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A DIGITAL ADAPTIVE TEXTBOOK FOR SECONDARY BIOLOGY EDUCATION: DEVELOPMENT AND TESTING

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Abstract

The digital transformation of educational materials has led to the development of adaptive textbooks that personalize learning according to individual student needs. This paper presents the development and pilot testing of an adaptive digital biology textbook (TSAU) for middle school students in Russia, based on the printed textbook by V. Pasechnik. The research aimed to transform traditional content into an adaptive digital format and evaluate its effectiveness in improving student academic performance. The digital textbook comprises 110 multimedia modules, each containing a video clip and six assessment tasks of varying difficulty levels. The adaptive platform processes student responses, provides immediate feedback, and creates individualized learning paths based on student progress. The study concludes that the adaptive digital textbook

significantly enhances biology instruction quality by promoting comprehensive material coverage, providing differentiated assignments, and increasing student engagement. The findings suggest that adaptive learning technologies can effectively support personalized education and improve academic outcomes in secondary school settings.

Keywords:
Adaptive Learning, Digital Textbook, Personalized Education, Biology Instruction, Semantic Analysis, Educational Technology

1. Introduction

Transformation of school textbooks from paper to digital adaptive formats is a response to multiple challenges of modern education associated with general digitalization, the need for intensive, effective learning, and the penetration of artificial intelligence into many areas of public life. Adaptive learning is based on the concept of multiple learning trajectories, allowing the educational process to be organized in accordance with the interests and needs of each student (Brusilovsky, 2022). This implies taking into consideration multiple personal, pedagogical and psychological traits and states, due to which students behave and act differently. (Muñoz, 2022) Even students from the same class might have a variety of cultural backgrounds, cognitive styles and educational history. Some of them may need more time to revise the material, others may tend to require more hands-on experience (Barria-Pineda 2022).

Contemporary digital learning platforms, supporting the functionalities of collating educational goals with achieved results, tracing students' digital footprints and modelling cognitive learning styles are powerful prerequisites for designing digital adaptive textbooks. Such functionality makes it possible to progress the student to the course materials and trace their learning trajectory (Holt 1994). Over the years of practical testing of adaptive learning, general requirements for such platforms have emerged. (Despotović-Zrakić 2021) First and foremost, they must be versatile enough to accommodate educational content in various formats, such as text, graphics, audio, video, or interactive components. (Chaudhri, 2013) An obvious advantage of an adaptive learning platform is support for modern protocols for hosting and processing digital learning objects, such as xAPI. Finally, the need to integrate the platform into modern learning analytics systems requires it to collect, store, and transmit data regarding learner behavior and activity on the platform (Mitrovic 2007). The use of digital learning platforms for hosting adaptive textbooks makes it possible to teach students in alternative settings, such as blended learning and flipped classrooms. Thus students may study new material at home and then master it in the classroom communicating with each other and the teacher (Howard 2006).

The effectiveness of the use of a digital adaptive learning textbook at school depends on multiple factors. First of all, the teachers should be well aware of teaching methods in digital adaptive learning textbook enhanced classrooms. It has been noted that simply converting school textbook content to a digital adaptive format does not solve the problem of achieving personalized learning goals. If the digital transformation process doesn't address the principles upon which

teachers build their teaching, even the use of digitally adaptive textbooks won't allow it to move beyond traditional instructional frameworks (Oussous 2023). Therefore, the introduction of innovative digital resources must inevitably be combined with the sharing of best teaching practices among teachers. Along with improving the overall digital culture of teachers and students, these factors are essential for the implementation of digital adaptive learning (Ghergulescu 2016). The project described in this paper enabled us to transform the content of a printed textbook into digital adaptive (TSAU) and to test the digital textbook teaching and learning in the middle school classroom settings.

2. Methodology

The TSAU digital adaptive textbook is based on the printed middle school biology textbook by V.Pasechnik, adopted in the Russian secondary school system. The foundation for creating the digital adaptive textbook was a deep semantic analysis of the text corpus comprising it. The TSAU was constructed as a network of interconnected didactic units, the nature of the relationships between which was determined by the semantic proximity of their key concepts. (Chau, 2021) To determine the degree of semantic proximity, we used the retrieval augmented generation graph pipeline based on Microsoft Graphrag pipeline. This pipeline leverages the capabilities of LLM to extract entities and relationships and summarize their descriptions, significantly improving its performance when processing larger volumes of text.

In our approach, we used Qwen 3:32 b as the LLM, installed locally and connected to the platform via the Ollama interface. This solution significantly improved the efficiency of the pipeline. To extract entities from the text corpus, we split the printed textbook into individual paragraphs. At the preprocessing stage, the text corpus was divided into chunks of 1,000 tokens each with an overlap of 200 tokens. This allowed for rapid text processing without sacrificing the accuracy of entity and relationship extraction. A total of 3,121 entities were extracted from the text corpus in this manner, forming the basis of the conceptual framework for the digital adaptive biology textbook. All extracted entities were expertly verified by the authors of the printed textbook.

