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INVESTIGATION OF THE IMPACT OF ELECTRONIC LEARNING RESOURCES ON LEARNING OUTCOMES IN THE "NANOTECHNOLOGY AND NANOMATERIALS" COURSE

Abstract. This research used a meta-analysis to assess the effectiveness of digital and electronic educational resources in teaching the subject "Nanotechnology and Nanomaterials". The results of twelve different studies were combined and a standardized mean difference index was calculated. The conclusion based on the random effects model showed that electronic resources contribute to students' academic achievement ($d = 0.59$, 95% CI: 0.14–1.05, $p = 0.011$). These results suggest that the use of electronic tools can be an effective basis for better mastering the subject.

Based on the research findings, an electronic textbook "Teaching Nanotechnology: Principles and Practices" was developed. The textbook includes theoretical sections, video lectures and interactive tasks, practical exercises, which allow students to increase their interest in the subject and organize the learning process flexibly. Its advantages include the availability of educational materials, the possibility of independent learning through digital platforms, and compatibility with modern methodological tools.

However, the developed electronic textbook has not yet been tested in specific empirical studies. The results of the study indicate the need for pilot testing of this textbook in the future, based on meta-analysis data proving the effectiveness of electronic resources. The results of the study show that the use of electronic educational resources and a specially developed textbook is effective in increasing the academic achievement of students in the subject "Nanotechnology and Nanomaterials". In addition, the need for the integrated use of adapted methodologies and interactive tools to increase their effectiveness is identified.

Keywords: nanotechnology education, e-learning resources, digital textbook, student achievement, meta-analysis, STEM education.

Introduction

Nanotechnology and nanomaterials are one of the strategically important industries that have a huge impact on the development of science and industry in the XXI century. Based on the study, Application, Control and management of particles from 1 to 100 Nm, this field develops at the intersection of physics, chemistry, biology, materials science and engineering [1]. Today, nanotechnology plays an important role in medicine, electronics, energy, defense, Environmental

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Protection and the development and processing of new materials. The global nanomaterials market size was estimated at USD 12.42 billion in 2023 and is projected to reach USD 32.77 billion by 2030, growing at a CAGR of 15.0% from 2024 to 2030 [2]. This indicates that highly qualified specialists in this area will be needed, and the importance of their training is growing.

The training of the course "Nanotechnology and Nanomaterials" presents significant difficulties due to the complexity and interdisciplinary nature of the topics. Traditional lecture and seminar lesson formats often do not provide for the comprehensive development of both modern deep theoretical understanding and laboratory skills of students [3]. The microscopic nature of nanostructures, their multidimensional properties and features of industrial technologies require the integration of adaptation and modeling tools into the educational process. As a result, the use of electronic educational resources (EOR) has become one of the main tools for improving the effectiveness of training [4].

EOR are state-of-the-art digital learning systems that deliver theoretical content through video lectures, virtual labs, 3D models, and interactive exercises. Studies have shown that the use of multimedia materials improves the understanding of complex and difficult concepts by 25-30% [5], and in this area, virtual laboratories can improve students' practical skills by up to 20% compared to traditional laboratory classes [6].

Meta-analysis analysis results show that integrating digital and mobile technologies (e.g. online platforms, mobile applications, interactive content, electronic textbooks, etc.) into teaching can increase student learning outcomes to a standardized average difference (Cohen's d) of 0.35-0.45 [7]. This effect is statistically significant at $p<0.01$, proving that e-learning resources surpass traditional teaching methods in teaching effectiveness. The degree of effectiveness of this effect may vary depending on the educational training of students, the quality of electronic resources, the qualifications of the teacher and the specific educational environment [8].

Information from the organization for Economic Cooperation and Development (OECD, 2023) said that new and modern digital resources are continuously developing. This showed that university students using recsources had a 12-15% higher average performance in STEM subjects compared to students from another educational institution [9]. UNESCO research has shown that the digitalization of education and the introduction of new technologies not only improve the quality of teaching, but also increase inclusive education in educational processes [10]. However, there are challenges such as digital inequality, limited access to platforms and the internet, and insufficient ICT competence of educators. This limits the benefits in digital education to be equally accessible to all learners [11].

