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An integrated digital library platform for higher education: system architecture, implementation, and usage analytics

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ABSTRACT

This study addresses fragmented access to academic resources in higher education by designing, implementing, and evaluating an integrated digital library platform. The platform enhances learning accessibility and supports data-driven educational decision-making. Its key contribution is demonstrating how an integrated digital library ecosystem can promote self-directed learning while generating learning analytics for evidence-based educational management. The study employed a research and development approach based on the system development life cycle. The platform integrated multiple electronic resource providers through representational state transfer application programming interface (RESTful APIs) and secure single sign-on authentication. Data were collected from anonymized system usage logs, borrowing records, access statistics, and routine operational evaluation during implementation. The results showed that the platform reduced the average time required to access academic resources from approximately 25 minutes to 4 minutes, representing an 84% reduction in access time. The system also demonstrated substantial adoption, with more than 2,500 registered users and over 2,400 electronic borrowing transactions. Operational evaluation further indicated positive usability, accessibility, and convenience across web and mobile environments. The findings suggest that integrated digital library systems can improve access efficiency, support flexible learning, and strengthen evidence-based academic resource management in higher education.

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1. INTRODUCTION

In higher education environments, effective access to academic resources plays a critical role in supporting self-directed learning, research skill development, and sustained academic engagement. However, fragmented access systems and disconnected digital platforms often create barriers that limit seamless access to scholarly content, reduce learning efficiency, and constrain students' ability to complete academic tasks effectively. Traditional library services, which frequently depend on physical access and isolated digital systems, may further restrict learning opportunities and negatively affect students' academic experiences and overall learning performance.

In the present era, the world has undergone rapid changes in all dimensions. The transition from the industrial era to the digital era has significantly reshaped labor market demands and transformed the ways in which learning resources are accessed [1]. Consequently, information systems have needed to evolve to accommodate emerging technologies that play a critical role in enabling access to digital information and knowledge. In addition, the COVID-19 pandemic has accelerated the adoption of digital technologies in everyday life, making the so-called new normal [2] an essential condition rather than an option. Users increasingly expect information access that is convenient, fast, and independent of physical location, supported by more stable and widespread telecommunications infrastructure and internet connectivity.

Digital libraries, or electronic libraries, have emerged as an information service model that responds to evolving educational and technological demands. They involve the organization, management, and provision of digital information resources that users can access directly through online platforms [3], [4]. By systematically collecting and storing digital content, digital libraries support information retrieval via the internet and mobile devices, providing access to diverse resources such as text, images, audio, and video. Compared with traditional libraries, they reduce physical storage limitations, minimize the risk of resource loss, and improve service efficiency to meet users' diverse needs [5], [6]. From an educational perspective, digital libraries function not only as information repositories but also as learning platforms that promote self-directed learning, support research skill development through access to scholarly resources, and enhance equitable access for distance and flexible learners. Today, numerous digital library platforms provide access to their own collections of digital information resources.

Although digital library platforms have become increasingly available, most operate independently and require separate authentication processes, resulting in fragmented user experiences that disrupt learning workflows and reduce opportunities for academic engagement. Such fragmentation limits both system efficiency and institutions' ability to monitor resource utilization and support evidence-based decision-making. While technologies such as single sign-on authentication [7] and standardized application programming interface (API) integration [8] offer potential solutions, limited research has examined how an integrated digital library architecture can simultaneously address access fragmentation, multi-publisher interoperability, and data-driven educational management within a higher education context. Therefore, this study investigates the design and implementation of an integrated digital library platform to improve access efficiency, support self-directed learning, and generate actionable usage data for educational decision-making.

The Khunying Long Athakravisunthorn Learning Resources Center at Prince of Songkla University (PSU) has developed a digital library system to support modern technologies and respond to user needs in the digital era. Under the digital library system development initiative, the system not only enhances access to existing and continuously expanding digital resources, but also supports integration with external service providers, enabling users to access a wider range of information sources. The development aims to support emerging patterns of learning and information use in the next normal, where flexibility, interoperability, and seamless access to knowledge are increasingly essential. The theoretical foundation of this study draws on three complementary frameworks that collectively explain how integrated digital library systems can support learning in higher education. First, self-directed learning theory, as conceptualized by Knowles [9], posits that adult learners are most effective when they can independently manage their access to learning resources and direct their own learning pathways. An integrated digital library platform supports this principle by reducing access barriers and enabling students to engage with academic resources at their own pace, time, and location, without dependence on institutional timetables or physical library availability. Second, the technology acceptance model (TAM), proposed by Davis [10], suggests that users' adoption of a technology system is primarily determined by their perceptions of its usefulness and ease of use. In the context of this study, the integration of single sign-on authentication, intuitive browsing interfaces, and streamlined borrowing processes is expected to enhance both perceived usefulness and perceived ease of use, thereby promoting sustained engagement with the platform. Third, the learning analytics framework [11] provides a conceptual basis for understanding how system-generated usage data can inform educational decision-making. By capturing patterns of resource access, borrowing behavior, and engagement trends, the platform produces actionable evidence that supports curriculum planning, resource acquisition, and institutional monitoring of learning resource utilization.

The novelty of this study lies in demonstrating how an integrated digital library ecosystem can simultaneously enhance learning accessibility, support self-directed learning, and provide learning analytics for evidence-based educational management, contributions that extend beyond technical infrastructure toward measurable educational outcomes. Unlike previous studies that have primarily addressed technical implementation or isolated information management functions, this study positions the integrated digital library platform as an educational support infrastructure grounded in self-directed learning theory [9] and the TAM [10], examining how system design decisions translate into learning behavior, resource engagement,

and institutional decision-making capacity. The study contributes theoretically by advancing the understanding of how integrated digital library architectures can operationalize learning analytics frameworks to support evidence-based academic resource management and curriculum planning in higher education. Practically, the study demonstrates how an integrated platform design can reduce access barriers, promote equitable and flexible engagement with academic resources, and generate actionable usage data to inform teaching, learning, and resource investment decisions at the institutional level.

