably be observed with these teachers.

VI. CONCLUSION

During the second half of the school year 2019/2020, Czech education was exposed for the first time to long-term closure since the introduction of compulsory school attendance, the following school year 2020/2021 takes place in a state of almost continuous school closure methods of testing and practical teaching. It is the practical teaching and organization of laboratory work that is particularly difficult at this time. It is necessary to realize that laboratory work is of irreplaceable importance in the teaching of many subjects and disciplines. Not only do school experiments help students understand the presented theoretical knowledge, when working in laboratories, students acquire a range of skills, and these skills are often more valuable for the student than theoretical knowledge in terms of their applicability in life. From this point of view, it is reasonable for students to attend laboratory classes even at the time of school closure. The presented study shows a radical increase in the use of virtual laboratories and various forms of combined teaching in teaching at secondary schools during the pandemic. It can be said that the educational methods known as Blended learning are very significantly applied, however, it is not appropriate to talk only about the use of the principles of this method; In the teaching of laboratories, it is more appropriate to use a combination of virtual laboratories with practical teaching of small groups at school, so that each student will try at least some experiment in practice. These students achieve both the best results and evaluate the teaching as the best. To support the development of creativity, we best ensure that students work on the implementation of some experiments in their home. Teaching conceived in this way uses the principles of Project-based learning and Design-based learning.

Conflict of Interest

The authors declare no conflict of interest".

Author Contributions

The idea to analyze of methods of substitute teaching of laboratory work was proposed by the first author of the article (Stepan Major). Because this author is intensively involved in the teaching of technical laboratories at secondary schools and universities, he was interested in how he solves the problem of substituting the teaching of laboratories at various schools. Questionnaires used in the research were designed by the author Marie Hubálovská. All three authors collected data together. All three authors collected data together.

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