The importance of electronic resources in teaching the field of nanotechnology is especially noticeable. For example, a global open access Science portal with more than 2 million users NanoHUB.org the platform provides students and researchers with access to more than 500 modeling tools and virtual laboratories [12]. In addition, the specially developed electronic textbook "teaching Nanotechnology: principles and practices" helps students to master complex theoretical concepts through structured content, practical exercises and interactive modeling [13]. Studies show that student groups using this textbook have an average 18% improvement in academic performance compared to those taught using traditional methods [14].

This study is aimed at a comprehensive assessment of the effectiveness of the use of electronic educational resources in teaching the discipline "Nanotechnology and Nanomaterials". Conduct a meta-analysis based on the data of twelve international and world scientific papers, statistically assess the impact of electronic educational resources on students' academic achievements and reveal the advantages of the electronic textbook "Nanotechnology teaching: principles and practices".

The results of this study will contribute to the development of strategies for the effective integration of electronic educational resources in the teaching of nanotechnology and nanomaterials, improving the quality of education and improving the professional competencies of future specialists.

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Research methods and materials

This study was aimed at a comprehensive assessment of the impact of electronic educational resources on learning outcomes in the discipline of "Nanotechnology and Nanomaterials" and was carried out in two main stages. In the first stage, a meta-analysis was conducted based on international scientific databases: a systematic search was carried out in Scopus and Web of Science for studies published between 2014 and 2024, in which the subject was related to nanotechnology or natural and technical fields, electronic educational resources (online platforms, virtual laboratories, video lectures, interactive tasks) were used during training, learning achievements were assessed quantitatively, and 10 articles were selected with sufficient data to calculate Cohen's d (standardized mean difference) and Standard Error (SE). All data were standardized based on sample size, mean values, and standard deviations, and the effect size was calculated. Statistical analysis was based on a random-effects model, taking into account the diversity of the study contexts [16; 17], resulting in the determination of the mean effect size (d), 95% confidence interval (CI), Z and p values, as well as the Q-test and I^2 indices to assess heterogeneity [20]. The analysis was performed using the Comprehensive Meta-Analysis (CMA) Version 4 program. In addition, the variance of the true effects (tau^2) and the prediction interval were determined [21].

The meta-analysis method was used to combine the data obtained from the studies and identify general patterns. This method allows you to systematize the results of various studies, determine their common direction, and draw generalized scientific conclusions. To describe the magnitude of the effect, the standardized mean difference was calculated using the equation (1):

$$Standardized\ difference = \frac{\overline{X_1} - \overline{X_2}}{S} \quad (1)$$

where S represents the total (combined) standard deviation, which is calculated based on the individual standard deviations of the two groups, as shown in Equation (2):

$$S = \sqrt{\frac{(n_1 - 1){S_1}^2 + (n_2 - 1){S_2}^2}{n_1 + n_2 - 2}} \quad (2)$$

The results of the meta-analysis showed that electronic educational resources have a significant positive impact on students' academic achievement.

Based on these scientific findings, an electronic textbook entitled "Teaching Nanotechnology: Principles and Practice" was developed. The textbook is designed in a modular structure consisting of theoretical texts, video lectures, and practical tasks aimed at developing students' research abilities and practical skills. This modular approach allows for a systematic organization of the learning process. While video materials make it easier to understand complex concepts, interactive exercises create conditions for consolidating knowledge.

At the same time, the digital format of the textbook allows students to independently learn, flexibly choose the pace of learning, and effectively master the material. These features pave the way for the systematic and effective use of the electronic textbook in traditional, blended, and distance learning environments.

Results and discussion

Based on the collected data, the effectiveness of electronic educational resources used in the process of teaching natural sciences disciplines is determined by meta-analysis. The analysis made it possible to quantitatively compare and combine the results of various studies aimed at identifying students ' academic achievements, the level of assimilation of subject knowledge and the impact on the development of digital competencies.

The summary indicators obtained on the basis of meta-analysis determined the level of influence of electronic resources on the educational process and served as the basis for systematic and reasoned conclusions on their effectiveness. The results of the data obtained from the scientific literature are summarized (Table 1).

