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## VIRTUAL LABORATORIES IN THE TEACHING OF MECHANICAL TECHNOLOGY

**Abstract:** The aim of this article is to familiarise the reader with the issue of virtual laboratories and to demonstrate their possible use on a concrete example. This example deals with the use of virtual laboratories in the teaching of mechanical engineering in high schools and universities. The Covid-19 pandemic has led to significant changes in the teaching process and its organisation. In this period, teaching usually took place online, which was implemented using resources such as Google Classroom or MS Teams. This article presents a sample task - a project on which students of the second and third year of study at a secondary technical school are working. The project has an interdisciplinary character, because during its implementation students apply and further develop skills and knowledge from several subjects, namely physics, mechanics, chemistry and CAD design. The project is dedicated to the design of a pulley casting for a steel rope.

**Keywords:** STEM education, virtual laboratories, mechanical technology, case study

### Introduction

This article deals with the use of virtual laboratories in the teaching of mechanical engineering in high schools and universities. The Covid-19 pandemic has led to significant changes in the teaching process and its organisation. During this period, teaching was usually conducted online, which was implemented using communication platforms such as Google Classroom, MS Teams and others [1-7]. This article deals with the use of virtual laboratories in the teaching of mechanical engineering in high schools and universities. Teaching science and technology usually requires laboratory work. In many ways, engineering is based on the application of knowledge from subjects such as physics. Technical education requires not only laboratory work, but also workshop training. The proportion of workshop or laboratory work varies depending on the type of technical education the student attends. In the Czech Republic, two types of secondary vocational schools can be distinguished in principle: secondary vocational schools whose graduates can work as technicians, and schools that prepare pupils primarily for the performance in blue-collar professions [8, 9]. The content of education at secondary schools with a matriculation exam provides the student with all the knowledge necessary for further study of the field at a technical college. Studying at a secondary school of this type usually lasts four years. The second type are secondary vocational schools (abbreviated SOU), which we meet in the Czech Republic. Students attend this type of school for three years.

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Studies at a secondary vocational school are completed by an apprenticeship exam. Graduates of this school cannot continue their studies at a university. The study plan at these schools is significantly dominated by practical training in workshop activities. Practical workshop activity represents fifty percent of the teaching time in the study plan. This study plan is organised as follows, the teaching is divided so that one-week students are educated in theoretical subjects in the classroom and then one week in the practical workshop.

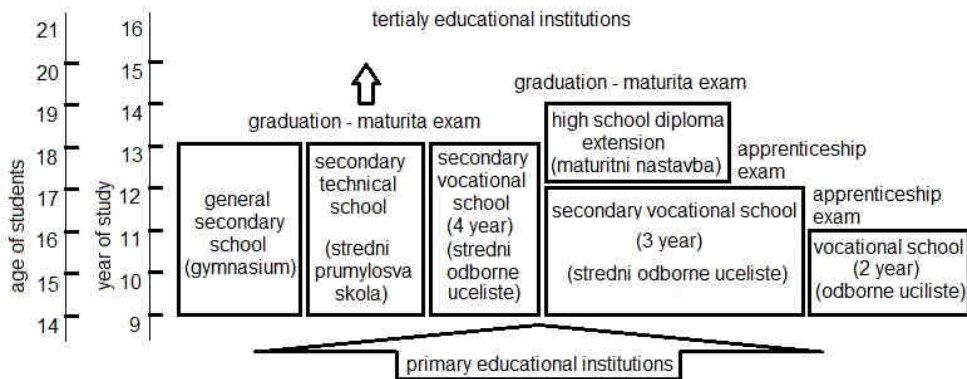


Fig. 1. Structure of Czech educational system

This division of types of high school programs is very old and corresponds to the middle of the twentieth century. The need for a larger number of moderately qualified professionals in addition to the passage of time to the emergence of fields of study with a high school diploma and high school diploma extensions - maturita exam extension. The first of these high schools' program is structured identically as three-year courses (i.e. one week of theoretical training in school and one week of practical training in the workshop for the entire period of study), but the duration is four years and the study ends with a high school diploma. The second type of study program represents a two-year theoretical preparation after a successfully completed three-year secondary vocational school. Graduates of both types of study programs just described can continue their studies at university. Both programs end with a school-leaving examination, but it should be added that, compared to standard four-year study programs, graduates of these fields achieve worse results at universities. This is mainly due to insufficient training in basic scientific disciplines such as mathematics, physics or chemistry. If graduates of these two study programs continue their studies at a university, they have about twice the failure rate of studies than graduates of a secondary industrial school. This fact is caused by a significantly lower level of theoretical training of graduates of these fields, which in turn is due to a lower hourly allowance for these subjects. Students in these degree programs complete, for example, only 60 % of math lessons compared to high school students (students of secondary industrial school). In addition to the secondary schools already described, there are also so-called vocational schools (Odborne uceliste OU, the word secondary has now been omitted in their title), which apprentices attend only for two years. Pupils with significantly below-average study results attend these schools. One of the often-cited shortcomings of the Czech education system, is the disproportionately high number of

pupils from ethnic minorities at these schools. Due to the greater clarity of our interpretation, we decided to display the structure of the Czech secondary education system graphically - see Figure 1. Although we have only mentioned technical secondary schools here, it is necessary to say that schools with a different curriculum (curriculum based in the fields of services, economics and trade or agriculture) have a similar structure.

The issue of teaching technical disciplines or teaching on technical school is closely related to one of the modern concepts often discussed in the literature in modern pedagogy. This term is the so-called STEM education [10-12]. We will address this issue in the next section.

