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Optimizing Adaptive Hypermedia Educational Systems: A Comparative Study of Frameworks

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Abstract

The majority of online educational systems deliver the same content to all learners, disregarding their individual needs, goals, and educational backgrounds. This approach often makes the learning process challenging and unengaging. Adaptive hypermedia addresses this issue by enhancing these systems through personalization and customization. Adaptive hypermedia-based educational systems (AHES) create a learner profile, known as a learner model, and tailor the content based on the learner's preferences and prior educational history. However, developing AHES is a complex and time-consuming task, as it requires the integration of adaptive features alongside communication tools, digital libraries, and more. To simplify this process, various authoring tools and frameworks, such as AHA! Moodle, Open edX, InterBook, and COFALE, are available. This study provides an analysis and comparison of these frameworks, facilitating the selection of an appropriate framework for developing high-quality AHES.

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1 Introduction

Adaptive Hypermedia Educational Systems (AHES) represent a significant advancement in e-learning technologies, focusing on delivering personalized learning experiences. These systems utilize adaptive algorithms to modify content based on a learner's profile, behavior, or progress, aiming to enhance engagement, retention, and overall learning outcomes. To achieve this, the underlying framework plays a pivotal role. Various frameworks for developing AHES offer different approaches to personalization, content delivery, and system adaptability. This study seeks to compare several of the most widely used AHES frameworks AHA! ACE, CFP, and CAMS highlighting

their respective features and assessing which framework best meets the diverse needs of modern educational environments.

We are currently living in the Information Age, where it is crucial that the right information reaches us at the right time, in an efficient and cost-effective manner. As a result, many institutions are increasingly adopting e-learning methods to enhance the quality of education. Information technology (IT) tools, such as online information resources, communication technologies (audio, video conferencing, virtual reality), simulations, and database management systems, play a vital role in this transformation [1]. E-learning has revolutionized education by utilizing these IT tools [2]. It encompasses various modes, with online education being one of the most prominent, relying on the web as the primary communication tool [3]. This type of education is often referred to as hypermedia-based education. As noted by Hodges and Saba [4], the benefits of hypermedia-based education extend not only to the learners but also to instructors and institutions.

For learners, hypermedia-based education offers significant advantages, such as the ability to study from home or the office without needing to commute to a college or university. This saves both time and travel costs. It is also adaptive, allowing learners to skip material they are already familiar with [5]. Furthermore, this mode of education fosters a collaborative environment, which is socially beneficial, as learners can interact with peers from diverse communities and cultures [6].

Instructors also benefit from online education. The study material for online courses is created once and can be used by multiple learners at any time, which saves time. The material can also be easily shared with other instructors globally or within specific educational communities [7]. Additionally, instructors can engage with a larger number of learners simultaneously, creating opportunities for more personal connections.

From an institutional perspective, hypermedia-based education is cost-effective. It eliminates the need for large buildings and classrooms, thereby reducing administrative overhead [8]. The time required to deliver education is shortened, allowing institutions to educate thousands of learners simultaneously, increasing potential revenue [9].

While these guidelines are crucial, online education still faces challenges, such as the possibility of learners not completing programs due to unmet expectations or a lack of interest. This can lead to an increased workload for learners, making it difficult for them to manage online learning effectively [10]. Personalization or customization of the learning experience can help resolve these issues [11].

2 Literature Review

An Adaptive Hypermedia-Based Educational System (AHES) is an advanced educational framework that utilizes hypermedia technology and adapts its content, structure, and interactions according to the needs, preferences, and progress of the learner. This system integrates various forms of media (text, images, audio, video, simulations) and incorporates adaptive features to enhance the learning experience [12]. The main goal of AHES is to provide personalized, flexible, and learner-centered education, improving both engagement and learning outcomes [13].

Adaptive Hypermedia-Based Educational Systems (AHES) such as Adaptive Presentation, Adaptive Navigation, JointZone, AES-CS, ActiveMath, and others are cutting-edge examples of systems that leverage adaptive hypermedia technology to personalize and enhance the learning experience [14]. Each of these systems incorporates unique features and methodologies to provide personalized educational content, navigation, and interaction. Here's a look at some of these systems.

Adaptive presentation refers to the system's ability to adjust the presentation of educational content based on the learner's characteristics, preferences, and progress [15, 16]. This can include the dynamic selection of content, modification of content formats (e.g., text, audio, video), and the layout or structure of the material. Content is adjusted based on the learner's prior knowledge, learning style, and performance. Supports multimodal content

delivery (text, images, video, etc.).