To address these challenges and research gaps, the objectives of this study were: i) to design and develop an integrated digital library platform that enables seamless and secure access to academic resources in higher education environments; ii) to examine the platform's capability to improve access efficiency and support flexible and self-directed learning through web and mobile-based technologies; and iii) to investigate system usage analytics as a mechanism for supporting evidence-based academic resource management and data-informed educational decision-making in higher education. Based on these objectives, this study addressed three research questions:

- How does an integrated digital library platform influence students' access behavior and engagement with academic resources in a higher education environment?
- How do users perceive the usability and usefulness of the platform, and how do these perceptions relate to sustained adoption and engagement?
- How can learning analytics derived from platform usage data support evidence-based educational decision-making regarding academic resource management and curriculum planning?

2. METHOD

This study employed a research and development approach integrated with system development processes. The approach was adapted from development research type I proposed by Richey and Klein [12], which emphasizes the systematic design and development of innovations or products. The development process was further informed by established software engineering principles [13], which provided guidance on requirements analysis, system design, implementation, and evaluation throughout the development lifecycle. The research design was structured into three phases: i) system design; ii) system development; and iii) system evaluation. Each phase was aligned with the study objectives of improving access efficiency and user experience, and included clearly defined procedures, data sources, and evaluation methods to ensure a rigorous and systematic development process [14].

The three phases were designed to ensure a structured development process, from identifying system requirements to implementation and evaluation, in order to improve access efficiency and overall system usability. Each phase was aligned with a specific study objective, ensuring that design decisions were grounded in user needs and institutional requirements. This phased approach allowed the development team to systematically address challenges at each stage and to iteratively refine the system before deployment. The evaluation was based on anonymized operational system data generated during routine implementation of the digital library platform. These data included system usage logs, registered user counts, borrowing transaction records, access statistics, platform availability across devices, and routine usability feedback obtained during system operation. No additional survey, interview, experimental intervention, or personally identifiable user-level data collection was conducted for this study.

2.1. Phase 1: system design

The digital library system was developed to enable users to access digital information resources, commonly referred to as electronic books (e-books), which had been converted from printed materials [15]. The system development approach was structured into two main components: the front-end and the back end. These components were integrated through a representational state transfer (REST) API protocol, as illustrated in Figure 1 [16]. The primary functions of the system included allowing users to read e-books through an online borrowing and returning mechanism, search for specific e-books, and generate reports on system usage.

The conceptual design of the system was based on an analysis of existing operational practices, current workflow challenges, and issues anticipated in future operations. These factors were used as guiding principles for the development of a new system to improve efficiency and overall usability. This approach enabled system developers to follow a shared and consistent development direction. In designing the system, the developers adopted the system development life cycle framework, which is a widely accepted standard in information system development [17]. The process began with identifying and understanding existing problems and potential solutions, conducting a feasibility study, collecting user requirements for the new system, and establishing an implementation plan [18]. Each stage of the development process was systematically defined and is described in subsection.

2.1.1. Problem definition

This stage involved an examination of the existing system and current operational processes. Issues related to system usage and workflow were identified through consultations with operational staff and a review of existing documentation. The results of the analysis were as:

- Information resources in the form of printed books had not been converted into digital formats.
- There was no systematic collection of digital information resources available for users to access via the internet.

2.1.2. Analysis

This phase involved an analysis of the feasibility of developing a new system to address the identified problems. The developers examined and selected appropriate tools and technologies for system development. The conclusions of this analysis were as:

- The selected technologies could support user access to information resources through electronic devices in the form of a web application. The system utilized a centralized database for data management and stored information resources on a centralized file server. In addition, the system supported access via RESTful APIs [19]. The tools and technologies used in system development included a web server, Hypertext Preprocessor (PHP) as a scripting language, jQuery, PostgreSQL, REST, and API.
- A study of copyright laws was conducted to determine the rights and limitations regarding actions that are permitted or prohibited in the conversion of printed books into digital formats [20]. Only books that had been granted permission for digital reproduction were included.

2.1.3. Design

This process applied the results of the analysis to define system requirements, considering the methods and sequential workflows of the existing system. Data and information related to the current system were collected, and discussions were conducted with existing users. Based on operational practices related to book borrowing and returning through an information system at the Khunying Long Athakravisunthorn Learning Resources Center, PSU (2017), the developers adapted established borrowing and returning procedures for use in the digital library system.

Based on the analysis of the collected data and the system requirements documentation, the system's functional design was developed using a process modeling approach, specifically flowcharts [21]. This method represents a traditional and widely adopted approach to system development. The designed system functions included the main menu, categories, new books, popular books, view all books, book details, related books, book borrowing, book returning, borrowed books, borrowing history, and search functions [22]. In this study, the primary system operations are explained, namely the book display system, the borrowing and returning system, and the book viewing (reading) system. The system displayed only electronic books that had been authorized for digital provision and for which copyright permission had been obtained. Each of these operations was designed to ensure that users could access digital content through a consistent and secure workflow, as described in the following sections.

