The application of 3D printing systems in the bachelor’s engineering educational process

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Abstract. In this article the abilities of 3D-printing technologies in the bachelor’s educational process are considered in the specialties of electric power industry and electrical engineering. An example of the 3D printing systems implementing in the educational process and the experimental modeling is presented in research works of students. The analysis of problems arising in the implementation of 3D printing systems was made and the assessment of the student’s interest degree and motivation in operating with this technology were carried out. As a result, it was concluded that 3D printing can help create an improved learning environment for students, and takes into account different methodological styles of the educational process.

1. Introduction
The modern approaches to the educational process require a flexible management to submission and training. As usual, it is required an attitude to the new technologies in the acquisition of knowledge [1-3]. At the same time, the applied educational methods can contribute the development of self-contained skills and the ability to learn, that are the key experiences in modern society and in the workplace.

The researches directed to the assessment of the interest degree, motivation and understanding of academic content by students and practical demonstrations which were prepared with using 3D printing show that about 70% students would like to have an ability to create their projects using 3D printers, and 30% are ready to apply this technology in their education. But at the same time, with the increasing of the amount of experience, capabilities and additional completeness of 3D printing systems, the percentage of customers interested in these technologies [4] is also growing.

2. 3D printing technologies in experimental education
The 3D printing technology is one of the forms of additive production (creating an object layer by layer). At the present time, it is possible to produce objects via 3D printing process with various colors, materials, physical and mechanical properties. The 3D printing is also widely applied in various industries for production and design of different kinds of products: jewelry, shoes, cars, aerospace industry, architecture, medicine, etc.

The numerous researchers note the main argument in favor of the 3D printing implementation that these technologies have no creative restrictions and can be implemented and tested in the real world [5].

The researches of 3D printing application in schools, universities, libraries and special education institutions describe six categories of usage: teaching of students to make 3D printing; training of
teachers to make 3D printing; as an auxiliary technology during education; the production of objects of study; the creation of ancillary technologies; the support of researching and educational activities [5].

The implementation of 3D technologies for the designing of various devices and models applying in the educational process, including the implementation of 3D printing systems as an auxiliary system in engineering education, provides the opportunity to expand and transform the ways of studying various topics of science, technology, engineering and mathematics. As an example, we can consider the series of Hapkit devices installed in classes at Stanford University. The devices are used as laboratory demonstrations associated with Simulink models to demonstrate to students the effects of PID regulators and advance/lag controllers, as well as the frequency response of the system [6]. The development of a one-to-ten-scale 110 kV step-down substation educational model designed to improve the educational process in the electric of power engineers education is a similar example [7].

Since 2014, the Department «Electric Power Engineering» of the Polytechnic Institute of the Siberian Federal University has been conducting a gradual study of opportunities and the introduction of press 3D technologies into the educational process. During this operation, several types of wind turbines and models of substation’s high-voltage equipment were modeled on the 3D printer (figure 1). The obtained achievements are actively used in career vocational guidance with schoolchildren and students (figure 2).

3. Study case of the effect of luminous flux inclination on illumination
On the basis of 3D modeling technologies, the methodology of educational and laboratory research was developed to study various optical systems of luminaires (diffusers) and their effect on the room’s illumination.
The luminous intensity curve is showing the distribution of the luminous intensity from the source in the space is usually presented in the form of tables or graphs (figure 3), in which the luminous intensity curve is represented in the polar coordinate system. The luminaire intensity distribution can be determined experimentally.

![Figure 3](image.jpg)

**Figure 3.** Typical luminaire intensity curves. $K$ – concentrated; $D$ – deep; $C$ – cosine; $L$ – semi-wide; $M$ – uniform; $W$ – wide; $S$ – sinus. Light intensity distribution measurement scheme.

During the selection of the lamp, it is also necessary to take into account several requirements for light sources established by regulatory literature:

- The conditional shielding angle of LED lamps at least 90° means the prohibition of ceiling lamps in which LEDs not covered by the diffuser are visible.
- The overall brightness of LED lamps is not more than 5000 cd/m² – it’s a condition that allows you to look at the lamp without visual discomfort. Such brightness corresponds to the brightness of the window opening visible from inside the room on a sunny day (figure 4).
- The condition of non-uniformity LEDs brightness $I_{max}:I_{min}$ smaller than 5:1 is the requirement to use a diffuser, behind which there are no unpleasantly bright LEDs [8].

![Figure 4](image.jpg)

**Figure 4.** The LED illuminator and measurement of non-uniformity of its brightness.

The 3D printing technology allows to create complex volumetric designs of luminaries with different degrees of transparency or reflectors to obtain the necessary light intensity curve (figure 5).
Figure 5. The luminaire models developed by students during education.