Table 1 – Results of meta-analysis on data from scientific literature

№	Study name	Std diff means	Sstandard error
1	Rafiq et.al. (2024) 1	0,079	0,057
2	Rafiq et.al. (2024) 2	0,14	0,059
3	Ibrohim et.al (2023)	0,207	5,046
4	Yao et.al (2022)	0,47	0,499
5	Zhou et.al (2021)	1,084	0,046
6	Shen et.al (2022)	0,994	0,056
7	Bakoush et.al (2022)	1,477	0,839
8	Kong & Wang (2022)	0,0227	2,535
9	Ma& Tian (2023)	0,328	2,461
10	Peng et.al (2023)	0,27	2,435
11	Provorova et.al (2020) 1	0,745	1,316
12	Provorova et.al (2020) 2	0,164	1,047

The data presented in Table 1 was entered into the comprehensive meta-analysis (V4) software and analyzed. The initial results of the program were visualized using a funnel graph, which is often used in order to assess the compatibility between the study and the possible distortion of the publication.

The funnel graph provides an effective visual method for determining the symmetry of research results, analyzing the features of data distribution, and assessing the likelihood of publication distortion in this graph, the magnitude of the impact of each study is compared with its standard error, which allows you to evaluate the balance and possible deviation in the aggregated data.

The funnel graph (Figure 1) obtained during this study determines the nature of the distribution of results related to the effectiveness of electronic learning resources and serves as the basis for assessing the reliability and adequacy of meta-analysis results.

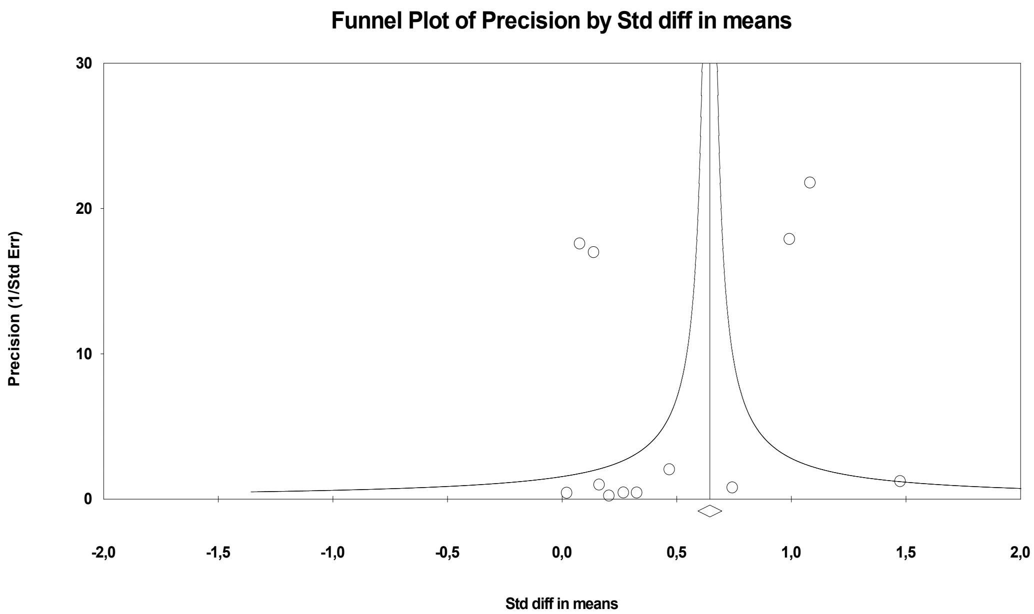


Figure 1 – Funnel plot illustrating potential publication bias

Analysis of the Distribution of True Effects

The results of the meta-analysis revealed that the overall average impact of interventions (electronic learning resources and similar training tools) is d=0.59. This indicator indicates that these interventions have an overall positive impact on learning outcomes. The confidence interval (S) of 95% was in the range from 0.14 to 1.05, which indicates that the determined average effect is statistically significant and significant.

The forecast interval (from -0.70 to 1.88) showed significant variability of results in the context of different studies. This, in turn, suggests that the amount of true impact in other similar populations can occur at any point in this range. Since the lower threshold of the interval extends to a negative value, it has been shown that interventions are more likely to give weak or even negative effects under certain conditions.

These findings indicate a high degree of heterogeneity across studies ($I^2 = 96\%$, as determined in earlier calculations). Nevertheless, the fact that the pooled effect size is positive and statistically significant confirms that electronic learning resources are generally effective in enhancing learning outcomes (Figure 2).

