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PROGRESSIVE WEB TECHNOLOGY-BASED IMPROVEMENT OF THE DISTANCE LEARNING ADAPTIVE SYSTEM

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Summary. *An analysis of the well-known distance education systems was made, which allowed us to highlight their advantages and disadvantages and identify some ways to improve the program by adding adaptive functionality and interactivity, aimed at improving the educational process quality. An interface for working with the system for different groups of users (students, teachers, developers) has been developed whose use allows you to download study materials and test tasks conveniently, to edit and adapt some meaningful links between information sections (Units), to pass training and test control, to form final reports of success and recommendations for further learning steps. The multi-set method of assessing the level of study of content units was described and the adaptive functionality of forming the content of educational lectures for review or in-depth mastering of the theoretical content was presented, which allows taking into account the initial level of student knowledge and his/her abilities to acquire new skills. The software has been improved with a system based on PWA (Progressive web app) technology, which has allowed us to realize such advantages of web applications as speed, convenience, and attractiveness. A technology of text questions and correspondent information units connection was proposed which was based on the theory of multiple approach use which has provided us with the mathematical determination of the indices of the unmastered pieces of knowledge which generate the text part of the adaptive training step. Implementation of PWA technology was performed using the following software tools Service Worker, Web App Manifest, HTTPS, and Application Shell, which allowed to perform client caching offline, speeded up the process of downloading and displaying graphic elements of the web page, provided the use of the proposed resource as a regular mobile application. It has made it possible for easy access to the system to be obtained as well as the system resource use to be reduced.*

Key words*: distance learning system, adaptive learning, PWA technology, information unit, multiset method.*

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Problem statement. The present state of the field of education is on the stage of radical changes influencing not only the Ukrainian education system but the global one as well. It was caused by the introduction of quarantine coronavirus restrictions in all spheres of human activity, first of all in the educational one, Moreover, in our country, the educational process has suffered from the military actions due to the Russian invasion.

So, various online platforms and distance learning programs are becoming more and more popular and needed as they are able to provide a high technological approach to the process of knowledge transfer and make it possible to create a system of mass continuous learning. Thus, the scientific problems of further development of some new teaching models, methods, and techniques, improvement of the functionality of the conventional system due to various additional program modules adding aimed at the educational process organization efficiency rise and distance learning quality increase are still urgent.

Analysis of the known results of research. The conventional distance programs and systems are quite different in their technical opportunities and are characterized by different levels of complexity of their functional components. First of all, these are the products of the companies Open Source: MOODLE, ATutor, Dokeos, Claroline; Oracle: i-Learning; IBM:

Learning Space; distance learning system WIKAMP of Lodz polytechnic university (Lodz) and a number of national decisions, namely, «Virtual university» of the Department NTUU «KPI», «Web-class-ХПІ» of Kharkiv polytechnic institute, D-Learn of Vasyl Stefanyk Precarpathian National University and many others.

Despite a number of advantages, for example, such as possible converting of the material from any office program into the system «Virtual university» [1], open source code and a license for free software GPL (Moodle) [2], compatibility of many standards that allows us to implement outside software developments (ATutor [3]), the majority of well-known analogs can't provide the distance learning process as a single complex. Such essential learning functions such as report writing support, development, and modification of timetables, and calendars synchronization are not supported unfortunately by all systems. Moreover, such systems are characterized by the low level of adaptivity and interactivity of the educational process organization, i.e. programmable study conducted according to the individual characteristics of each student, speed of mastering, and the level of new knowledge acquiring [4].

Paper purpose. The purpose of the study under discussion is to develop an information technology aimed at the improvement of the distance learning adaptive system on the basis of web development PWA technology use.