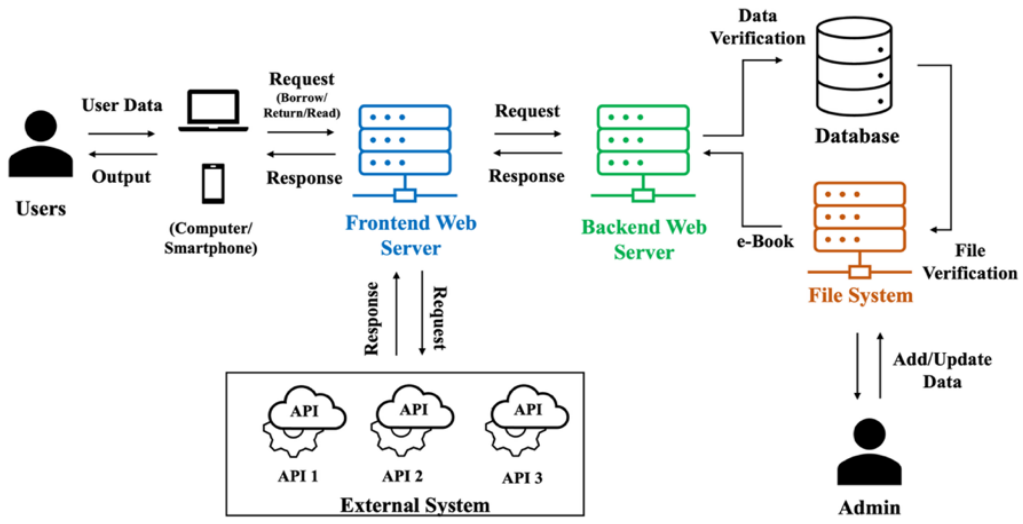


Figure 1. Conceptual framework of the system

Figure 2 displays the process of accessing the list of electronic books. Users were required to authenticate their identity through the PSU passport system [23]. The system then verified that the user was connected to the university's internal network. If an external network was detected, users were required to connect via a virtual private network (VPN) [24]. Once authentication and network verification were successfully completed, the system directed users to the page displaying the list of electronic books.

Figure 3 displays the process of borrowing and returning electronic books. After users selected a book, the system evaluated two conditions before allowing the borrowing process to proceed: the availability of the book in the system and the remaining borrowing privileges of the user. If both conditions met the predefined criteria, the borrowing transaction was successfully completed. The returning process occurred in two cases: users could manually return the book through the system, or the system automatically returned the book upon reaching the due date. During the return process, the system verified whether the user had previously borrowed the selected book. If a valid borrowing record was found, the system completed the return and immediately updated the information in the database.

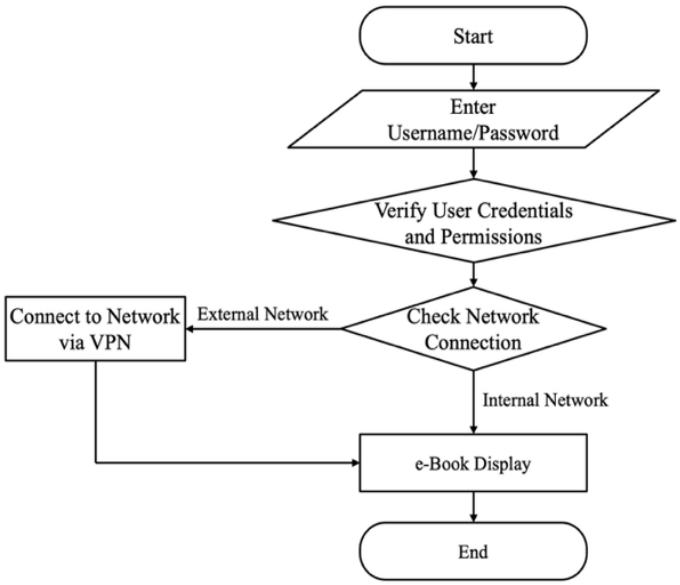


Figure 2. The process of displaying the list of electronic books after user authentication

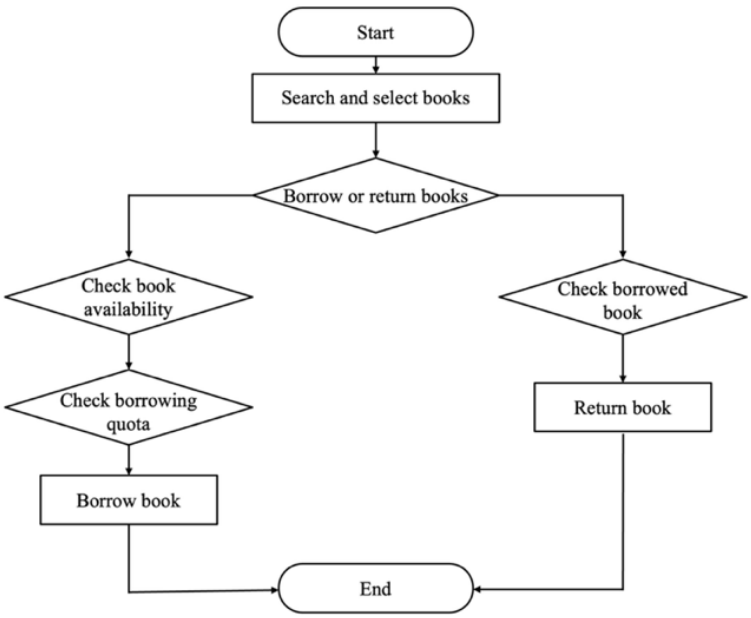


Figure 3. The process of borrowing and returning electronic books

Once users selected a book and successfully completed the borrowing process according to the specified conditions, the system immediately granted access to the reading interface. If the required conditions were not met, access to the selected book was not permitted. The system was designed to prevent users from downloading electronic books and to mitigate copyright infringement by embedding a watermark on every page of the e-book [25]. The watermark contained borrower identification information and could not be modified. In the event of copyright violations, usage data could be retrospectively examined through the system's usage history.

The API design for connecting with electronic resources from various publishers. This component represented a critical part of the digital library system, as it enabled users to access a wide range of content from multiple providers without switching platforms. Figure 4 displays the API design, which emphasizes flexible data connectivity based on RESTful API standards to ensure smooth and efficient communication between the university system and publisher platforms.

