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ORIGINAL RESEARCH ARTICLE

DESIGN AND IMPLEMENTATION OF AN OFFLINE-OPTIMIZED WEB-BASED COURSE MATERIAL MANAGEMENT SYSTEM FOR ENGINEERING EDUCATION IN RESOURCE-CONSTRAINED UNIVERSITIES

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ABSTRACT

Access to structured academic materials has been a major problem for engineering education in university system. This is because students always depend on fragmented channels, including social media groups, photocopied handouts, and peer-to-peer sharing to obtain learning resources. This study aims to design, implement and evaluate an offline-optimized web-based course material management system for engineering education in resource-constrained universities. The design of this system was carried out by mixed-method research design in combination with questionnaire-based needs assessment, and software development. Furthermore, post-deployment performance evaluation was carried out for the research design. The study collected a total population consisting of six hundred and forty (640) valid student responses,. The system development was carried out using ReactJS for the frontend interface, Flask for backend services, PostgreSQL for structured data management, and Amazon Web Services S3 for secure cloud storage. Other tools included in the development of the system were Docker and Digital Ocean hosting. Security features such as password hashing, HTTPS communication, and role-based access control. The usability post-deployment test was carried out at score rate of 5, the results showed that respondents' (students) experienced difficulty in accessing academic materials at 95%. In addition, students expressed willingness to adopt the proposed platform at 91%. The usability post-deployment test showed a high overall satisfaction score of 4.62 of 5 score, at strong ratings for navigation, file accessibility, and download speed. The technical evaluation result showed reliability of system performance at an average response time of 1.84 seconds and 99.2% uptime. Hence, the system developed has provided a sustainable model that could be replicated across engineering faculties and similar higher education institutions in need.

1.0 Introduction

The adoption of digital learning technologies has become central to modern education systems, enhancing accessibility, flexibility, student engagement, and learning continuity (Bond *et al.*, 2021; Zawacki-Richter & Qayyum, 2019The depending of universities in developed countries has increasingly on learning management systems (LMS), institutional repositories, and cloud-based learning platforms to support teaching and learning activities (Costa *et al.*, 2012; Martin *et al.*, 2020). More so, higher institutions in many developing countries continue to face substantial barriers to educational digitization (Adarkwah, 2021; Almaiah *et al.*, 2020; World Bank, 2021), including poor internet connectivity, unstable electricity supply, inadequate funding, and limited institutional technological capacity.

As has been reported, the frequent dependent students on split channels, including social media groups, photocopied handouts, and peer-to-peer file sharing, which often results in unequal access to learning materials, outdated resources, and reduced academic efficiency (Adarkwah, 2021; UNESCO, 2022). The peculiarity of engineering education depended on timely access to structured learning materials such as technical lecture notes, laboratory manuals, design handbooks, software tutorials, and past examination questions (Eze *et al*., 2021; Oye *et al*., 2012). This is unlike in some non-technical disciplines, engineering curricula require iterative problem-solving skills, visual learning aids, and frequent access to updated course resources (Agarwal, 2013; Jordan, 2014). As has been reported, most of the African universities, students still depend on photocopied handouts, peer-to-peer messaging groups, and personal flash drives for resource sharing, leading to information fragmentation and academic inefficiency (Mtebe & Raphael, 2018; Andersson & Grönlund, 2009).

The students of University of Benin in the Faculty of Engineering face persistent challenges in accessing relevant course materials across departments and academic levels. There is lack of unified digital system for organized storage, retrieval, and controlled sharing of academic resources in the Faculty of Engineering at University of Benin. Besides, the students regulary rely on informal social networks, class representatives, and alumni contacts to obtain vital materials. This regularly reliance of students may lead to unequal access, poor version control, delayed distribution, and reduced preparedness for assessments.

The global utilization of Moodle, Canvas, and Blackboard Learn developed LMS platforms have been successfully (Coates *et al*., 2005; Costa *et al*., 2012; Al-Busaidi & Al-Shihi, 2010). Though, a lot of these systems are optimized for institutions with stable internet connectivity, dedicated IT teams, and subscription budgets. Additionally, their direct transfer into low-resource educational environments is often limited by sustainability and infrastructure constraints (Unwin, 2009; Bhuasiri *et al*., 2012). Additionally, their direct transfer into low-resource educational environments is often limited by sustainability and infrastructure constraints (Unwin, 2009; Bhuasiri *et al*., 2012). Therefore, there is the need for a localized, low-cost, scalable, and partially offline-capable platform tailored to the needs of engineering students in developing countries. Hence, this study aims to link this gap by developing a web-based course material management system optimized for low connectivity and scalability.

