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Virtual Laboratory as Progressive Web Application

N. Koceska* and S. Koceski*

* Faculty of Computer Science, University Goce Delchev – Shtip, Shtip, R. North Macedonia

{natasa.koceska, saso.koceski}@ugd.edu.mk

Abstract - In contemporary education, especially in natural and technical sciences courses, it is important for students to gain practical experience through the use of laboratory exercises.

Although theory classes were conducted online during the COVID-19 pandemic, educational institutions found it difficult to complete the laboratory experiments. With the increasing availability, sophistication and power of web-based tools and computer simulations, a growing number of virtual laboratories are developed and published.

In this study we are proposing an architecture for a virtual laboratory designed and developed as a progressive web application (PWA). The concept of the PWA together with its advantages are also explained in this paper.

I. Introduction

The pace of information and communication technologies progress is so fast that novel products and solutions emerge almost on a daily basis, shaping our way of live. Recent advances in artificial intelligence (AI), robotics and IoT have contributed to development of multiple sectors [1-12]. In addition, contemporary smartphones are fare beyond just communication devices. They have been transformed into tools for healthcare, work, shopping and entertainment. All these technologies have significant impact and are transforming the education systems nowadays.

This has been especially evident during the latest COVID-19 pandemic. During the pandemics we have witnessed the largest disruption of education systems in history, affecting nearly 1.6 billion learners in more than 190 countries on all continents. All educational institutions in Republic of North Macedonia were also closed on March 10, 2020.

To ensure learning continuity during this disruption, educational institutions were constrained to adopt the online teaching and learning models in a relatively short period of time. This need for rapid shift to online learning revealed many problems in the education systems all over the globe but, it also revealed a deep gap in our overall approach to education [13]. One of the major problems in Republic of North Macedonia, evidenced during the pandemics, was the access to education, especially for vulnerable groups, such as children at risk of poverty, Roma children and children with disabilities. Although multiple initiatives and institutions have tried to provide hardware devices (primarily portable devices), needed for the education process of these categories, continuous access to the online teaching and learning resources is still a big challenge.

In contemporary education, especially in natural and technical sciences courses, it is important for students to gain practical experience through the use of laboratory exercises.

Although theory classes were conducted online during the COVID-19 pandemic, educational institutions found it difficult to complete the laboratory experiments.

Many research studies have evidenced the fact that computer simulations i.e., virtual laboratories, can mimic the real-world laboratory workflow and have the potential to be a useful supplement to the theory classes.

With the increasing availability, sophistication and power of web-based tools and computer simulations, a growing number of virtual laboratories are developed and published [14-18]. They are also integrated with the existing learning management systems (LMS).

Most of the recently developed virtual laboratories are developed as a web-based applications suitable for usage on various devices, while some of them are published as a stand-alone software application aimed to be installed on desktop and mobile devices.

In this study we are proposing an architecture for a virtual laboratory designed and developed as a progressive web application (PWA). The concept of the PWA together with its advantages are also explained in this paper.

II. Progressive Web Applications – Basic Concepts

Until recently native mobile applications were the first choice for smartphones and tablets as hybrid cross-platform apps and web-apps for portable devices were lagging behind them. However, a new set of standards advocated by the Google Web Fundamentals group seeks to bridge that gap by introducing features such as offline support, background synchronization, and home-screen installation to the web [19]. These standards incited the development of new architecture type called Progressive Web App. PWAs already gained popularity in the last couple of years. Some studies and reports estimate that PWA will replace half the existing mobile applications based on native, hybrid, and mobile web architecture.

The main characteristics and advantages of PWAs are:

- Low Development and Maintenance Costs
- No Dependence on App Distribution Services
- App-Like Look and Feel
- Platform- and Device-Agnosticism
- No Updating Issues
- Fast Installation
- Better Performance
- Seamless Offline Operation
- Push Notification Functionality
- Enhanced Security
- Hardware Integration

PWAs are offering great hardware integration capabilities. This includes some of the following features:

- Geo-Location
- Real-Time Camera
- Data Storage
- Payments
- Biometric Authentication
- USB/Bluetooth
- Motion Sensors
- Native Push Notifications

Real-time content synchronization is what gives PWAs a significant advantage over native or hybrid mobile applications. Moreover, one of the biggest advantages is the fact that the data synchronization is possible even in the offline mode, and that is important for remote students who may be located in places where the internet coverage is intermittent.

