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An in-depth framework for analyzing the outcomes of computer science instruction in an adaptive educational environment

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Abstract

This article presents a comprehensive methodology for evaluating the effectiveness of the educational process in computer science within an adaptive learning environment. Adaptive learning is an approach in which the content, pace, and form of educational material presentation are adjusted to each student's characteristics, such as their level of knowledge, learning style, interests, and the pace of mastering the material. Unlike traditional methods, where all students receive the same amount and structure of knowledge, the adaptive system offers flexibility and individualization of learning. The developed methodology includes designing, implementing, and evaluating the effectiveness of an interactive digital platform that enables students to diagnose their initial educational level, identify their strengths and weaknesses, and automatically select educational materials and practical assignments aligned with their learning trajectory. An experimental study was conducted at Atyrau University named after Khalel Dosmukhamedov (Atyrau, Kazakhstan) involving 118 students studying in the field of Computer Science. The article describes the stages of integrating adaptive technologies into the educational process and presents comparative learning outcomes for students using the adaptive platform versus those studying with traditional methodologies. The results indicate that the use of an adaptive learning environment facilitates deeper assimilation of educational material, increases motivation, and improves students' academic results in computer science. The presented methodology can be utilized by educators and educational institutions to enhance teaching quality through modern digital and analytical tools.

Keywords: Adaptive learning, Computer science, Education, Efficiency, Individual needs.

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1. Introduction

Adaptive learning is an effective approach to organizing the educational process, especially relevant in teaching computer science. Due to its ability to consider individual characteristics, the level of training, and the pace of learning, adaptive technologies enable the creation of a more flexible and effective educational environment [1]. With the development of digital platforms and analytical tools, it becomes possible to accurately track the progress of each student, which is especially important when studying complex disciplines such as computer science. Already today, several educational institutions are introducing elements of adaptive learning, demonstrating a positive impact on student engagement, the quality of learning, and the level of formation of key competencies. A comprehensive methodology for evaluating the effectiveness of the learning process and an adaptive environment allows us to obtain an objective picture of learning outcomes [2]. Firstly, it promotes the rational use of study time: each student works on assignments that correspond to their current level and individual educational needs. Secondly, this method provides the teacher with detailed information about the progress of the course, allowing them to adjust pedagogical strategies promptly. In addition, the introduction of an adaptive learning environment contributes to the development of students' skills in self-organization, critical thinking, and digital independence, key competencies of modern education in the field of computer science.

Adaptive learning is becoming an integral part of the modern educational process, including in the study of computer science. This approach allows us to consider the individual characteristics of students and to build an educational trajectory based on their level of training, style of information perception, and the speed of material assimilation [3]. This is especially important in technical disciplines, where learning requires a step-by-step mastery of complex concepts and skills. Within the framework of the “Computer Science” discipline, the use of adaptive digital platforms makes it possible to provide students with personalized assignments, interactive modules, as well as various formats for explaining educational material, depending on their level of understanding [4]. This contributes to a deeper development of theoretical foundations and practical skills, as well as the formation of sustainable digital competencies. A comprehensive methodology for evaluating the effectiveness of such training allows not only tracking the progress of each student but also identifying the most effective forms of presentation and types of tasks [5]. The introduction of adaptive technologies into educational practice in computer science improves its effectiveness as a means of enhancing the quality of student training and developing their skills in demand in the digital economy.

One of the key factors justifying the need to introduce adaptive learning into the educational process in computer science is the recognition of the individuality of each student. Students have different levels of training, styles of perception of information, and the pace of material assimilation [6]. The traditional system, based on uniform curricula and methods, is not always able to account for these differences, which reduces the overall effectiveness of learning.

The adaptive approach makes it possible to overcome this barrier by flexibly adjusting the content, complexity, and form of presentation of the material to the needs of each student [7]. The results of several studies confirm that the use of adaptive technologies contributes to a deeper assimilation of educational material and increased motivation, engagement, and satisfaction with the learning process.

This is especially true in teaching computer science, a discipline that requires logical thinking, step-by-step mastery of algorithms, and active practice. In an adaptive learning environment, students demonstrate higher rates of developing critical thinking skills, problem-solving abilities, and the capacity to learn independently [8].

It should be emphasized that educational institutions focused on the introduction of adaptive approaches into the educational process, including within the framework of Computer Science training, make a significant contribution to improving the quality of education, academic results, and the development of key professional and digital competencies of students [9]. Adaptive learning contributes to the development of students' skills that are in demand in the context of society's and the economy's digital transformation. The development of such practices is an important direction for the modern education system, as it not only improves learning outcomes but also increases graduates' readiness for professional activity in the face of rapidly changing labor market requirements [10]. A comprehensive methodology for evaluating the effectiveness of learning in an adaptive environment thus becomes a tool for ensuring a high level of training for qualified specialists capable of independent learning, critical thinking, and productive work in a digital environment.

