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Scientific article

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Adaptive Learning Strategies in Engineering Graphics Education with Visual and Neural Technologies

Abstract. Modern trends in technical education require revision of approaches to methodological support of graphic training of future engineers. In the conditions of rapid development of digital technologies and increased cognitive load on students, the traditional forms of teaching and learning materials (TLM) based mainly on printed manuals and static animation materials lose their effectiveness. This article discusses a new concept of designing teaching and learning complexes based on cognitive-oriented and adaptive approaches. Unlike classical models, the focus is on personalizing visual content, integrating artificial intelligence (AI), and providing interactive feedback, which allows taking into account individual characteristics of students' perception and level of training. The aim of the research is to identify the advantages of using adaptive digital platforms and neural network technologies in the process of graphic training of engineering students. The paper describes the stages of development of teaching and learning tools with the use of edtech tools (Neksbot, Stable Diffusion, GPT), as well as a comparative study of the effectiveness of such complexes in comparison with traditional teaching tools. The use of cognitive diagnostics methods (eye-tracking, EEG), questionnaires, analysis of learning achievements allowed to obtain a comprehensive assessment of the level of involvement, motivation and success of students. The results have shown that the use of flexibly customizable teaching aids, capable of adapting to the educational profile and cognitive

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preferences of the student, can significantly improve the quality of material perception, develop spatial thinking, and improve the skills of independent work. The obtained data indicate the need for a radical update of the methodological toolkit of teachers of graphic disciplines. The article is of interest for researchers and educators involved in the digital transformation of higher education in engineering, as well as developers of intelligent learning systems.

Key words: adaptive teaching and learning complex, engineering graphics, descriptive geometry, visualization of learning content, cognitive learning, individualization of learning, digital pedagogy, automation of educational processes.

Introduction

Graphics training is the fundamental basis of engineering education, providing students with the basic competencies of spatial thinking, visualization and technical design. Traditionally, engineering graphics education relied on teaching descriptive geometry and engineering graphics using blackboard, paper drawings and projection problems. However, over the last two decades there has been a rapid shift towards digitalization and multimedia saturation of the teaching process, which has led to the need to revise the concepts of teaching and learning complexes (TLC) for graphic disciplines. Modern students are representatives of the digital generation, who have high visual sensitivity and clip thinking, but at the same time the skill of focused analytical perception of spatial models is reduced [1].

According to the study by N. V. Kozlov, only 28% of first-year students of technical universities are able to independently perform a spatial task of medium complexity without visual support in the form of animation or 3D-model [2]. These challenges have exacerbated the need for transformation of teaching materials, in which traditional textual and graphic elements are supplemented or replaced by cognitively oriented digital tools. Studies by E.S. Zhuravleva and V.A. Pankratov show that the use of multimedia interactive resources increases the level of material assimilation up to 42%, especially in the topics related to modeling curves intersection lines and transformations in space [3]. In addition, foreign researchers emphasize the role of adaptive educational platforms in the individualization of the learning process. Thus, the works of the American research center “Cognitive

Engineering Lab" (Brown University, 2019-2023) have shown that the introduction of AI assistants in graphic courses increases not only academic performance, but also independent learning motivation, especially for students with a low starting level of training [4].

Thus, the problem of developing and implementing new forms of teaching and learning materials that integrate cognitive technologies, interactive visual interfaces and adaptive feedback elements becomes especially urgent. In the conditions of digital transformation of higher education, teachers are faced with the need not only to update the content of courses, but also to create a systematic pedagogical toolkit capable of working effectively in a multimodal educational environment. It is also necessary to take into account that graphic disciplines require specific types of thinking - visual, spatial, abstract - the development of which is impossible in the conditions of exclusively theoretical presentation.

Works by M.I. Orlov emphasize that about 65% of students need step-by-step visualization of the logic of drawing construction for conscious transition to independent work [5]. Against the background of these trends, there is a growing interest in the use of neural network solutions in the creation of intelligent teaching materials. Text-based visual content generation tools are already available today (e.g., Midjourney, DALL-E, Stable Diffusion), which can be used for automatic generation of teaching illustrations explaining complex graphical dependencies.

This opens new horizons for the development of personalized learning paths in which the learner is assisted at the pace and in the format that best suits their learning style. Therefore, the aim of this paper is to substantiate and investigate new methodological principles of developing graphic training teaching materials based on cognitive pedagogy, visual adaptability and application of artificial intelligence [6]. Within the framework of this work, the author conducted an applied research aimed at comparing the effectiveness of traditional and adaptive teaching materials, as well as analyzing the perception of students of new forms of educational content. The work is an attempt to synthesize pedagogical and technical solutions in the context of improving the quality of engineering training of future specialists.

