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Methods of introducing additive technologies into the educational process in the training of future graphic designers

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Abstract. Additive technologies provide many opportunities for improving activities in various fields, but the specifics of exploring their work and application in the educational process of students enrolled in design education programmes have been understudied. The purpose of this study is to develop methods of implementing additive technologies in the educational process of training future graphic designers and to test their effectiveness. To achieve this purpose, the research methodology used was a mixed-methods study. The study involved students and teachers of Khortytsia National Academy. Through video conferencing and discussions between teachers, the implementation of the "Additive Technologies" course in the educational process (study of 3D printing and modelling) and ways to use additive technologies in other subjects were developed and agreed upon. It was established that before the experiment, students had virtually no experience in learning or working with additive technologies, which was the foundation for the course curriculum. The students' assessment of the quality of learning on the scale "The instructional materials motivation survey" before and after the experiment was examined. A questionnaire has been developed to explore students' opinions on the effectiveness of using additive technologies in the work of a graphic designer, and their impressions of the methods of introducing additive technologies into the educational process. The survey found that the majority of students highly appreciated the impact of using additive technologies in the work of a graphic designer and believe that their study is necessary for effective learning and work in the future. In addition, students highly appreciated the teachers' ability to use additive technologies in the learning process. The methods of introducing additive technologies proposed in the study can be used in the training of higher education students in the field of 02 – Art, considering the specifics of the curriculum. In addition, there are prospects for using additive technologies to perform design work, internships using additive technologies, and defending qualification projects with real-time object manufacturing

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Keywords: design; 3D printing; modelling; 3D printer; design products

INTRODUCTION

Digital technologies have become an integral part of people's activities, and their rational use can greatly improve the learning process. Additive technologies allow for the production of objects for various purposes in a three-dimensional format, which significantly improves the production process of design products and has a wide range of applications in various fields of art and design. For example, using additive technologies for visual expression and exploring artistic production for future graphic designers allows them to model and produce designer and non-standard products, plan the design of various items in detail, and many other possibilities. Using additive technologies allows designers to take advantage of digital manufacturing in the early stages of design, balance the choice of different characteristics of the object being designed, adjust them, and calculate in detail the costs of establishing a particular product (Pelliccia *et al.*, 2021). The above leads to an increase in the number of jobs for specialists who can work effectively with additive technologies, as it is necessary to properly design and manufacture objects for further production and design objects for various purposes. In turn, graduates of higher education institutions do not have the necessary skills to meet the market's needs for using additive technologies. Changes in the curriculum are required due to the need for particular specialist knowledge and the development of the additive technology industry (Perez-Perez *et al.*, 2018).

Articles exploring using 3D printing in higher education institutions describe the acquisition of subject knowledge through the establishment of 3D printing systems, scientific and test models, using 3D printing in project-based learning, integrating 3D printing into the curriculum by incorporating it into existing courses and introducing new courses, and exploring 3D printing outside the university (Kalita *et al.*, 2019). When exploring how additive technologies are used in educational institutions of different levels, six categories of their use are identified: for teaching students 3D printing, teacher training, assistive technology for learning, making artefacts to assist learning, design of assistive technologies, and support for information activities (Ford & Minshall, 2019).

Authors C. Seidel and R. Schatz (2019) proposed the implementation of an additive manufacturing curriculum of students' choice. In addition, the problems of using 3D printing in student education are noted. It includes the material and technical base of each higher education institution and the skills, knowledge and abilities of the teachers themselves. Therewith, the introduction of 3D printing into the educational process has not been explored and requires development and testing of its effectiveness. The effective use of additive technologies in the educational process requires the development, implementation and study of the impact of using programmes that help to master the features of 3D printing for use in the field of design and the adaptation of existing curricula to the introduction of additive technologies. In addition, it is necessary to evaluate the effectiveness of various methods for specific learning objectives. Considering the obvious advantages of using additive technologies in students' education and the small number of studies and recommendations in this area, the purpose of this study is to develop methods for introducing additive technologies into the educational process of future graphic designers.

Research objectives: to explore the issues in the available sources of scientific literature, to select possible areas for the introduction of additive technologies in the education of students in the chosen speciality; to develop methods for introducing additive technologies into the educational process of future graphic designers; to explore the effectiveness of the methods used and students' opinions on using additive technologies in the educational process and the work of a graphic designer.