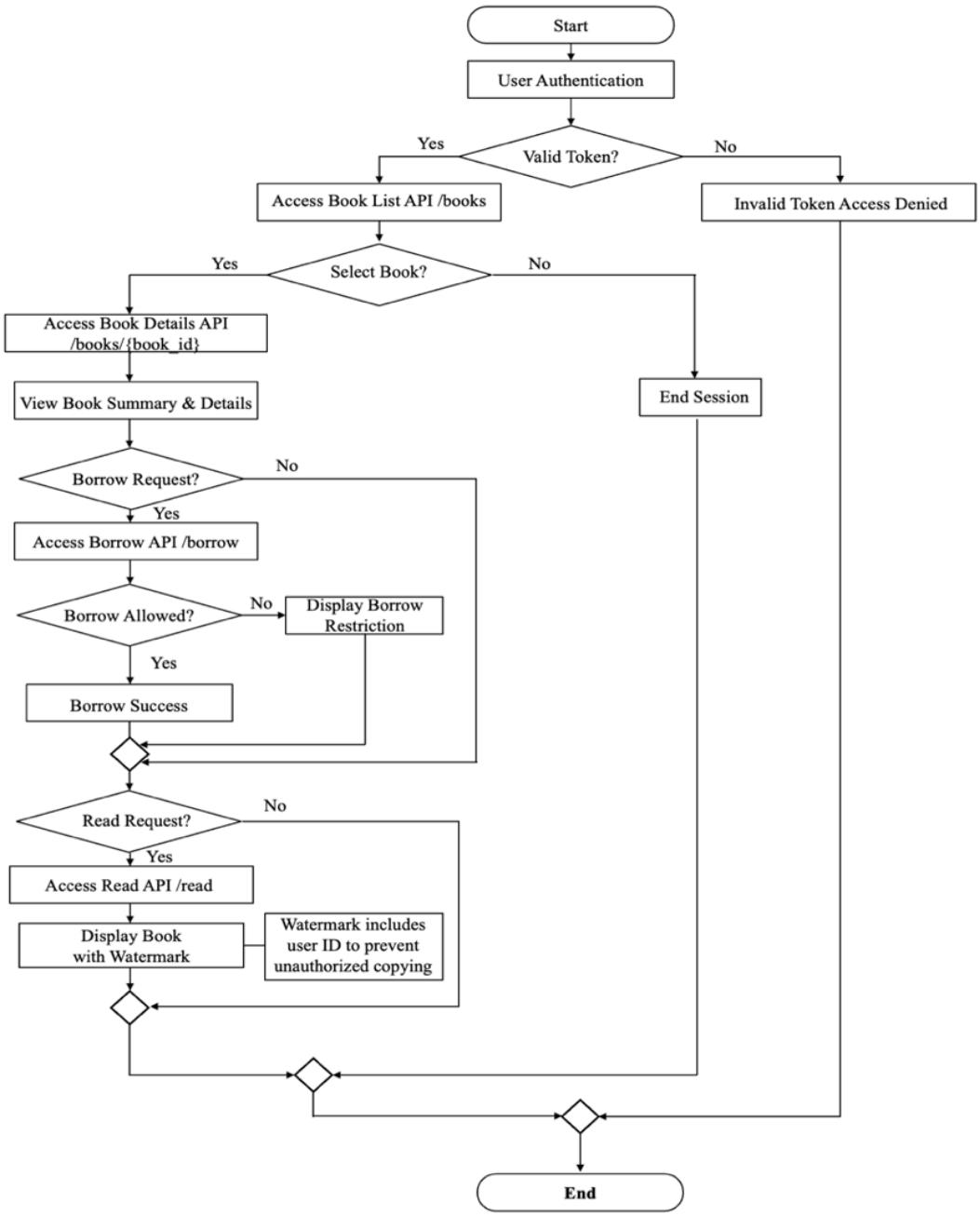


Figure 4. API design for integrating electronic resources from publishers

a. API structure design
- Authentication: user authentication was implemented using token-based mechanisms to prevent unauthorized access to resources, with support for OAuth 2.0 to enhance data security.
- Data format: data transmitted through the API were formatted in JavaScript object notation (JSON), a lightweight and widely adopted format that facilitated efficient communication.
- Rate limiting: request rate limits were defined to prevent excessive access that could degrade system performance and to protect against denial of service (DoS) attacks [26].

b. Core endpoint management
- Books: an endpoint used to retrieve lists of electronic books from publisher databases, supporting search parameters such as category, title, and author.
- Books/{book_id}: an endpoint for accessing detailed information about a specific book, including publisher information, summaries, and the number of pages available for online access.
- Borrow: an endpoint for borrowing books, which verified user borrowing eligibility, such as remaining borrowing quotas and permitted loan periods.
- Return: an endpoint for returning books, either automatically upon reaching the due date or manually when users canceled borrowing before the due date.
- Read: an endpoint for accessing books in an online reading format, incorporating download prevention mechanisms and watermarking to protect against copyright infringement.

c. API security design
- Encryption: data encryption was applied during both data transmission and reception using hypertext transfer protocol secure (HTTPS) to prevent data interception [27].
- Access control: role-based access control was implemented to define user permissions, such as reading and borrowing rights.
- Watermarking: watermarks containing user identification details were embedded in displayed book pages to prevent unauthorized copying and copyright violations.

d. Multi-publisher integration

The API was designed to support simultaneous connections with multiple publishers. Publishers could be selected through specified request parameters, enabling users to access resources from various providers according to their needs. This design approach allowed the system to accommodate a growing number of content providers without requiring structural changes to the core API architecture.

e. Testing and performance evaluation following API development

The system underwent testing and performance evaluation, including response-time testing and concurrent usage testing under high-load conditions [28], [29]. These measures were implemented to minimize latency and reduce the risk of service disruption.

