

DEVELOPING AND THEORETICALLY JUSTIFYING A METHODOLOGY FOR DEVELOPING GRAPHIC THINKING BASED ON AN ADAPTIVE APPROACH

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Abstract. This article addresses the development of an adaptive methodology for developing students' graphic thinking and its theoretical and methodological justification. The methodology is built on a four-stage systemic model comprising initial diagnostics, formation of an individual learning trajectory, ongoing monitoring, and final assessment. Its theoretical foundation rests on L.S. Vygotsky's concept of the zone of proximal development, J. Piaget's theory of cognitive development, and the individualized-instruction ideas of B. Bloom and F. Keller. A review of international research shows that individualized, technologically supported teaching methods yield higher gains in spatial and constructive thinking than conventional methods, supporting the theoretical soundness of the proposed methodology. The article also proposes a research design — participants, measurement instruments, procedure, and statistical analysis plan — for a future pedagogical experiment to empirically test the methodology's practical effectiveness.

Keywords: Graphic thinking, adaptive methodology, individualized learning, spatial imagination, zone of proximal development, engineering graphics, research design.

ADAPTIV YONDOSHUV ASOSIDA GRAFIK TAFAKKURNI RIVOJLANTIRISH METODIKASINI ISHLAB CHIQISH VA NAZARIY ASOSLASH

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Annotatsiya. Maqolada talabalarning grafik tafakkurini rivojlantirishga qaratilgan adaptiv metodikaning ishlab chiqilishi va uning nazariy-uslubiy asoslari yoritilgan. Metodika boshlang'ich diagnostika, individual o'quv traektoriyasini shakllantirish, joriy monitoring va yakuniy baholash bosqichlaridan iborat to'rt bosqichli tizimli model asosida ishlab chiqilgan. Metodikaning nazariy negizini L.S. Vygotskiyning yaqin rivojlanish zonasi kontseptsiyasi, J. Piagening kognitiv rivojlanish nazariyasi hamda B. Blum va F. Kellerning individuallashtirilgan ta'lim g'oyalari tashkil etadi. Xalqaro tadqiqotlar tahlili shuni ko'rsatadiki, individuallashtirilgan va texnologik jihatdan qo'llab-quvvatlangan o'qitish usullari fazoviy va konstruktiv tafakkurni rivojlantirishda an'anaviy usullarga qaraganda yuqori natija beradi, bu esa taklif etilayotgan metodikaning nazariy jihatdan asoslanganligidan dalolat beradi. Maqolada, shuningdek, metodikaning amaliy samaradorligini kelgusida pedagogik eksperiment orqali tekshirish uchun tadqiqot dizayni taklif etilgan.

Kalit so'zlar: grafik tafakkur, adaptiv metodika, individuallashtirilgan ta'lim, fazoviy tasavvur, yaqin rivojlanish zonasi, muhandislik grafikasi, tadqiqot dizayni.

РАЗРАБОТКА И ТЕОРЕТИЧЕСКОЕ ОБОСНОВАНИЕ МЕТОДИКИ РАЗВИТИЯ ГРАФИЧЕСКОГО МЫШЛЕНИЯ НА ОСНОВЕ АДАПТИВНОГО ПОДХОДА

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Аннотация. В статье рассматриваются разработка адаптивной методики развития графического мышления студентов и её теоретико-методологическое обоснование. Методика построена на четырёхэтапной системной модели, включающей начальную диагностику, формирование индивидуальной образовательной траектории, текущий мониторинг и итоговую оценку. Теоретическую основу методики составляют концепция зоны ближайшего развития Л.С. Выготского, теория когнитивного развития Ж. Пиаже, а также идеи индивидуализированного обучения Б. Блума и Ф. Келлера. Анализ международных исследований показывает, что индивидуализированные и технологически поддерживаемые методы обучения дают более высокие результаты в развитии пространственного и конструктивного мышления по сравнению с традиционными методами, что свидетельствует о теоретической обоснованности предлагаемой методики. В статье также предложен дизайн исследования для последующей эмпирической проверки практической эффективности методики в рамках педагогического эксперимента.

Ключевые слова: графическое мышление, адаптивная методика, индивидуализированное обучение, пространственное воображение, зона ближайшего развития, инженерная графика, дизайн исследования.