LITERATURE REVIEW

The influence of 3D printing in the scientific community is constantly growing, as evidenced by the increase in the number of scientific publications on the subject since 2015 (Loy, 2018). For example, additive technologies are increasingly being used in manufacturing to make models (Wang *et al.*, 2020). Additive technologies have become a technological innovation in manufacturing, engineering, and design and allow for the establishment of large-scale and multifunctional products (Jin *et al.*, 2020). Additive manufacturing is the process of joining materials to make objects, combining a set of technologies with similar characteristics in terms of production forms with the ability to generate parts with or without digital applications (Kumar *et al.*, 2023). Additive technologies have many advantages over simple geometric design and are one of the revolutionary processes of the next few years (Jimenez *et al.*, 2019). It allows for more efficient use of materials and more design freedom compared to conventional production.

Additive manufacturing technologies allow for the production of complex and customised products, but the technologies themselves still need to be improved and shortcomings addressed (Akhavan & Manoochehri, 2022). When printing on 3D printers, there are still problems with the mismatch between theoretical design expectations and practical production capabilities (Chen *et al.*, 2021). These problems can be solved by implementing algorithms to detect flaws and modulate printing in real-time (Diao & Shih, 2019). Despite the productivity potential of additive technologies, their distribution and use are still quite limited (Monzon *et al.*, 2019). In addition, the industry of additive technologies is quite dynamic, which necessitates the implementation and continuous improvement of training programmes for students and individuals who acquire additional knowledge. The study of the specific features of additive technologies in curricula is frequently not provided for, and there is a lack of research on methods of introducing additive technologies into the educational process of students of various specialities. Using and researching 3D printing features is mostly done in scientific laboratories, and only a small part of higher education institutions and private educational institutions study 3D printing features, modelling and using them in the educational process.

The analysis of scientific research on the study of additive technologies in the educational process has allowed identifying certain methods and ways that can be used to teach future graphic designers. S. Ford and T. Minshall (2019) noted that additive technologies open up opportunities for new practices of teaching several subjects in educational institutions of different fields. To effectively use 3D printing in the educational process, experts recommend that the first step is to get acquainted with the technology and only then search for creative ways to use it as an auxiliary tool in the graphics industry. M. Sable-Meyer *et al.* (2022) propose a programming language similar to Logo, which can be used to design various graphic drawings in 3D. Other researchers have proposed such methods of exploring the features of additive technologies as a literature review on the subject in the Scopus database, and project-based learning (exploring the features of a 3D printer, balanced practical use of the printer for printing itself).

O. Diegel *et al.* (2019) proposed training courses to maximise the effectiveness of using additive technologies in manufacturing and design based on problem-based learning. Using additive technologies outside of the classroom allows for expanding students' learning experience, developing their self-learning capabilities and gaining new and interesting work experience. Effectively apply project-based learning with the manufacture and testing of various models, which contributes to the development of the necessary skills for future work. Project-based learning with specific work purposes and constraints is more effective than tasks with fewer specific constraints and purposes (Prabhu *et al.*, 2020).

Researchers D.R. Calderaro *et al.* (2020) explored the characteristics of additive technologies to make decisions about their choice for use in production systems and analysed the competitive characteristics of printers and printing materials. Most of the 3D printing applications have been established through project-based learning and integration with the course curriculum. Students made a car model on their own and tested it. As a result of the experiment, it was found that the introduction of additive technologies had a positive impact on the learning process of students and their relationships with teachers. It allows using 3D printing as a tool for experimentation, product development and proof of concept, which allows for exploring new ideas and designing innovative products. The introduction of additive technologies has made learning more interesting and engaging. Printing allows for the integration of lectures and the practical work of students. In addition, students have the opportunity to make their models, which greatly increases their motivation to learn. The application of 3D printing in the curriculum for students in the Department of Graphic Engineering and Design will improve the learning process, outcomes, and teaching experience and contribute to the digital literacy of designers (Bernard *et al.*, 2019; Assuncao *et al.*, 2019).

MATERIALS AND METHODS

The experiment was conducted using a mixed-methods research methodology. In the beginning, consultations were held between teachers who teach subjects in the graphic design specialisation to resolve the issue of how to introduce additive technologies into the students' learning process. The discussions were attended by lecturers with a scientific degree (Doctor of Philosophy) who have more than 5 years of teaching experience. Three discussions were held, and methods were agreed upon that could be implemented in the educational process, considering the material and technical support and the specifics of the curriculum of the higher education institution where the experiment was planned.