IIn this regard, we have formulated the goal of developing and implementing an adaptive learning environment at the university, focused on the individual educational needs of students studying computer science [11, 12]. This approach will improve academic performance, motivation to study, and student engagement, as well as enhance the overall quality of the educational process within the framework of information technology disciplines. The implementation of this initiative creates conditions for the development of sustainable digital and professional competencies that meet the requirements of the modern digital economy and labor market [13].

The purpose of the research is to identify the theoretical foundations, as well as to develop and implement practical tools for adaptive learning in higher education aimed at improving the effectiveness of the educational process in computer science [14].

As part of the study, it is planned to:

1. To study the existing theoretical approaches to adaptive learning and determine the possibilities of their application in the context of teaching computer science at the university.

2. Analyze modern methods and digital tools, including adaptive educational platforms and learning management systems.

3. To develop and implement an adaptive learning platform focused on the individual educational needs of students.

4. To conduct an experimental study in which the results of students studying according to the traditional model will be compared with the results of students using an adaptive learning environment.

In the following sections, a research model is presented that allows for a systematic study and evaluation of the effectiveness of adaptive computer science education in higher education institutions, as well as practical recommendations for its implementation and further development [15].

2. Literature Review

The adaptive learning system continues to evolve and improve, representing one of the promising areas in the field of education, especially in teaching programming and computer science. In the article "Learning Performance in Adaptive Learning Systems: A Case Study of Web Programming Learning Recommendations," the authors evaluate the effectiveness of an adaptive learning system based on individual recommendations in the process of learning web programming. To analyze the effectiveness of the system, a pedagogical experiment is conducted, in which the learning outcomes of students using adaptive recommendations are compared with the results of students studying traditionally. The data obtained indicate the positive impact of the adaptive approach on the motivation and academic achievements of students, which confirms the potential of such systems in improving the quality of the educational process in the field of computer science [16].

In the article "Systematic review of adaptive learning research designs, context, strategies, and technologies from 2009 to 2018," the authors examine the effectiveness and benefits of adaptive learning in educational environments. It is noted that this approach can mitigate differences in access to education, especially among socially vulnerable groups and regions with limited resources. Special attention is paid to the role of technologies based on artificial intelligence and data analysis, which enable the identification of individual students' needs and the provision of targeted support and appropriate resources. This approach contributes to a more equitable and high-quality educational process [17].

The article "Adaptive educational hypermedia system using cognitive style approach: Challenges and opportunities" examines the impact of students' cognitive styles on the effectiveness of adaptive learning. In the educational context, cognitive style is understood as individual characteristics in the perception, processing, and application of information. The authors emphasize that taking these differences into account when designing and implementing adaptive educational systems plays a key role in improving the quality of learning. This approach can serve as a basis for further research aimed at creating educational programs and platforms that best meet the individual needs and thinking strategies of each student [18].

The article "Assessing the Effectiveness of Personalized Adaptive Learning in Teaching Mathematics at the College Level" contains a comparative study analyzing the differences in performance between adaptive personalized learning and static personalized learning. The following key points: In conclusion, the article notes that adaptive personalization can be useful for both formal and informal learning and that its use should be considered as one of the strategies for improving the quality of education [19].

The article "Learning style detection based on cognitive skills to support adaptive learning environment–A reinforcement approach" presents a study that proposes a framework for developing adaptive learning environments, taking into account the cognitive and stylistic characteristics of students. This approach is especially relevant in the context of computer science, where the successful assimilation of educational material largely depends on individual strategies for perceiving and processing information. The framework presented in the article can be useful in developing a comprehensive methodology for evaluating the effectiveness of the educational process in an adaptive learning environment. Its provisions and recommendations can be applied both in the creation of computer science curricula and in the design of digital educational platforms focused on taking into account the individual characteristics of students [20].

In the Republic of Kazakhstan, the availability of adaptive learning in the field of computer science is gradually expanding. More and more schools, colleges, and universities are introducing modern digital technologies and learning platforms that allow them to adapt the learning process to the individual characteristics of each student. This creates the basis for the development and testing of a comprehensive methodology for evaluating the effectiveness of the educational process in computer science within an adaptive learning environment.