Overall, the API design for integrating publishers into the digital library system played a crucial role in enhancing system capability, ensuring that digital information services were delivered smoothly and aligned with user requirements in an electronic library environment. The structured approach to API design, encompassing authentication, data formatting, rate limiting, endpoint management, and security controls, provided a comprehensive framework for managing complex interactions between the university system and multiple external publisher platforms. These design decisions collectively strengthened the reliability, scalability, and security of the integrated digital library system.

2.2. Phase 2: system development

The system was developed following a structured development process aligned with the predefined system architecture and technical requirements. The development environment was configured to support secure storage, controlled access, and reliable delivery of electronic book resources within an intranet-based digital library system. Emphasis was placed on data protection mechanisms implemented at both the infrastructure and application layers to ensure system security and content integrity.
- Operating system and server configuration: Ubuntu Server version 22.04 was deployed as the core operating system to manage server resources and application services. The operating system provided a stable and secure environment for hosting web services, file-sharing services, and database management systems. System configurations included service isolation, permission management, and network access control policies to ensure that only authorized system components were permitted to interact with protected resources. These configurations contributed to minimizing security risks and enhancing overall system reliability.
- Secure file storage and resource management: Samba was implemented as a file-sharing service to support centralized storage of electronic book files within the intranet environment. Prior to storage, electronic book files were encrypted to prevent unauthorized access at the file system level. Encrypted files were retained on the server and made accessible to the application layer exclusively through

controlled service interfaces. This design prevented direct access to raw electronic book files and ensured that content could not be read or copied without proper system authorization.

- Web server, database, and encrypted data management: Apache hypertext transfer protocol (HTTP) server version 2 and PHP version 8.0 were employed to manage web-based interactions and server-side processing. PostgreSQL was utilized as the database management system to store structured data, including user credentials, access control parameters, and encrypted metadata associated with electronic book resources. Sensitive information stored in the database was protected using encryption techniques to enhance data confidentiality and reduce the risk of unauthorized disclosure at the database layer.
- Application architecture and secure content delivery: the system architecture was designed based on a client–server model, with a clear separation between back-end and front-end components. The back end, developed using PHP, was responsible for application logic, data processing, and enforcement of security policies. When a user requested access to an electronic book, the system performed authentication and authorization checks prior to initiating content access. Encrypted electronic book files were decrypted dynamically at the server side only when all access conditions were satisfied.

To further strengthen content protection, a watermarking mechanism was integrated into the content delivery process. During page rendering, each electronic book page was dynamically embedded with user-specific information, such as a unique user identifier, serving as a digital watermark. This mechanism was incorporated to deter unauthorized redistribution and to enhance content traceability at the application level.

The front-end of the system was developed as a web-based application using hypertext markup language (HTML), JavaScript, and cascading style sheets (CSS) standards. The adoption of a web application framework provided a structured and standardized development approach, supporting modular design, code reusability, and maintainability of the user interface [30]. The framework facilitated consistent implementation of layout components, navigation structures, and responsive design patterns, which are essential for contemporary information systems. Additionally, the use of a standardized framework supported system scalability and future enhancements while ensuring compatibility across multiple web browsers and devices.

2.3. Phase 3: system evaluation

After the system development was completed, testing was conducted using the black box testing method. This approach focused on evaluating the correctness of system outputs by inputting test data and examining the resulting outputs. All system processes were tested to verify the integration and interaction among different components. Subsequently, system administrators and end users participated in usability testing. When operational errors were identified, the developers revised the program to ensure that the system functioned correctly and met the intended requirements.

- Implementation once development was completed, the system was deployed on a production server for actual use. The system configuration on the production server was set to mirror that of the development server to ensure consistency and stability.
- Expert review the system was then reviewed by experts. The evaluation results indicated that the developed system was rated at a very good level and was suitable for practical implementation.
- Maintenance after the system had been successfully installed and put into operation, maintenance activities were required to align the system with user needs and to further enhance system performance [31]. This phase was included in the operational plan and consisted of the following activities: i) corrective maintenance was performed to fix issues identified after the system had been in use for a period; ii) users or system administrators reported certain errors that had not been detected during the testing phase, prompting the developers to make necessary corrections to meet user requirements; and iii) adaptive and perfective maintenance was conducted to improve system functionality. After a period of use, users or system administrators coordinated with the developers to request additional features or workflow enhancements to improve convenience and usability.

3. RESULTS AND DISCUSSION

The results of this study are presented in terms of system accessibility, access efficiency, and user-based evaluation outcomes following the deployment of the digital library system at PSU. The findings demonstrated that users were able to access the system through a web browser via the internet. In addition, the system was accessible on both computers and smartphones through the PSU LibX application on iOS and Android platforms. The overall system usage is summarized in the following sections.

3.1. Digital library architecture design

This section presents the architectural design of an integrated digital library system developed to support efficient access to electronic books digitized from printed materials. The proposed architecture

adopts a modular and service-oriented approach, in which core system components including the user interface layer, application layer, and data management layer are interconnected through standardized APIs. These APIs facilitate seamless interoperability with external publisher platforms, enabling automated content exchange and real-time integration of e-book resources into the digital library system. The system architecture consists of front-end and back-end components connected through RESTful APIs, enabling efficient communication between the user interface and the system database.

The platform supports several core functions, including electronic book browsing, searching, borrowing and returning mechanisms, and online reading services. Users can access the system through web browsers or mobile devices, allowing flexible and location-independent access to digital resources. The architecture also incorporates security and copyright protection mechanisms, including user authentication through the PSU passport system, encrypted data transmission using HTTPS, and dynamic watermarking embedded in electronic book pages to prevent unauthorized distribution.