The study involved students (n=48 – 37 female students, 11 male students; age – 18-20 years) and teachers (n=17, work experience – more than 5 years) enrolled in the Graphic Design study programme at Khortytsia National Academy. The curriculum of these students included a course on additive technologies and their use in other subjects. Before the experiment, the presence of students' experience of learning or working with additive technologies and students' assessment of the learning process using the scale "The instructional materials motivation survey" proposed by J.M. Keller (2010) were explored. This questionnaire is effective for researching various aspects of student learning using innovative technologies, as noted by (Anuar *et al.*, 2021). The survey allows exploring four aspects of the evaluation of training sessions, namely, whether the training sessions contribute to confidence, whether the training material is sufficiently focused, satisfaction with the organisation and content of the training sessions and the relevance of the material being taught. After that, the teachers developed the content of the additional course "Additive Technologies" for students majoring in Graphic Design and ways to use additive technologies in the study of other subjects. The course content was agreed upon by the teaching staff at a meeting of the Academy's Academic Council. A detailed description of the methods of implementing additive technologies is provided in the results. The pedagogical experiment to implement the course was conducted during one academic semester (2021/2022).

A student survey was used to test the effectiveness of methods of introducing additive technologies into the educational process. For this purpose, the author's questionnaire was developed that allows evaluating of the impact of using additive technologies on the educational process of students and their opinions on the effectiveness of using additive technologies in future work. It allows evaluating of their attitude towards additive technologies for use in future work, which is a prerequisite for their willingness to explore them.

The questionnaire consists of seven subscales, each with several questions, and an additional question at the end of the survey: "Please indicate your impressions of using additive technologies in the educational process". The survey covered seven aspects of using additive technologies, namely: using additive technologies to improve the products made by graphic designers, optimising the work

of a graphic designer, exploring the impact of additive technologies on the work of a graphic designer, the impact of using additive technologies on the educational process of future graphic designers and assessing teaching competence in using additive technologies. In addition, students evaluated the methods of implementing additive technologies used in the educational process.

Students answered the questions on a five-point Likert scale. The questions were agreed upon and refined during consultations between the teachers. The validity of the proposed questionnaire was checked by completing it by twelve teachers (who voluntarily agreed to participate in the experiment and completed the questionnaire online and sent suggestions for improving the questionnaire questions if desired) during the pre-testing of the questionnaire. The questionnaires were completed using Google Forms, the answers to the questionnaires were recoded and processed using SPSS Statistics, and the results were discussed and interpreted. To determine the reliability of the developed questionnaire, the value of the Cronbach alpha coefficient was calculated, and to explore the differences between the results before and after the experiment, the Student's T-criterion was calculated.

RESULTS

The pre-experiment study, which allowed examining whether students had experience learning or working with additive technologies, demonstrates the following results (Table 1).

Table 1. Students' experience or training in 3D printing prior to the experiment

Description of existing experience	Number of students, %
Explored additive technologies during training courses	0.43%
Explored additive technologies on my own	4.68%
Interested in 3D printing and 3D modelling	9.36%
Have a 3D printer at home or with friends, tried to work	4.26%
Visited scientific laboratories where he had experience with additive technologies	2.55%
Did not explore the peculiarities of 3D printing	78.72%

The results demonstrate that most students have no experience working and learning with additive technologies. Considering this, teachers developed methods for introducing additive technologies into the educational process with a detailed study of their features, and they were used in the educational process of other subjects after learning the fundamentals and some basic details of working with a 3D printer. Additive technologies were introduced into the educational process of future graphic designers through immediate learning of the features of additive technologies and their use in the study and completion of tasks in other subjects. The ways of introducing additive technologies into the educational process, which were previously considered by experts, are used – gaining subject knowledge by creating scientific and test models, using 3D printing in project-based learning, integrating 3D printing into the curriculum by including it in existing courses and introducing new courses and exploring 3D printing outside the academy.

Additive technologies were implemented considering the classification of teaching methods in higher education institutions, namely, methods of organising and implementing educational and cognitive activities, which are divided into:

1. Verbal methods – by the source of educational information (narration, explanation, conversations and lectures in various formats).

2. Visual methods – illustration (demonstration of the results of working with a 3D printer, demonstration of the features of printers and work with different types of material), and demonstration (use of video and multimedia during lectures, demonstration of the features of additive technologies).

3. Practical methods – working with a 3D printer, printing own models, working with them, improving them.

In addition, these methods are classified as synchronous – video conferencing and asynchronous – video lessons, discussions in online forums, e-mail correspondence and the Moodle platform. Lectures, discussions, and video conferences were held on the subjects:

1. Explore the features of 3D printers, their types, differences and specifics.

2. Explore the specific features of modelling objects in 3D format (features of modelling software).

3. Convert 2D images to 3D.

4. Features of printing the same established 3D models on different printers, differences in the operation of printers, and differences in modelling the same models in different programmes.

