

Use of 3d Modelling and Printing Capabilities in Students' Project Activities in the Study of Comparative Anatomy of Animals

T.Yu Kolpakova¹

Federal State Budgetary Educational Institution of Higher Education Omsk State Pedagogical University, Omsk, Russia

¹ ORCID: 0000-0001-6213-7844, kolpakova@omgpu.ru

Abstract

The article discusses the possibilities of using 3D technologies in biological laboratories of the Technopark of universal pedagogical competencies of Omsk State Pedagogical University when training future bioecologists and biology teachers. The features and potential of using new methods in training students - biologists and future teachers - are revealed. The authors present the results of using new equipment in teaching comparative animal anatomy in a pedagogical university. The article discusses the possibilities of development and creation of a training 3D model, features of printing on a 3D printer and subsequent refinement of the model of different types of animal vertebrae, which allows you to clearly demonstrate the features of their morphology and spatial arrangement, which increases the efficiency and quality of education of students. It is shown that the use of modern 3D technologies provides a certain advantage by adapting the educational process to the modern requirements of the digital educational environment, increasing the visibility of anatomical objects, which increases the efficiency and quality of students' learning. Project activity of students involves an independent creation of three-dimensional anatomical models of different types of animal vertebrae, which contributes to the development of a creative approach in acquiring knowledge and skills. Such creative work creates a good emotional atmosphere, increases motivation for learning and the level of self-esteem, and significantly complements the process of studying comparative animal anatomy.

Keywords: comparative anatomy, modeling, axial skeleton, three-dimensional printing, technology park of universal pedagogical competencies.

1. Introduction

The new federal state educational standards of higher professional education, introduced in Russian universities, transform the concept of teaching subject-methodological disciplines [1,2]. These changes imply more independent work for students and for teachers - the search and implementation of new effective educational technologies in the educational process.

3D printing technologies have been known for almost 40 years. In recent years, the use of such modern technologies plays an increasingly important role in business, in everyday life, and in the world of education, significantly improving the quality of learning, improving the perception of educational material [3,4,5,6].

In modern biology, 3D technology has found a wide range of applications. One of the many practical applications of CPS is interactive exhibits in museums [7]. Despite the development of this technology, its impact on education is relatively less due to the lack of necessary knowledge among both students and teachers [8]. But currently there is a significant increase in the use of three-dimensional modeling and printing in educational institutions, where these technologies are excellent assistants in organizing the educational process [9,10]. 3D printing technologies have the potential to improve both science, technology, engineering and

mathematics (STEM), as well as professional and technical (STEM) education, as well as to bridge the two educational fields and provide opportunities for cross-curriculum collaboration [6]. This applies especially to the study of human and animal anatomy. Therefore, nowadays the teachers of these disciplines are faced with the task of significant transformation of the educational process; the tasks of activation of students' cognitive interest, namely, stimulation of their independent cognitive activity are put in the foreground.

Thus, the teaching of comparative anatomy of animals requires improvement of the technology of teaching students and solving problems to develop their thinking and creative potential, self-organisation in the acquisition of knowledge. And it is especially important to maximise the use of the opportunities of practice-oriented education, which includes: active methods of acquiring and mastering knowledge; motivated support of educational activities; support for freedom of scientific inquiry; analysis of personal experience; strengthening social integration in the educational process.

3D technologies can provide significant assistance in solving these tasks.

Three-dimensional modelling is the construction of a virtual model of an object in three-dimensional space. This process conveys the shape, appearance of the model and other parameters as accurately as possible.

When studying the course of comparative anatomy of animals, it is not often necessary to conduct anatomical studies and use the dissection method in the classroom, due to the lack of sufficient zoological anatomical material and limited classroom time, therefore, 3D models have an advantage. Working with 3D models is much easier, as you can examine any anatomical organ in detail from all sides, even the smallest, simply by zooming in on the object. Files with 3D models can be sent, posted on an educational portal and discussed remotely.

With 3D printers becoming more affordable, educators have more opportunities to use these technologies in their labs, making their research more interesting and fulfilling.