2. Materials and Method

2.1 Study Area

This study was carried out at the Faculty of Engineering, University of Benin, Benin City, Nigeria (Figure 1). The faculty consists of multiple departments, including agricultural and biosystems, civil, mechanical, electrical/electronic, industrial, chemical, petroleum, structural, materials and metallurgy, marine, mechatronics, computer, and production engineering.

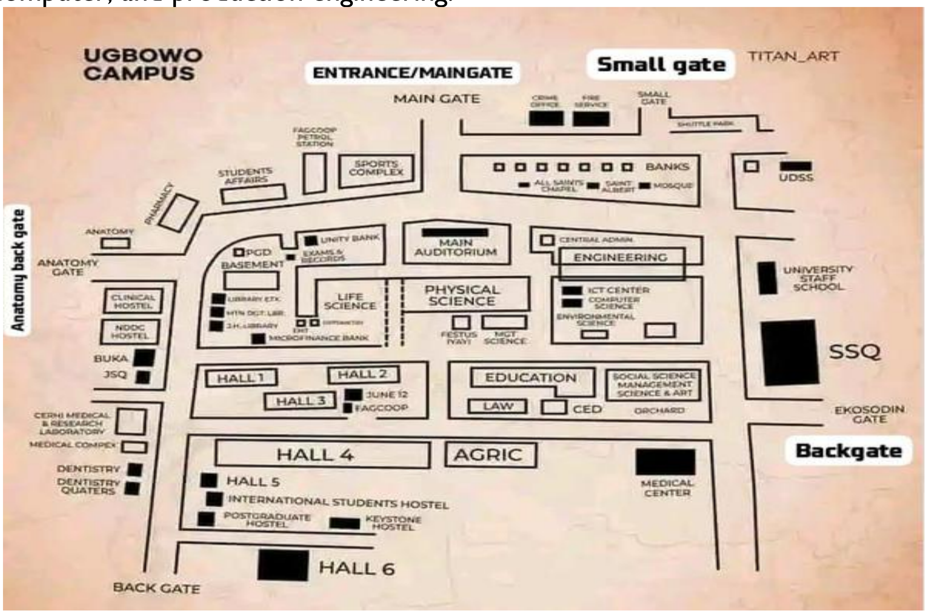

Figure 1: Map of University of Benin

2.2 Research Design

The study adopted a mixed-method research design, combining the following:

i. Quantitative survey for needs assessment

ii. Software engineering design methodology
iii. Post-deployment performance and usability evaluation

This design method adoted has been recommended for educational technology assessment studies (Creswell & Creswell, 2018; Dhawan, 2020).

2.3 Sample Size and Participants

The student population targeted was estimated to be 5,000, and sample size was determined using Yamane's formula:

$$n = \frac{N}{1+N(e)^2} \quad 1$$

Where n = sample size, N = population size, e = sampling error (0.05). Substituting values:

$$n = \frac{5000}{1+5000(0.05)^2} = 370.37$$

A minimum respondent number of 370 were required; however, the improvement of statistical reliability was by 640 valid responses obtained from the sampling.

2.4 Instrumentation and Data Collection

The structured questionnaire was distributed electronically via departmental communication channels. Assessed variables includes:

i. Difficulty accessing materials
ii. Preferred content types
iii. Desired system features
iv. Willingness to adopt a digital platform

Survey-based approaches are widely used in user adoption studies (Venkatesh et al., 2003; Davis, 1989).

2.5 System Development

The system platform was developed by an agile iterative model (Pressman & Maxim, 2020) involving:

1. Requirement analysis
2. Wireframing and UI/UX design
3. Frontend development
4. Backend/API development
5. Database integration
6. Security implementation
7. Testing and deployment

2.6 Technology Stack

Software and infrastructure components used in this study are presented in Table 1.

Table 1: Software and infrastructure used

Component	Technology
Frontend	ReactJS
Backend	Python Flask
Database	PostgreSQL
Cloud Storage	AWS S3
Containerization	Docker
Hosting	DigitalOcean
Version Control	GitHub

2.7 System Architecture

The course material management system architecture proposed was designed by a modular client-server framework to ensure scalability, maintenance ability, and secure access to academic resources. The multi-layer system architecture selection was due to its separate's presentation, application logic, data management, and file storage components, by this means enhancing performance and simplifying future upgrades (Pressman & Maxim, 2020; Stallings, 2017). This system architecture comprises of five major layers, including client interface layer, frontend application layer, backend service layer, database layer, and cloud storage layer.

By the client interface layer, students and administrators access the system with web browsers on smartphones, tablets, or desktop computers. The system layer was optimized for responsive rendering to support multiple screen sizes and devices, which is vital in developing-country learning environments where mobile devices are the dominant access medium (Bond et al., 2020; UNESCO, 2022).