5. Differences in modelling the same models in different programmes.

6. Selecting the most efficient printer for printing certain objects based on the examined printer characteristics.

7. Selection of materials and printers depending on the characteristics of the object to be designed, the cost of printing and material, and the quality of the printed model.

Independent work on the subjects was completed:

1. Calculating the cost of printing specific objects on different printers (each student is given separate objects.

2. Calculate the cost of materials for printing objects in 3D.

A lesson was held using problem-based learning on the subject of "Printing advertising and design objects in 3D format, considering the specific features of the printing material", and the specific features of object modelling and se-

lection of printing characteristics were discussed. A playlist of videos on working with 3D printers and materials, and software for modelling objects in 3D format were included in the learning process to help students learn about printing, 3D printer characteristics, and materials. The students watched the videos on their own and discussed them in class.

The methods of organising and implementing educational and cognitive activities using additive technologies are divided into inductive methods – summarising the experience of lectures and practical classes, and independent work, summarising the conclusions about the operation of printers with different operating principles, the specifics of using materials to perform certain tasks; deductive methods – learning the educational material based on generalisations. These methods are used both in the immediate study of additive technologies and in using additive technologies in the study of other subjects. Methods of stimulating and motivating learning and cognitive activity. Reproductive – reproduction of ready-made samples and work on ready-made samples, instructions and tasks. Creative, problem-solving methods – independent modelling, work using 3D printing and modelling, completion of tasks from the teacher with the possibility of independent completion and correction. Problem tasks with an independent search for their solution. Methods of control (self-control, mutual control), correction (self-correction, mutual correction) of the effectiveness of the educational and cognitive activity. The control methods used were a review of the established and printed models and a discussion of the possibilities for their correction.

Students completed learning tasks under the guidance of a teacher and independently. Methods of stimulating and motivating learning and cognitive activity using additive technologies are divided into methods of stimulating interest in learning and methods of stimulating duty and responsibility. Methods of stimulating interest in learning – establishing situations of interest during the teaching of certain material – games, videos, independent creation and printing of 3D models, didactic games, educational discussions, analysis of life situations and experiences (from the teacher's story or a video). Methods of stimulating duty and responsibility – completion of assignments within the timeframe set by the teacher, while evaluation of completed models was either not conducted or was rather descriptive (it is since students need both to complete the assignment and to develop modelling and creative skills, and self-learning skills).

During the actual study of additive technologies, binary teaching methods are widely used, namely: visual illustrative method, visual problematic method, visual research method, problematic research method, and verbal reproductive method. When using additive technologies in the educational process in other subjects, integrated methods were used, namely using 3D printing in the teaching of subjects from the educational programme. Training in additive technologies and their use in the study of other subjects was conducted during the first academic semester of the 2022-2023 academic year. At the end of the semester, students were surveyed using the author's questionnaire.

After the questionnaire survey, a descriptive statistical analysis of the results on students' opinions about using additive technologies in the educational process of graphic designers was conducted. The question about using additive technologies in the work of a graphic designer demonstrates that students see effective applications in almost all areas of future work. In addition, students mostly agree that using additive technologies in the work of a graphic designer can significantly optimise it. Table 2 presents a general descriptive statistical analysis of students' responses.

Table 2. Results of a student survey on using additive technologies in the work of graphic designers and their effectiveness

Answer options	Strongly agree (%)			Agree (%)			Probably yes (%)			Doubtful (%)			Disagree (%)
1	2			3			4			5			6
	Female students (n=133)	Male students (n=102)	Total (n=235)	Female students (n=133)	Male students (n=102)	Total (n=235)	Female students (n=133)	Male students (n=102)	Total (n=235)	Female students (n=133)	Male students (n=102)	Total (n=235)	-
1. Using additive technologies will be effective in improving such graphic design products:													
Book layouts and illustrations	66.92	86.27	75.32	24.06	9.8	17.87	9.02	3.92	6.81	0	0	0	0
Advertising and information posters	69.17	77.45	72.77	21.05	17.65	19.57	9.77	4.9	7.66	0	0	0	0
Design of postcards and postage stamps	75.94	80.39	77.87	9.02	9.8	9.36	9.02	9.8	9.36	6.02	33.4	6.02	0
Product design	71.43	91.18	80	17.29	6.86	12.77	7.52	1.96	5.11	3.76	22.13	3.76	0
Company logos	77.44	85.29	80.85	9.02	11.76	10.21	10.53	2.94	7.23	3.01	11.7	3.01	0
Advertising printing products	78.2	83.33	80.43	7.52	12.75	9.79	9.02	3.92	6.81	5.26	22.98	5.26	0
Souvenir products	58.65	76.47	66.38	16.54	17.65	17.02	17.29	5.88	12.34	7.52	44.26	7.52	0