III. Design Principles of the Virtual Laboratory Application

In the design of the simulation two specific things are considered: Coherence Principle and Consistency.

Coherent principle argues that simulations may not contain unnecessary material that distract the student thus disrupts the learning process. Consistency between simulations is also very important. Users who have more experience with simulations will learn to use simulations faster if they have a consistent design.

With the simulations, students are provided with animated visual model for easier understanding of the physical phenomenon. By doing interaction with the simulation, the student can participate in changing the parameters and analysis of results. Therefore, it is necessary to take into account the design of the simulations, because students give equal importance to the overall visual design.

Simulations are not supposed to reflect the reality in details, but to maintain the concept of the physical area that they simulate. For simulation to be sufficiently realistic it is necessary to:

- implement connections and principles of the system which simulates;
- contain components with enough detail for the user to connect to the same components from the real world;
- allow the user to change parameters like in the real system;
- give the user the feeling that he or she directly controls the components of the simulation without any intermediate steps.

In short, the simulation should function as the actual system. Moreover, it should offer:

- a single and clear goal for the user;

- objects that can be interacted to successfully complete the simulation;
- environment that provides an appropriate context in the simulation;
- interactions, reactions, challenges, situations and effects that are equivalent to those of the real experiment;
- feedback after the simulation or the task is completed successfully;
- opportunities for returning simulation in initial state or to a previous state, such as back button or restart;
- allow users to have a sense that they control the application.