ReactJS was used for the development of frontend application layer. The creation of reusable components was enables by it, including dynamic rendering, and efficient state management. The handling of user interactions by ReactJS including login, search queries, file browsing, course filtering, and dashboard navigation were also carried out. This communicates asynchronously with the backend through RESTful APIs by JSON data exchange, by this process reducing page reloads and improving user experience (Martin et al., 2020).

The Flask was used for the implementation of backend service layer. This was used for service as the application engine and is in control for user authentication, request validation, session management, authorization control, and business logic execution. This application was utilized when a student requests course materials, the backend verifies the user's department and level before returning only authorized resources. OWASP (2021) stated that this was a kind of server-side filtering improves both privacy and relevance of content delivery. The management of data layer structured was conducted with the usefulness of PostgreSQ. This helped in the storage of user profile in the database stores, information of the departments, course metadata, file references, access logs, and administrative records. This was selected was selected due to its strong transactional consistency, security features, and scalability for concurrent users (Costa et al., (2012).

Again Amazon Web Services S3 object storage was used for the implementation of the storage layer of the file. The essential academic resources that were stored externally rather than directly accessed in the relational database are lecture notes, PDF textbooks, past questions, laboratory manuals, and multimedia tutorials were stored externally. Almaiah *et al.* (2020) used similar approach in their study that this design minimizes database load while ensuring secure and reliable file delivery through signed access requests. The complete application stack meant for development was containerized by Docker and hosted on a virtual private server environment. Consistent performance across development, testing, and production systems was carried out by containerization. Hence, the architecture of the system developed provides modular expansion, fault isolation, and future integration of mobile applications, analytics modules, and AI-based recommendation engines.

2.8 Security Measure

The implemented controls in this study were as follows:

i. Password hashing using bcrypt
ii. HTTPS secure communication
iii. Session-based authentication
iv. Role-based access control
v. Controlled file authorization

These above-mentioned controls are consistent with secure web application recommendations (OWASP, 2021; Stallings, 2017).

2.9 Statistical Analysis

Descriptive statistics, including frequency, percentage, mean ± standard deviation were used, and results were analyzed with spreadsheet and statistical software.

3. Results and Discussion

3.1 Students Challenges Before System Development

The result on the difficulty in accessing materials by respondents is presented in Table 2. It was observed that access to learning materials was a major challenge among engineering students prior to implementation of the system. Out of the 640 respondents, 608 (95%) reported difficulty in obtaining lecture notes, past questions, tutorials, or other academic materials, while only 32 respondents (5%) reported no less difficulty in accessing materials. The results show that the previous material distribution model was highly inefficient and largely dependent on informal channels such as class representatives, peer sharing, and messaging groups. This is in line with the finding of Adarkwah (2021). In addition, this study identified inadequate digital infrastructure and decentralized resource management as common barriers in Nigeria higher education institutions. The finding also confirmed that poor access to academic materials could affect examination preparation, independent study habits, and overall poor academic performance. The findings are in line with the need for a centralized digital repository tailored to engineering education (Andersson and Grönlund (2009).

Table 2: Reported difficulty in accessing materials

Parameter	Frequency	Percentage (%)
Experienced difficulty	608	95.0
No major difficulty	32	5.0
Total	640	100

3.2 Preferred Academic Resources

Faculty of Engineering students preferred academic resources (i.e., materials types) respondents results are presented in Table 3. This shows different categories adopted for identification of learning materials were by respondents, and they were considered most important for academic success. Based on this study results, it was observed that past examination questions ranked highest (92%), followed by lecture notes (89%), tutorials/videos (71%), laboratory manuals (63%), and project reports (54%). It was also discovered that students prioritize materials directly linked to coursework, assessment preparation, and practical understanding. This confirmed the importance of examination orientation within university systems that caused increase the demand for past questions, whereas the study also revealed trong demand for lecture notes indicates the need for reliable and timely classroom content access. Besides, this awareness in tutorials and laboratory manuals also make known that engineering students require practical and visual learning support beyond traditional text-based materials (Eze *et al.*, 2021; Oye *et al.*, 2012). Still, the design of the system platform was to prioritize these file categories within its search and upload structure.