Table 2. Continued

1	2			3			4			5		6
UI UX design of mobile applications, and websites (designing 3D objects for the website and printing them if necessary for work)	66.17	86.27	73.19	18.8	12.75	16.17	13.53	4.9	9.79	1.5	0.85	1.5	0
2. In your opinion, does using additive technologies in the work of a graphic designer allow for:													
Optimise the design process	76.69	81.37	78.72	12.03	14.71	13.19	11.28	3.92	8.09	0	0	0	0
Reduce waste compared to other technologies	76.69	83.33	79.57	11.28	11.76	11.49	9.02	4.9	7.23	33.01	1.7	3.01	0
Accelerate the product testing phase	79.7	82.35	80.85	10.53	12.75	11.49	7.52	4.9	6.38	22.26	1.28	2.26	0
Personalise products	82.71	79.41	81.28	8.27	13.73	10.64	9.02	6.86	8.09	0	0	0	0
Enables the manufacture and machining of complex parts	76.69	84.31	80	10.53	13.73	11.91	11.28	1.96	7.23	11.5	0.85	1.5	0
Provides more design possibilities	79.7	76.47	78.3	9.02	12.75	10.64	11.28	10.78	11.06	0	0	0	0
3. The impact of additive technologies on the work of a graphic designer:													
Enables the development of new products	66.92	82.35	73.62	24.06	13.73	19.57	9.02	3.92	6.81	0	0	0	0
Accelerates product development	66.17	84.31	74.04	18.05	9.8	14.47	15.79	5.88	11.49	0	0	0	0
Improves the level of knowledge and skills of designers	75.94	86.27	80.43	15.79	12.75	14.47	8.27	0.98	5.11	0	0	0	0
Facilitates the production of personalised products	72.93	76.47	74.47	15.79	13.73	14.89	9.02	9.8	9.36	2.26	1.28	2.26	0
4. Using additive technologies in the educational process allows:													
Optimise the learning process	71.43	76.47	73.62	18.8	14.71	17.02	9.77	8.82	9.36	0	0	0	0
Accelerate the learning of certain aspects of design	65.41	77.45	70.64	18.05	17.65	17.87	16.54	4.9	11.49	0	0	0	0
Better understand the specifics of product manufacturing	78.2	72.55	75.74	9.02	14.71	11.49	11.28	12.75	11.91	1.5	0.85	1.5	0
Promotes interest in learning	82.71	74.51	79.15	15.79	12.75	14.47	1.5	12.75	6.38	0	0	0	0
Stimulates learning beyond the classroom	73.68	74.51	74.04	10.53	17.65	13.62	15.79.	7.84	12.34	0	0	0	0
5. For the effective use of additive technologies in the work of a graphic designer, it is necessary to:													
Learn the features of printers from different companies and with different operating principles	73.68	76.47	74.89	18.8	14.71	17.02	7.52	8.82	8.09	0	0	0	0
Explore the features of printing materials	72.93	74.51	73.62	21.05	24.51	22.55	6.02	0.98	3.83	0	0	0	0
Explore the basics and features of 3D modelling	77.44	88.24	82.13	16.54	11.76	14.47	6.02	0	3.4	0	0	0	0
Research progress in the development of additive technologies	78.95	85.29	81.7	16.54	7.84	12.77	4.51	6.86	5.53	0	0	0	0
6. Knowledge and skills of teachers in teaching additive technologies:													
Teachers are fully equipped with the skills to teach additive technologies	65.41	82.35	72.77	18.05	7.84	13.62	1.5	9.8	5.11	0	0	0	0
Teachers have pedagogical skills to work with additive technologies	69.17	79.41	73.62	8.27	11.76	9.79	6.02	8.82	7.23	1.5	0.85	1.5	0
Cooperation with teachers on the study of additive technologies was effective	58.65	80.39	68.09	16.54	11.76	14.47	9.02	7.84	8.51	0.75	0.43	0.75	0