We combined the use of text mining and analysis methods in developing a digital adaptive biology textbook based on a graph approach with experiments using artificial intelligence technologies to generate questions needed to monitor student knowledge and test the system's

ability to adequately evaluate student responses to questions. We found that graph-based semantic analysis methods implemented in the Microsoft Graphrag pipeline yield results at least 8% better than the naive RAG approach and 15% better than using LLM without RAG context.

An analysis of the teaching units comprising the biology textbook corpus, based on the resulting concept map, allowed us to identify key elements and fundamental relationships that determine students' successful mastery of the subject. It was discovered that, at the initial stages of the school biology curriculum, units such as "plant structure," "the interrelationships of living organisms," and "cell structure" play a key role in students' learning. At later stages, the units of "mechanisms of heredity in nature," "the interrelationships of living organisms," and so on are of primary importance. These units are essential points in students' individual learning trajectories. The specific trajectories themselves, the timeframe and pace of their mastery, and the number of attempts required to master them can vary significantly.

Each TSAU content unit was designed so that it was available for students as a text and a video material, an animated 2D video clip, clearly explaining the concepts, included in it. The videos were made as comprehensive as possible and still, completely compliant with the printed textbook course materials. Content units also contained questions for controlling students' understanding of the material. The questions were arranged in two levels, basic and advanced. The basic level generally consisted of multiple choice questions, for which the student was supposed to choose one correct answer. The advanced level consisted of questions for which the student was supposed to choose two out of five possible answers. If the students successfully passed all the basic level questions, they were transferred by the platform on the advanced level. Students can make several attempts in answering the questions. If the student failed to answer questions to a particular content unit, they were advised by the system to review the prerequisite modules, depending on the kind of the mistake that the student made.

A gamification system was embedded in the adaptive digital textbook platform. Students could collect virtual badges for solving most tasks and advancing further on the platform. As their badges were exhibited in their profiles on the platform, the gamification system helped students to build motivation for exploring the platform and advancing through the learning materials.

Teachers could review all their students' progress through their interface, which provided them with the opportunities to analyze the whole picture of the class advancement through the material or go deeper into the statistics of a particular student. In this mode, the teacher

could analyze in detail the number of assignments a student had completed and how well they had completed them. Assignments could be filtered for a specific period or by selected topics. The interface supported downloading all statistical reports for the class, which could be analyzed using specialized software. Moreover, by seeing the overall performance of the class and identifying obvious gaps in learning, the teacher could make adjustments using the homework tool, selecting the combination of materials for independent study that would best facilitate the achievement of the best results.

3. Results

The TSAU was piloted in five schools in Moscow, Russia, during the 2024-2025 academic year. A total of 421 students in grades 5 and 6 participated in the pilot. Teachers working with the TSAU were pre-trained and briefed by the project team on the technical features of the platform and pedagogical scenarios that the digital textbook could be used with. The pilot lasted throughout the academic year. To monitor the pilot, the project team contacted teachers weekly to resolve technical issues related to the platform and to discuss organizational and pedagogical issues that arose during the pilot. Specifically, the most frequently used TSAU scenarios in the educational process were discussed. 100% of teachers found that TSAU was most effective when students were working on homework. Furthermore, 50% of teachers used the platform to explain new material in class. Students' knowledge tests were administered twice, in September and May, to measure the impact of using the TSAU in the educational process.

To determine the effectiveness of teaching biology with the TSAU, we measured the success of learning in the control (196 students) and experimental (225 students) groups. In the experimental group, before the start of training, 35% of students scored 80 out of 100 or higher on the test, 58% scored between 50 and 80, and 7% scored less than 50 out of 100. After training using the adaptive textbook, 55% of students scored 80 out of 100 or higher on the test, 42% scored between 50 and 80, and 3% scored less than 50 out of 100. Thus, 23% of students were able to improve their score. In the control group, before the start of training, 29% of students scored 80 points out of 100 or higher, 56% scored between 50 and 80 points, and 15% scored less than 50 points out of 100. After training without using the adaptive textbook, 32% of students scored 80 points out of 100 or higher, 56% scored between 50 and 80 points, and 11% scored less than 50 points out of 100. On average, students in the control group improved their score by no more than

2%. Thus, testing a digital adaptive textbook in four experimental schools revealed a significantly higher increase in test completion success in the experimental group – 23% (from 69% to 92%) – than in the control group – 2% (from 69% to 71%). These results were confirmed by the Chi-Square statistical test.