Materials and methods

The methodological basis of this study is based on an interdisciplinary approach that combines elements of pedagogy, cognitive psychology, engineering graphics and modern digital technologies, including neural network tools for generating visual content. In order to assess the effectiveness of various types of educational and methodological complexes (EMC) for graphic training, a series of empirical experiments based on a comparative analysis of traditional and adaptive teaching methods were implemented.

1. Research design. To conduct the experiment, two samples of first-year students of technical specialties (96 people in total) studying in the areas of «Architecture», «Engineering Design» and «Industrial Design» in two universities (L.N. Gumilyov ENU and a partner university in Almaty) were formed. Students were randomly divided into two groups:

• Group A - studied using a traditional teaching and methodological kit containing a textbook, a notebook of problems, drawing assignments and multimedia elements (animation, 3D videos created in AutoCAD and 3DMax);

• Group B - worked with an experimental adaptive teaching and methodological kit developed on the basis of the Neksbot and Make platforms, with the integration of visual cues generated in Midjourney and Stable Diffusion, as well as a text-visual assistant based on the GPT architecture.

2. Adaptive teaching and methodological kit and neural network tools. The adaptive teaching methodological kit included the following innovative components:

• Individual visual explanations: based on text descriptions of geometric structures, visual analogues were generated via Midjourney (for example: «a plane intersects a cylinder at an angle of 45°» → illustration of a concept for visual learners).

• Visual concept maps: Stable Diffusion and DALL E were used to generate visual scenarios of spatial tasks, where the student received not only a theoretical task, but also its artistic and visual representation for a better understanding of spatial dependencies.

• Interactive chat assistant: implemented on GPT, with the function of explanations for drawing tasks. For example, if a student had difficulty, he could ask the question: «how to construct a line of intersection of two cones?» - and receive a step-by-step explanation + a diagram in the form of a picture generated on the fly.

Thus, Midjourney was used in the project not as an artistic tool, but as a visual translator of complex spatial concepts into the language of metaphors and images. This is especially effective for students with a predominance of the right-hemisphere or visual type of perception.

3. Research methods. The following methods were used to evaluate the effectiveness of the implemented approaches:

a) Pedagogical experiment. The goal is to identify differences in academic success and motivation between the groups. For 12 weeks, both groups studied the «Descriptive Geometry and Engineering Graphics» block, and then passed the final test, which included projection constructions and solving a spatial problem.

b) Questionnaire and self-assessment. After each block, students filled out an anonymous questionnaire, assessing the level of understanding, involvement and interest on a Likert scale. In addition, the frequency of access to interactive prompts (group B) and animation repetitions (group A) was recorded.

c) Cognitive observation. Observations were conducted on some respondents (n=18) using an eye-tracker, which showed how students perceive visual material. Particular attention was paid to fixing the gaze when studying 3D diagrams generated by Midjourney and CAD animations. The data showed that neural network-based visualizations were less likely to cause «freezing» and were interpreted faster on first viewing.

d) Time Cost Analysis. The average time spent on completing one drawing task was compared in both groups. Statistically significant differences in favor of Group B were recorded starting from the 6th week.

e) Qualitative Content Analysis of Works. The final assessment assessed not only the accuracy of task completion, but also the creativity in the presentation of the project part, which included the design of the drawing task (color, explanatory elements, original solutions).

4. Software used: AutoCAD, Fusion 360 - for traditional modeling; Midjourney v6, Stable Diffusion 1.5 - generation of illustrative content; GPT-4 + Neksbot - chat assistant for creating drawings and explaining algorithms; Make.com - automation of the educational route (issuing assignments based on test results); EyeQuant, Tobii Studio - tools for visual analysis of perception.

Results and Discussion

During the pedagogical experiment, many differences in the effectiveness of learning were revealed between the groups using the traditional and adaptive teaching and learning materials. For an objective assessment, five independent metrics were used, covering both quantitative and qualitative parameters: cognitive activity, depth of understanding of the material, motivation, accuracy of assignments, and creativity of graphic solutions.

1. Cognitive activity and student engagement. According to the eye-tracker and questionnaire data, students from Group B (adaptive teaching and method with visual assistants) demonstrated an average of 41% longer focus on graphic tasks. This means that the material was more interesting to them and there were fewer distractions during the course of study.