INTRODUCTION

The professional competence of specialists trained in engineering and technical fields is largely determined by their level of graphic thinking, since the ability to read and produce drawings, diagrams, and technical documentation is an integral part of engineering practice. Under the conditions of the modern digital economy, this competence encompasses not only drawing on paper but also three-dimensional modeling, working in computer-aided design (CAD) systems, and analyzing complex technical information in spatial terms. International research shows that a large proportion of first-year students at technical higher education institutions face systematic difficulties in completing tasks involving spatial visualization and projective representation. The causes of such difficulties are related not only to students' differing levels of preparation during preschool and school years, but also to the fact that the teaching methodology used at the higher-education stage applies the same approach to all students. In existing teaching practice, learning tasks in graphic disciplines are, as a rule, presented at the same level of difficulty for all students, which fails to account for differences in students' initial level of preparedness and, as a result, leads to a decline in the quality of learning among less-prepared students and, at times, to a loss of interest in the subject. One promising direction for

overcoming this problem is the introduction of an adaptive methodology that takes into account students' individual characteristics. The purpose of the study is to develop an adaptive methodology for developing students' graphic thinking, to provide its theoretical justification on the basis of the scientific literature, and to design a research protocol for empirically testing its practical effectiveness through a future pedagogical experiment. To achieve this purpose, the following tasks were set:

- to clarify the concept of graphic thinking and its structural components on the basis of the scientific literature;
- to develop a model of an adaptive methodology consisting of initial diagnostics, an individual trajectory, ongoing monitoring, and final assessment, and to provide its theoretical justification;
- to scientifically predict the methodology's expected pedagogical effectiveness by analyzing the findings of comparable international studies;
- to design a pedagogical-experiment protocol for the future empirical testing of the methodology's practical effectiveness.

The study puts forward the following scientific hypothesis: if an adaptive methodology incorporating initial diagnostics, an individual learning trajectory, ongoing monitoring, and flexible assessment is introduced into the teaching of graphic disciplines, then students' graphic-thinking indicators are expected to be significantly higher than under a conventional methodology. Testing the validity of this hypothesis is not the aim of the present article; rather, it is planned to be carried out in a separate pedagogical experiment based on the research design proposed in a later section.

LITERATURE REVIEW

The psychological foundations for developing graphic thinking are reflected in L.S. Vygotsky's concept of the zone of proximal development and in J. Piaget's theory of cognitive development, both of which establish that the learning process should be organized at a level of difficulty slightly above the learner's current capabilities, yet achievable with guided assistance. The historical roots of the idea of individualization in education are likewise found in B. Bloom's concept of mastery learning and in F. Keller's Personalized System of Instruction, both of which argued for the necessity of allowing each learner to progress at their own pace. The problem of developing spatial-visualization ability has been studied in depth in a number of international studies. In particular, studies conducted in engineering-graphics courses aimed at improving spatial-visualization skills have shown that integrating augmented reality (AR) technologies with CAD systems has a positive effect on the development of students' spatial perception and visual conception. Likewise, in experimental work on developing spatial thinking among first-year engineering students, the group that used a combination of conventional and digital tools was found to achieve the highest results. Standardized instruments such as the Purdue Spatial Visualization Test: Rotations and the Mental Rotations Test are widely used in international practice to assess spatial-visualization skills, which allows the results of studies in this field to be compared with one another. Experiments conducted at the secondary-school level using three-dimensional modeling software have likewise confirmed the effectiveness of digital tools in developing spatial thinking; that study involved 166 pupils and included pre- and post-tests across experimental and control groups. In recent years, artificial-intelligence-based adaptive learning systems, including intelligent tutoring systems and adaptive diagnostic platforms, have begun to be applied to the teaching of

engineering graphics. Systematic reviews indicate that AI tools contribute to improved learning outcomes by adapting instructional material to an individual's profile in real time, continuously assessing learner performance, and providing personalized feedback. At the same time, the analysis conducted shows that there is still insufficient research devoted to developing an adaptive approach as a unified methodological model specifically aimed at developing graphic thinking. In particular, most of the sources reviewed are limited to describing the effect of a single technological tool, while studies devoted to developing a comprehensive methodology that unites diagnostics, an individual trajectory, monitoring, and assessment into a single cyclical system are almost nonexistent. This gap defines the scientific novelty of the present study: the proposed model is not a single technological solution but has been developed as an integral pedagogical cycle aimed at developing graphic thinking.

THE PROPOSED ADAPTIVE METHODOLOGY MODEL

Drawing on the theoretical foundations reviewed above and on the analysis of international practice, a four-stage systemic methodology model for developing students' graphic thinking was developed (Figure 1): (1) initial diagnostics is used to determine the student's level of graphic thinking; (2) based on the diagnostic result, the student is directed to a group of modular tasks at a low, medium, or high level of preparedness, and an individual learning trajectory is formed; (3) during the learning process, the complexity of tasks is dynamically readjusted through ongoing monitoring and rapid feedback; (4) a final assessment is conducted at the end of the semester, and the results serve as the basis for the next diagnostic cycle.