Table 2. Continued

1	2			3			4			5			6
7. Establishment of scientific laboratories in higher education institutions with the possibility of using additive technologies:													
Promote effective learning	73.68	76.47	74.89	18.8	13.73	16.6	7.52	9.8	8.51	0	0	0	0
Increase students' interest in learning	76.69	83.33	79.57	17.29	11.76	14.89	6.02	4.9	5.53	0	0	0	0
Increase the efficiency of design work	76.69	77.45	77.02	18.8	14.71	17.02	4.51	7.84	5.96	0	0	0	0
Promote independent study of 3D printer functions and material properties	79.7	74.51	77.45	16.54	14.71	15.74	3.76	10.78	6.81	0	0	0	0

The answers to the last question of the questionnaire ("Please indicate your impressions of using additive technologies in the learning process"), which summarises the impact of the methods of introducing additive technologies in this experiment, demonstrate that almost all students enjoyed the learning process very much:

- enjoyed it a lot (75.32%);
- enjoyed (14.47%);
- normal (5.95%);
- slightly difficult (4.26%);
- did not enjoy it (0%).

According to the results of the survey, almost all students enrolled in Graphic Design see the prospects and high efficiency of using additive technologies in the educational process. The assessment of each of the areas of application of additive technologies included internal reliability and average correlation between different items. The internal reliability study demonstrates that the Cronbach's alpha coefficient is:

- subscale 1 – using additive technologies will be effective in improving graphic design products (0.754);
- subscale 2 – opportunities for the effective use of additive technologies in the work of a graphic designer (0.841);
- subscale 3 – the impact of additive technologies on the work of a graphic designer (0.833);
- subscale 4 – effectiveness of using additive technologies in the educational process of future graphic designers (0.782);
- subscale 5 – key points for the effective use of additive technologies in the work of a graphic designer (0.853);
- subscale 6 – teachers' knowledge and skills in teaching additive technologies (0.738);
- subscale 7 – additional benefits and opportunities for students from the establishment of scientific laboratories in higher education institutions with the possibility of using additive technologies (0.788).

The questionnaire "The instructional materials motivation survey" was conducted before and after the implementation of methods of introducing additive technologies into the students' learning process. The results demonstrate that students rated the quality of learning in general with using the course of additive technologies and using these technologies in other subjects significantly higher than before the experiment (Table 3).

Table 3. Results of a student survey on the quality of learning with and without using additive technologies

Questionnaire subscales	Before the experiment	After the experiment	t	p
Confidence	3.11	4.23	1.98	<0.05
Attention	3.25	4.32	2.21	
Satisfaction	3.45	4.38	3.11	
Relevance	3.48	4.44	2.38	

Thus, students who attended the course "Additive Technologies" rated the educational process and the educational material of the entire course significantly higher than students who did not study additive technologies. It could indicate a strong impact of using additive technologies on students' learning in general, as it allows them to be integrated and used with other subjects. In addition, these results confirm the effectiveness of the selected methods of introducing additive technologies into the educational process of second-year students.

DISCUSSION

Using additive technologies in the educational process of students enrolled in the field of study 02-Art is a rather promising area of development of educational programmes. It allows working with real models, which is very important for future designers. This technology allows producing the necessary models in a reduced or required size, exploring their functionality and shortcomings, and adjusting them before the final product is made (Jin *et al.*, 2020). The interest of the scientific community in additive technologies and their use in the educational process is constantly growing (Dube & Wen, 2022).

In this study, some methods of introducing additive technologies into the students' learning process were used, including those identified by A. Stern *et al.* (2019). Additive technologies are used to teach students 3D printing, such as: auxiliary technology for teaching other subjects of the curriculum, making artefacts to assist learning and support for information activities. The teaching methods described in this study are based on conventional teaching methods. The course planning was based on the data from

B. Banjanin *et al.* (2020) about the initial familiarisation and then application of this technology as an auxiliary tool in the learning process. Therewith, the implementation of an additive manufacturing curriculum of student choice was not used, as recommended, as it was planned to teach all students a particular course (Seidel & Schatz, 2019).

After the implementation of the course "Additive Technologies" and their use in the study of other subjects, a survey was conducted, which confirms the data of O. Diegel *et al.* (2019) on the benefits of using technology in the educational process. Students agree that additive technologies allow for the production of complex and customised products, which is a big advantage over other technologies (Gong *et al.*, 2022). And for future designers, the ability to design individual orders that differ from mass production, functional products, and interesting logos is especially important, which can be learned using 3D printing. In addition, the majority of students noted that using additive technologies in the work of graphic designers has many areas and will significantly optimise and improve the work of a designer.