## Concept of STEM education

Currently, we can find many definitions in the literature, which often differ, not only in details [13-17]. In general, we can define STEM education as education that develops students' knowledge not only in fields such as physics, mathematics and technical sciences, but also arouses interest in these fields and enables students to creatively use the acquired knowledge and skills in their future employment. We will list a few of them here and try to describe the most important features of STEM education. For example, Sander in 2009 and a quartet of authors consisting of Bozkurt, Ucar, Durak and Idin in 2019 described STEM education as a teaching and learning method that integrates the content and skills of science, technology, engineering and mathematics, acting as an input [18, 19].

According to the book "The Language of Science Education - An Expanded Glossary of Key Terms and Concepts in Science Teaching and Learning" by William F. McComas, one of the most widely used definitions of STEM education comes from Tsupros [20]. Tsupros described STEM education as "an interdisciplinary approach to learning where rigorous academic concepts are connected to real-world lessons as students apply science, technology, engineering and mathematics in a context that creates connections between school, community, work and global enterprise, which enables the development of STEM literacy and, with it, the ability to compete in the new economy". In the literature, we currently encounter many other definitions, which, due to the limitations of this text, will not be presented here, see for example [21-23]. We currently come across many other definitions in the literature, which we will not present here due to the limitations of this text. In general, governments now place considerable emphasis on STEM education and believe that there is a need to provide enough skilled scientists and technicians to develop the domestic economy.

It must be said that while the concept of STEM is relatively new, the governments' interest in improving the teaching of technical and science subjects and the effort to arouse pupils' interest in these fields is not new. Interest in this area is usually driven by economic or other problems that governments face. In the last century, for example, a major impetus for the United States government's interest in the subject was the fact that a rival power had previously managed to put a satellite into orbit. It goes without saying that a topic often discussed in pedagogy, such as STEM education, also meets with criticism, probably the most significant work criticising the concept of education is contained in the work "The myth of the lack of science and technology", authored by the famous demographer Michael S. Teitelbaum, senior researcher in the "Program on Work and Working Life" at Harvard Law School. For example, critics of the STEM education concept point to the fact that in the United States, only about a quarter of STEM graduates work in STEM fields,

while less than half of STEM workers have a STEM degree [24, 25]. Which means, for example, that most graduates work in other fields. This is due to a combination of factors such as automation and the transition to a service economy. On the other hand, in emerging economies (such as East Asian nations), the need for STEM graduates is indeed very high. This article is specifically devoted to the use of virtual laboratories in the teaching of engineering technology, which reminds us of the pair of letters T and E from the acronym STEM. While authors dealing with STEM education define technology as a process in which the natural is modified to suit human desires and needs, we will understand the term technology in our text much more narrowly, that is, from the point of view of the technicians whose education this article is devoted to. The concept of engineering in the theory of education can be defined as a profession in which the knowledge of mathematical and natural sciences improves the ways of economic use of materials and forces of nature for the benefit of the entry of mankind [26]. Engineering technology is essentially the application of engineering principles and technological developments to create useful products and manufacturing machines. Thus, in the subject of technology, students become familiar with the issues of production, production procedures and individual technologies such as forming, casting, and machining. However, the necessary condition of practical training in workshops does not mean that graduates are prepared for manual work in production. It is supposed to be medium-sized technical workers who are supposed to, for example, prepare production processes, design single-purpose products intended for production, such as dies for closed fittings, etc. It is therefore a discipline in which there is a wide spectrum of knowledge, where other fields such as mechanics, physics, geometry, mathematics. This interdisciplinary nature of the field, along with its constant development, requires a high degree of creativity and learning ability from graduates. In addition, computer science is currently widely used in the given field, where students get to know the issues of numerically controlled machine tools or 3D printing. Computer graphics are necessary not only for the creation of technical documentation, but also for computer-assisted machining.

## **Issues of online teaching and applied teaching methods**

The global pandemic has also caused significant problems in education. A large number of schools around the world were closed for a long time, and in the Czech Republic pupils and students were forced to complete a total of three semesters in a locked state. The period of long-term blocking forced radical changes in the teaching process and the transition to online teaching, e-learning, etc. However, there are courses in which students learn practical activities, and these courses are much harder to replace with online teaching than in the case of a more theoretically oriented subject. A typical example is courses or lessons that are based on the work of students in laboratories.

These laboratories often use measuring devices and other materials that students do not have at home, whether for economic, safety or other reasons. Typical examples are physical and technical laboratories, such as materials testing equipment, tensile testing machines. Considering the importance of practical experience in professional training, it is generally not desirable to give up teaching in laboratories. People working in education therefore had to look for suitable ways of organising laboratory teaching [1, 3, 9].

The concepts on which virtual labs are based vary greatly from case to case. Also, the way students work with these different types of virtual labs varies significantly. Some

teachers have implemented a complete transition to virtual platforms, both commercial and developed directly for teachers for their own lessons, which has been a common phenomenon among university teachers [3, 27-29].

The simplest laboratories essentially use only film footage or animation of the phenomenon being studied. In the case of these simple labs, neither the student nor the teacher can in any way enter the action on the screen and change the outcome of the experiment. Very often, virtual laboratories are based on platforms that allow the student to choose the input parameters and thereby influence the results of the experiment. In this case, the animation will show the course of the experiment and its result. A very typical example of such a virtual experiment in physics is the oblique throw. The student enters parameters such as initial speed and flight direction defined by an angle, and the simulation shows the result in the form of flight trajectory and impact coordinates. Such a virtual laboratory can, for example, offer the results of this experiment without the effect of environmental drag (which high school students can calculate analytically by solving the equations of motion) and the results obtained after taking into account the aerodynamic drag of the environment (which students cannot calculate). The student can then be given the task of compiling a table in which he will estimate the effect of different projectile shapes. Students can familiarise themselves with a similarly designed virtual laboratory in optics by studying the reflection and refraction of light rays. In this case, the student can, for example, choose the direction of the light beam hitting the mirror surface, and the program will show the direction of the reflected beam in the resulting animation. It would be similar in the case of refraction of light when a ray passes through the interface of two optically different media. In this way, students can study the basic laws of optics such as Snell's law in online classes.