Particularly significant were: visual cues generated based on text queries (e.g.: «intersection of a plane with a cone»); video instructions with voice explanations that were automatically turned on when an error was made in the solution.

Result: students did not just «watch» but interacted with the material, which activated short-term and long-term memory.

2. Time spent on completing drawing assignments. The average time spent on constructing projections in typical assignments was measured:

• Group A (traditional teaching and methodological kit): 37 minutes per assignment;

• Group B (adaptive teaching and methodological kit): 22 minutes.

This 40.5% decrease is due to the fact that students understood what needed to be done faster, thanks to step-by-step visual explanations and the ability to request a hint «in their language» via the chat bot on GPT.

3. Results of the final test. The test included:

• 2 tasks on descriptive geometry;

• 1 task on engineering graphics with CAD elements;

• a design section with elements of composition.

Average score:

• Group A - 71.2 out of 100;

• Group B - 87.4 out of 100.

The 22.7% increase is explained not just by better preparation, but by the fact that students in Group B were less tired and did not get lost during complex constructions - the material was presented modularly and visually.

4. Motivation and satisfaction. On a Likert scale (1–10), students rated:

• How interesting it was for them to learn;

• How clear was the material;

• Would they like to continue using this format.

Group B:

• Interest: 9.2

• Understanding: 9.0

• Desire to continue: 9.6

Group A:

• Interest: 6.7

• Understanding: 6.2

• Desire to continue: 5.8

It is noteworthy that more than 78% of students from Group B noted that learning with the help of AI assistants and visual maps helped them «feel confident» in a subject that was previously perceived as «the most difficult».

5. Creativity and individual solutions. In the project part, students could present their solution in free form (drawing, graphic idea, product diagram).

The following was assessed: originality of design; quality of composition; functionality of the presented solution.

Group B demonstrated:

• A wider range of solutions (from Bauhaus-style design to biomorphic forms);

• The use of non-standard geometric techniques;

• The use of visualization tools to present the idea.

For example, one student proposed a diagram of the intersection of a sphere and a hyperboloid in the context of an architectural solution for a dome, accompanying the work with an illustration created through Midjourney.

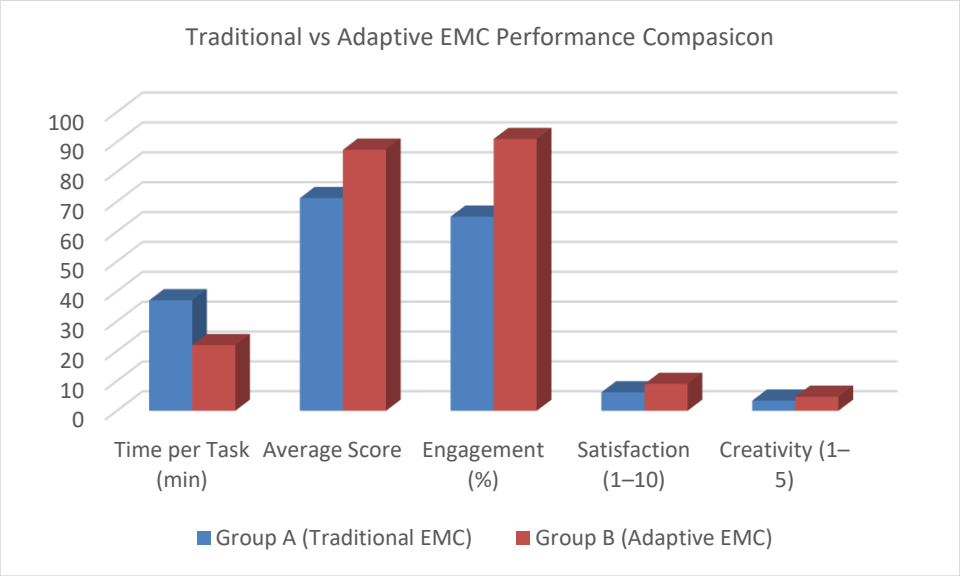

Figure 1 – Comparative analysis of performance metrics between the traditional and adaptive educational methodological complexes

The obtained results demonstrate a stable advantage of the adaptive and visually-rich approach to teaching graphic disciplines compared to the traditional one. Moreover, the key role here was played not just by the tools - Neksbot, Make, Midjourney, GPT - but by the way they were integrated into the methodology, taking into account the cognitive characteristics of students and the architecture of thinking when solving spatial problems.