The process of three-dimensional modelling of anatomical structures implies a good knowledge of anatomy, understanding of the spatial organisation, and topography of individual organs. Mastering the comparative anatomy of animals is more successful if students actively participate in research work, with special emphasis placed on the features of the evolution and morphology of individual organs and systems. Here, the project method allows students to create reality, form and develop a learning situation.

One of the main issues in the study of the musculoskeletal system is the structure of the axial skeleton of vertebrates and its development in phylogenesis.

The spine is the segmented biomechanical basis of the locomotor apparatus and the entire body of any vertebrate animal; its structural unit is the vertebra. The vertebral bodies of representatives of different groups of animals are very diverse in shape. For example, in cyclostomes, the function of the axial skeleton is performed by the notochord, vertebral bodies are absent, and only the rudiments of the upper arches are present. In cartilaginous fish, vertebral bodies are formed as a result of the penetration of skeletogenic mesenchyme cells into the fibrous membrane of the notochord, they cause its cartilage. These vertebrae are amphicoelous in shape; the body of such vertebrae has the appearance of a short cylinder, concave at both ends.

In most modern bony fish, the vertebral bodies are formed as dermal or superimposed bones; they remain amphicoelous in shape and are connected through the remainder of the notochord, which is surrounded by an elastic connective tissue membrane.

Modern amphibians have two types of vertebrae. In representatives of tailless amphibians, vertebral bodies develop from the base of the upper arch, procoelous vertebrae are formed, intervertebral cartilage develops between the vertebrae, displacing the notochord, and the bodies of these vertebrae are convex posteriorly. In tailed and legless amphibians, the vertebral bodies form a thin bony cylinder that arises without a cartilaginous precursor (as in bony fish). In higher tailed amphibians, opisthocoelous vertebrae are formed; between the vertebrae there is also intervertebral cartilage; the bodies of these vertebrae are convex in front and concave in back. In reptiles, as well as in higher tailless amphibians, the vertebrae are

procoelous. The vertebral bodies of birds acquire a complex heterocoelous or saddle-shaped shape. Mammalian vertebrae have flat intervertebral discs that consist mainly of fibrous cartilage, similar to platycolic vertebrae.

Despite the information available in numerous educational literature on the structure of the animal skeleton, the functional, biomechanical and evolutionary transformation of the spine has been much less studied than the structure of the limbs. This can probably be explained by its position deep in the animal's body and its structure of a large number of short bones - vertebrae.

In the process of studying the axial skeleton of animals, students encounter some difficulties in creating a three-dimensional visual image, a spatial representation of the anatomy of different shaped types of vertebrae.

Therefore, the goal of the project work is to create a collection of different types of animal vertebrae using modern 3D modelling and printing technologies.

2. Material and methods

In the project work, the freely available professional program Blender was used to create three-dimensional models of five different types of animal vertebrae [11]. This program allows you to use different types and techniques of modelling, which makes it possible to develop more accurate models.

UltiMaker Cura software was used to prepare models for printing. After moving the file to the editor (slicer) and some preparation, the program itself "slices" the model into layers, places supports for overhanging elements, and calculates the time. Slicer settings play one of the main roles in 3D printing. They determine the printing time, strength and appearance of the finished product [2,3,11]. The range of settings variation depends on the required properties of the finished product, the type of plastic and the functionality of the printer. There are also no completely universal settings. All settings may vary from model to model, even when printing with the same type of plastic on the same printer. The main parameters that we paid attention to first of all were table temperature, nozzle (printing) temperature, layer height, wall thickness, bottom (lid) thickness, printing speed, and filling.

So the temperature of the table ensures the adhesion of the first layer of plastic to the table itself, which prevents the printed product from moving during the printing process. A table temperature that is too low does not provide sufficient adhesion, while a table temperature that is too high softens the plastic so much that it deforms from the load from above. In our case, the table temperature varied between 60-65°C.