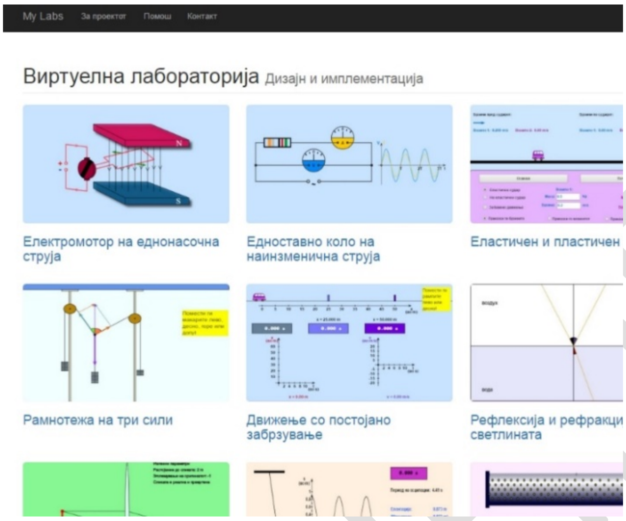

Figure 1. UI/UX of the developed Virtual Laboratory Application

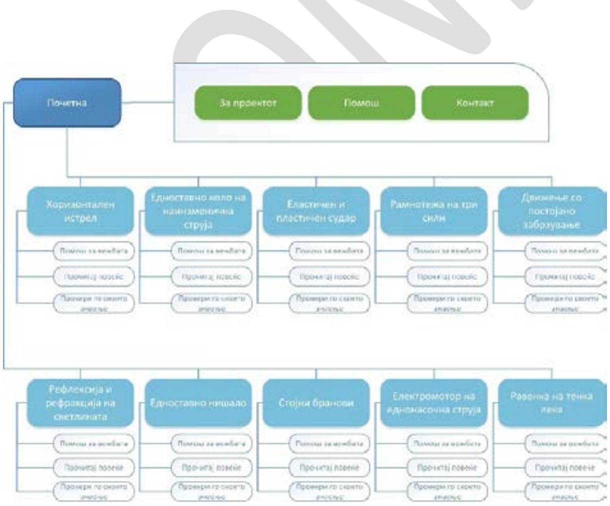

Figure 2. Site Diagram of the developed Virtual Laboratory

Figure 3. Lab excersise describing the concept of equilibrium of three forces

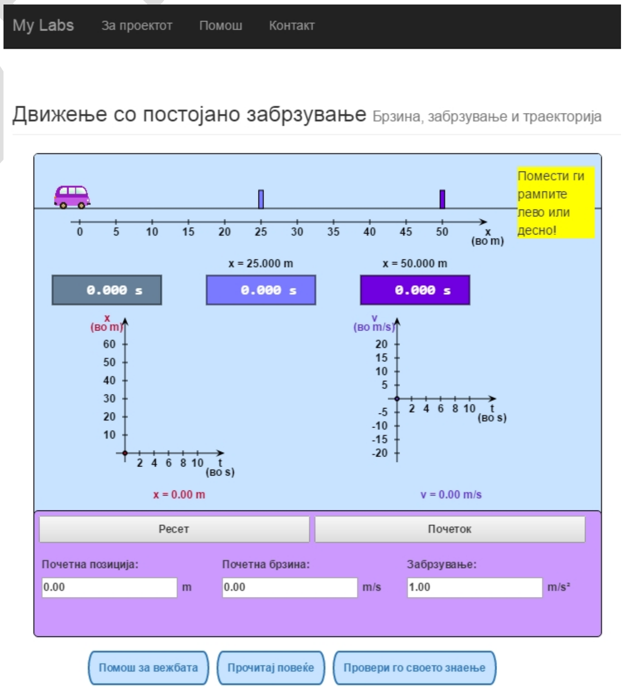

Figure 4. Lab excersise describing the concept of Motion with constant acceleration

IV. PROPOSED ARCHITECTURE OF THE VIRTUAL LABORATORY APPLICATION

Usability of the traditional web applications as well as user experience can be significantly increased by transforming them into progressive.

The architecture of the PWA relies on two main components: App shell and Service Worker. Its architecture is given on the Figure 5.

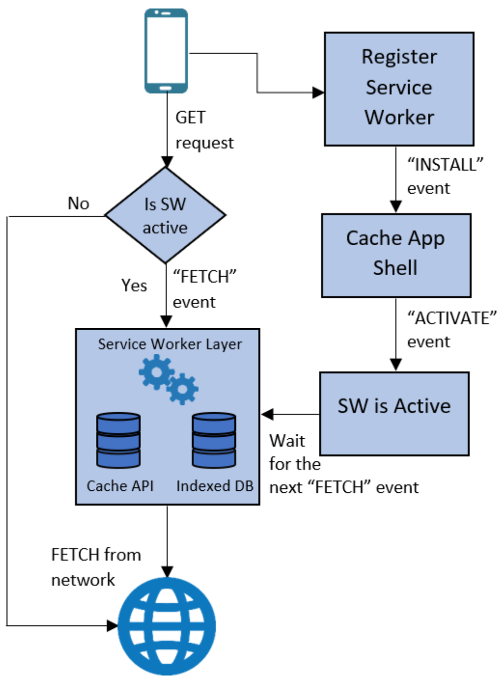

Figure 5. Proposed architecture of the Virtual Laboratory

A. *App shell*

The application shell contains the minimal portion of HTML, CSS, and JavaScript the necessary for creation of the user interface. In our case certain local resources like the navigation and footer bars as well as the graphical resources of the app are loaded in the shell just to provide a functional skeleton of the application.

Application shell also ensures that the loading time of the app will be reduced every time the user revisits the app. We have tested the performances on four laboratory exercises and the results are given in the Table I.

B. *Service worker*

Service worker another very important component that provides the offline working mode of the web applications. However, the use of service worker is limited only to pre cache the resources and serve the content upon loading the page. This is performed during the background synchronization.

TABLE I. LOADING TIMES

Lab name	**Loading Time for Repetitive Visits (ms)**				
	Number of visits performed				***Min. loading time***
	1st	***2nd***	***3rd***	***4th***	
Motion with constant acceleration	2.36	1.86	1.07	0.86	0.86
Equilibrium of three forces	2.15	1.32	0.76	0.81	0.76
Accelerated movement	1.96	1.34	0.92	0.68	0.68
Elastic and non ellastic collisions	2.97	1.25	0.85	0.97	0.85
Electric circuits	4.23	3.15	2.38	1.11	1.11

When the user makes a request to the server via the app in the absence of network, the request gets stored in the cache. Even if the user quits the app after making the request, it still gets stored up in the cache. As soon as the network connection is back, the request gets executed and the app is populated again with the requested data in the background.

Offline capability of an app can be implemented by using a client-side storage called IndexedDB.

V. CONCLUSION

In this study we are proposing an architecture for a virtual laboratory designed and developed as a progressive web application (PWA).

Students can benefit from the Virtual Laboratory developed as an educational PWA by its installation on the smartphone's home screen. Once installed, loading of the content becomes a breeze.

On the developers' side there are also multiple benefits. Namely, developers can easily add or remove some features without having to update the entire app, so real-time content syncing is what gives PWAs a considerable advantage over native apps.

Moreover, such synchronization is possible even in the offline mode, and that is important for remote students who may be located in places where the internet coverage is intermittent.

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