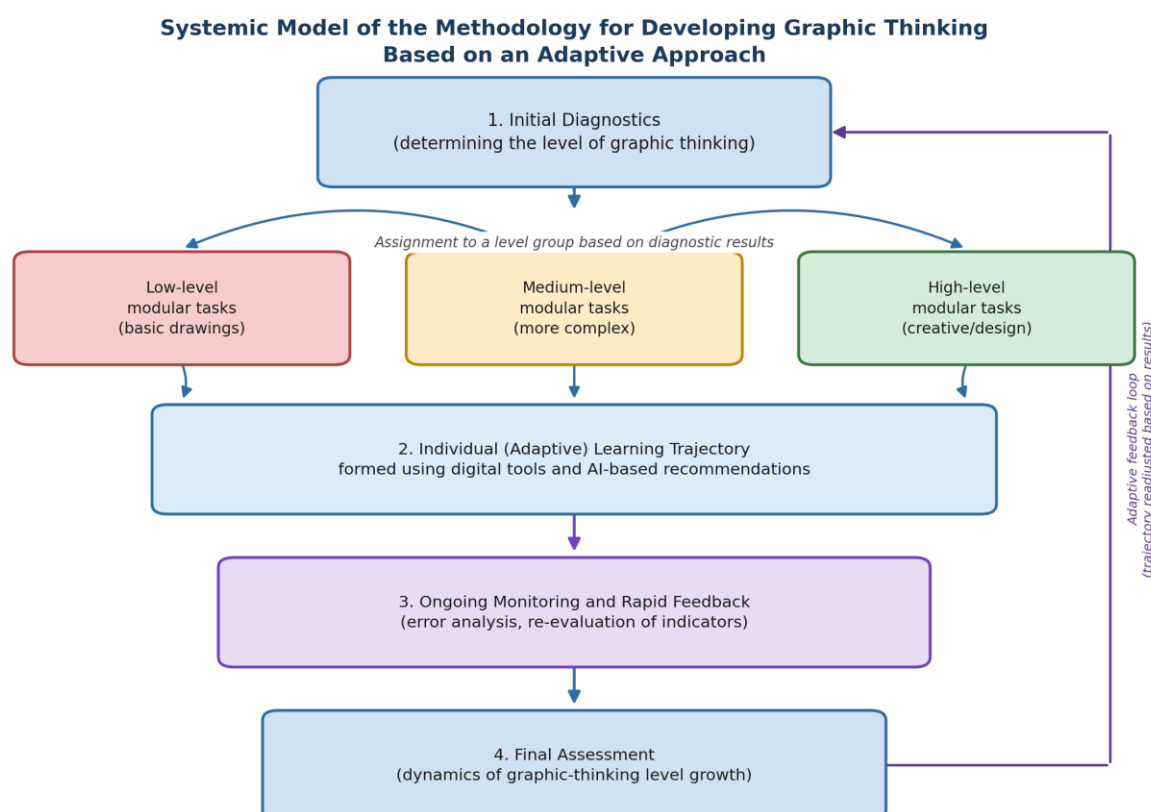


Figure 1. Systemic model of the methodology for developing graphic thinking based on an adaptive approach (author's design).

Each stage of the model draws on the theoretical foundation discussed above: the first stage is aimed at determining the student's "actual level of development," while the second and third stages are designed to ensure that work takes place within L.S. Vygotsky's "zone of proximal development." The fourth stage, in line with B. Bloom's idea of mastery learning, makes it possible to monitor each student's progress toward the goal at their own pace. The cyclical nature of the model — the feedback loop running from stage 4 back to stage 1 — is designed to make it not a one-time intervention but an ongoing pedagogical process. The model can be implemented in three ways in practice: on the basis of a conventional (paper-based) task bank, on the basis of a digital platform (for example, a module integrated into a learning management system), or enriched with artificial-intelligence tools (automated diagnostic and recommendation algorithms). All three implementation options preserve the four-stage cycle described above; the only difference lies in the degree to which the diagnostic and adaptation process is automated.