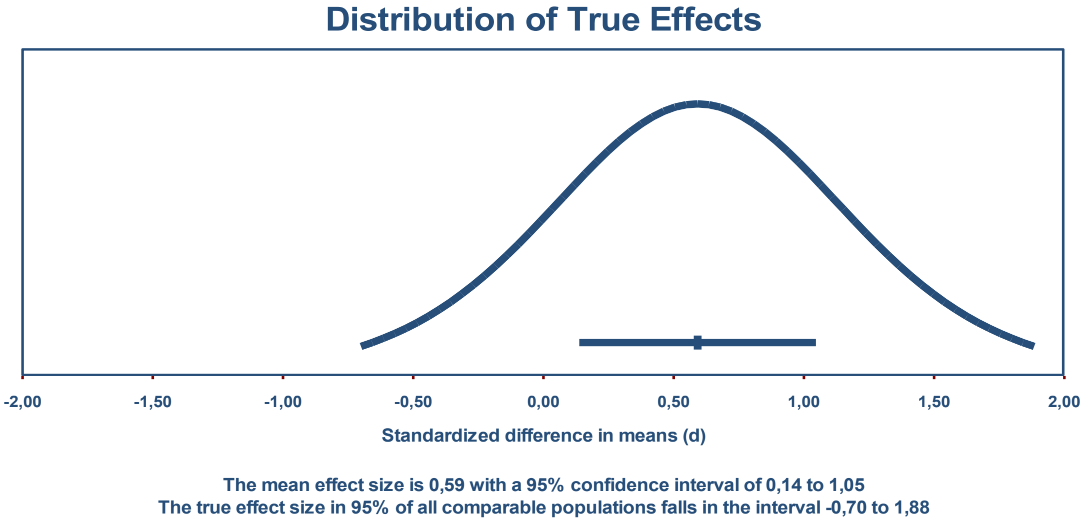
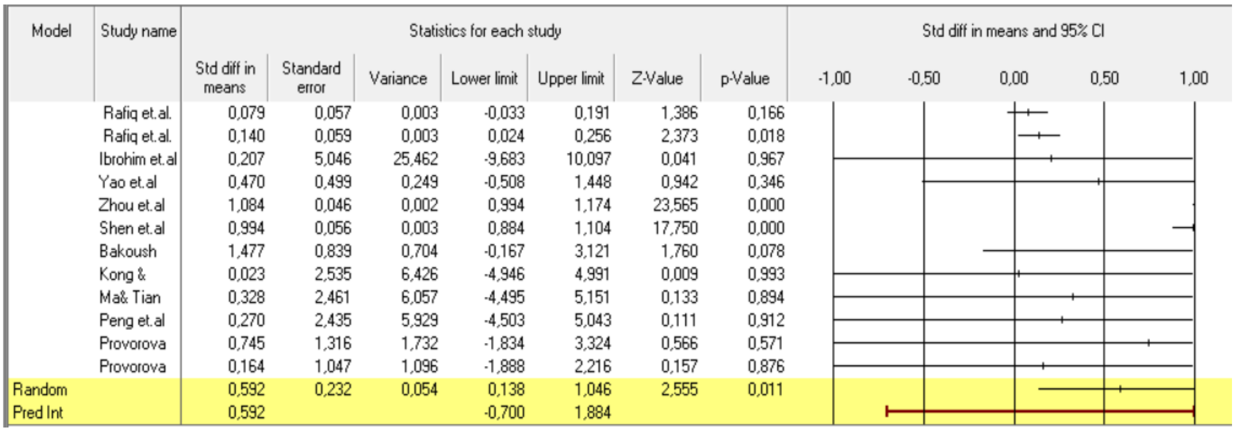


Figure 2 – Distribution of True Effects

As one of the key outputs of the meta-analysis, a forest plot was generated. This type of graph is among the most commonly used visualization tools in meta-analysis, as it displays the effect size and corresponding confidence intervals for each individual study while also presenting the pooled overall effect estimate derived from all studies. For this research, the resulting forest plot is presented in Figure 3, visually summarizing the combined findings of the meta-analysis.