Some virtual laboratories are even more sophisticated and allow, for example, to assemble a virtual electrical circuit from various components. So that students can watch flow of electric current through components in the circuit such as electrical resistors, switches, light bulbs, various diodes or appliances such as electric motors or power supplies and determine the voltage on the individual elements of the circuit using virtual voltmeters. Students can then compare the results obtained by their own calculation on paper with the results obtained in a virtual laboratory. The described virtual experiment is a suitable supplement to teaching which the teacher wants to acquaint with Kirchhoff's laws.

Although these virtual laboratories 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 educational institutions, which place great emphasis on the practical part of teaching. 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. It should be added that it is of course appropriate to design home experiments for primary school students. But care must be taken to ensure that these tasks do not become a task for parents instead of pupils, which is also not uncommon.

Homework experiments designed for students may include, for example, experiments on Archimedes' law in the case of primary school pupils and experiments devoted to the periodic motion in the case of high school or first-year college students. An example of a very popular experiment is, for example, the determination of the value of gravitational acceleration based on the study of the motion of a mathematical pendulum. In this section, we have described as examples the most common virtual laboratories we have encountered,

but these virtual experiments are used in the teaching of physics and not in the subject of interest of this article, namely in mechanical engineering technology. The use of virtual laboratories in the teaching of mechanical engineering technology will be described in a separate section.

The aim of this work was to carry out research, the aim of which was to describe the procedures chosen by individual schools to implement more practically oriented teaching, which requires students to work in laboratories and workshops. Another goal was to assess the effectiveness of individual approaches to learning and its organisation during the pandemic lockdown period. This part of the research was implemented using questionnaires.

When assessing the effectiveness of individual methods, it is important to quantify the results. This part of the research was implemented using questionnaires. The qualitative part of the research included interviews with individual teachers.

One of the authors of this research also personally teaches mechanical laboratories both at the high school and at the university. He also prepared and implemented virtual laboratories for teaching engineering technology and technical physics. Students' work in laboratories is closely related to the pedagogical concept known in the literature as "experimental learning" [30-32]. The educational process conceived in this way enables the use of other tools known from teaching methods such as "Project based learning" or "Design based learning" [33-36], and at the same time there are elements known from teaching based on the use of information technology, such as "Blended learning" [35, 37]. We will now briefly look at how these teaching methods are characterised. These methods will be described in the following sections of this text.

### **Experimental learning**

This method known as "Experimental Learning" can be defined as learning through experience and in the literature, it is narrowly defined as "learning through reflection on doing" [38-40]. It is already clear from its name that this method could be combined with laboratory work of students, but experimental learning is in fact a much broader concept. Practically all learning not only from humans but also from animals is in fact linked to everyday life experience. To be precise, this teaching concept is not only related to online learning, on the contrary, it applies to all teaching and is much older than the use of ICT in education, but we mention it here because of its relationship to laboratory and workshop teaching.

Nevertheless, this point of view on the problem is too broad for our purposes, and would be 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" [31, 32, 39, 40]. It is necessary to mention, that experimental learning is both conducted outside of school and in a school building while experimental education is specifically linked directly with carried out school activities. This fact is also evident from the previous mention of learning based on everyday experience in the previous section. Feedback or reflection is an important condition for this method to become truly effective. The very concept of "Experimental learning" comes from Hahn and Dewey. The methodologies reflected in experiential education have evolved since the time of their originators. Concept of "Experimental learning" is based on set of general assumptions precisely defined by the trio

of authors at whose head was Walker [41]. If we cite Walker's work published in the early 1990s, these assumptions will be:

- 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.

Now that we have become familiar with the term "Experimental learning", we can look at the method known as "Design based learning" and the related concept of "Project based learning" [42].

### **Problem based learning**

Originally, the term "Problem based learning" was related to the training of medics, but gradually spread to all areas of education. The aim of this method is primarily the development of skills for future student practice. The role of the tutor is rather supportive and monitoring. This approach to learning is an example of strongly student-centred pedagogy. Therefore, it is not the teacher's job to pass on information to the student, the role of the tutor is to facilitate learning process. This learning approach was pioneered by duo of American physicians Barrows and Tamblyn at McMaster University in Hamilton in the 1960s in order to streamline school preparation of medicine students. The main advantages of this approach to teaching are: Enhance student-centred learning; Upholds lifelong learning; Prominence on comprehension not facts; In-depth learning and constructivist approach; Augments self-learning; Better understanding and adeptness; Reinforces interpersonal skills and teamwork; Self-motivated attitude; Enriches the teacher-student relationship, Higher level of learning. Now list the disadvantages of this method here: Time-consuming; Restrictions arising from pupil's evaluation; High demands of implementing this approach. In conclusion, this approach also served as a basis for further educational methods, especially for "Design-based learning", as stated by De Graff [43].

### **Project based learning and Design based learning**

The terms "Design based learning" and "Project based learning" are two different terms, although they are often confused, even in the specialised pedagogical literature. We will first look at the definition of "Project based learning", which is defined in the literature as instructional methodology which encourages students and pupils to learn by applying knowledge and skills through an engaging experience [33, 34, 44, 45]. "Project-based learning" presents various opportunities for deeper learning in-context and for the development of important skills which are tied to and readiness for college study and future career [33, 46]. On the other hand, "Design-based learning" can be understood as form of project-based learning [46-50]. The form in which students learn what they need to learn in a just-in-time fashion while trying to design something [49, 50]. Sometimes in the literature we can find the name "Learning by design" which is just another term for "Design based learning", but this name is rarely used. In the ideal situations students and pupils work in groups, they work on one task for one to two months. These groups activities devout to solving educational tasks can be understood as specific educational units for high school math, physics, chemistry or informatics and technology classes. Students which are participating in these activities apply methods which are typical for engineering design processes, so these methods serve as a foundational structure for the learning units.