In the context of this area, it is important to note the research of Kazakhstani authors working on the problems of adaptive learning, including an emphasis on the development of digital competencies and the use of adaptive technologies:

- Kenenbayev Serik, in the study "Adaptive Landscape Agricultural Development in the South-East of the Republic of Kazakhstan," analyzes the impact of adaptive learning systems on the academic performance and motivation of university students in Kazakhstan. Special attention is paid to the individualization of educational routes using digital educational resources [21].
- Bekaulova Zhansaya, in the article "Adaptive Learning Model and Analysis of Existing Systems," examines the creation and implementation of an adaptive electronic course that allows each student to consider their level of training and the pace of mastering the material [22].
- Tekesbaeva Nazym, in her work "Digital Technologies as an Adaptive Learning Tool in Higher Education," offers an integrated approach to evaluating learning outcomes using big data analytics and learning activity monitoring systems [23].
- Mukhamadiyeva Saltanat, in the study "Adaptive Learning to Maximize Gifted Education: Teacher Perceptions, Practices, and Experiences," describes the experience of implementing and the results of using adaptive modules and testing within an educational program in computer science [24].

- Yessingeldinov Baurzhan, in the article "Utilizing a Differentiated Assessment Method in Mathematics Class: Computer Adaptive Testing for Tracking Student Progress," emphasizes the need to improve teachers' skills for the effective use of adaptive technologies in IT education [25].

These studies create a solid foundation for the further development and testing of methods for evaluating the effectiveness of computer science teaching using adaptive digital environments and personalized approaches.

An analysis of scientific literature and online resources has shown that adaptive teaching methods in the field of computer science are increasingly being implemented in educational programs around the world. Teachers and educational institutions note the significant advantages of this approach and strive to apply it to improve the quality of the educational process and motivate students to study computer science.

3. Materials and Methods

To the objectives of the study, an adaptive computer science learning platform was developed, which automatically adjusts the level of difficulty of tasks for each student, taking into account their characteristics and current level of knowledge. The platform also provides tools for monitoring student progress, analyzing learning data, and generating reports on learning outcomes. The Computer Science course can be integrated into various curricula, depending on the type of educational institution and the level of training. For example, in school curricula, computer science is included in the compulsory curriculum at various stages of education.

In colleges and universities, the Computer Science course can be either compulsory or selective, depending on the field of study and the profile of the faculty. In general, the key aspects of adaptive computer science teaching, starting with taking into account the individual needs of students, the use of modern technologies and various teaching methods, and ending with a system of testing, assessment, motivation, and support, are presented in Figure 1.

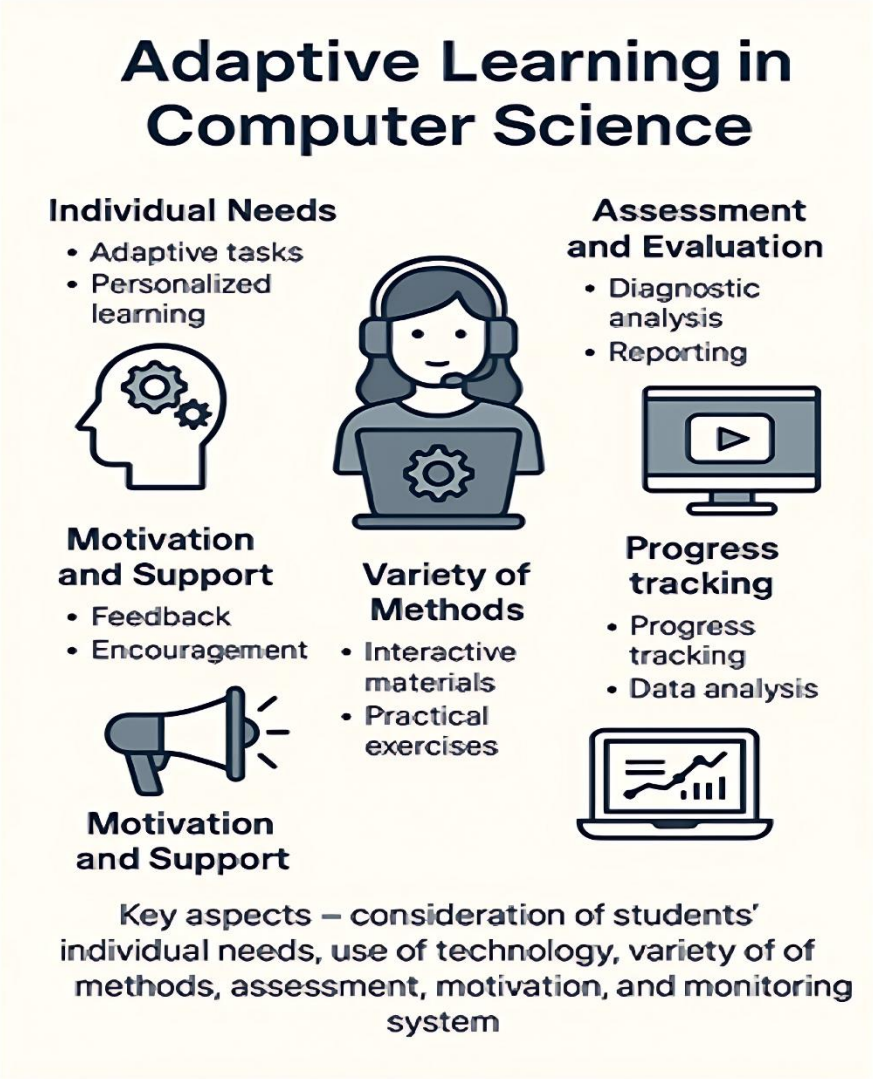

Figure 1.
The concept of adaptive computer science learning.