The nozzle temperature determines the operating temperature of the supplied filament. Correctly selected temperature allows you to avoid possible artefacts during printing. Often, plastic manufacturers indicate the recommended printing temperature of their plastic, but in any case, each type of plastic has its own range. In our case, the optimal temperature, depending on the conditions, was 205-210°C.

The layer height determines the height of the plastic layer, the number of layers in the model, the printing time (more layers - longer printing) and, in cases of complex shapes, the detailing of the finished product. Through trial and error, it was discovered that a layer height greater than the nozzle diameter leads to a significant deterioration in print quality. For us, the optimal steel height is 0.1-0.2 mm.

Wall thickness allows you to adjust the thickness of the walls in the printed product. Most often it is based on the diameter of the nozzle (a thickness of 0.8 mm means two layers of wall with a nozzle diameter of 0.4 mm). In this setting, we most often left the standard value (0.4 mm), but for some models where greater reliability was needed, we set the value to 0.8 mm or more.

The thickness of the bottom (lid) allows you to adjust the height of the first and last layers, printing speed, etc. Separate from the general model. This allows you to change the printing

pattern to save time or change some properties of the product. Most often, this parameter did not exceed 4 layers for the bottom and 1 for the lid.

Print speed controls the speed of filament flow, the speed of movement of the print head over the workpiece and, directly, the printing time. In addition to time, it affects the strength of the finished product (lower speed - slower flow - greater adhesion between layers). For us, the optimal speed was 40 mm/s.

Infill plays a huge role in strength, weight, cost and printing time. Since completely filling the model is very time-consuming and resource-intensive, the product is often printed hollow, but with stiffening ribs. This parameter allows you to configure the pattern of stiffness lines, their density and location in the product.

Direct printing was carried out on a ZENIT printer, model ZENIT DUO. This printer belongs to the so-called FDM (Fused Deposition Modeling), all devices of this type are quite simple to operate and do not require specialised training [11]. Thermoplastic was used as a printing material, in the form of a spool of thread, black and white.

The development of the model of each type of vertebra took place in four stages:

- 1) development of a 3D model of the future vertebra;
- 2) preparing it in a special program for 3D printing;
- 3) actual printing on a 3D printer;
- 4) processing of the printed part.

3. Results and discussion

Biology uses a huge variety of visual teaching aids: tables, diagrams, models and, of course, natural objects. These learning tools make classes more interesting, facilitate understanding and assimilation of material, attract interest, and develop thinking and memory. But modern students prefer, when preparing for classes, to use various kinds of information and communication technologies, including 3D technology products, for example, the electronic anatomical atlas "Pirogov" that we have at our disposal. With the introduction of digital technologies into the learning process, teachers also need to use a wide variety of forms and methods of presenting educational material [12].

Three-dimensional modelling is an effective way to study individual organs and systems in animal anatomy. Modelling is not used directly in the educational process, when studying the comparative anatomy of animals; it has received the greatest interest in the educational, research and project activities of students.

The Department of Biology and Biological Education of Omsk State Pedagogical University has quite a variety of visual aids, models on the comparative anatomy of animals, and there are osteological sets of natural vertebrae of five different types: amphicoelous, procoelous, opisthocoelous, heterocoelous and platycoelous. But the vertebrae are small and in a fixed state (glued into a box), which complicates their detailed study.

Therefore, as part of the students' project work, it was decided that the students would independently develop 3D models of different types of vertebrae and print them on a 3D printer.

But this was preceded by a lot of work. In the Technopark of Universal Pedagogical Competencies of Omsk State Pedagogical University a master class was held for university teachers on the basics of 3D modelling and 3D printing, where we studied the basic principles of model construction, stages and methods of working with a 3D printer. Then a similar event was held for students, where 3rd year students majoring in bioecology had the idea of creating a collection of different types of animal vertebrae. Work on the project began with studying theoretical material about 3D printers, their types, printing materials and their features were studied. The project team members learned to work in programs for creating models for printing, learned to prepare models for 3D printing in programs designed to work with three-dimensional objects, and create simple three-dimensional models (Fig. 1 - 4).