It is obvious that this structure provides better organisational framework of the science learning that takes place inside the classroom and improves the learning outcomes in the same way as it would be in design process. On the other hand, it is very difficult if not downright impossible to organise this course as teaching units in schools which take one or two months.

In practice, however, from an organisational point of view, much shorter organisational units devoted to the work on task are much more often used than the multi-week blocks just described. This can often be, for example, all-day blocks dedicated to a given problem that are repeated every week. This is due to the fact that in order to implement this form of teaching, school principals would have to rebuild the entire structure of teaching in their schools. Thus, forms known from the literature adapt differently in many respects to the conservative environment.

Concept of design-based learning is closely related to the specific form of thinking which is called by Razzouk "Design thinking" [50, 51]. Alexander is describing "Design thinking" as thinking with human-centered core [51]. According Razzouk, when you engage design thinking, you're pulling together what's desirable from a human point of view, with what is technologically feasible and also economically viable at the same time [50].

### **Software instruments of E-learning**

We currently have a number of software tools at our disposal, we have already mentioned Microsoft Teams and Google Classroom. MS Teams, which was the dominant tool for online learning during the pandemic lockdown in the Czech Republic, was not developed primarily as a teaching tool, but a tool intended as a business communication platform. It is a platform whose important function is video communication. In addition, this platform allows you to share text materials, videos, screens, etc. Due to its origin, this software does not include testing facilities in the basic version. In the period before the pandemic, Moodle software was used intensively in Czech schools. Moodle is used for blended learning, distance learning, flipping the classroom, etc. A big advantage of Moodle is the possibility of creating variable tests and evaluating them. Another frequently used program is Google Classroom, which allows schools to create, distribute, or evaluate learning materials for free. The primary purpose of the service is file sharing between student and teacher. Other specialised training programs designed for e-learning are: Edunext; Pocket study; Extramarks; Merits; Toppr; Docebo; Eurekos; Clarify; Adobe e-learning; eLucid [52]. However, the virtual labs presented in this article are based on other platforms that were not designed for educational purposes. In our case, the TeamViewer cloud platform was used to ensure interaction between students and the teacher. TeamViewer is used to provide remote connectivity and enable secure remote access to any device, across platforms, from anywhere, anytime. SolidWorks and Autodesk Inventor student licenses were then used to create the teaching models themselves.

### **Virtual laboratories for Mechanical engineering technology**

As already mentioned, engineering technology deals with production methods, ie what procedure I choose to create a product or component. High school-educated technicians typically very often occupy the position of technologist in production, although it is true that recently, due to the growing number of tertiary graduates, we have met in a very close



position with bachelor's degree holders. Specialists with a master's degree have always worked as constructors and designers rather than technologists. At present, graduates of secondary technical schools most often work as programmers of CNC machine tools. As part of the educational process, students are introduced to a general overview, but at some point, there is a certain specialisation. This early specialisation is often dependent on the company with which the school cooperates.

If we look at the structure of teaching the subject of engineering technology at secondary industrial schools of mechanical engineering. Thus, this subject is taught throughout the four-year study. At the beginning of the first year, students get acquainted with the basics of materials science and the structure of basic technical materials. This part of the study is closely connected with the subjects of chemistry and physics. Students must get acquainted with the phase diagram, Gibbs phase rule, two components system. Particular emphasis is placed on the Iron-carbon eutectic phase diagram and allotropes of iron. Furthermore, students get acquainted with the production processes of pig iron, steel and other materials, the study is based on the application of knowledge from chemistry because it solves problems for basic chemical reactions such as decarbonisation, oxidation, calcination, etc. Due to the limited equipment of laboratories, this part of the teaching is mainly theoretical in nature. It must be said that it is in this part of the study that students achieve, on average, the worst study results in the period of four years of studying mechanical engineering technology.

This phase of teaching is followed by a section devoted to the mechanical properties of materials. This part is closely related to the teaching of physics. Technical laboratories are explicitly applied here, the topics covered in this part are tensile test, determination of yield strength or Charpy impact test.

In the second year, students are typically introduced to the technology of casting, hot forming (i.e. forging and rolling) and finally welding. Within the practical part of the course, students are engaged in a pair of projects, the first of which is a proposal for the production process of a product obtained by casting and the second is devoted to a product obtained by the technique of die forging. In the following sections, we will show one of these models created in a virtual laboratory. In the first semester of the third year, students typically engage in cold forming and cutting. This part corresponds to a practical exercise devoted to the design of a cutting device. For the rest of the study, students then focus on machining such as turning, milling, drilling, grinding and special finishing operations. It is obvious that here, within the framework of technology, students work both with technical concepts and with problems from fields such as physics and chemistry. Each of these study subjects has quite complex didactics by itself [53-55], in our case we can focus on, for example, the propagation of heat in or cooling of castings or forgings which is related to teaching physics. At the same time, the students get acquainted with the problem of the chemical composition of forms and chemical reactions during the processing of metal melts, which is an area deeply connected to the areas of inorganic chemistry and the teaching of chemistry at school. For example, the just-mentioned process of cooling and the transport of heat associated with sleep is an interesting topic for lessons in primary and secondary schools [56]. However, when teaching technical subjects, we must not forget about work safety [57], and environmental aspects of technological processes, so the teaching of these problems is also related to environmental education and ecology [58-60].