Model	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Rafiq et.al.	0,079	0,057	0,003	-0,033	0,191	1,386	0,166
	Rafiq et.al.	0,140	0,059	0,003	0,024	0,256	2,373	0,018
	Ibrohim et.al	0,207	5,046	25,462	-9,683	10,097	0,041	0,967
	Yao et.al	0,470	0,499	0,249	-0,508	1,448	0,942	0,346
	Zhou et.al	1,084	0,046	0,002	0,994	1,174	23,565	0,000
	Shen et.al	0,994	0,056	0,003	0,884	1,104	17,750	0,000
	Bakoush	1,477	0,839	0,704	-0,167	3,121	1,760	0,078
	Kong &	0,023	2,535	6,426	-4,946	4,991	0,009	0,993
	Ma& Tian	0,328	2,461	6,057	-4,495	5,151	0,133	0,894
	Peng et.al	0,270	2,435	5,929	-4,503	5,043	0,111	0,912
	Provorova	0,745	1,316	1,732	-1,834	3,324	0,566	0,571
	Provorova	0,164	1,047	1,096	-1,888	2,216	0,157	0,876
Random		0,592	0,232	0,054	0,138	1,046	2,555	0,011
Pred Int		0,592			-0,700	1,884		

Figure 3 – Forest plot of meta-analysis results based on the collected data

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The analysis is based on twelve studies. The effect size index is the standardized difference in means (d). The random-effects model was employed for the analysis. The studies in the analysis are assumed to be a random sample from a universe of potential studies, and this analysis will be used to make an inference to that universe.

The mean effect size is 0,592 with a 95% confidence interval of 0,138 to 1,046. The mean effect size in the universe of comparable studies could fall anywhere in this interval.

The Z-value tests the null hypothesis that the mean effect size is zero. The Z-value is 2,555 with p = 0,011. Using a criterion alpha of 0,050, we reject the null hypothesis and conclude that in the universe of populations comparable to those in the analysis, the mean effect size is not precisely zero.

The Q-statistic provides a test of the null hypothesis that all studies in the analysis share a common effect size. If all studies shared the same true effect size, the expected value of Q would be equal to the degrees of freedom (the number of studies minus 1). The Q-value is 303,212 with 11 degrees of freedom and p < 0,001. Using a criterion alpha of 0,100, we can reject the null hypothesis that the true effect size is the same in all these studies.

The I-squared statistic is 96%, which tells us that some 96% of the variance in observed effects reflects variance in true effects rather than sampling error.

Tau-squared, the variance of true effect sizes, is 0,283 in d units. Tau, the standard deviation of true effect sizes, is 0,532 in d units.

If we assume that the true effects are normally distributed (in d units), we can estimate that the prediction interval is -0,700 to 1,884. The true effect size in 95% of all comparable populations falls in this interval. Overall, the meta-analysis indicates that electronic learning resources exert a statistically significant positive effect on learning outcomes in the “Nanotechnology and Nanomaterials” course. The pooled mean effect size (d = 0.592; 95% CI: 0.138–1.046) demonstrates that such interventions meaningfully enhance student achievement (Z = 2.555, p = 0.011).

Advantages of the Teaching Nanotechnology: Principles and Practices e-textbook

The main feature of the Teaching Nanotechnology: Principles and Practices e-textbook is that its content begins with an introductory section to the field of nanotechnology and covers the main areas of the subject step by step. The material begins with an introductory part and includes the emergence, Development, place of nanotechnology in science and technology and the main sections of the discipline in a step-by-step manner. The structure of the textbook is designed in the form of consistency and continuity. It consists of three main components: lectures, practical tasks and video lectures (Figure 4).