The platform recorded both successful and unsuccessful completion of all assignments. Based on the analysis of students' learning paths, two parameters were identified that influence successful learning: the number of assignments completed and the correctness of answers. Having correctly completed the tasks assigned by the teacher in a module, students could move on to tasks in subsequent modules. Some students completed over 170 tasks. The accuracy of their answers varied, ranging from 54% to 93%. Based on the number of tasks completed and their accuracy, students were divided into four groups: Group 1 – high achievers; Group 2 – experimentalists; Group 3 – inactive; Group 4 – perfectionists.

The first group (high achievers) included students who completed more than half of the available assignments. They completed at least 67% of the assignments correctly. In the experimental sample, high achievers constituted 33% of the total number of students. The second group (experimenters) included 7% of students who completed more than half of the available assignments. Of these, less than 67% of the assignments were completed correctly. The third group (inactive students) included 15% of students who completed less than half of the available assignments. Of these, less than 67% of the assignments were completed correctly. The fourth group (perfectionists) included 43% of students who completed less than half of the assignments. However, students in this group completed more than 67% of the assignments correctly.

4. Conclusion

Thus, it can be argued that the comprehensiveness of the material covered while using an adaptive textbook, as well as the differentiation and high variability of the assignments within the adaptive textbook itself, contribute to improved student performance even more than the active learning of the adaptive textbook. This is because among the students who most fully covered the textbook topics, there were also those who completed less than 75% of the assignments. This means that they did not solve all the problems in the topic, but they solved at least half of the problems in each topic.

It can also be argued that students' increased engagement in using the adaptive textbook contributes to improved academic performance. This is especially true if students make mistakes and review previous material, thereby better absorbing knowledge and subsequently applying it on tests. Based on the experimental work and statistical data processing, it can be concluded that teaching with the developed digital adaptive textbook does improve the quality of biology instruction and contributes to students' academic performance, as confirmed by the dynamics of their academic performance based on test results, as well as statistical data processing.

References

Ain, Q. U., Chatti, M. A., Bakar, K. G. C., Joarder, S., & Alatrash, R. (2023). Automatic Construction of Educational Knowledge Graphs: A Word Embedding-Based Approach. Information, 14(10), 526.

Barria-Pineda J., Narayanan A.B., Brusilovsky P Augmenting digital textbooks with reusable smart learning content: Solutions and challenges // Proceedings of the Fourth International Workshop on Intelligent Textbooks 2022, volume 3192 of CEUR Workshop Proceedings, CEUR-WS.org, 2022. P. 77–91.

Brusilovsky, P., Sosnovsky, S., & Thaker, K. (2022). The return of intelligent textbooks. AI Magazine, 43(3), 337-340.

Chaudhri, V. K., Cheng, B., Overtholtzer, A., Roschelle, J., Spaulding, A., Clark, P., & Gunning, D. (2013). Inquire biology: A textbook that answers questions. AI Magazine, 34(3), 55-72.

Chau, H., Labutov, I., Thaker, K., He, D., & Brusilovsky, P. (2021). Automatic concept extraction for domain and student modeling in adaptive textbooks. International Journal of Artificial Intelligence in Education, 31, 820-846.

Despotović-Zrakić, M., Marković, A., Bogdanović, Z., Barać, D., & Krčo, S. (2012). Providing adaptivity in Moodle LMS courses. Journal of Educational Technology & Society, 15(1), 326-338.

Ghergulescu, I., Flynn, C., & Sullivan, C. O. Learning effectiveness of adaptive learning in real world context // EdMedia: World Conference on Educational Media and Technology. 2016. P. 1385–1390.

Holt, P., Dubs, S., Jones, M., & Greer, J. (1994). The state of Student Modelling. Student Modelling: The Key to Individualized Knowledge-Based Instruction.

Howard, L., Remenyi, Z., Pap, G. Adaptive blended learning environments // International Conference on Engineering Education. 2006. P. 23-28.

Mitrovic A., Martin B., Suraweera P. Intelligent tutors for all: constraint-based modeling methodology, systems and authoring // IEEE Intell. Syst. 2007. Vol. 22(4). P. 38–45

Muñoz, J. L. R., Ojeda, F. M., Jurado, D. L. A., Peña, P. F. P., Carranza, C. P. M., Berríos, H. Q., ... & Vasquez-Pauca, M. J. (2022). Systematic review of adaptive learning

technology for learning in higher education. Eurasian Journal of Educational Research, 98(98), 221-233.

Oussous, A., Menyani, I., Srifi, M., Lahcen, A. A., Kheraz, S., & Benjelloun, F. Z. (2023). An Evaluation of Open Source Adaptive Learning Solutions. Information, 14(2), 57.