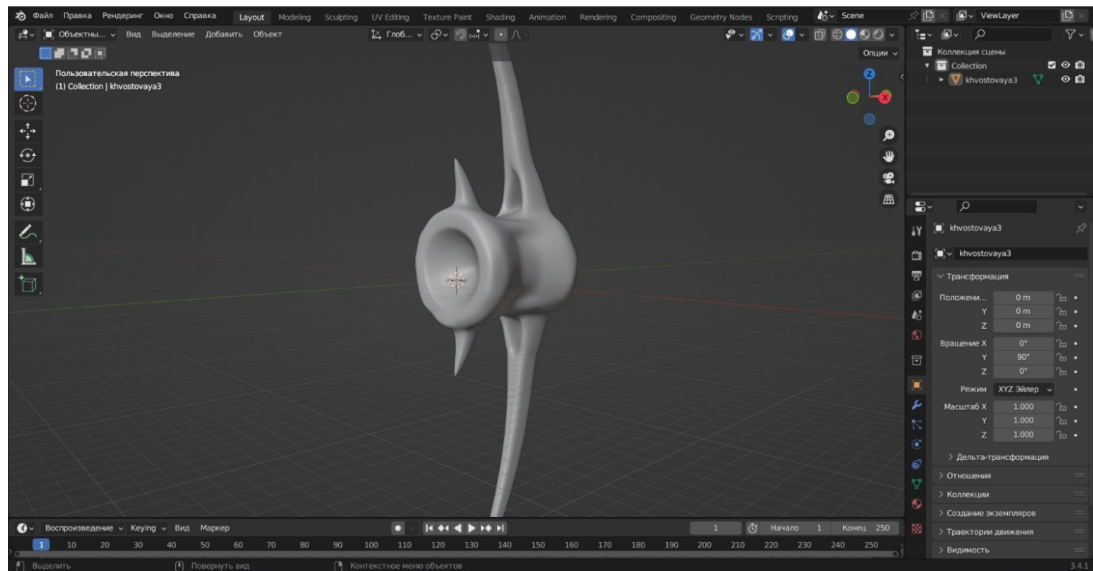


Fig. 1. Working in Blender to create a model of an amphicoelous vertebra of a fish