## Examples of projects implemented in a virtual laboratory

In this part, we will get acquainted with a sample task - a project on which students in the second and third year of study at a secondary technical school are working. The project has an interdisciplinary character, because during its implementation students apply and further develop skills and knowledge from several subjects, namely physics, mechanics, chemistry and also CAD design. The project is dedicated to the design of a pulley casting for a steel rope. The issue of technologies discussed here is described in a whole range of textbooks, while students in the Czech Republic work with different types of textbooks and materials created by the teachers themselves are used to a large extent. Considering that these texts are in the Czech language and unavailable to the readers of the article, we can refer to one of the basic textbooks in the English language, see [61-64].

### Cast pulley design

This project is dedicated to casting technology. The goal of the project is to familiarise students practically with the process of the production process of a casting obtained by pouring it into a sand mould. It is important that students working on the design master the method of choosing the geometry of the mould, while this geometry is closely related to the physical characteristics of the solidifying material. Therefore, students have to solve several physics problems on the topic of volumetric shrinkage of castings. Furthermore, knowledge from chemistry is applied during the design, which is related to the optimal choice of sand and binder from which the mould is made. Now we proceed to the description of the entire project.

Students first receive an order, i.e. a drawing of the required product, which they would receive from the design office. The students themselves represent the employees of the technological office of the foundry. It is an application of the approaches known as design-based learning and project-based learning. However, students, on the other hand, since these pedagogical approaches are defined, the project is preceded by a lecture dedicated to casting technology, as full self-study would not be time-efficient. However, let's focus on the project itself. In Figure 2 we see a picture of the 3D model and in the Figure 3 is displayed the technical drawing that the students will receive as an assignment.

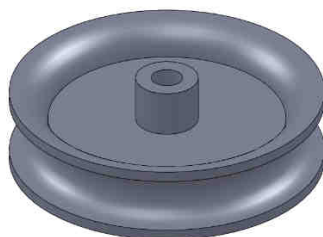


Fig. 2. 3D model of a pulley without technological additions created in the graphics program SolidWorks as part of the project assignment

Furthermore, the students are prescribed the material from which the casting will be made. As we can see in Figure 3, the pulley has the same thick non-bevelled walls everywhere. Therefore, the student will first have to modify the geometry in accordance

with the rules for the production of castings. The student selects the appropriate wall slopes from the table. These slopes depend on the dimensions of the product, the type of material used and the material of the mould (for example, in a sand mould). The design of the shape of the product from the technological additions and bevels can be seen in Figure 4. Now it is necessary to check the dimensions due to the change in shrinkage and the appearance of defects such as macro shrinkage cavity, microporosity (which form of micro shrinkage cavity), cold shut, scab, hot tears, misrun or sand blow and microporosity. The control of the geometry of the mould is realised using a method known as the Heuvers' circle method. Here, students can practice the basics of geometry on a practical case. They can make the relevant measurements either using a ruler and a compass on a drawing on paper and scan the result. Or they can process everything using a graphics program.

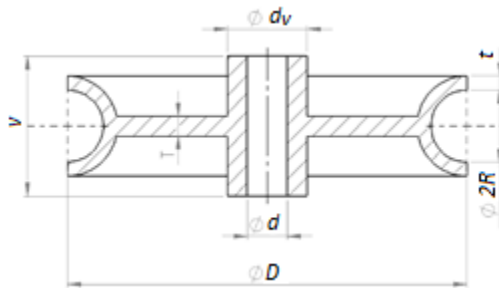


Fig. 3. The technical drawing of the pulley that the students will receive as part of the project assignment

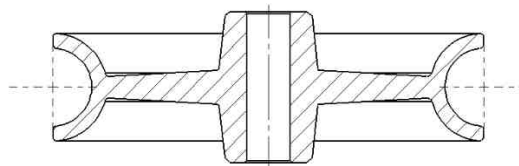


Fig. 4. Technological drawing of the pulley. The creation of a technological model and its drawing is already the task of the students, who must design appropriate technological additions, rounding and bevelling of the casting of the pulley

This is followed by a numerical check of shrinkage on cooling. This allows students to enter several problem questions to be solved. We will present one such here. In the following image - Figure 5, we see an alternative ending of the guide groove for the rope with the edge bent inwards. This edge is to prevent the rope from slipping out due to vibrations or due to a drop in tension in the rope. In this case, the fake core used for modelling the groove will be partially closed (Fig. 5). Students are tasked with analysing the behaviour of the secondary core during cooling or more exactly interaction between secondary core and cast. Furthermore, students have to determine what effect the different thermal expansion of the metal material from which the casting is made and the material from which the core is made has on the internal stress in the casting and in the core.

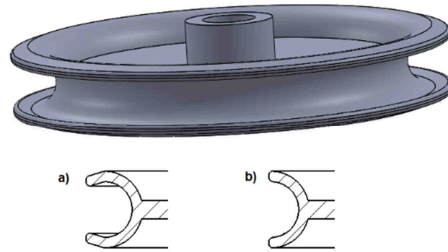


Fig. 5. The 3D model of cast pulleys with a modified groove profile. In sketch a) we see a section of a pulley with a modified, i.e. semi-closed groove, while in sketch b) the original (semi-circular) profile of the groove is visible. In the case of profile 8a, the probability of the rope slipping out of the stop is reduced if we stop tensioning the rope. In this case, however, a higher stress occurs in the casting material during cooling, and therefore an increased incidence of casting homogeneity disorders may occur