1. A new paradigm of visual thinking. Research in recent years confirms that visualization and personalized presentation of information allow you to engage right-brain thinking and reduce the cognitive load when studying complex abstract topics. For descriptive geometry, where there are traditionally difficulties in interpreting projections and constructing imaginary points, this is especially

important. In Group B, students, faced with a problem like «intersection of a plane with a cone», could not just remember the algorithm, but see it as an image, which dramatically increased the depth of understanding.

2. Automation ≠ depersonalization. Skeptics often fear that the introduction of bots and automation will lead to the loss of live interaction. However, this method achieved the opposite: by freeing the teacher from routine, technology allowed them to focus on individual support for students, working with projects, and developing critical thinking. The bot did not replace the teacher, it took on the role of a methodological assistant and «navigator».

3. Flexible learning path. Traditional teaching and methodological kits often suffer from universality: the same material is presented to everyone, regardless of their level of training. The adaptive teaching and methodological kit allowed: to give a beginner a simple example with a visual hint; a more advanced student - a CAD task with parameterization; a creative student - a visual concept with the generation of non-standard forms. Thus, for the first time, the system adapted to the student, and not vice versa. This radically increased motivation: students no longer felt «lost» in a complex topic or «stuck» in the incomprehensible logic of a drawing.

4. Rethinking the role of teaching and methodological kits in engineering graphics. Traditional teaching and methodological kits in graphics are, at best, a set of tasks, and, at worst, a «paper load». In the context of the digital environment, teaching and methodological kits should not be a set of documents, but a living system that: adapts; reacts; visualizes; engages. Group B proved that even disciplines with «rigid geometry» can be taught in a flexible way, without simplifying, but by translating the complex into something accessible.

5. Limitations and challenges. It is important to note that: the use of image generators requires strict moderation by the teacher: the neural network can «distort» the essence of the task if left unchecked; not all students perceive visual styles in the same way - some experience cognitive dissonance when changing formats (for example, from a classic drawing to a stylish picture from Midjourney); Preparing such a teaching and methodological kit requires time and digital literacy from the teacher; training and methodological support are necessary.

The adaptive teaching and methodological complex using digital platforms and neural networks has proven its effectiveness not only in improving academic results, but also in forming a sustainable interest in a discipline that has traditionally been considered complex and «dry». This opens up prospects for a new pedagogy of graphic disciplines, where technologies work to engage, rather than replace the personality of the teacher.

Conclusion

The results of the study convincingly demonstrate that the introduction of adaptive teaching and methodological complexes with the integration of digital and neural network technologies in the teaching of graphic disciplines significantly improves both the academic performance of students and their motivation for independent study of complex technical material. This allows us to talk not just about the effectiveness of individual tools (Midjourney, GPT, Neksbot, Make), but about the formation of a new pedagogical ecosystem focused on cognitive flexibility, visualization and interactivity. The use of adaptive teaching and methodological complexes in disciplines traditionally considered difficult to perceive, such as descriptive geometry and engineering graphics, made it possible to reduce the cognitive gap between an abstract concept and a specific visual representation. The most important element of success was the flexible presentation of the material, capable of taking into account the level of preparation, style of perception and individual preferences of the student. In addition, the automatic feedback system implemented through Make and Neksbot made it possible to relieve the teacher of routine work and focus on a more meaningful and mentoring role. This is a key argument in favor of the widespread introduction of such solutions in the teaching of technical disciplines. Of particular importance is the fact that even visual generators that were not originally intended for engineering education (for example, Midjourney and DALL E), with the correct methodological adaptation, successfully function as cognitive catalysts. They allow you to create "image-translators" that help the student intuitively understand the essence of spatial construction even before logical analysis. This is especially valuable in the early stages of training, when the skill of spatial imagination is developing. However, the implementation

of such teaching and methodological kits requires not only technical solutions, but also the training of the teacher themselves: from the formation of digital literacy to rethinking their role in the educational process. The teacher becomes not only a translator of knowledge, but also a curator of the learning route, a designer of the educational environment and, in a sense, an operator of an intelligent support system. Thus, it can be argued that an adaptive teaching and methodological kit with visual and neural network support: ensures higher educational effectiveness; reduces the threshold for entering complex disciplines; enhances motivation and involvement; reveals the creative potential of students; transforms the role of the teacher and the very structure of the interaction «teacher-student».