Fig. 2. Working in Blender to create a model of an amphibian procoelus vertebra

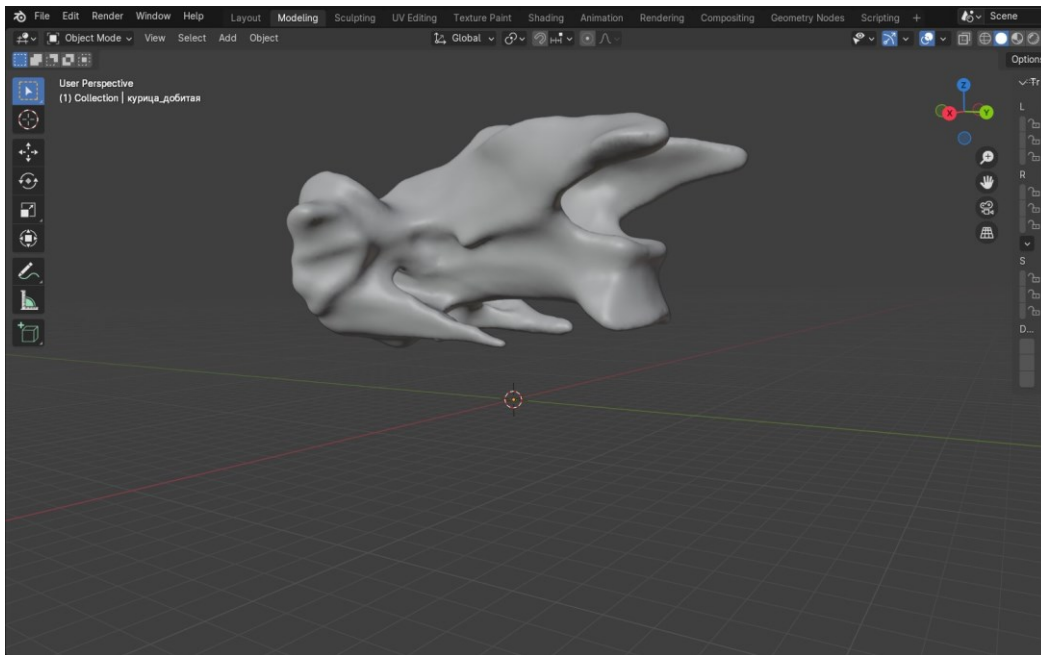


Fig. 3. Working in Blender to create a model of a heterocoelous vertebra of a bird

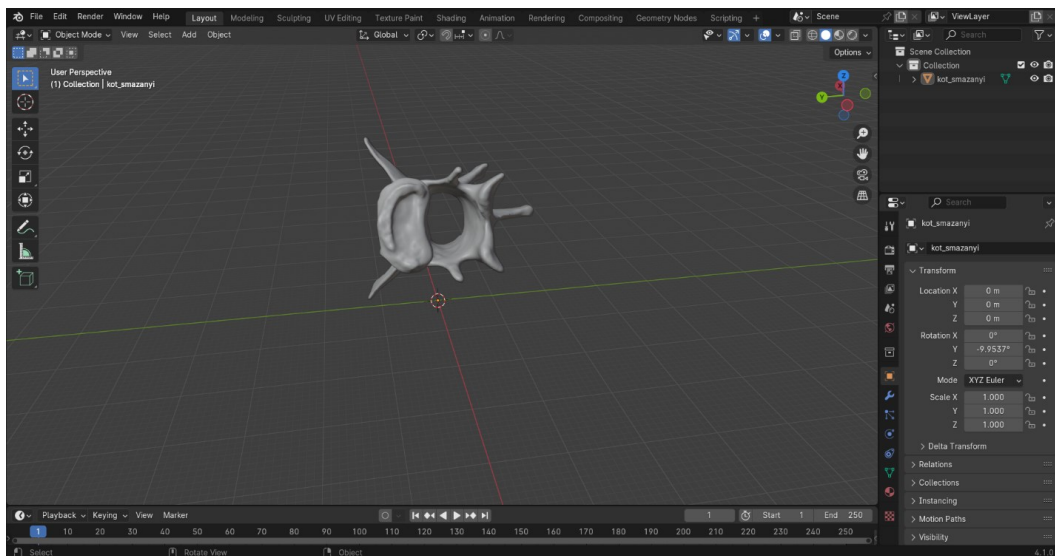


Fig. 4. Working in Blender to create a model of the platyclerium vertebra of a mammal

We learned to work with an FDM printer, its auxiliary parts and software. This is how the slicer program allows you to customise the parameters of the printed model. Printing is done by feeding filament onto the printing surface. The main part of the printer consists of the guides and the extruder, which consists of a hot-end, a heating block and a nozzle. Printing occurs at temperatures up to 70°C. After the part has cooled, it can be removed. The finished model still has auxiliary supports and an uneven surface [13].

The supports are simply removed by hand while the part is still warm. In thin places it is better to use cutting tools, such as a stationery knife. The final treatment of the part was carried out with a solvent (dichloromethane) using a brush. The method of coating with a solvent in a “bath” did not suit us, since the part had many thin elements that began to change the geometry before the main part took on an acceptable appearance. Solvent bath dipping was abandoned due to the fact that the solvent flowed and remained in hard-to-reach places for too long, which also greatly deteriorated the appearance of the part [13].

Members of the project group simultaneously studied the anatomical features and morphometric characteristics of amphicoelous, opisthocoelous, procoelous, heterocoelous and platycoelous vertebrae of animals. We found out that vertebral bodies come in different

shapes, they may have additional processes. The shape of the articular surfaces of different types of vertebrae changes due to the animals' need for body mobility.

After a lot of preparatory work, we began the actual implementation of the project, 3D modelling and printing.