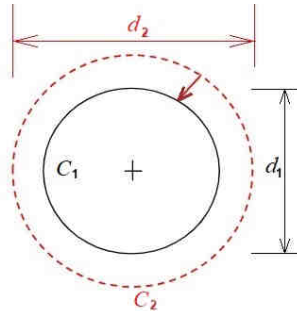


Fig. 6. Reduction of the length of the circumferential groove on the pulley during cooling. The black circle drawn with a solid line represents the groove circumference of the cooled casting at a temperature of 20 °C. We refer to this circuit as  $C_1$ . The circle marked with a red dashed line represents a groove in a heated oil whose temperature is just below the solidification temperature of the metal. We refer to this circuit as  $C_2$ . The red arrow then represents the decrease in diameter during solidification. Circuits  $C_1$  and  $C_2$  will receive a pair of diameters  $d_1$  and  $d_2$

When numerically analysing the thermal expansion of a body with a hole, it should be noted that the size of the body increases as if this hole (cavity) were filled with the given material. However, the task cannot be calculated as a length change in diameter, it must be calculated as a change in circumference, first we calculate the circumference  $C_1$  of the cooled pulley - not shrunken, or cold false core (Fig. 6). It should also be noted that the temperature drops during the solidification and cooling of the casting. The relevant relationships for calculating the circumference and diameter that express their temperature dependence are here:

$$C_1 = \pi d_1 \text{ and } C_2 = \pi d_2 \quad (1)$$

There is a drop in temperature,  $t$ , so the following will apply:

$$\Delta t = t_2 - t_1 \quad (2)$$

Now we calculate the circumference  $C_1$  after cooling the cast pulleys

$$C_2 = C_1 \cdot (1 + \alpha \Delta t) = \pi d_1 \cdot [1 + \alpha(t_2 - t_1)] \quad (3)$$

here it must be said that in our case it is a cooling of the casting and therefore the temperature difference  $\Delta t$  is a negative number ( $\Delta t < 0$ ). Then the diameter  $d_2$  will be:

$$d_2 = d_1 \cdot [1 + \alpha(t_2 - t_1)] \quad (4)$$

We will implement this calculation once for the case of cooling the metal from which the pulley was cast. In the second case, we will consider cooling the false core, which is a ceramic material with a thermal expansion lower than that of the metal from which the casting is made.

If the coefficient of thermal expansion of the core (and also of the false core) of the casting is  $\alpha_{Ceramics}$ , the coefficient of thermal expansion  $\alpha_{Alloy}$  (whereas  $\alpha_{Alloy} > \alpha_{Ceramics}$ ), then using the previous relations we obtain:

$$d_{2,Pulley} = d_1 \cdot [1 + \alpha_{Alloy}(t_2 - t_1)] \quad (5)$$

$$d_{2,False\_Core} = d_1 \cdot [1 + \alpha_{Ceramics}(t_2 - t_1)] \quad (6)$$

Respectively:

$$C_{2,Pulley} = d_1 \cdot \pi \cdot [1 + \alpha_{Alloy}(t_2 - t_1)] \quad (7)$$

$$C_{2,False\_Core} = d_1 \cdot \pi \cdot [1 + \alpha_{Ceramics}(t_2 - t_1)] \quad (8)$$

Then the stress in the cooling material can be estimated using the relation

$$\sigma_T = \frac{C_{2,Pulley} - C_{2,False\_Core}}{C_{2,False\_Core}} \cdot E = \frac{d_1 \cdot \pi \cdot (\alpha_{Alloy} - \alpha_{Ceramics})(t_2 - t_1)}{C_{2,False\_Core}} \cdot E \quad (9)$$

$$F_T = \sigma_T \cdot S_{Node} \quad (10)$$

This relationship is an application of Hooke's law to an arch element - see Figure 7. The area marked as the area of the node is equal to the size of the area described by the Heuvers' circle.

The force  $F_v$  in Figure 6 is then responsible for the formation of structural inhomogeneities in the casting. After identifying the areas of their origin, the entire process can be simulated on a PC. At the same time, however, it is clear that elementary analysis of the process can be carried out by students using simple relations of high school physics.

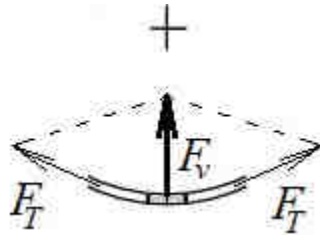


Fig. 7. Scheme of stress on the hoop element, with the help of this scheme it is possible to calculate force on the circumference of the pulley caused by internal stress. Internal stress is the cause of defects in the structure of the cast material

Figure 8 shows a model of an already cooling pulley casting in a mould. Figure 9 shows a volume model of a pulley with a core which is used to create a cavity in a sand mould in the process of its forming. While in the past these models were mainly

made of wood, nowadays these models are also obtained by 3D printing, which can be another task of the students during the work on the project. Model used for cavity forming in is on the Figure 8 marked in blue and the model of the inlet system is marked in red. In the picture we can also see the cavity of the inlet system with the pouring well without the model of the inlet system (sprue system) inserted, see "inlet system with a well".