In addition, the system supports integration with multiple electronic resource providers through API-based communication. This architecture enables seamless access to digital resources from different publishers without requiring users to switch platforms. Such interoperability expands the scope of available academic resources beyond the university's own collection, providing users with a broader and more diverse range of learning materials.

3.2. Implementation of the digital library platform

Following the system design phase, the digital library platform was implemented in a real university environment. The system was deployed using a client–server architecture supported by Ubuntu Server, Apache HTTP Server, PHP for application logic, and PostgreSQL as the database management system. This technology stack was selected to provide a stable, secure, and scalable foundation capable of supporting concurrent access by a large and diverse university user population.

Electronic book files were stored on a centralized server and protected through encryption and controlled access mechanisms. When users request access to electronic resources, the system verifies user identity and authorization before dynamically delivering encrypted content. The system interface allows users to browse electronic books, view book details, borrow and return books online, and read digital content directly through web browsers or mobile devices. Authentication is integrated with the university's PSU passport system to ensure secure access to digital resources. The implementation also supports automated book return processes and borrowing history tracking, which improve the overall efficiency of digital resource management. The automated return feature eliminates the risk of overdue penalties by returning borrowed items on behalf of users upon reaching the due date. Borrowing history records further enable users to review their past access patterns and support administrators in monitoring resource utilization across the system.

For early returns, users were able to select the return button immediately. If the user did not initiate the return, the system automatically returned the book upon reaching the due date, thereby preventing any overdue penalties. This dual return mechanism provided users with flexibility in managing their borrowing sessions while ensuring that resources remained available for other users within the system. The system presented electronic books through a structured listing interface that allowed users to browse available titles and initiate borrowing directly, as illustrated in Figure 5.

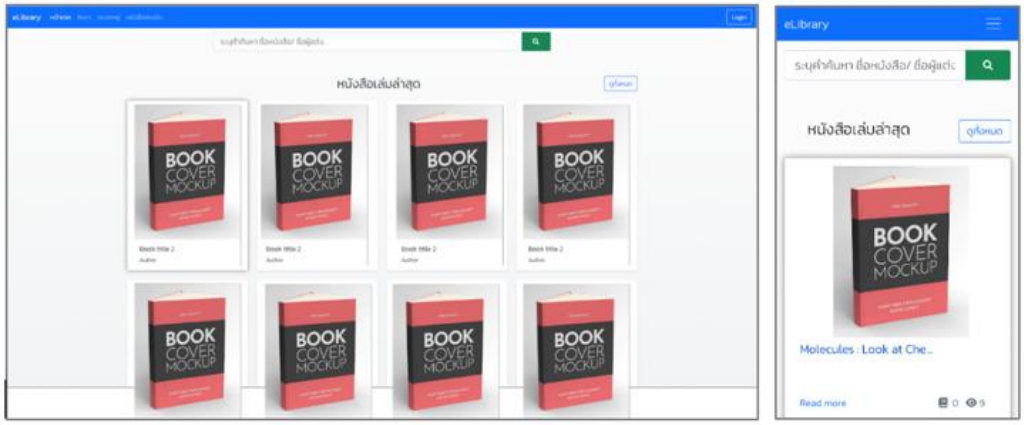


Figure 5. An example of the electronic book listing system

For the display of electronic book details, once users selected a book of interest, the system directed them to a detailed information page. This page presented an enlarged book cover along with comprehensive bibliographic information, including the author, publisher, year of publication, category, borrowing status, and the number of available copies. In addition, a QR code was displayed to allow users to scan and access the selected book on a smartphone for reading.

As shown in Figure 6, when users wished to borrow an electronic book, they could select the borrowing button directly. The system then verified the user's borrowing status and the number of available copies in the system. If the specified conditions were satisfied, the system notified the user and displayed a reading button, as illustrated in Figure 7.

When users selected the reading option, the system directed them to the electronic book reading interface on a smartphone or computer, as illustrated in Figure 8. While a book was being accessed, other users were allowed to read the same book concurrently, subject to the borrowing limits defined by the system administrator. If the maximum number of permitted borrowings had been reached, additional users were unable to borrow or access the electronic book.



Figure 6. The electronic book listing interface

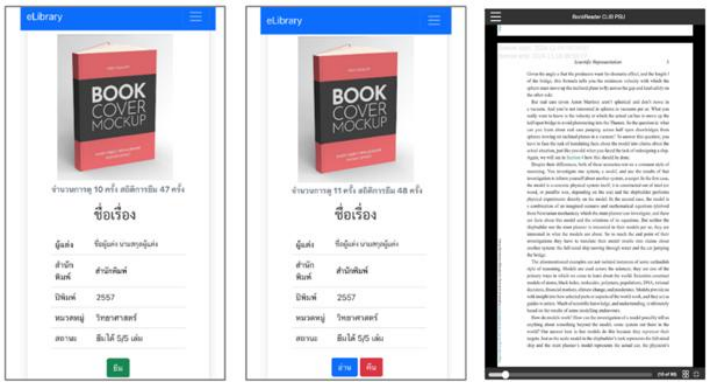


Figure 7. The electronic book borrowing, returning, and reading system accessed via a smartphone

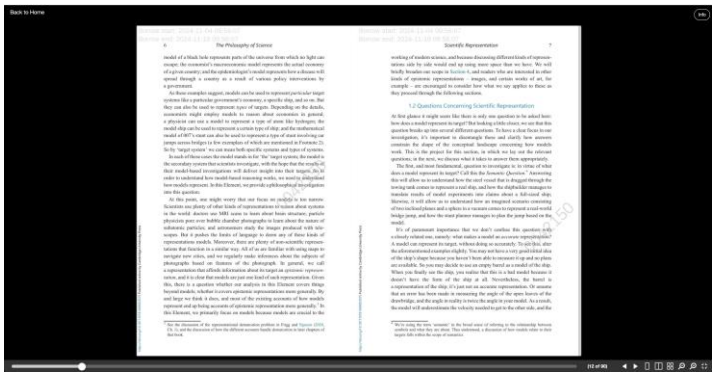


Figure 8. The electronic book display system accessed via a computer

Figure 9 presents the results of connecting to electronic resources from external publishers through the API. The system displayed the API responses as book details. When users selected to view detailed information about a specific book, the system sent a request to retrieve updated book details from the publisher's server. Subsequently, when users initiated the borrowing process by selecting the borrow button, the system verified the user's access privileges. If the user was authorized, the borrowing process was successfully completed. The PSU e-Library system then transmitted a request to the publisher's API to validate and record the transaction.