There are certain requirements for manufactured models: proportionality, information content, sketchiness, low labour intensity [7]. Based on these requirements, the morphology of future vertebral models of different classes of animals was presented (Fig. 5).

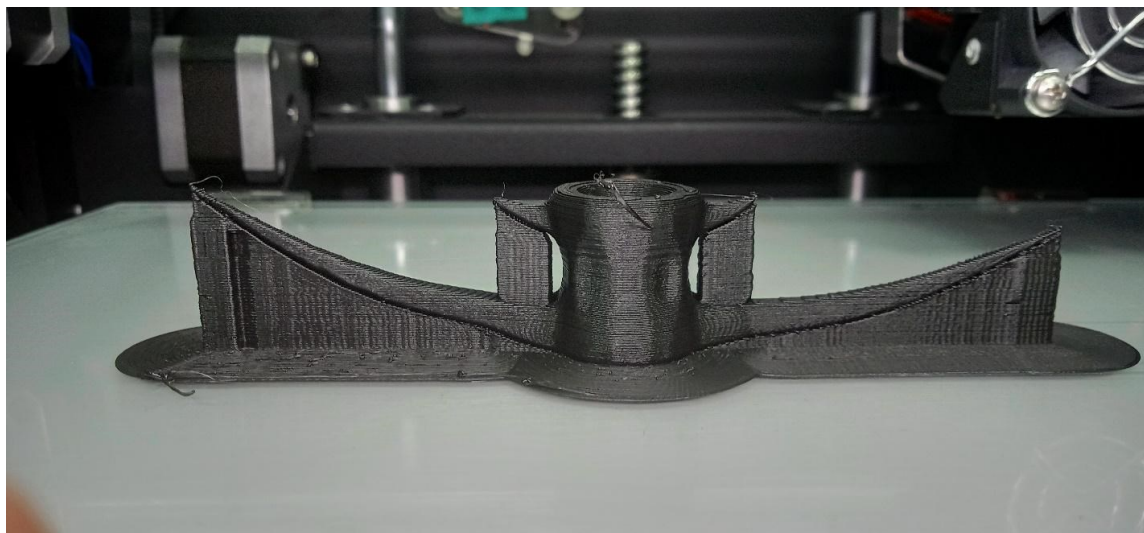


Fig. 5. The process of creating a scaled model of an amphicoelous vertebra using FDM printing

The printed vertebral models are good scaled copies that accurately convey the complex anatomy, spatial structure of each type of vertebra and allow for detailed study.

4. Conclusion

In the process of working on the project, students studied the axial skeleton more qualitatively and identified the main morphophysiological adaptations in a number of vertebrates during the transition from an aquatic lifestyle to an active terrestrial one. During the work on the project, the capabilities of 3D modelling and printing technologies of anatomical objects were studied. Models of 5 different types of vertebrae were made, which are used in the study of the axial skeleton of vertebrates in the discipline of comparative animal anatomy. The manufactured vertebrae are scaled replicas of natural animal vertebrae. The defects present on them can be easily eliminated by subsequent processing.

Work on the project contributed to the activation of students' cognitive activity and the ability to work in a group. The creation of three-dimensional models of different types of vertebrae contributed to the development of abstract thinking and the development of skills in working in the information space. This kind of creative work creates a good emotional atmosphere, increases motivation for learning and the level of self-esteem, and significantly complements the process of studying comparative anatomy of animals [14].

Project activities contribute to the long-term growth of future biologists and biology teachers, increasing the motivation of students to engage in scientific work and the formation of their subsequent scientific connection with other disciplines. The results of the work were reported by students at two conferences of Omsk State Pedagogical University: IV All-Russian student scientific and practical conference "Digitalization of education: theory and practice" and student scientific and practical conference "Youth. Natural Sciences and Education".

Interim results of the project were published in the journal *Ratio et Natura*. 2023. No. 1 (7), the results of all project work are presented in the final qualifying work "The use of additive technologies to study the morphological adaptations of vertebrates."

But despite the high pace of development and integration of information technologies, 3D technologies cannot yet fully compete with natural objects.