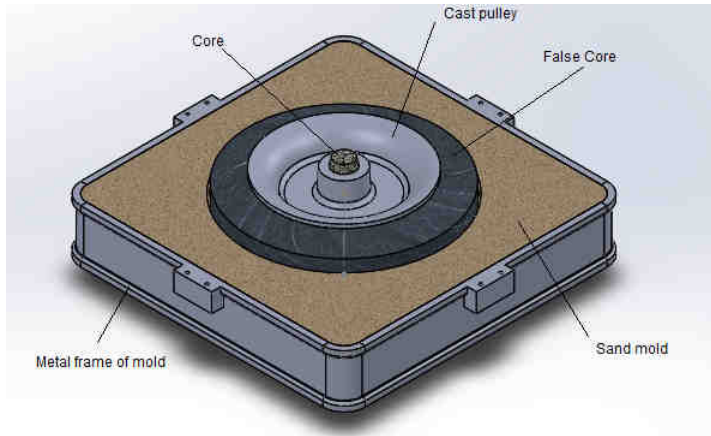


Fig. 8. The lower part of an open two-part mould is containing an already solidified casting of a pulley with a true core forming the central cavity and a false core forming the peripheral groove. This image is a screenshot of a virtual lab designed to teach casting technology

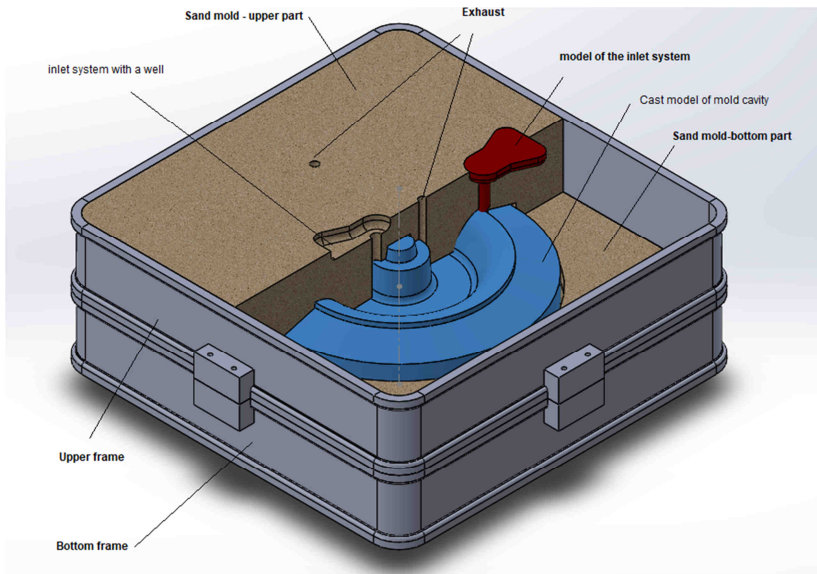


Fig. 9. Mould production in a virtual laboratory. A model that has the same volume and shape as the desired product, supplemented with a core, and in this case also a fake core, is inserted into the frame and covered with sand. After tamping the sand, a cavity of the desired shape is created in the sand

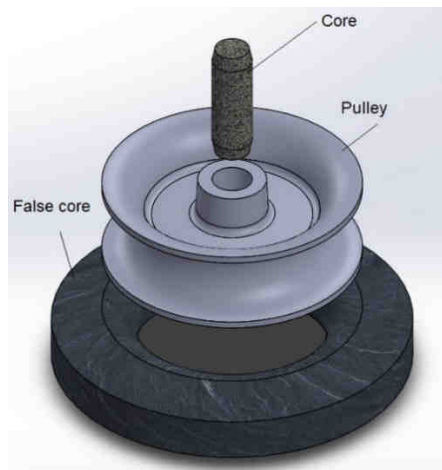


Fig. 10. Dismantled assembly of cast pulley, core and false core in virtual laboratory. In our case function explode was used for dismantling assembly in Virtual laboratory based on SolidWorks 2021

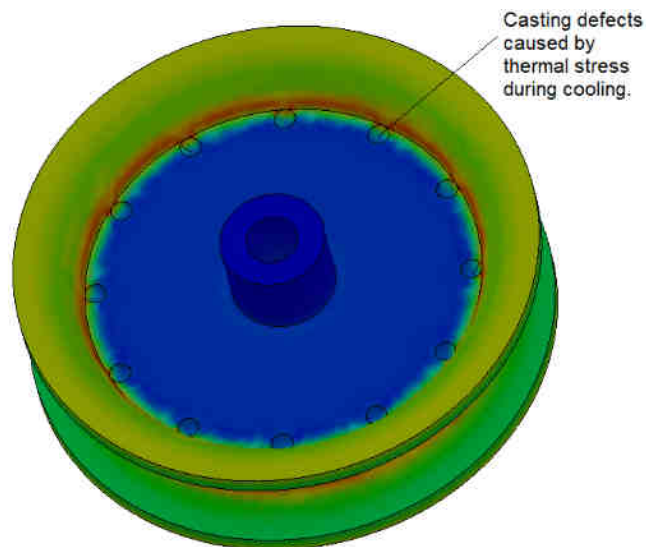


Fig. 11. The simulation of the formation of casting defects in the virtual laboratory is used to verify calculations and to identify places where significant thermal stress occurs in the casting

In the following image from the virtual laboratory, see Figure 10, we see the final casting of the pulley and both cores. These cores are broken when removing the casting from the mould in the virtual laboratory, but we can separate them without destroying them. The last image dedicated to this example then shows a screenshot of the virtual laboratory on which the formation of defects in the casting is simulated - see Figure 11. In this image, the size of the internal tension in the casting is marked with colours, while the red colour represents its maximum value. We see twelve small circular defects on the circumference

as dimples. In reality, these disturbances would not be uniformly distributed around the circumference and would not be identical in size. Which shows that the virtual laboratory does not work with probability and random distribution of impurities in the material, but on the contrary works with the material of the casting as completely homogeneous.

## Realised teaching at school and its evaluation

The virtual laboratory conceived in this way was used in teaching at secondary and higher vocational schools, however, secondary school students used the parts prepared by the teacher to a greater extent. Another significant difference was in the time devoted to the project. The design was implemented in a simple design, it was a geometrically simple casting without a false core (see Fig. 12). Students had a smaller time allowance for this simpler project.