Adaptive navigation involves altering the way users interact with the system's content. It adapts the structure of the website or learning platform so that learners are guided toward the most relevant or needed material [17]. Dynamic content suggestions based on the learner's past actions or performance, the system suggests the next best step in the learning path. Personalization of navigation tools that navigation system (e.g. menus, buttons) may prioritize content or paths based on user needs.

A framework for the development of Adaptive Hypermedia-Based Educational Systems (AHESs) refers to a structured set of tools, guidelines, and methodologies designed to support the creation and implementation of adaptive learning systems [18]. These systems use hypermedia technology (which combines multimedia elements like text, images, audio, and video) and adapt the learning experience to the needs, preferences, and behaviors of individual learners.

3 Theoretical Models

The development of Adaptive Hypermedia-Based Educational Systems (AHESs) relies on frameworks and authoring environments that enable dynamic content adaptation to the learner's needs. KBS-Hyperbook, Multibook, WEAR, MOT, and ACCT provide foundational frameworks for creating adaptive systems, each with a focus on different aspects of adaptation such as user modeling, mobile learning, and collaborative learning. Authoring environments like AHA! Moodle, open edX, InterBook, and COFALE provide tools for educators and developers to create personalized learning experiences more easily. These tools and frameworks are essential in supporting the development of adaptive systems that can meet the diverse needs of learners in various educational contexts.

3.1 Adaptive Hypermedia Architecture (AHA!)

Adaptive Hypermedia Architecture (AHA!) is a framework for creating adaptive learning environments and hypermedia systems. It allows for the delivery of personalized content, adapting dynamically to the learner's needs and interactions. The architecture of AHA! is designed to offer flexibility and scalability, making it suitable for various educational contexts [19].

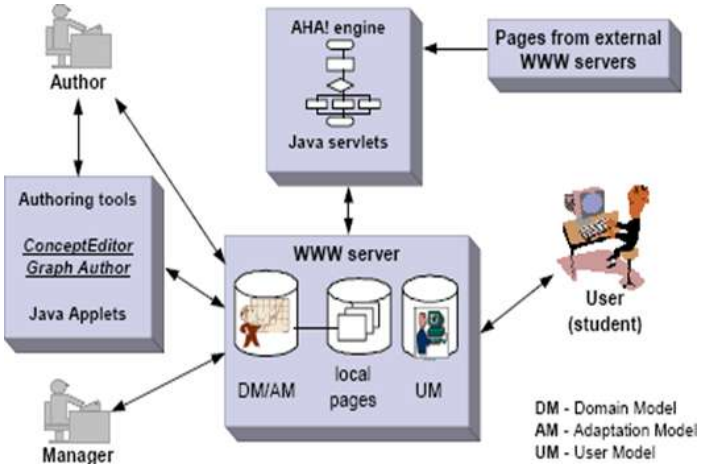

Figure 1. Adaptive Hypermedia Architecture

Java servlets are triggered when a user requests web pages. The AHA! Engine delivers pages to the user from either local or external servers.

These pages are generated by combining the domain model and the adaptation model, and are also adapted accordingly. Additionally, the user or learner model is updated using event-condition-action rules. All data related

to the domain, adaptation, and learner models is stored as XML files or in a unified MySQL database. AHA! Operates on the Tomcat server, which is also open-source. AHA! Supports an overlay learner model. Each concept in the domain model has a corresponding concept attribute and Boolean value in the learner model. When a learner interacts with a concept, the attribute value is updated to reflect whether the learner understands that concept.

Initially, at the start of a course designed by AHA! All attributes are set to "false." Another concept, "Personal," exists in the learner model and includes attributes that describe the learner's preferences and characteristics [20].

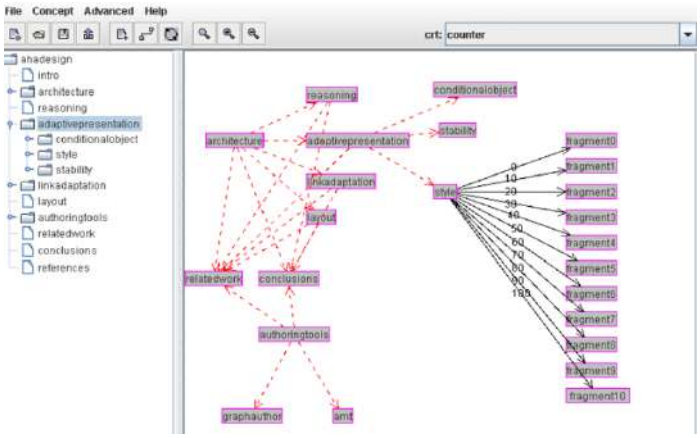

Figure 2. Graphical Author tool window in AHA!