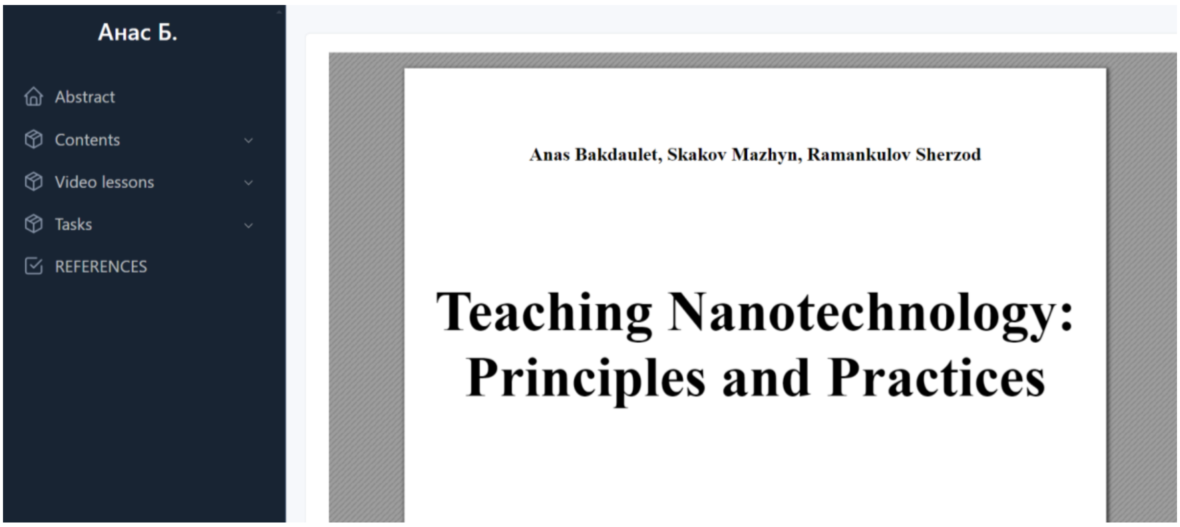

Figure 4 – Teaching Nanotechnology: Principles and Practices e-textbook

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Lecture sections allow students to gain in-depth theoretical knowledge of nanotechnology and nanomaterials. The materials are developed based on modern scientific data and research results. In each section, the main terms and concepts are explained using specific examples and create conditions for a deep understanding of the content of the subject. The video lecture section presents theoretical content in a visual format, which allows you to easily perceive the understanding of complex topics. In addition, the videos create a favorable environment for students to learn independently, develop the educational process according to their personal abilities and assimilation of knowledge. Practical tasks and exercises are aimed at increasing the theoretical knowledge of students, forming the skills of search and assimilation of knowledge [22].

This textbook is developed in accordance with the principles of STEM education and is aimed at combining students' theoretical knowledge with practice. Such an integrated structure of the textbook not only facilitates the mastery of the subject, but also ensures the development of students' research and practical skills. In addition, it contributes to improving students' critical thinking skills and forming teamwork experience through project work. Learning through digital platforms supports students' independent learning, effective time management, and professional skills development. As a result, this textbook improves the quality of the learning process and allows training competitive specialists with modern knowledge in the field of nanotechnology.

The electronic textbook “Teaching Nanotechnology: Principles and Practices” consists of 11 sections. Each section consists of several thematic lectures and systematically covers the main areas of the field of nanotechnology. The content includes: introduction to quantum mechanics; principles of atomic arrangement; synthesis of nanomaterials - I (physical methods); self-assembly processes; methods of analysis and characterization; types of nanomaterials and their properties; basics of nanolithography; nanoelectronics; some specially used nanomaterials; applications of nanotechnology; nanotechnology and the environment.

This electronic textbook can be effectively used both in the process of distance online learning and in traditional classroom lessons. The format, which allows you to download materials in advance and use them without an Internet connection, gives students flexibility in their learning. The structure of the textbook is aimed at the gradual acquisition of theoretical knowledge and is designed to facilitate the learning process through modern digital resources (Figure 5).