The students noted that the opening of scientific laboratories with the possibility of visiting and using additive technologies outside the classroom allows for improving the quality of project work, develops opportunities for self-study and increases students' interest in learning. In addition, it will contribute to the development of students' practical skills and knowledge. An in-depth study of the principles of additive technologies and the practical features of printing can optimise the learning process, making it more productive and interesting (Ford & Minshall, 2019).

Teachers need to constantly monitor the development of additive technologies, and design teaching materials in such a way as to familiarise students with the basic principles of work and the possibilities of their use in future professional activities (Yang, 2018). In this study, students highly appreciated the skills of teachers in teaching knowledge of additive technologies. However, it is necessary to keep abreast of new products, innovations and developments in modern additive manufacturing in the chosen field to provide students with quality knowledge for future work. After all, education should provide knowledge that meets the requirements of the Fourth Industrial Revolution. And experts H. Kalita *et al.* (2019) recommend training teachers themselves for effective student learning. It is necessary to develop cognitive (knowledge of mathematics, logic, data management) and non-cognitive skills (critical thinking skills, teamwork, problem-solving and interpersonal skills). The implementation of additive manufacturing technologies requires the study of various disciplines, such as materials science, fluid mechanics, graphic design, etc. Using additive technologies in education accelerates the learning process and makes it more interesting. Using additive technologies in the training of future graphic designers allows developing non-cognitive skills, such as teamwork, communication skills, concentration, planning, and others necessary for solving work situations.

Further research into the specifics of materials and printing for different products is needed. In addition, students agreed that in the work of a graphic designer using additive technologies, it is necessary to constantly explore the features of technology development, improvement and correction of printing defects (Akhavan & Manoochehri, 2022). A detailed examination of the characteristics of materials and printers is necessary, as printing parameters are difficult to adjust to fully match the required model, and they have a major impact on the microstructure of the print and the quality of the established models (Qi *et al.*, 2019). Machine learning and print correction methods are used for this purpose, but it still requires research and study by future designers and monitoring during future work. For this purpose, machine learning and print correction methods, and artificial intelligence are used to correct and improve the technology, which can significantly improve the results of work (Liu *et al.*, 2020). However, object modelling and customisation, specifically in graphic design, where parts to be printed or modelled are frequently non-standard, are creative, requiring designers to learn the specifics of printing and modelling. After all, to establish perfect models and individual orders, it is necessary to thoroughly develop models and adjust printing, and select materials for a high-quality result (Jiang *et al.*, 2022).

Students noted that learning using additive technologies improves the educational process makes it interesting and motivates learning, which is an indicator of the effectiveness of the methods used in this research. In turn, student satisfaction with the learning process is an indicator of the quality of education in general and has long-term positive consequences for self-education in the future for each individual (Rajabalee & Santally, 2020). The students of the experimental group rated the effectiveness of learning significantly higher than the students of the control group, in whose educational process additive technologies were not used. Therefore, using additive technologies, in addition to the positive impact of their study, has a positive impact on the study of other subjects in the curriculum. The immediate impact of using additive technologies on the quality of learning can be explored in future experimental studies. An important and promising continuation of the introduction of additive technologies into the educational process of future graphic designers is their use during control and laboratory work with real-time model printing. It will increase responsibility when learning the features of 3D printing, materials for it and 3D modelling in various programmes. When choosing methods of introducing additive technologies into the educational process, it is necessary to explore whether students have previous experience learning or working with these technologies and the previous curriculum.

Consider the constant variability and updates in the operation of 3D printers and modelling tools, and teach students to compare old and new versions of certain applications, programmes and their versions, printers and materials (as newer versions of printers, programmes or materials are not always better for certain jobs). Using courses

in additive technologies of students' choice will have a positive impact on their learning. Therewith, the basics of additive technologies and 3D modelling should be taught to all students – future designers, and in-depth study can occur at the students' discretion (Seidel & Schatz, 2019). An effective method for an in-depth study of additive technologies would be to perform control and diploma works using additive technologies in real-time.