As part of the research, a comprehensive methodology for evaluating the effectiveness of the educational process in the discipline of Computer Science using an adaptive learning environment was developed and tested. The study was

conducted among 1st-year students of the Faculty of Information Technology at Atyrau University named after Khalel Dosmukhamedov.

The methodology involved comparing the results of two groups: the control group, which studied using the traditional method, and the experimental group, which used an adaptive educational platform. The platform was developed by specialists in the fields of pedagogy, computer science, and educational technologies. It made it possible to individualize the learning process by automatically selecting the level of difficulty of tasks corresponding to the current knowledge, academic preferences, and progress of each student.

The computer science course included a wide range of topics, from basic concepts of information technology and the fundamentals of algorithm design to application programming and databases. Special attention was paid to the development of practical skills, solving problems of various levels of complexity, and the use of modern ICT tools.

The comprehensive assessment methodology included quantitative and qualitative indicators such as:

- Academic performance dynamics;
- Active in learning;
- The level of independence;
- The quality of practical assignments;
- Results of intermediate and final testing;
- Indicators of engagement and motivation.

The analysis of the collected data showed that the students in the experimental group demonstrated higher results compared to the control group. This confirms the effectiveness of the adaptive learning environment and the validity of an integrated approach to assessing the educational process in the context of the digital transformation of education.

As part of the project to improve the educational process, the authors have developed a methodological guide and an adaptive web application, ICT Mentor, designed to support learning in the field of information and communication technologies within a digital educational environment. The project aims to create and implement a new educational platform that provides access to theoretical materials, practical tasks, and tools for developing professional skills. The platform is focused on adapting educational content depending on the user's level of training and their current difficulties. To start working in the ICT Mentor system, a student must complete the registration procedure, after which access is granted to an adaptive program that includes sequential lessons and assignments. The system automatically generates a learning trajectory based on the results of preliminary testing, user responses, and user activity during the learning process.

The introduction of the ICT mentor platform into the learning process provides ample opportunities for implementing an adaptive approach, increases student engagement, and allows for an objective assessment of learning effectiveness based on digital footprints, progress analytics, and test results shown in Figure 2.

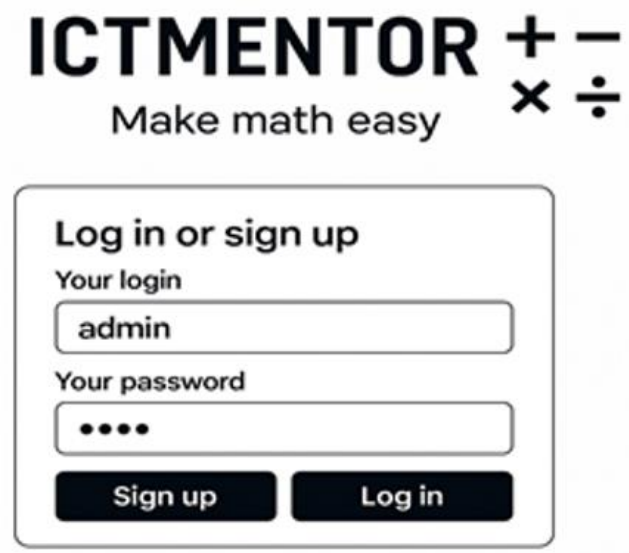

Figure 2.
The application login page.

These materials were developed to integrate an adaptive computer science course into the learning process and enable students to work with materials that best meet their individual needs and levels of knowledge. The course architecture consists of several levels and tasks that allow for the personalization of the educational process and its adaptation to the individual needs and knowledge levels of each student. At the first level of the course architecture, some tasks evaluate the student's prior knowledge and skills. This may include testing or other forms of assessment to determine their level in the domain to be studied in the course. At the next level of architecture, there may be different tasks designed for different levels of students. For example, there may be course content for beginners, intermediate, and advanced learners. In general, the architecture of the levels and tasks of the adaptive course contributes to more effective and engaged learning, taking into account the individual needs, knowledge level, and interests of students, and it is presented in Figure 3 as follows:

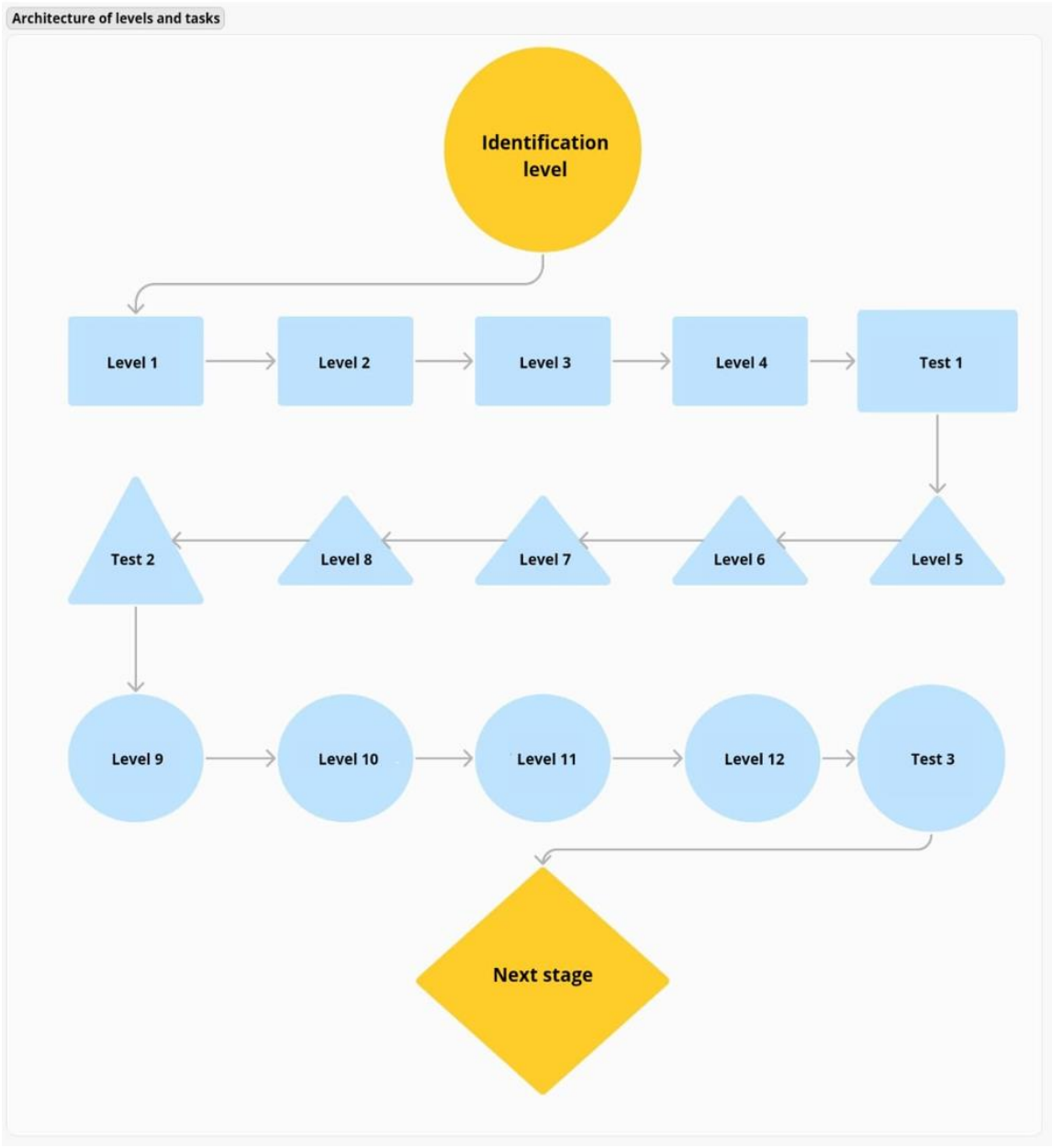

Figure 3.
Architecture of adaptive course levels and tasks.

To progress to the next stage of an adaptive computer science course, you must meet certain requirements or achieve a specific level of success. Here are a few steps that will help you advance to the next stage:

1. Successful acquisition of basic concepts and skills at the current stage of the course. Completing all the exercises and passing the tests demonstrates faultless performance of computer science tasks.

2. Checking learning progress and evaluating strengths and weaknesses. If there are certain topics or skills that are difficult to master, you need to spend extra time studying them. Refer to additional materials or ask for help from a teacher or tutor.

3. See what requirements you need to meet to move on to the next stage of the course. You may need to achieve high marks in tests or complete special tasks. Write down these requirements and ensure that you have completed all the necessary steps.

4. If you have any questions or difficulties, do not hesitate to ask for help. Contact your teacher, tutor, or other students for support and additional explanation of the material.

5. Try to be organized and plan your time. Divide the material into smaller parts and set yourself small goals for each day or week. This will help you follow the curriculum and make gradual progress.

6. Don't forget to practice. Computer science requires repeated practice and application of skills. Regularly solve exercises and tasks, and apply computer science concepts in real life to consolidate your knowledge.