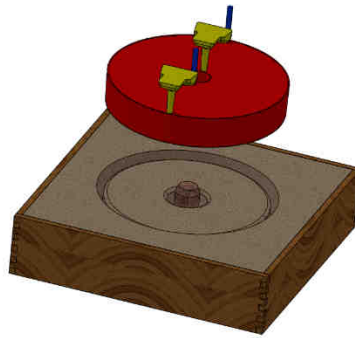


Fig. 12. Model of simple cast pulley (without false core). On the contrary, from the first example, we used the wooden frame of the form

In Table 1 we see basic information about the teaching. This table contains the class (school year) in which the project was implemented along with the type of school. Furthermore, whether the created parts were available for rapid assembly of the model or whether the student had to reprocess everything himself, longer time devoted to work in class and the time the student had to hand in the project, i.e. time for independent work on the project.

Table 1

The use of virtual engineering technology laboratories in teaching

School/ NCG	Year	PAP [%]	TC [hours]	NWD [weeks]	NPY [-]
Uni-1 /3	1	0	12	3.5	3
Uni-2/2	2	50	12	3	6
THs-1/2	2	20	16	4	3
THs-2/3	2+3+4	0	24	8	3
THs-3/1	3	50	12	4	4
THs-4/2	2+3	20	18	6	2
THs-5/2	2+3	20	24	6	2

When we look at Table 1, we see that the type of school is listed in the first column. The abbreviation Uni stands for university and the abbreviation THs stands for Technical



High School. Abbreviation NCG stands for number of classes or study groups. In the second column, the grades (years) at the given school are marked with a simple number. In the third column, it is indicated whether the teacher provided any completed parts to the students for editing and what percentage of the total assembly these provided parts represented. This column is denoted by the abbreviation PAP for the proportion of available parts. The next two columns contain the time allowance intended for teaching. The first of these columns contains the time subsidy intended directly for teaching in the lesson. In our case, when it comes to online teaching, it is the time when the teacher and the student are in direct contact through one of these systems such as google.class, TeamViewer and many others (as it was during the pandemic or as it may be in the case of distance learning). During this time, they share screens, as well as individual parts with the teacher, etc. This time is referred to as TC, which stands for time in the class. This time is given in hours. It is clear from the table that with the number of parts available to students, the time needed to implement individual projects decreases and the number of projects implemented per semester increases.

The next column then shows the number of weeks for which the students worked on the project, so it is rather the time that was left for the students to work independently at home, NWD. We can say that it is also a matter of determining the deadline for handing in homework from the beginning of the project. This time is given in weeks and is indicated in the table by the abbreviation NWD, which indicates the number of weeks until the deadline. The last column shows the number of projects implemented in teaching. The last column shows the number of projects implemented in teaching. The corresponding abbreviation is NPY as number of projects per year.

Table 2

Student failure and teacher and student evaluation of teaching

School/ NCG	ANS [-]	SNC [%]	SEG [-]	TEG [-]	ESW [-]
Uni-1 /3	28	52	3	4	3.2
Uni-2/2	14.5	32	2.1	3	2.9
THs-1/2	13.5	13	3	2.5	2.9
THs-2/3	12.5	16	2.1	2.4	2.4
THs-3/1	17	7	1.3	2	1.8
THs-3/2	13	12	2.5	2.2	2.1
THs-5/2	14.5	9	2	2.5	2.7

Table 2 then shows the students' success rate and their teaching evaluation. The second column in the order contains the average number of students, ANS in the group. Considering that this is a lesson that was originally conceived as a lesson in a computer room, the lesson is in most cases carried out in smaller groups from 9 to 17 students (the average was then 13.8). Only at one school was the average number of students higher, namely 28 students. This first school listed in the table three groups and thus significantly increased the number of students in the study. The total number of students was 249 and of these 84 were in the school designated as Uni-1. If we include the students of this school in the statistics, the average number of students in a class will be 16.5. The third column of this table shows the proportion of students who did not complete the work at all, which was related to reduced motivation during the Covid period. This column is marked with the abbreviation SNC as filled in unsuccessfully. The following column indicates the average grade that the students evaluated the form of teaching in the

virtual laboratory, here we used the abbreviation student evaluation grade SEG. The fourth column indicates the degree with which the teachers evaluated the form of teaching in the virtual laboratory, here we used the abbreviation teacher evaluation degree TEG. Both students and teachers rated the lesson from 1 to 5 as in classroom teaching. In the last column is the degree of classification that the students received from the teachers for their work. In this case too, a classic scale of 1 - the best and 5 - the worst was used. In this case, the column is labelled ESW, so this abbreviation stands for Student Work Evaluation.

Apparently, student evaluation was often influenced by personal experience with communication with the teacher rather than technical issues. Furthermore, students positively evaluated a lower burden if they were provided with some already prepared parts for the design. Teacher evaluation was apparently strongly influenced by the number of student failures, which is evident in the case of university students. The high rate of failure among university students is probably related to low motivation and the fact that at the beginning of university studies they are already without parental supervision and at the same time many of them work in various part-time jobs. So, it is not a mistake from the presented teaching approach. It is clear from the results of the table that students achieved the best results when working in the laboratory with the highest proportion of prefabricated parts.

## Conclusion

The paper presented here showed one of the possible approaches to the use of ICT in the teaching of technical subjects. The approach is based on the fact that we will build a virtual laboratory - a design or technological office based on one of the commonly used programs such as SolidWorks, and in the lessons, we will combine it with the use of programs used for communication with teachers and classmates, such as TeamViewer or Google class.

Teaching conceived in this way is relatively easy to implement and was positively received by the students. The total number of students participating in the study was 249 from seven different schools. Teaching was carried out in a total of 15 different classes or study groups. The average number of students in the group was 16.5. Teaching, in this way makes it possible to apply approaches known from STEM teaching and to combine knowledge from mechanical engineering, physics, engineering sciences and information technology so that students can develop their practical skills in these disciplines.

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