3.1.1 Adaptation Support

The adaptation process in AHA! Is driven by the conceptual structure stored in the combined domain and adaptation model, along with the information in the learner model. AHA! Facilitates both adaptive presentation and adaptive navigation [21]. The system supports various adaptive presentation techniques, such as conditional text and fragment variants. Additionally, adaptively can be applied to the inclusion of external objects in the course. Another presentation style, known as "dimming fragments," allows fragments to be either highlighted or dimmed based on the learner model. AHA! Also enables adaptive navigation techniques, including link sorting, link hiding, link annotation, and direct guidance[22].

3.2 InterBook

InterBook is designed to create adaptive online educational courses in the form of textbooks. Its architecture is based on the ELM-ART textbook, one of the pioneering adaptive systems. Developed using CL-HTTP, a Common LISP HTTP server, CL-HTTP is employed for building online intelligent systems. InterBook is only compatible with Apple Macintosh systems.

InterBook employs an overlay learner model to provide adaptive navigation support. When a learner registers in the electronic textbook system, they are prompted to select their experience level with online systems. Based on this selection, the interface layout is dynamically adjusted to suit their preferences.

3.2.1 Course Authoring

Creating an electronic textbook in InterBook involves several steps. Initially, the textbook is written as a Microsoft Word document, adhering to specific formatting requirements. For instance, titles and subtitles must use text styles such as "Header 1" or "Header 2" to ensure compatibility with InterBook's adaptive annotation features. The

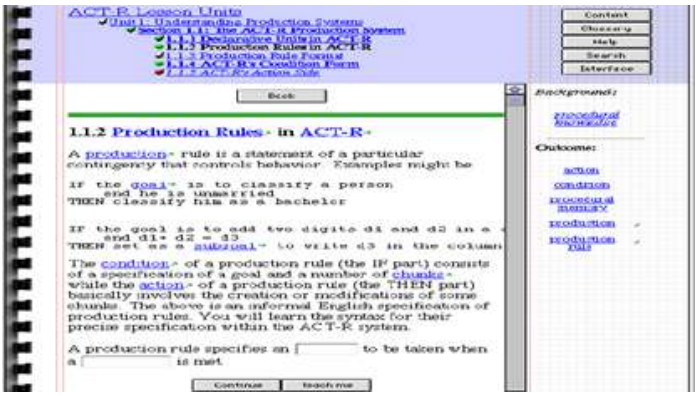

Figure 3. Detail of concept “production rules” and its position in textbook

Word file is then saved in RTF format and converted to an HTML file using a conversion tool[23]. The file extension of the resulting HTML document is subsequently changed to “inter,” making it recognizable by InterBook.

3.2.2 Adaptation Support

InterBook offers robust capabilities for adaptive presentation and adaptive navigation. For adaptive navigation, it provides features like local and global guidance through direct guidance functionality.

3.3 Cognitive Flexibility in Adaptive Learning Environment (COFALE)

COFALE is an open-source adaptive learning content management system (LCMS) built on the A Tutor platform. Designed to support the development of adaptive educational systems with cognitive flexibility, COFALE is implemented using PHP and stores all data related to domains, adaptations, and learners in a MySQL database. The system operates on an open-source Apache server.

3.3.1 Course Authoring

COFALE includes authoring tools to facilitate the creation of adaptive online courses. Authors can create pages in either plain text or HTML editor mode, and previously developed web pages can also be uploaded. Additionally, various types of images can be imported into COFALE to enhance course content.

3.3.2 Adaptation Support

COFALE supports both adaptive navigation and adaptive presentation. It provides direct guidance along with local and global views of content. Additionally, learners can customize the system layout by adjusting options based on their personal preferences[24]. With the help of My Tracker, learners can check their progress and see how many pages they have visited and for how long. The My Test tool provides information on which tests have been cleared and the scores.

3.3.3 Communication Support

COFALE also provides adaptive communication support through which the learner is given the facility to find peers according to their model for interaction. Different communication tools are part of COFALE like discussion forums, chat, email, and instant messaging facility for online learners.

3.4 Open edX

Open edX is a versatile, cloud-based, open-source learning management system developed by edX, designed to support online education and training needs for organizations of all sizes. The platform enables users to build

course structures and upload content, such as videos. Administrators can manage course schedules, set grading criteria, and publish courses in sections. A course launch checklist is included to streamline the process. Learners can take notes, highlight text, and monitor their progress throughout the course. Additionally, custom certificates and digital badges can be created to recognize achievements[25]. It offers robust course authoring and adaptation support features to enhance the learning experience.