In conclusion, a personalized adaptive computer science course promotes more effective learning and the development of student skills. Due to the adaptability of the course, it analyzes the student's knowledge and level and offers appropriate exercises and materials. In addition, such a course provides continuous feedback and support to the student, helping them overcome difficulties and achieve success in studying computer science.

4. Results and Discussion

Let's analyze the experience of implementing the adaptive "ICT Mentor" course. The content and structure of the module are aimed at implementing an individual approach to teaching and supporting students' independent work on mastering computer science. An analysis of the effectiveness of the adaptive training course was conducted for students studying in the specialty "Computer Science".

Let's consider the first direction in evaluating the effectiveness of using the "ICT Mentor" platform. The degree of achievement of the educational result was determined by evaluation, implemented within the framework of the point rating system (BRS). According to the BRS, the types of student activities were identified, which were evaluated in points, taking into account the complexity of the intended actions of the students and the importance of the result obtained in mastering the discipline.

Table 1 shows the results of passing the final exam and completing the entrance test for the above groups of students. The relatively low performance of the entrance test among students in groups 2-4 is probably due to the extended summer holidays and superficial knowledge of computer science. On the contrary, higher grades for the entrance test compared to the results observed for "strong" students are because the entrance test lacked complex tasks of part "C", and the level of residual knowledge in this group of students turned out to be high.

Table 1.
The results of the initial training of students by groups of students.

No. groups	The entrance test. %	Output test. %	WS (weighted assessment). %	Exam score
1	72.5	69.9	58.1	3.9
2	52.7	66.9	50.9	3.3
3	32.9	61.5	48.4	3.0
4	48.7	58.0	44.2	3.2

It follows from Table 1 that the score for completing the final test for "strong" students has not changed much. Thus, working with the ICT Mentor platform for this group had no effect on the ability to complete test tasks. Although the average score for completing the final test turned out to be quite high, the level of knowledge met the requirements of secondary vocational education.

The results of the test and homework are shown in Figure 4, 5.

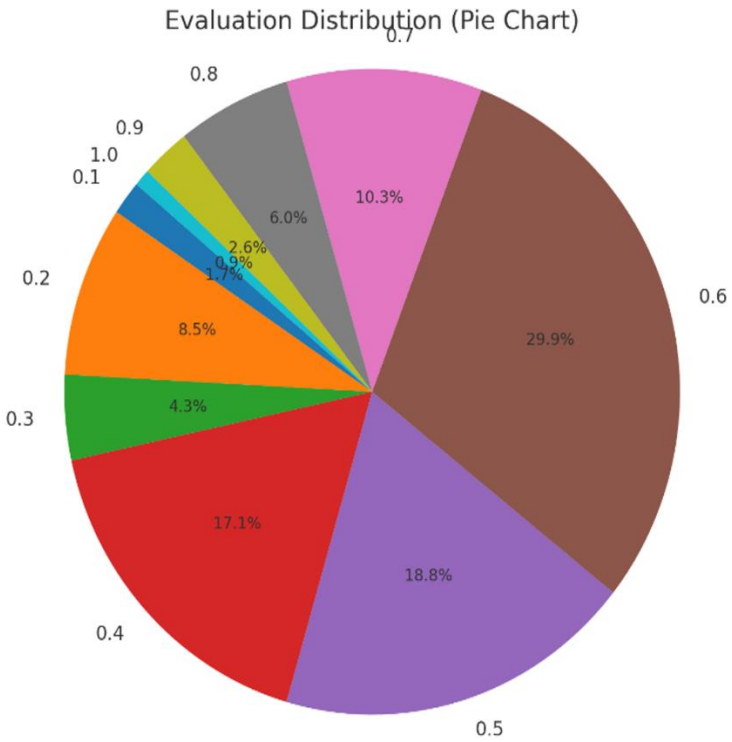

Figure 4.
Histogram of test task results.