Task setting. Among urgent tasks dealing with the distance learning systems use, the training web systems adaptable to the student's knowledge and abilities are especially becoming more and more important since they have a number of advantages [1]:

- allow reducing the nonproductive expenses of teachers' work;
- motivate students to study which results in changing the teacher's leading role;
- reach a higher level of the operations of control and assessment of learning outcomes;
- guarantee constant link in relations «teacher-student»;
- contribute to the individualization of an educational activity (learning pace differentiation, training tasks complexity, etc.);
- increase the motivation to master new knowledge due to the individual approach;
- facilitate the students' productive, creative functions development, intellectual capabilities rise, operation style of thinking formation.

The system of distance learning, which is being developed, is characterized by the following advantages:

- makes possible the adaptive control of a student's study trajectory, i.e. write an individual plan of the next learning step for each student taking into account his/her level of the current study material mastering;
- provides interactive ties with students that make it possible to eliminate some current gaps in knowledge by necessary theoretical content formation for review or deeper learning, provide information support while a certain topic is studied in the form of messages, additional materials, some keys, references, etc.;
- due to the program web technology development PWA broadens the system functionality and enables us not only to use the service in an offline mode more efficiently but use it as a regular mobile application as well and also adapt it taking into account different needs of an educational establishment, which makes the system more universal.

Results of the research. Being implemented in the system the adaptive functional has allowed it to be software-adapted to some individual characteristics of a student's mastering a new topic or a course taking into account his/her initial level and personal abilities of new knowledge acquiring.

As for the teacher, the system allows downloading theoretical material as conveniently as possible (i.e. *.doc, *.docx). A downloaded lecture file is an object whose main fields are the file type, its title, and a buffer (buffer is a massive of bites where the file content is recorded). For further processing of the file, the HTML converting is taking place which provides both,

its easy editing and unit formation as well. «Unit» is referred to as the smallest meaningful unit of a text (for example, a separate abstract, a rule, a definition, a theorem, a formula, a figure, etc.). The converting takes place using the outside library mammoth [5].

The units are formed automatically while writing a lecture. The converted lecture is divided into the tags formed by the library. After that, each tag is written into a new unit which will further form the whole lecture content.

Some new opportunities for lecture editing are available for users after the successful download of the lecture (fig. 1):

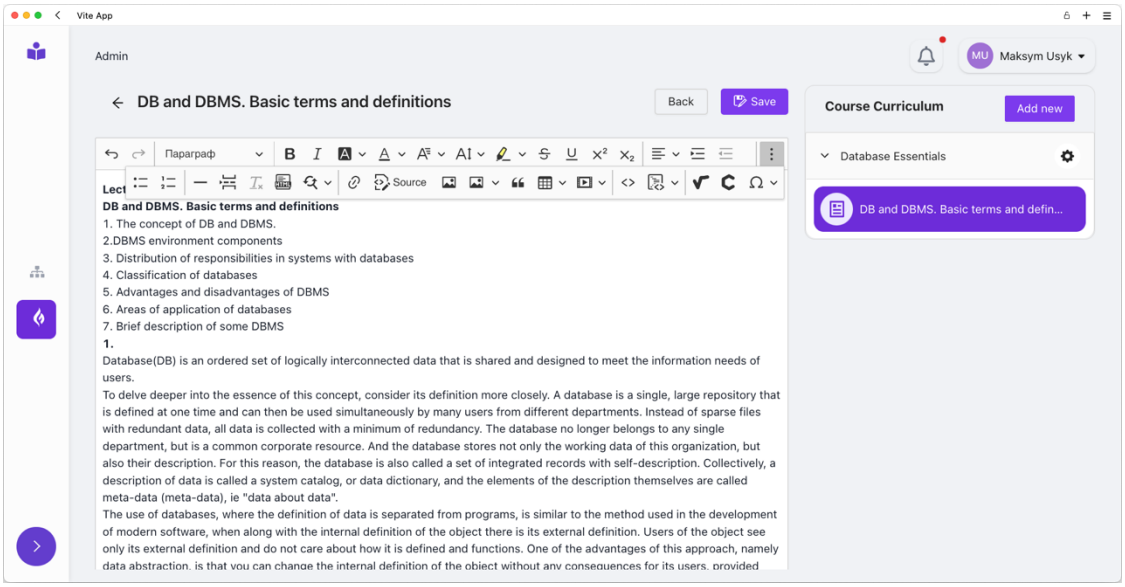

Figure 1. Lecture editing window

After that, thanks to the developed possibility of the unit editing and the tie coefficient adjusting between them, the system generates study material for some further adaptive steps (fig. 2).