Figure 10 illustrates the system output after users had successfully borrowed a book and selected the reading option. The system transmitted a request to the publisher's server to obtain the book's encrypted access credentials, which were then sent to the PSU e-Library system. These credentials were decrypted to render the book pages; each embedded with a watermark displaying user identification details.

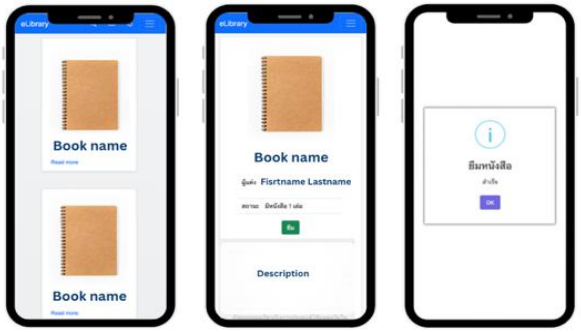


Figure 9. An example of the display after API integration with a publisher



Figure 10. An example of book display after API integration with publishers

3.3. Usage analytics and access efficiency

The system usage statistics demonstrated a substantial level of adoption and engagement following the deployment of the digital library system. At the time of data collection, the system recorded a total of 2,527 registered users, significantly exceeding the initial target. The number of electronic books borrowed reached 2,435 items, while the total number of electronic books available in the system was 1,836 items, indicating active utilization of digital resources across the university. Table 1 summarizes the key system performance indicators recorded following deployment of the digital library platform.

Table 1. Summary of digital library platform utilization and resource availability

Indicator	Result
Registered users	2,527
e-book borrowings	2,435
Available e-books	1,836
Access time (traditional)	25 min
Access time (digital)	4 min
Access time reduction	84%
Access platforms	Web, iOS, Android
Usability assessment	Positive across all key functions

Figure 11 presents the usage analytics, which reveal clear usage patterns over time, with noticeable peaks in user registration and book borrowing activities during specific periods. These trends suggest that the system effectively supported user access during high-demand intervals. In addition, analysis by academic units indicated that users from multiple faculties actively accessed electronic resources, reflecting broad adoption across disciplines rather than concentration within a single user group and aligning with prior studies on e-book engagement patterns in higher education [32].



Figure 11. The digital library system dashboard

Content-level analysis showed that certain electronic books and creators were accessed more frequently than others, highlighting user preferences and demand-driven resource utilization. Such insights provide valuable evidence for informed decision-making regarding future content acquisition and digital resource management. Understanding which resources are most actively used also enables librarians and educators to align available materials more closely with the academic needs and learning interests of the university community.

Overall, the dashboard data confirm that the digital library system successfully facilitated large-scale access to electronic books, supported diverse user groups, and enabled data-driven monitoring of resource usage. These findings underscore the effectiveness of the system in enhancing access efficiency and strengthening digital library services within the university context, consistent with the broader role of learning analytics in supporting evidence-based educational decision-making in higher education. The volume and diversity of recorded usage further suggest that the system's integrated design was well-suited to the varied academic needs of the university community [33].

Access efficiency was evaluated by comparing the time required to complete a single book access session using the traditional library process and the digital library system. The traditional process involved physical travel to the library, manual searching, borrowing, and returning, whereas the digital library system enabled remote access through electronic devices. As shown in Table 2, the comparison between the traditional library process and the digital library system highlights a significant reduction in access time.

Table 2. Comparison of the traditional book access process and the digital library system

No.	Process	Traditional process (minutes)	Digital library system (minutes)
1	Users travel to the library	8	-
2	Users search for books	4	3
3	Users retrieve books from the shelves	8	-
4	Users borrow books through library staff or an application	2	1
5	Users return books to library staff	3	-
	Total	25	4

The results indicate that the digital library system reduced access time from approximately 25 minutes to 4 minutes, representing an 84% improvement in access efficiency. By eliminating physical travel and manual borrowing procedures, the platform enabled faster and more convenient access to learning resources. The time saved can be redirected toward academic activities, allowing students to engage more effectively with learning materials. These findings support the study's objective of enhancing self-directed learning and improving learning efficiency in higher education.

Operational usability assessment of key functions, including e-book searching, borrowing, returning, and online reading, demonstrated positive user experiences across both web and mobile environments. Integrated authentication and location-independent access improved accessibility, while automated returns and the elimination of overdue penalties enhanced convenience and reduced procedural barriers. These findings suggest that streamlined access and improved usability can promote continuous engagement with academic resources and support self-directed learning in higher education.

Table 3 presents the most frequently accessed subject categories in the digital library platform. Health sciences was the most popular category, reflecting strong demand for resources in medicine, nursing, psychology, and related fields. Science and technology ranked second, indicating substantial interest in science, technology, engineering, and mathematics (STEM)-related knowledge and digital competencies. Social sciences, education, and humanities followed, demonstrating continued demand for resources supporting teaching, research, and interdisciplinary learning. Overall, the results suggest that the digital library platform effectively supports diverse academic, professional, and lifelong learning needs across multiple disciplines.