EXPECTED PEDAGOGICAL EFFECTIVENESS OF THE METHODOLOGY BASED ON INTERNATIONAL PRACTICE

Because the author has not yet conducted a pedagogical experiment, the effectiveness of the proposed methodology is substantiated in this section not by the author's own empirical data, but indirectly, through the findings of international studies that have applied similar approaches. Such an approach is a standard and honest scientific practice for a pedagogical model that has not yet been empirically tested. In studies that integrated augmented reality (AR) technologies with CAD systems, students' spatial perception and visual conception were found to improve significantly compared with a conventional, non-individualized approach. Similarly, in an experiment based on three-dimensional modeling software (SketchUp) involving 166 pupils, the experimental group showed greater gains than the control group. These findings support the theoretical soundness of using digital tools within the second and third stages of the proposed model. Large-scale meta-analyses devoted to the effectiveness of intelligent tutoring systems (ITS) have likewise shown that intelligent tutoring approaches human tutoring in effectiveness and produces significantly better results than conventional "one-size-fits-all" instruction. This finding lends theoretical support to the prospect of enriching the third stage of the proposed model with AI-based tools. At the same time, it should be emphasized that the studies cited above were conducted under different conditions, and their results cannot be directly transferred to the proposed model. For this reason, the research design proposed below is needed to specifically examine how the methodology performs under the conditions of graphic disciplines and the four-stage model described here.

PROPOSED RESEARCH DESIGN FOR THE EMPIRICAL TESTING OF THE METHODOLOGY

To objectively evaluate the practical effectiveness of the proposed methodology, the following pedagogical-experiment design has been developed. This design has not yet been implemented and is planned for the next stage of the research. Research design. It is proposed that the experiment be organized using the classic pretest-posttest control group design, one of the most reliable approaches for evaluating intervention effectiveness in educational research. This design makes it possible to compare the experimental and control groups under identical conditions and to verify the initial equivalence of the groups. Participants. It is proposed that



students from a technical higher education institution be recruited and randomly assigned to two equal groups — an experimental group (EG) and a control group (CG). The groups should be balanced in terms of gender, age, and initial academic performance, and participation should be voluntary and based on informed consent. Measurement instruments. It is recommended that graphic-thinking level be assessed using a specially developed set of test tasks covering three components: spatial imagination, projective thinking, and constructive-technical thinking. The reliability of the test tasks should be verified beforehand through expert review and pilot testing. Procedure. It is planned that the experimental group be taught using the proposed adaptive methodology and the control group using the conventional methodology over the course of one semester. Both groups should complete the same set of test tasks at the beginning (pretest) and at the end of the semester. Statistical analysis plan. To determine the statistical reliability of the results, it is recommended to use Student's t-test for independent and paired samples, with the significance level set at $p < 0.05$. The initial equivalence of the groups should also be confirmed by separately comparing the pretest results. Possible limitations. In implementing the proposed design, it will be important to ensure a sufficiently large sample size, to replicate the study across several institutions and semesters, and to control for the teacher-expectancy factor by introducing an alternative, non-adaptive new methodology in the control group as well.

PRACTICAL RECOMMENDATIONS

On the basis of the developed model and its theoretical foundations, the following practical recommendations were formulated: first, it is recommended that mandatory initial diagnostics be conducted at the beginning of the semester in graphic disciplines, with students subsequently divided into conditional groups based on the results; second, it is advisable to create a bank of modular tasks with differentiated levels of difficulty for each group; third, ongoing monitoring should be conducted at least two to three times during the semester, with individual trajectories revised accordingly; fourth, wherever possible, it is recommended that the adaptive methodology be enriched with digital platforms and AI tools. These recommendations follow from the logic of the proposed model and from the findings of the international studies reviewed above; their practical effectiveness should be tested separately on the basis of the research design proposed above.

CONCLUSION

As a result of the study, a four-stage adaptive methodology model for developing students' graphic thinking was developed, and its theoretical and methodological foundations were substantiated on the basis of the classic pedagogical-psychological theories of L.S. Vygotsky, J. Piaget, B. Bloom, and F. Keller. An analysis of international research showed that the constituent elements of the proposed methodology have produced strong pedagogical results under comparable conditions, which confirms the theoretical soundness of the model. It should be particularly emphasized that this article does not draw a final conclusion regarding the methodology's practical effectiveness, since such a conclusion can only be based on the results of an actual pedagogical experiment. For this reason, a complete research design (participants, measurement instruments, procedure, and statistical-analysis plan) for the empirical testing of the methodology has been proposed, to be implemented at the next stage of the research. The results of the study can be used as a theoretical basis for improving the methodology of teaching engineering graphics and technical drawing at higher education institutions, as well as for developing digital learning tools. Future research should proceed in the following directions:



first, conducting an actual pedagogical experiment on the basis of the proposed design and subjecting its results to statistical analysis; second, exploring possibilities for integrating artificial-intelligence tools into this adaptive model; third, testing the methodology at institutions of different profiles and over a longer period of time.

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