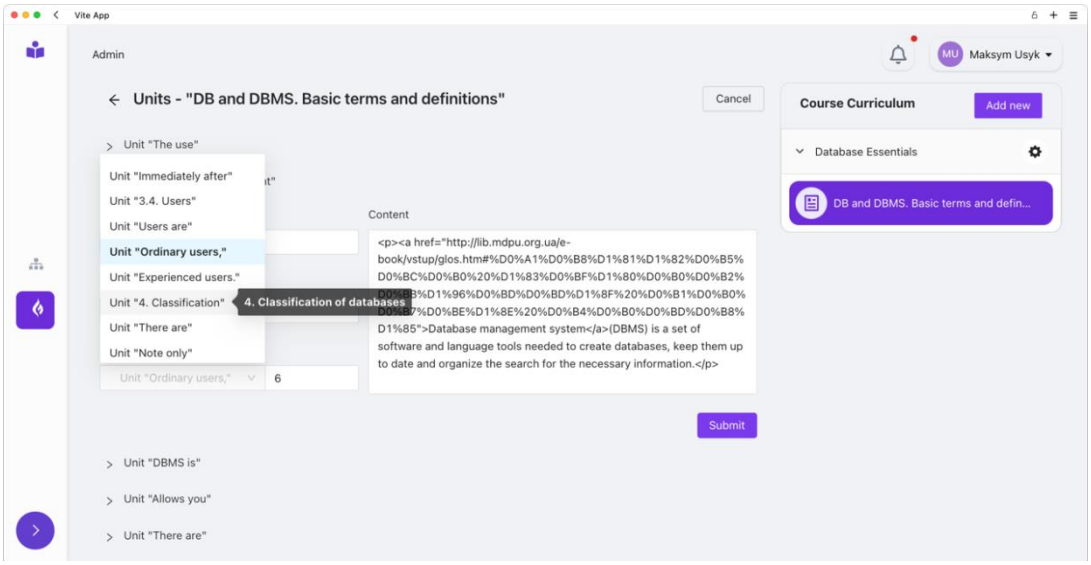

Figure 2. Unit editing window

As far as we know, the main idea of the adaptation technique involves the implementation of the control algorithm by correspondent modules to obtain the optimal value [6]. The algorithm for the functioning of the adaptive module of the system under discussion was developed on the basis of the multiset analysis method [7]. With this aim, the analysis of the student's test results has been made to form a set of units for review or advanced learning. The tests have to identify the level of mastering of every lecture. Each task of the test has to check mastering-not mastering the specified unit by a student. Besides, a few test tasks can be added to the unit as a piece of information. So, as a rule, there are a few questions in a test set to check the level of mastering the same unit of information. Based on the theory of multiple approaches, it is necessary to study a set of objects where the same elements occur.

It is also well-known, that the structures studying the sets of elements that can be repeated a random number of times are called multisets [8].

The division of educational material of the course (topic) into the simplest indivisible information units k_j, $j=1,2,\ldots,m$ enables every test set $t_i, i=1,2,\ldots,n$ to have a correspondent multiset $T_i=\{k_1^{\lambda_{i1}}, k_2^{\lambda_{i2}},\ldots,k_m^{\lambda_{im}}\}, i=1,2,\ldots,n$ of units that must be known or be able to use, making the required conclusions.

Moreover, in multiset T_i the indices above the number of each unit mean the number of tasks in a certain test set which checks the level of its mastering (for example, index λ_{im} means that the unit k_m mastering is checked by tasks λ_{im}).