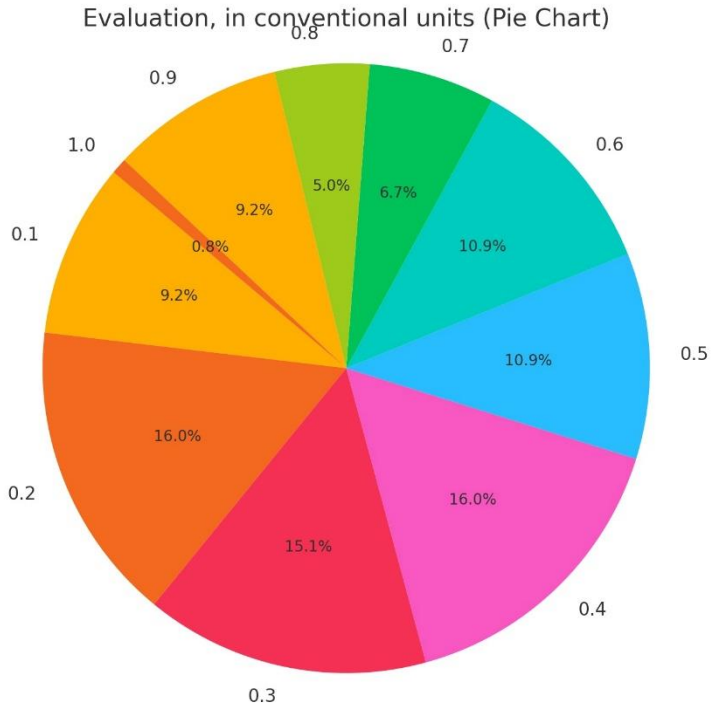

Figure 5.
A histogram of homework results.

The results of the course are shown in Figures 4, 5, and Table 1. As a result of the implementation of the ICT Mentor platform, the weighted assessment of students was in the range of 15-85% with an average value of 51%.

Table 2.
The results of the initial training of students by groups of students.

WS	Number of students	The grade for the exam and the number of students who received this grade
100 ÷ 80	7	«5» – 7
80 ÷ 65	24	«5» – 2, «4» – 22
65 ÷ 50	44	«5» – 2, «4» – 17, «3» – 22, «2» – 3
50 ÷ 40	24	«5» – no, «4» – 1, «3» – 23, «2» – 1
40 ÷ 30	10	We were not allowed to take the exam–5; We got admission and passed the exam later – 5
< 30	8	We were not allowed to take the exam

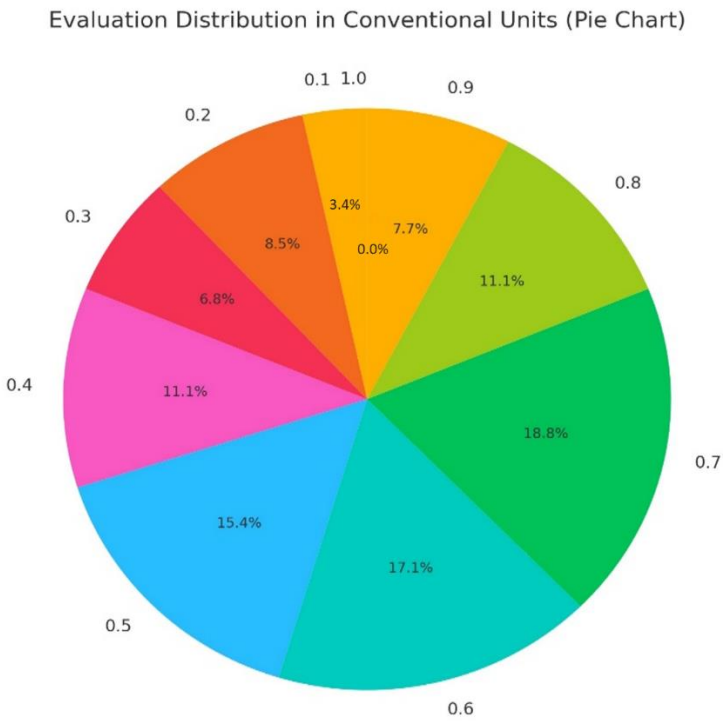

Figure 6.
A histogram of the results of the control work.

The step in the weighted assessment, observed near 50%, is because this indicator value, according to the BRS, was a threshold, i.e., a student could get a "good" grade on the exam if he was > 50%. The results of the course are shown in Figures 6 and in Table 2.

Table 3.
The results of the initial training of students by groups of students.

No. groups	Computer Science entrance exam, points	WA (weighted assessment), %	Course exam score	The average score for the exam in all disciplines
1	59.2	58.1	3.9	4.1
2	53.7	50.9	3.5	3.5
3	53.0	48.4	3.2	3.4
4	-	44.2	3.4	3.3

The results of the entrance exam correlate fairly well with the weighted and exam grades for the course (Tables 2, 3). By the accepted BRS, a "good" grade was given to a student if his weighted score exceeded 65%, and he could receive a "satisfactory" grade only after successfully passing the exam. In 22 cases out of 35, if the student's WA was in the range of 55-65%, then he passed the oral exam with a grade of "good" or "excellent." If the WA is < 55%, then, as a rule, the exam score is "satisfactory." It should be noted that the rather low WA among the students of the 4th group is probably explained by their weak motivation to systematically master computer science. During the session, this disparity was eliminated, which may be due to the great abilities or diligence of this group of students (Table 3).

The effectiveness of using the adaptive learning platform is evidenced by the fact that the difference in grades for the entrance exam in computer science and other subjects was eliminated during the training. This can be seen by comparing the average grades for the entrance exam and the average grades of the session shown in Tables 1, and 3.