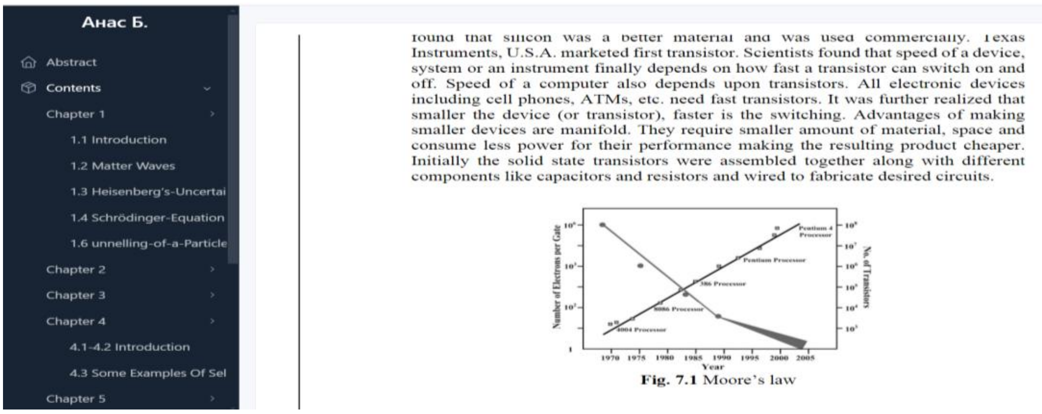

Figure 5 – E-textbook lectures

The video lectures presented in the electronic textbook are aimed at comprehensively explaining the main aspects of the field of nanotechnology. The video materials describe the history of the development of nanotechnology, its current scientific and technical achievements and the possibilities of its application in various fields (medicine, energy, electronics, environmental technologies). In addition, the video lectures consider the impact of nanomaterials on the environment, environmental safety issues and their role in terms of sustainable development (Figure 6).

These video lectures convey complex theoretical concepts in a visual format, facilitating the easy perception of the material by students. The materials also analyze the future development directions of nanotechnology, its integration with such areas as artificial intelligence and biotechnology, and the opportunities they bring to research and industry.

Thus, the video lectures allow students to master the theoretical foundations of the subject, as well as understand the practical significance and prospects of nanotechnology, as well as assess its impact on society and the environment.

Figure 6 – Video lectures in the electronic textbook

The electronic textbook "Teaching Nanotechnology: Principles and Practices" contains, along with theoretical materials, tasks and practical work designed to develop students' practical skills. Solutions to each task are shown, allowing students to independently understand the topic in depth and compare the correct answers.

Practical sections provide examples of determining the properties of nanomaterials, analyzing the characteristics of synthesis methods, using analysis methods, solving specific problems and interpreting results. This allows students to master real practical situations and consolidate their theoretical knowledge.

Such a structure allows the textbook to be used not only as a theoretical source, but also as a full-fledged educational tool focused on practice. As a result, students develop their research and analytical skills in the process of mastering the subject and practice applying their knowledge in practice.

In conclusion, the results of the meta-analysis showed that electronic educational resources have a significant positive impact on academic achievement

In education, the use of electronic manuals and digital platforms in online and traditional classes, with pre-download, there are also opportunities for remote use at any time.

The effectiveness of e-learning tools is also often noted in the scientific literature. For example, the Jono, Sudiyanto, Sukmavati, and Salimi reviews [23] focus on studying the impact of digital learning materials on academic achievement at different levels of Education based on their classification. Giassolli et al. have shown that the field of "nanotechnology" and its connection to scaled objects is effective in using it to arouse participants' interest and enthusiasm for STEAM [24]. Borenstein et al. explained the main assumptions of two popular statistical models of meta-analysis, the effects model and the random effects model, and described the differences between the models [16]. A study by Aderibigbe concluded that online discussions can promote deep learning if teachers provide students with clear instructions and reasonable time to connect with their peers [25].

The results of this study also showed us that the effective use of electronic textbooks and digital learning resources can be useful for students to master the discipline in depth, improve their research and analysis skills.

Conclusion

Results of the study by conducting a meta-analysis, we were able to evaluate the effectiveness of electronic educational resources in studying the discipline “Nanotechnology and Nanomaterials”.

We noticed that the impact of electronic resources on educational achievements gives a significant positive result through conclusions based on the model of random effects ($d = 0.59$, 95% CI: 0.14–1.05, $p = 0.011$).

The electronic textbook “Teaching Nanotechnology: Principles and Practices” has received a certificate of authorship. The textbook is aimed at systematically mastering theoretical knowledge, in-depth understanding of complex concepts, and developing practical skills. Lectures, video lectures and practical tasks in the textbook are built in logical connection with each other, which allows students to master the educational material step by step.

This makes the learning process more flexible and creates conditions for students to learn independently. As a result, the learning process is effectively implemented in traditional, mixed and distance learning formats.

In general, this study proved that electronic educational resources, including the electronic textbook “teaching nanotechnology: principles and practices”, play an important role in improving the quality of education, increasing students' interest in the subject and developing their professional competence. Modern requirements in the future, the use of electronic educational resources and platforms for teaching the field of nanotechnology and natural science disciplines requires the training of competitive specialists in accordance with the labor market.