According to the results of tests, some resulting multisets $T_{ci}=\{k_1^{\mu_{i1}}, k_2^{\mu_{i2}},\ldots,k_m^{\mu_{im}}\}, i=1,2,\ldots,n$ are formed for each student, based on the units connected with the test tasks, where the wrong answers were obtained. Moreover, the indices above each unit μ_{im} mean a number of test tasks with the wrong answer in the test set compared with the unit k_m. Having summed the resulting multisets T_{ci}, and indices rationing with the same number of units, we can find the total number of test questions with a wrong answer in each separate unit k_m.

In the next stage, the system forms a set of units for the review or advanced learning based on the analysis of the initial multiset and the resulting multiset T_{ci}. The indices of these units are found by the multisets T_i and T_{ci} rationing according to the method of division by maximum among the components.

Moreover, to choose for every student a personal list of units that is the most helpful for the most successful review of the proposed topic, the system additionally analyzes the numerical value of the final grade N, obtained by the student for tests (expressed in 100 %). Depending on N there are three possible trajectories for further continuation of the adaptive educational process:

- mode «learning» (if average grades $N>75$) – the next step of the course (topic) learning is available for a student, an information message appears on the monitor with some recommendation to review the material, formed of the units connected with test questions which were wrong done by the student;
- mode «extra learning» ($50 \le N \le 75$) – the study material has been formed for a student on the basis of the set of units which had not been mastered enough;
- mode «relearning» ($N<50$) – a student must learn the previous study step once again, i.e. study the theoretical material of the current lecture and get familiar with some

additional information resources, visiting the correspondent references (the list of references for advanced learning of the units of the current lecture is formed by the teacher while the lecture is developed).

For example, a multiset rationing diagram according to the lecture material of 10 units is presented in fig. 3.

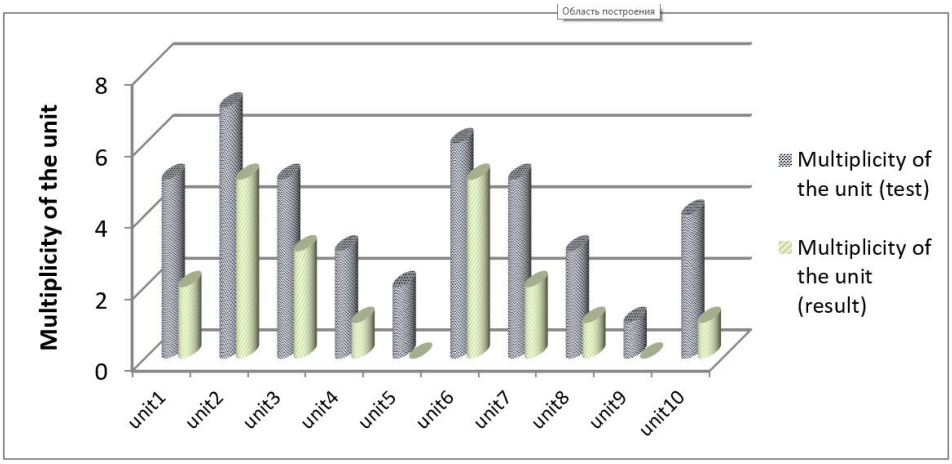

Figure 3. Multiset rationing diagram

We assume, that a student has $N = 60\%$ for the test. Then, taking into account 40% of not mastered educational content, the system forms the required material for review, based on units k_6, k_2 та k_3, which are the most important in this case (fig. 3).

After that, the content is converted into Buffer. The conversion is necessary to download the created material on the hosting Amazon S3. After downloading the material, a new kind of lecture is formed which will be available for the student to review according to the mode «additional study». An example of learning content formed from the series of units, which were not mastered, is given on fig. 4:

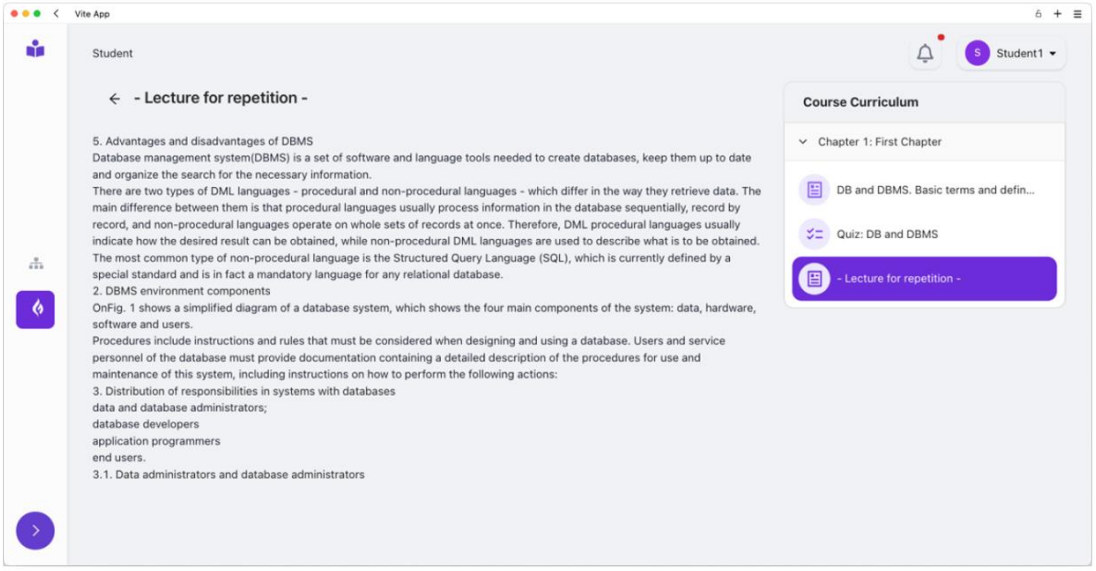

Figure 4. An example of an adaptive lecture for review

Thus, the developed service allows each student, according to his/her current level of knowledge (units, study material) mastering, correct his/her learning trajectory individually due to the sending only such information which is currently the most important for his further learning of the topic proposed.

PWA technology implementation. PWA (Progressive web app) [9] is a type of web application that can be used both as a web page and a web application on any mobile device. PWA is developed taking into account meeting most of the requirements listed in the control list of Google. As a result, the progressive web application becomes quick, reliable, and attractive.

Thanks to the progressive web programs, the developers can focus on one project that maintains all operating systems and browsers instead of developing programs for different devices.

The «progressive» web applications have the following characteristics**:**

- PWA – quick: after a page downloading, the site smoothly reacts to the users' behavior, without the necessity to be downloaded once more;
- PWA – reliable: the reliability of progressive web programs is based on their independence from the Internet connection: PWA can operate autonomously providing stable work no matter what the connection quality is. It allows the users to be involved so long how much they need, and they can continue reviewing the study material or editing it even offline;
- PWA – attractive: PWA has access to the functions of the device that makes it possible for the user's experience to be broadened and avoids any problems with reconnecting. Moreover, PWA has easy access immediately from a browser, they can be easily fixed on the user's main screen. The brands may send some push messages to their customers with special offers in real-time mode, updating and reminding, them that they can abandon their carts, which may cause an increase in the clients' loyalty.

The technology PWA introduction into the system takes place after the development of the main part architecture of the web application. It enables us to describe the parameters of adjustment more accurately, which is a very important step for the application stable operation.

The basic technologies for the PWA introduction are the following:

Service Worker (SW) [10] – is the heart of PWA: this is the layer which is between the client and server parts. All inquiries of the browser are passing through it.

Web App Manifest [11] – it is JSON file with parameters of an application. Its main data are recorded in it: title of application, its description, icon etc.. Thanks to this file, a user can «install» the application under discussion on his/her smartphone, as well as on the computer in some cases.

For PWA operation one should provide all the resources of the application were transferred according to protocol HTTPS [12].