References

1. Federal state educational standard of higher education in the field of training 44.03.05 Pedagogical education (with two profiles of training) (bachelor's level). [Order of the Ministry of Education and Science of Russia dated 02/09/2016 No. 91] [Electronic resource]. Access mode: <https://fgos.ru/fgos/fgos-44-03-05-pedagogicheskoe-obrazovanie-s-dvumya-profilnyami-podgotovki-91> (access date: 11/29/2023).
2. Federal state educational standard of higher education in the field of training 06.03.01 Biology (bachelor's level). [Order of the Ministry of Education and Science of Russia dated 08/07/2014 No. 944] [Electronic resource]. Access mode: <https://fgos.ru/fgos/fgos-06-03-01-biologiya-944> (access date: November 29, 2023).
3. Patsko V.S., Starodubtsev I.S., Fedotov A.A. Physical visualization of sets in control problems // GRAPHICON 2015. Proceedings of the 25th International Scientific Conference 2015. pp. 22 – 27.
4. https://www.researchgate.net/publication/333330077_Additive_Manufacturing_A_Tool_for_Better_Education
5. Ramdhani F.F., Mulanti B. at the IOP conference 2020. Ser.: Mater. Sci. English 830 042093, DOI 10.1088/1757-899X/830/4/042093 (<https://iopscience.iop.org/article/10.1088/1757-899X/830/4/042093>).
6. Shelley, K., Anzalone, G., Wijnen, B., Pearce, J. M. (2015). Open source 3D printing technologies for education: Bringing additives into the classroom. *Journal of Visual Languages and Computing*. 28 (2015) 226–237. DOI: 10.1016/j.jvlc.2015.01.004 (https://www.academia.edu/11810477/Open_source_3_D_printing_Technologies_for_education_Bringing_Additive_Manufacturing_to_the_Classroom).
7. Ryabinin K.V., Kolesnik M.A., Akhtamzyan A.I., Sudarikova E.V. Cyberphysical museum exhibits based on additive technologies, material interfaces and scientific visualization (2019). *Scientific Visualization* 11.4:27 - 42, DOI: 10.26583/sv.11.4.03 (<http://sv-journal.org/2019-4/03/>).
8. Sharma, F., Dixit. The impact of additive manufacturing technologies on education: a review. In: Kaushik, H.B., Dixit, US, Jose, J., Jaganathan, B.G. (ed.) *Trends in Teaching and Learning Technologies*. NERC 2022. Springer, Singapore. https://doi.org/10.1007/978-981-99-4874-1_7 (https://link.springer.com/chapter/10.1007/978-981-99-4874-1_7).
9. Bodin O.N., Kuzmin A.V., Mitroshin A.N. Development of a visual model of the heart for training medical students // *News of higher educational institutions. Volga region. Medical Sciences*. 2007. No. 2. P. 3 - 10.
10. Stepanov A.Yu., Dyagilev D.V., Vladimirov A.A. Development of a three-dimensional anatomically accurate human model // *Science, technology and education*. 2016. No. 11 (29). pp. 28-32.
11. Prakhov A. A. *Blender: 3D modeling and animation. A guide for beginners* - St. Petersburg: BHV-Petersburg, 2013. - 272 p.
12. Denisov O. E., Levashov I.A., Kuzmin A. V. Information system for studying human anatomy // *Models, systems, networks in economics, technology, nature and society*. 2014. No. 2 (10). pp. 153 – 157.
14. Zhukov I.V., Novikova A.I., Dubel A.N. Development and production of fish vertebrae using the capabilities of 3D modeling and 3D printing // *Ratio et Natura*. 2023. No. 1 (7).
14. Derevyanko N., Zalevskaya E. Methodology for introducing additive technologies into the educational process in the preparation of future graphic designers. *Khortytsia National Academy. Scientific newsletter of Mukachevo State University. Series “Pedagogy and Psychology”* 2023; 9 (1): 69-79 (<https://journals.indexcopernicus.com/search/article?articleId=3844791>).