Figure 6. The study case of point directional luminaire.

During the designing of the luminaire with a narrow light irradiator (figure 6) is possible to change the angle and shape of light by simply changing the diffuser, and the point light can become a scattered light or a directional spotlight. From the designer's point of view, it is also better to have a light irradiator with a narrow angle of the light intensity curve, and then changing the output angle from very narrow to wide to get the desired lighting effect.

Figure 7. The study case of point directional luminaire with the diffuser.

For example, if a source of the light has an angle of 5°, it is possible to obtain a very narrowly directed ray of light with high light intensity or using a diffuser to obtain an angle of up to 80°. You can also change the shape of the ray from circular to highly elliptical (figure 7).
During this work, students faced the following problems: printing did not stick to the printing platform; insufficient plastic was extruded, holes appeared on the extreme layer, hairs or a web; there was displacement of layers or poor filling layers; filament was stuck; the extruder was clogged; the extrusion process was arbitrarily terminated; the layers separated and split; uneven angles and scratches appeared on the finished figure; holes and gaps appeared between the angles; too small parts were not printed; non-uniform extrusion occurred, etc. All these troubles caused the delays in operation and numerous reprints of the same project. These problems, as well as the limited time to complete the work, led to the fact that the project "surrendered" in the form of a 3D drawing without producing a real model, and later students refused to print their 3D projects, preferring to work with software.

There were also many students who received the model after printing faced to the problems in applying their results because in practice there is a need to use special plastics that must meet the requirements of safety, environmental friendliness, aestheticity, etc. Without taking into account the mechanical properties led to the need to make changes to the model, for example, a lens or cover should have thicker walls using plastic grades with high impact resistance. Without taking into account the conditions of the installation site led to a rapid aging of the model, for example, an ultraviolet-sensitive absorber should be introduced into the plastic in the bulk material or an additional protective layer should be used. In some cases, improvements in fire resistance were required, especially when the project had to meet fire standards.

4. Conclusion
The various researchers of direct and indirect learning methods are unanimous in the knowledge that learning occurs when interacting with other people or interacting with the environment. All teaching methods have their advantages and disadvantages, so the teacher must be able to adapt the teaching methods to the training profile of his students. The combination of theory, practice and experimentation is the ability to develop in learning and arouse interest in one's discipline and learning in general.

Although in most of disciplines studying in universities dominate the theoretical learning profile, various examples show that students appreciate more active and experimental teaching methods.

In the example of the study case, the ability to observe and to experiment with light scattering at different light sources led to students a completely different experience comparing to traditional approaches with images and even animation in multimedia presentations. This provided a real translation of theoretical concepts and associated numerical calculations, which students could not fully appreciate or understand. It can be noted that disciplines using the 3D printer can improve the performance of various groups of students according to their own preferred learning styles: active, reflexive, theoretical and pragmatic. However, the opposite action can also be noted when performance deteriorates, and students start working with reality, preferring the virtual world of 3D models and theoretical reasoning. This leads to the need for a clear plan with the dosed introduction of new technologies, when teachers and students gradually study and work with their projects in a number of disciplines, creating an educational environment that meets the new conditions.

References
[1] Kovalenko I V 2018 Application of 3d technologies in teaching bachelors In the collection: Breakthrough scientific research as the engine of science International Scientific and Practical Conference 70-3
[2] Kovalenko I V and Mogilevets F A 2019 The use of augmented reality systems in the systems of maintenance and repair of energy enterprises In the collection: Energy: management, quality and efficiency of energy resources use Proceedings of the IX International Scientific and Technical Conference 92-6
[3] Mogilevets F A 2019 Analysis of the use of augmented reality systems in industry based on a smartphone In the collection: Theory and practice of modernization of scientific activity Collection of articles of the International Scientific and Practical Conference ed Sukiasyan
Asatur Albertovich 73-8

[4] Fernandes C F and Simoes R 2016 Collaborative use of different learning styles through 3D printing 2nd International Conference of the Portuguese Society for Engineering Education (CISPEE) 1-8 doi: 10.1109/CISPEE.2016.7777742

[5] Ford S and Minshall T 2019 Invited review article: Where and how 3D printing is used in teaching and education Additive Manufacturing 25 131-50

[6] Martinez M O et al. 2016 3-D printed haptic devices for educational applications IEEE Haptics Symposium (HAPTICS) 126-33

[7] Egorov A, Larionova A and Kovalenko P 2019 3D Printing of 35, 100, 220, 330 and 500 kV Gas-Insulated Current Transformers (UETM TRG Series) IEEE 60th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON) 1-5

[8] Sharakshane A 2012 The minimum area of the diffuser at which the luminaire does not dazzle Modern lighting technology 3 27