Application Shell [13] is a graphic skeleton of a web application. It allows storing its graphical part so that it won't be downloaded from the very start during the next updating. It means, that while passing to the next page, at first, some stored graphical elements will be shown whose data are dynamically sent from the server.

A separate library Vite Plugin PWA is used to attach PWA technology [14]. This library enables Manifest to be generated automatically under the right configuration conditions and work with Service Worker correctly according to the declaration. For the initial adaptation of Manifest in the configuration file «vite.config.ts» an object with the required parameters is being developed (fig. 5).

ui-adaptive_lms - vite.config.ts

```
const pwaOptions: Partial<VitePWAOptions> = {
    mode: 'development',
    base: '/',
    includeAssets: ['favicon.svg'],
    registerType: 'autoUpdate',
    manifest: {
        name: 'PWA LMS',
        short_name: 'PWA LMS',
        theme_color: '#ffffff',
        icons: [
            {
                src: 'pwa-192x192.png', // <== don't add slash, for testing
                sizes: '192x192',
                type: 'image/png',
            },
            {
                src: '/pwa-512x512.png', // <== don't remove slash, for testing
                sizes: '512x512',
                type: 'image/png',
            },
            {
                src: 'pwa-512x512.png', // <== don't add slash, for testing
                sizes: '512x512',
                type: 'image/png',
                purpose: 'any maskable',
            },
        ],
    },
    devOptions: {
        enabled: true,
        /* when using generateSW the PWA plugin will switch to classic */
        type: 'module',
        navigateFallback: 'index.html',
    },
    srcDir: 'src',
    filename: 'claims-sw.ts',
    strategies: 'injectManifest',
};
```

Figure 5. Object with Manifest configuration fields

Development of SW layer is made by the instrument Workbox [15], that includes a set of certain libraries. The above-mentioned instrument allows us to simplify and accelerate the process of SW development (fig. 6).

ui-adaptive_lms - claims-sw.ts

```
import { clientsClaim } from 'workbox-core';
import {
    cleanupOutdatedCaches,
    createHandlerBoundToURL,
    precacheAndRoute,
} from 'workbox-precaching';
import { NavigationRoute, registerRoute } from 'workbox-routing';

declare let self: ServiceWorkerGlobalScope;

// self.__WB_MANIFEST is default injection point
precacheAndRoute(self.__WB_MANIFEST);

// clean old assets
cleanupOutdatedCaches();

// to allow work offline
registerRoute(new NavigationRoute(createHandlerBoundToURL('index.html')));

self.skipWaiting();
clientsClaim();
```

Figure 6. An example of the developed SW layer

The PWA correct operation is tested by the instrument Chrome DevTools [16]. One can see the above-described Manifest (fig. 7), as well as the current problems which can influence the unpredictable behavior of the application on the inset «Application». Moreover, the developed SW are shown on the same inset (fig. 8), where their status, the cycle of updating etc. are given.

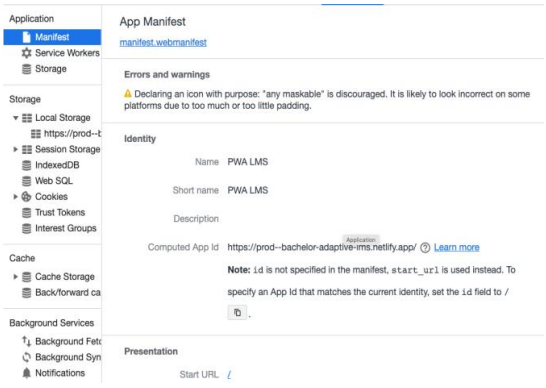

Figure 7. View of Generated Manifest in Chrome DevTools

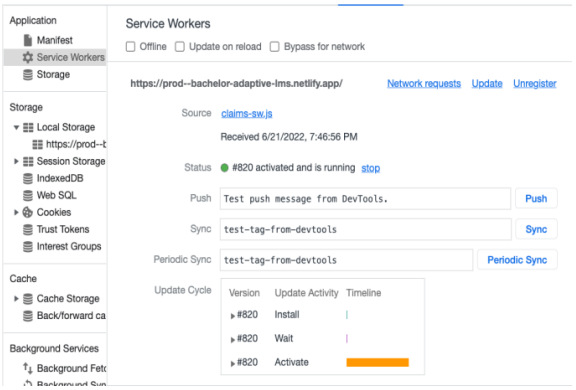

Figure 8. View of the developed SW in Chrome DevTools

Thus, the use of PWA technology allows implementing of the following advantages in the distance learning system:

- using web resource as a regular mobile application that provides not only easier access to the system but reduce the system resources of the device as well;
- improvement of the system due to providing practically the constant access to the system (access to the data processing: lecture development, analysis of tests results, work with additional educational content is possible even in case of internet-connection loss);
- perspective possible organization of a chat between a lecturer and a student, conducting high-quality video conferences with possible recording and further watching in the system, automation and improvement of units and test questions formation processing due to the artificial intelligence introduction, complete access to the system implementation offline due to some extra instruments (libraries) of the development.

Conclusions. The information technology is described in the paper under consideration whose objective is to improve the distance learning system due to the use of an adaptive model of educational trajectory construction and the latest work-bench of the development.

The proposed multiset method allows forming the theoretical content for a training step that most accurately meets the student's requirements. The method is based on using the program-established content ties between the information units and the relations «test question-unit». It provides the construction of individual trajectories according to the established modes of learning and makes possible the implementation of an adaptive functional in the system.

The system program has been improved by the «progressive» web technology PWA, whose implementation will enable the teachers and students successfully use the service offline, and will also allow reducing the loading on the device system resources use and apply the software under discussion as a regular application in their smartphones.

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ВДОСКОНАЛЕННЯ АДАПТИВНОЇ СИСТЕМИ ДИСТАНЦІЙНОГО НАВЧАННЯ НА ОСНОВІ ЗАСТОСУВАННЯ «ПРОГРЕСИВНОЇ» ВЕБ-ТЕХНОЛОГІЇ

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Резюме. *Проаналізовано відомі системи дистанційної освіти, що дозволило виділити їхні переваги й недоліки та визначити шляхи програмного вдосконалення за рахунок додавання адаптивної функціональності й інтерактивності, направлених на підвищення якості навчального процесу. Розроблено інтерфейс для роботи із системою для різних груп користувачів (студенти, викладачі, розробники), застосування якого дозволяє у зручний спосіб завантажувати навчальні матеріали й тестові завдання, проводити редагування та налаштовування змістовних зв'язків між інформаційними одиницями (юнітами), проходити навчання й тестовий контроль, формувати підсумкові звітності успішності й рекомендації щодо подальших навчальних кроків. Описано мультимножинний метод оцінювання рівня вивчення змістовних одиниць та представлено адаптивний функціонал формування вмісту навчальних лекцій для повторного чи поглибленого засвоєння теоретичного контенту, який дозволяє враховувати початковий рівень знань студента, його схильність до здобуття нових умінь і навиків. На основі використання теорії множинного підходу запропоновано технологію прив'язки тестових питань та відповідних інформаційних юнітів, що забезпечило математичне визначення індексів незасвоєних порцій інформації, з яких генерується текстова частина адаптивного навчального кроку. Програмно вдосконалено систему на основі технології PWA (Progressive web app), що дозволило реалізувати такі переваги веб-застосунків, як швидкість, зручність і привабливість. Упровадження технології PWA виконано за рахунок інструментів Service Worker, Web App Manifest, HTTPS та Application Shell, що дозволило виконувати кешування клієнтських запитів у офлайн-режимі, пришвидшило процес завантаження та відображення графічних елементів веб-сторінки, забезпечило використання запропонованого ресурсу як звичайного мобільного додатку. Це надало можливість для зручнішого доступу до системи, а також зменшення використання системних ресурсів.*

Ключові слова: *система дистанційного навчання, адаптивне навчання, технологія PWA, юніт інформації, мультимножинний метод.*

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