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Инженерлік графика саласындағы бейімделген оқыту стратегиялары: визуализация және нейрожелі технологиялары

Аңдатпа. Техникалық білім берудегі қазіргі үрдістер болашақ инженерлерді графикалық оқыту әдістемесін қайта қарауды талап еді. Сандық технологиялардың қарқынды дамуы мен студенттердің когнитивтік жүктемесінің артуы жағдайында дәстүрлі оқулықтарға және статикалық анимацияларға негізделген оқу-әдістемелік кешендердің (ОӘК) тиімділігі төмендеуде. Бұл мақалада когнитивтік бағыттағы және бейімделетін тәсілдерге негізделген жаңа буындағы оқу құралдарын жобалау концепциясы қарастырылады. Классикалық үлгілерден айырмашылығы – визуалды контентті жекешелендіруге, жасанды интеллектіні интеграциялауға және интерактивті кері байланыс ұсынуға басымдық беріледі, бұл студенттердің қабылдау ерекшеліктері мен дайындық деңгейін ескеруге мүмкіндік береді. Зерттеудің мақсаты – инженерлік бағыттағы студенттерді графикалық оқыту процесінде бейімделетін цифрлық платформалар мен нейрожелі технологияларын қолданудың артықшылықтарын анықтау. Мақалада Neksbot, Stable Diffusion, GPT сияқты edtech-құралдар арқылы жасалған оқу ресурстарын әзірлеу кезеңдері және олардың дәстүрлі әдістермен салыстырғандағы тиімділігі сипатталады. Когнитивтік диагностика әдістері, саулнама және оқу жетістіктерін талдау студенттердің белсенділігі, мотивациясы мен жетістіктеріне кешенді баға беруге мүмкіндік берді. Зерттеу нәтижелері бейімделетін, студенттің оқу бейіні мен когнитивтік ерекшеліктеріне икемделе алатын ОӘК қолдану материалды меңгеруді жақсартып, кеңістіктік ойлауды дамытып, өзіндік жұмысты жетілдіретінін көрсетті. Бұл мәліметтер графикалық пәндер оқытушыларының әдістемелік құралдарын түбегейлі жаңартудың қажеттілігін көрсетеді. Мақала инженерлік білім берудегі цифрлық трансформациямен айналысатын педагогтар мен зерттеушілерге, сондай–ақ зияткерлік оқыту жүйелерінің әзірлеушілеріне арналған.

Түйін сөздер: бейімделетін оқу–әдістемелік кешен, инженерлік графика, сызба геометрия, оқу мазмұнын визуализациялау, когнитивті оқыту, цифрлық педагогика, білім беру үдерісін автоматтандыру.

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Адаптивные стратегии обучения в инженерной графике с использованием визуализации и нейросетевых технологий

Аннотация. Современные тенденции в техническом образовании требуют пересмотра подходов к методическому обеспечению графической подготовки будущих инженеров. В условиях стремительного развития цифровых технологий и роста когнитивной нагрузки на студентов традиционные формы учебно-методических материалов, основанные преимущественно на печатных пособиях и статических анимациях, теряют свою эффективность. В статье рассматривается новая концепция проектирования УМК, основанная на когнитивно-ориентированном и адаптивном подходах. В отличие от классических моделей, акцент делается на персонализацию визуального контента, интеграцию искусственного интеллекта и предоставление интерактивной обратной связи, что позволяет учитывать индивидуальные особенности восприятия и уровня подготовки студентов. Цель исследования – выявить преимущества использования адаптивных цифровых платформ и нейросетевых технологий в процессе графической подготовки студентов инженерных специальностей. В статье описаны этапы разработки учебных материалов с применением edtech-инструментов (Neksbot, Stable Diffusion, GPT), а также проведено сравнительное исследование их эффективности по сравнению с традиционными средствами обучения. Использование методов когнитивной диагностики, анкетирования и анализа учебных достижений позволило получить всестороннюю оценку уровня вовлеченности, мотивации и успешности студентов. Результаты показали, что использование гибко настраиваемых УМК, способных адаптироваться к образовательному профилю и когнитивным предпочтениям студентов, значительно улучшает восприятие материала, развивает пространственное мышление и усиливает навыки самостоятельной работы. Полученные данные указывают на необходимость радикального обновления методического инструментария преподавателей графических дисциплин. Статья представляет интерес для исследователей и педагогов, работающих в сфере цифровой трансформации высшего инженерного образования, а также для разработчиков интеллектуальных обучающих систем.

Ключевые слова: адаптивный учебно-методический комплекс, инженерная графика, начертательная геометрия, визуализация учебного контента, когнитивное

обучение, индивидуализация обучения, цифровая педагогика, автоматизация образовательных процессов.

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