Table 3: Most requested material types

Resource Type	Percentage (%)
Past questions	92.0
Lecture notes	89.0
Tutorials/videos	71.0
Lab manuals	63.0
Project reports	54.0

3.3 Willingness to Adopt the Platform

The willingness to adopt the developed system platform was extremely high as shown by the respondents in Figure 2. it was found that 91% of the respondents showed their willingness to use the web-based course material management system if installed. However, only 9% of the students expressed indecision or unwillingness to adopt the platform. This observed that the students clearly identified the practical value of having a centralized and easily accessible repository sytems for lecture notes, past questions, tutorials, and other academic materials. The students' adoption willingness increase noticeable in this study is reliable with the Technology Acceptance Model (TAM), which states that users are more likely to accept a system when they perceive it as useful and easy to use. This is in line with the study by Davis (1989), also similar to the finding of Venkatesh et al. (2003) whose reported that the Unified Theory of Acceptance and Use of Technology (UTAUT) explains that performance expectancy and facilitating conditions significantly affect behavioural intention toward new technologies. The study shows that most respondents believed the proposed system will improve access to learning materials, save time, reduce dependence on informal sharing channels, and improve academic preparation.

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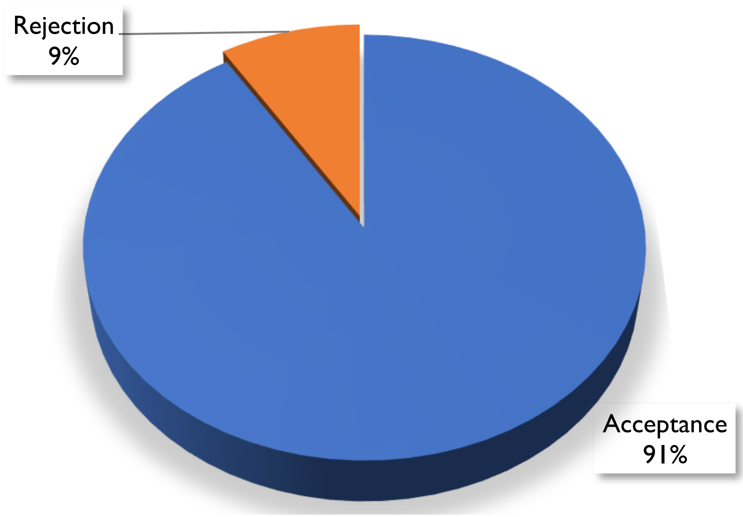

Figure 2: Willingness to adopt the platform

3.4 Post-Development User Evaluation

Post-development user evaluation or user satisfaction rating was carried out to ascertain the effectiveness of the system developed. This was done using a sample of user's evaluation of the platform by a five-point satisfaction scale in a pilot test. Based on this rating, Table 4 show the evaluation result, including the file accessibility recorded highest score of 4.71, followed by download speed score of 4.65, with overall satisfaction score of 4.62, ease of navigation of score of 4.58, and interface attractiveness of 4.43. These strong usability performance across critical functional dimensions were above the specified scores rating, and the students were able to locate relevant materials quickly without confusion because of the accessibility and navigation scores increase. These findings revealed that academic systems where poor navigation often reduces sustained engagement. This agrees with the findings of Al-Busaidi and Al-Shihi, (2010); Bond et al. (2021), that reported that intuitive user interface designed to predicts continued LMS use and satisfaction.

Table 4: User satisfaction rating (n = 12 pilot users)

Metric	Mean Score (5-point scale)
Ease of navigation	4.58
File accessibility	4.71
Interface attractiveness	4.43
Download speed	4.65
Overall satisfaction	4.62

3.5 System Performance

The system performance was evaluated technically, and the result showed efficient performance during pilot test (Table 5). The result revealed an average response time of 1.84 seconds, concurrent load testing successfully supported 100 users, system uptime up to 99.2%, and failed requests were below 1%. From the results it was found that the stable and responsive system suitability for moderate institutional deployment. This showed that the rapid response times are crucial for user retention and satisfaction, as delays beyond a few seconds often caused increment in abandonment rates (Nielsen, 2020). Furthermore, it was found that the decrease in failure rate also shows the effectiveness backend request handling and proper integration between frontend, database, and storage services. Additionally, the increase in uptime shows reliability, which is exclusively crucial in universities where students may access materials late at night or close to examination periods. Generally, the developed system showed satisfactory technical robustness for scale-up across departments and future university-wide adoption to ascertain students ability in use of academic materials.

Table 5: Technical performance indicator

Parameter	Value
Average response time	1.84 s
Concurrent users tested	100
Uptime during pilot	99.2%
Failed requests	<1%

4. Conclusion

The conclusion drawn from the study on design, implementation, and evaluation of an offline-optimized web-based course material management system to address the problem of insufficient access to academic resources among engineering students in resource-constrained universities are follows:

i. The findings establish that the developed system can improve the accessibility, organization, and delivery of engineering course materials in a resource-constrained university environment.
ii. Its combination of centralized resource management, user acceptance, high satisfaction, and satisfactory technical performance makes it suitable for further departmental deployment and potential institutional scaling.
iii. Future development should focus on strengthening offline synchronization, mobile integration, analytics, and other features that can enhance the system's scalability and usefulness.

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