Table 3. Most frequently accessed subject categories in the digital library platform

Rank	Subject category	Educational domain
1	Health sciences	Medicine, nursing, psychology, veterinary science
2	Science and technology	Science, engineering, technology, computer science, mathematics
3	Social sciences	Sociology, political science, economics
4	Education	Teaching, learning, curriculum, educational research
5	Humanities	History, philosophy, religion, language and literature

3.4. Discussion

The high level of system adoption, reflected by 2,527 registered users exceeding initial targets, suggests that the integrated authentication mechanism effectively reduced access barriers. By enabling access through a single institutional credential, the platform simplified user access and minimized the complexity associated with multiple authentication processes, a factor previously identified as a barrier to digital library usage [7], [8]. This finding is consistent with the TAM, which highlights perceived ease of use as a key determinant of technology adoption [10]. Compared with digital library systems requiring multiple authentication procedures [6], the integrated approach appears to support broader and faster adoption across diverse user groups.

The 84% reduction in access time demonstrates the platform's effectiveness in improving learning resource accessibility. By removing physical and procedural barriers, users were able to access academic resources more efficiently and devote greater attention to learning activities. This finding aligns with self-directed learning theory [9], which highlights the importance of independent access to learning resources. Previous studies have similarly shown that reduced access barriers contribute to higher levels of resource engagement and more effective learning experiences [32].

The positive usability outcomes observed across key system functions support the TAM, particularly the constructs of perceived usefulness and perceived ease of use [10]. Users' favorable perceptions of the unified authentication mechanism and location-independent access suggest that the platform effectively addressed common barriers to digital library engagement identified in previous study [6]. Consistent with prior research, seamless authentication and interface simplicity appear to promote continued system use [33]. In addition, automated return functions and the elimination of overdue penalties enhanced user convenience and reduced barriers to resource engagement.

The platform's usage analytics demonstrate how learning analytics frameworks [11] can support evidence-based educational management within a digital library environment. Insights into usage patterns, engagement trends, and high-demand content areas enable educators and librarians to make informed decisions regarding curriculum support and resource development. Unlike traditional learning analytics studies that focus on learning management systems, the findings highlight the value of integrated digital library platforms as a complementary source of behavioral data for educational decision-making. The results also suggest that usage analytics can support strategic planning and digital learning transformation initiatives at the institutional level.

Taken together, the findings demonstrate that the educational value of digital library systems extends beyond technical functionality. The combination of high adoption, improved access efficiency, positive usability outcomes, and actionable usage analytics indicates that integrated digital library platforms can enhance accessibility, user experience, and data-informed educational management. These findings are consistent with educational technology literature emphasizing the role of digital systems in supporting both learning processes and institutional decision-making [11].

These findings provide practical implications for higher education stakeholders. Usage analytics can support curriculum planning and resource management, while the multi-publisher architecture offers a scalable model for digital collection development. The demonstrated adoption and efficiency gain further support institutional investment in integrated digital library infrastructure and digital transformation initiatives.

4. CONCLUSION

This study demonstrates that an integrated digital library platform can serve as an educational infrastructure that enhances learning accessibility and supports evidence-based resource management. The platform achieved an 84% reduction in access time, attracted 2,527 registered users, and recorded 2,435 borrowing transactions, indicating strong adoption and effective resource utilization. Operational evaluation results further suggest that integrated authentication, multi-publisher interoperability, and streamlined workflows can reduce access barriers and promote more flexible engagement with academic resources.

The study's educational contribution lies in demonstrating that the convergence of self-directed learning principles, TAM constructs, and learning analytics frameworks can be operationalized within a unified digital library deployment to advance learning accessibility, promote equitable resource engagement, and strengthen institutional capacity for data-informed educational decision-making. By positioning the integrated digital library platform as an educational support infrastructure rather than a purely technical system, this study extends the conceptual boundaries of digital library research toward the intersection of educational technology, learning behavior, and evidence-based academic resource management. The findings have important implications for higher education stakeholders. For educators, usage analytics can support curriculum planning, monitor resource engagement, and help align learning materials with students' academic needs. For librarians, the multi-publisher API architecture provides a scalable and efficient approach to expanding digital collections and responding to changing user demands. For university leaders and policymakers, the demonstrated adoption, improved access efficiency, and broad disciplinary engagement provide evidence to support continued investment in integrated digital library infrastructure and digital transformation initiatives. Overall, the findings suggest that integrated digital library systems can enhance access to academic resources, promote flexible and self-directed learning, and strengthen data-informed educational management in higher education. Furthermore, the findings provide empirical evidence that integrated digital library platforms can serve as a strategic educational infrastructure for supporting digital transformation and lifelong learning in higher education.

This study was conducted within a single university context and primarily relied on operational system data and usage analytics. The study did not directly examine long-term learning outcomes or academic achievement. Future research may further investigate the relationship between digital resource accessibility, learner engagement, and academic performance across diverse higher education environments. In addition, the study did not employ experimental or comparative research designs to directly measure causal impacts on student learning outcomes.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
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I : **I**nvestigation
R : **R**esources
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O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
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P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

Informed consent was not applicable because the study utilized anonymized operational system data and routine service evaluation data collected during institutional system implementation.

ETHICAL APPROVAL

This study utilized anonymized operational system data, access statistics, borrowing transaction records, and routine service evaluation data collected during the implementation of the digital library platform. No personally identifiable information was collected, disclosed, or analyzed. The study focused on operational system evaluation within an institutional environment and did not involve clinical procedures, sensitive personal data, or interventions involving human subjects. Therefore, ethical approval from an institutional review board or equivalent committee was not required. The research was conducted in accordance with relevant institutional policies and applicable guidelines.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author, [OK], upon reasonable request. The data are not publicly available because they contain anonymized institutional operational records and are subject to data management and privacy restrictions.

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