CONCLUSIONS

The results obtained in the study demonstrate the importance of introducing additive technologies into the educational process of future graphic designers and the positive impact on their assessment of learning in general. Students see many opportunities to use additive technologies in their future work, and this, in turn, contributes to effective learning using additive technologies. The pre-experiment survey on the evaluation of the learning process demonstrates an average level of evaluation of the quality of learning (3.11-3.48, max 5). It indicates that students are not fully engaged in the learning process and that there is a need to use innovative technologies and teaching methods to increase motivation and assess the quality of learning. Considering the effectiveness of using additive technologies in the educational process and the lack of methodological support in this area, the teachers developed and approved a training course on the study of additive technologies for future graphic designers and methods of their use in teaching other subjects of the curriculum. Therefore, the methods of introducing additive technologies used in this study are the introduction of a new course on additive technologies and using additive technologies in the study of other subjects. The study of the features of additive technologies was based on conventional teaching methods.

Notably, this research involved students who had not previously explored the specifics of additive technologies during their educational programmes (independent study and use of additive technologies were possible). The experiment did not involve using additive technologies in the implementation of projects that are assessed according to the curriculum. The projects and models during the experiment were of an introductory and informative nature. Only students from Ukraine participated in the study, without foreign students, considering the situation in the country. The survey demonstrated that students highly appreciated the value and possibilities of using additive technologies in the work of a graphic designer, and the assessment of the quality of education after the implementation of the course increased significantly ($p<0.05$). It confirms the effectiveness of the proposed methods of introducing additive technologies into the educational process but does not exclude the need and possibility of using other methods.

The students highly appreciated the possibility of using additive technologies to improve the efficiency and effectiveness of graphic design products, the effectiveness of using additive technologies in the work of a graphic designer, and the impact of additive technologies on the work of a graphic designer. The majority of students agree that using additive technologies in the educational process allows them to optimise the learning process, accelerate the study of certain aspects of design, better understand the specifics of product manufacturing, increase their interest in learning and stimulate learning outside the classroom. It demonstrates that additive technologies facilitate extracurricular learning, which is a criterion for the positive impact of the applied technologies on learning. Most students agreed that for the effective use of additive technologies in the work of a graphic designer, it is necessary to explore the features of printers from different companies and with different principles of operation, the features of printing materials, the basics and features of 3D modelling, and to explore the progress in the development of additive technologies.

For further research, it is recommended to develop methods that allow for a deeper study of additive technologies in senior courses and to test their effectiveness, explore the effectiveness of using additive technologies in the study of certain subjects, and perform project work.

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CONFLICT OF INTEREST

None.

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Методи впровадження адитивних технологій у навчальний процес під час підготовки майбутніх графічних дизайнерів

Анотація. Адитивні технології дають чимало можливостей для удосконалення діяльності в різних сферах, проте особливості вивчення їхньої роботи та застосування в навчальному процесі студентів, які навчаються за освітніми програмами з дизайну, досліджені мало. Мета цього дослідження – розробити методи впровадження адитивних технологій у навчальний процес підготовки майбутніх графічних дизайнерів та перевірити їхню ефективність. Для досягнення мети використано методологію змішаного дослідження. У дослідженні взяли участь студенти та викладачі Хортицької національної академії. За допомогою відеоконференцій, дискусій між викладачами розроблено та узгоджено впровадження курсу «Адитивні технології» в навчальний процес (безпосереднє вивчення особливостей 3D-друку та моделювання) і способи застосування адитивних технологій під час вивчення інших предметів. Досліджено, що до експерименту студенти практично не мали досвіду навчання чи роботи з адитивними технологіями, на основі чого складено навчальний план курсу. Вивчено оцінку студентів щодо якості навчання за шкалою «Інструктивно-методичне дослідження мотивації» до та після експерименту. Розроблено анкету, яка дає змогу вивчити думку студентів щодо ефективності використання адитивних технологій у роботі графічного дизайнера, їхні враження від методів впровадження адитивних технологій у навчальний процес. За результатами опитування з'ясовано, що більшість студентів високо оцінили вплив застосування адитивних технологій у роботі графічного дизайнера та вважають, що їх вивчення є необхідним для ефективного навчання та праці у майбутньому. Студенти також високо оцінили вміння викладачів щодо застосування адитивних технологій у навчальному процесі. Методи впровадження адитивних технологій, запропоновані в дослідженні, можна використовувати під час навчання здобувачів вищої освіти напряму 02 – Мистецтво, ураховуючи особливості навчальних планів. Має перспективи також використання адитивних технологій для виконання проєктних робіт, проходження практики з використанням адитивних технологій, захист кваліфікаційних робіт з виготовленням об'єктів у реальному часі

Ключові слова: проєктування; 3D-друк; моделювання; 3D-принтер; дизайнерські вироби

ЗМІСТ