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«Нанотехнология және наноматериалдар» пәніндегі оқу нәтижелеріне электрондық білім беру ресурстарының ықпалын зерттеу

Аңдатпа. Бұл ғылыми зерттеуде «Нанотехнология және наноматериалдар» пәнін оқытуда цифрлық және электрондық білім беру ресурстарының тиімділігін бағалау мақсатында мета-талдау әдісі пайдаланылды. Әр түрлі он екі зерттеудің нәтижелері біріктіріліп, стандартталған орташа айырмашылық индексі есептелді. Кездейсоқ әсерлер моделі негізінде алынған қорытынды электрондық ресурстардың білім алушылардың оқу жетістіктеріне ықпал ететінін көрсетті ($d = 0{,}59$, 95% CI: 0,14–1,05, $p = 0{,}011$). Бұл нәтижелер электрондық құралдарды пайдалану пәнді жақсы меңгеру үшін тиімді негіз бола алады.

Зерттеу қорытындыларына сүйене отырып, «Teaching Nanotechnology: Principles and Practices» атты электрондық оқулығы әзірленді. Оқулық теориялық бөлімдерден, бейнедәрістер мен интерактивті тапсырмалардан, тәжірибелік жаттығуларды қамтып, студенттердің пәнге қызығушылығын арттыруға және оқу процесін икемді ұйымдастыруға мүмкіндік береді. Оның артықшылықтары ретінде оқу материалдарының қолжетімділігі, цифрлық платформалар арқылы өз бетінше білім алу мүмкіндігі және заманауи әдістемелік құралдармен үйлесімділігі атап өтіледі.

Дегенмен, әзірленген электронды оқулық арнайы эмпирикалық зерттеулерде әлі сынақтан өткізілмеген. Зерттеу нәтижелері электрондық ресурстардың тиімділігін дәлелдейтін мета-талдау деректеріне сүйене отырып, бұл оқулықты болашақта пилоттық апробациядан өткізу қажеттігін көрсетеді. зерттеу нәтижелері электрондық білім ресурстары мен арнайы әзірленген оқулықты пайдалану «Нанотехнология және наноматериалдар» пәнінде білім алушылардың оқу жетістіктерін арттыруда тиімді екенін көрсетеді. Сонымен қатар, олардың тиімділігін арттыру үшін жағдайға бейімделген әдістемелер мен интерактивті құралдарды кешенді қолдану қажеттілігі айқындалады.

Кілт сөздер: нанотехнологияны оқыту, электрондық білім беру ресурстары, цифрлық оқулық, студенттердің жетістіктері, мета-талдау, STEM білім беру.

Исследование влияния электронных образовательных ресурсов на результаты обучения по дисциплине «Нанотехнология и наноматериалы»

Аннотация. В данном исследовании был использован метаанализ для оценки эффективности цифровых и электронных образовательных ресурсов при преподавании предмета «Нанотехнологии и наноматериалы». Результаты двенадцати различных исследований были объединены, и был рассчитан стандартизированный индекс средней разности. Вывод, основанный на модели случайных эффектов, показал, что электронные ресурсы способствуют повышению академической успеваемости студентов ($d = 0{,}59$; 95% ДИ: 0,14–1,05; $p = 0{,}011$). Эти результаты свидетельствуют о том, что использование электронных инструментов может стать эффективной основой для лучшего усвоения предмета.

На основе результатов исследования был разработан электронный учебник «Преподавание нанотехнологий: принципы и практика». Учебник включает в себя теоретические разделы, видеолекции и интерактивные задания, практические упражнения, что позволяет студентам повысить интерес к предмету и гибко организовать процесс обучения. К его преимуществам относятся доступность учебных материалов, возможность самостоятельного обучения с использованием цифровых платформ и совместимость с современными методическими инструментами.

Однако разработанный электронный учебник пока не проходил конкретных эмпирических исследований. Результаты исследования указывают на необходимость проведения пилотной апробации данного учебника в будущем, основанной на данных метаанализа, подтверждающих эффективность электронных ресурсов. Результаты исследования показывают, что использование электронных образовательных ресурсов и специально разработанного учебника эффективно повышает академическую успеваемость студентов по предмету «Нанотехнологии и наноматериалы». Кроме того, выявлена необходимость комплексного использования адаптированных методик и интерактивных инструментов для повышения их эффективности.

Ключевые слова: преподавание нанотехнологии, электронные образовательные ресурсы, цифровой учебник, успеваемость студентов, метаанализ, STEM-образование.

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