The second approach to evaluating the effectiveness of learning involves assessing students' perceptions of the ICT Mentor platform. The most practical method for this assessment is a questionnaire administered at the end of the semester. A total of 118 participants responded to the questionnaire developed by the authors of the article.

The questionnaires offered to students contained 44 questions on all aspects of learning, including:

- How do students evaluate the quality of the ICT Mentor platform and teaching methods?
- How effective are the learning tools used?
- There is a need to improve the organization of work with the ICT Mentor platform and the forms of presentation of educational material.
- Satisfaction with the score gained as a result of studying the discipline;
- BRS usage efficiency;
- network efficiency;
- labor costs for completing the proposed tasks;
- The nature of the technical and software tools used, etc.

The majority of students are satisfied with the quality and presentation of the educational material on the ICT Mentor platform (57% rated it "good" and 28% – "excellent"). From the perspective of usability, the proposed course was quite effective. The organization of students' access to their results caused the greatest comments (25% of students scored "satisfactory" and "unsatisfactory" for the same indicator). Regarding the low activity of online communication, most students noted that they could not identify topics for substantive communication, and some students indicated that they preferred to find out their questions from the teacher in face-to-face consultations (Figure 7). Most of the online communication in ICT Mentor was conducted through email and a forum.

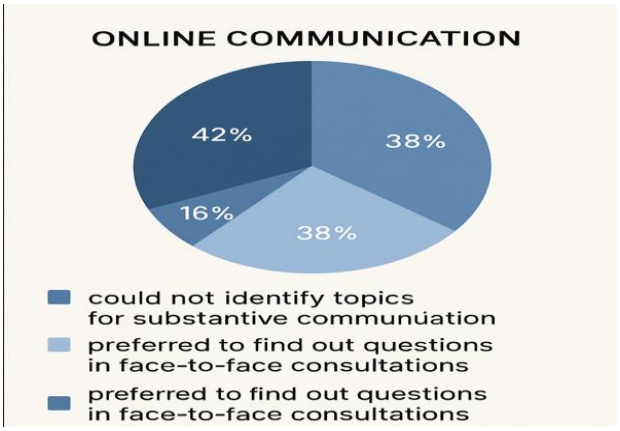

Figure 7.
A diagram reflecting the students' need to use online communication in ICT Mentor.

More than 90% of students rated the effectiveness of lectures, practical, and laboratory classes as "good" and "excellent." The effectiveness of independent work with the ICTMentor platform, according to the students, was somewhat lower: two-thirds of the students rated it as "good" and "excellent." Here, apparently, both the lack of independent work skills and insufficiently clear instructions on the order of students' actions are factors. Nevertheless, the majority of students (74%) considered the proposed technology of adaptive education effective. Only 12% of the respondents noted that the traditional form of education is preferable for them. Regarding the technical means available to students and online learning opportunities, they are quite modern. A significant majority of students used laptops in their work (61% of responses) and PCs (36%), while tablets and smartphones were used in other cases.

The organization of the educational process using the ICT Mentor platform made it possible to eliminate the difference in the relatively poor training of students in computer science compared to other academic disciplines. With the help of the BRS integrated into the platform, it was possible to ensure a uniform course of independent work and motivate students to study computer science. E-learning using an adaptive learning platform has made it possible to adapt most of the first-year students to learning, to build individual learning trajectories. Based on monitoring, it became possible to justify and regulate the time required for both individual tasks. The vast majority of students considered e-learning technology using an adaptive learning platform to be effective.

5. Conclusion

To create and implement the methodology of adaptive teaching in computer science, the following tasks were performed:

1. Study existing methods of teaching computer science and evaluate their effectiveness. This allowed us to identify the main problems and weaknesses in the existing teaching approach.

2. Development of adaptive methods for teaching computer science. This involved defining the main goals and principles of the methodology, selecting appropriate educational materials and assignments, and creating tools to monitor and evaluate students' academic performance.

3. Testing the methodology on a small group of students to assess its effectiveness. During the testing, data were collected on students' academic performance and their level of understanding of the material.

4. Analyzing the data obtained and making adjustments to the methodology, if necessary. Based on the results obtained, it is possible to determine which aspects of the methodology require changes or improvements.

5. Implementation of the methodology at the university, including the training of teachers and students to use a new approach to teaching computer science. This may include conducting training sessions for teachers, developing additional educational materials, and supporting students in the learning process.

6. Evaluation of the effectiveness of the methodology over a certain period of time. Comparing students' academic performance in computer science using the new methodology and the traditional approach can help evaluate the effectiveness of the new approach and make the necessary adjustments.

7. Continuous improvement of the methodology based on the collected data and the reactions of teachers and students. The methodology should be flexible and adaptive to meet the needs and requirements of students and teachers.

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