3.4.1 Course Authoring

Open edX provides powerful tools for creating and managing courses. Users can design course structures, upload multimedia content like videos, and create interactive learning experiences using drag-and-drop editors and built-in templates. The platform supports modular course design, allowing educators to build and update courses efficiently.

3.4.2 Adaptation Support

To ensure accessibility and inclusivity, Open edX offers adaptation support features, allowing courses to be tailored to different learning needs and preferences. This includes options for customizable course content, translation capabilities for multilingual learners, and compatibility with assistive technologies[26]. Combined, the course authoring and adaptation support capabilities make Open edX an ideal platform for delivering scalable, inclusive, and engaging online education and training programs.

3.5 Moodle

Moodle is an open-source Learning Management System (LMS) widely used in education and corporate training to create and manage online learning experiences. Here's how Moodle integrates with course authoring and provides adaptation support.

3.5.1 Course Authoring in Moodle

Moodle offers robust tools for creating and managing online courses, Customizable Content, Modular Approach, SCORM and IMS Compliance, Drag-and-Drop Interface, and Plugin Ecosystem.

3.5.2 Adaptation Support in Moodle

Moodle supports learning adaptation to meet diverse learner needs. Personalized Learning Paths, Language and Localization, Analytics and Feedback, and Integration with AI Tools.

4 Comparison of Frameworks

After examining the adaptation features offered by AHA, InterBook, Open edX, Moodle, and COFALE, we have conducted a comparison, which is summarized in separate tables. Best express the results, we can use binary encoding for support and feature aggregation.

4.1 Support Encoding:

Assign binary or numerical values to the support levels:

- 0: Not Supported (e.g. X)
- 0.5: Limited Support or Required Customization
- 1: Supported with Plugins or Basic Support
- 1.5: Fully Supported

Features of Framework	AHA	InterBook	COFALE	Open edX	Moodle
Platform Independence	1.0	1.0	1.0	1.5	1.5
Auxiliary Information	0.0	0.0	0.0	0.5	1.0
Pre-learning Guidance	0.0	0.0	1.0	1.0	1.0
Contrastive Descriptions	0.0	0.0	1.0	0.5	0.5
Alternative Interpretations	0.0	0.0	1.0	0.5	1.0
Sequence Management	0.0	0.0	1.0	1.0	1.0

Table 1. Frameworks Comparison for the Adaptive Presentation

4.1.1 Feature-by-Platform Matrix

4.1.2 Feature Level Support across Platform

Here's an analysis and breakdown of feature support across these platforms

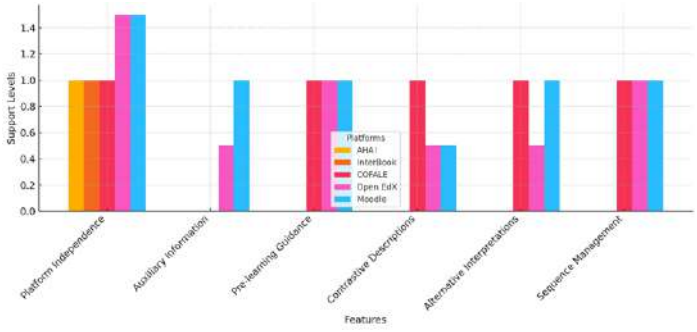

Figure 4. Feature Level Support across Platform

4.1.3 Heatmap Representation Feature Level Support across Platform

4.1.4 Aggregate Scoring

Computing the total support score for each platform:

$$T(\text{AHA!}) = 1.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 1.0$$

$$T(\text{Moodle}) = 1.5 + 1.0 + 1.0 + 0.5 + 1.0 + 1.0 = 6.0$$

4.1.5 Normalized Scores

Normalize the Scores to a Range of 0–1 for Easier Comparison

For $N(\text{AHA!}) = \frac{1.0}{6.0} \Rightarrow 0.167$

For $N(\text{InterBook}) = \frac{1.0}{6.0} \Rightarrow 0.167$

For $N(\text{COFALE}) = \frac{5.0}{6.0} \Rightarrow 0.83$

For $N(\text{Open edX}) = \frac{5.0}{6.0} \Rightarrow 0.83$

For $N(\text{Moodle}) = \frac{6.0}{6.0} \Rightarrow 1.0$

4.1.6 Comparative Analysis

By using the normalized scores $N(p_j)$ to rank platforms by their overall support level.

$$N(\text{Moodle}) > N(\text{Open EdX}) > N(\text{COFALE}) > N(\text{AHA!}) = N(\text{InterBook}) \quad (1)$$

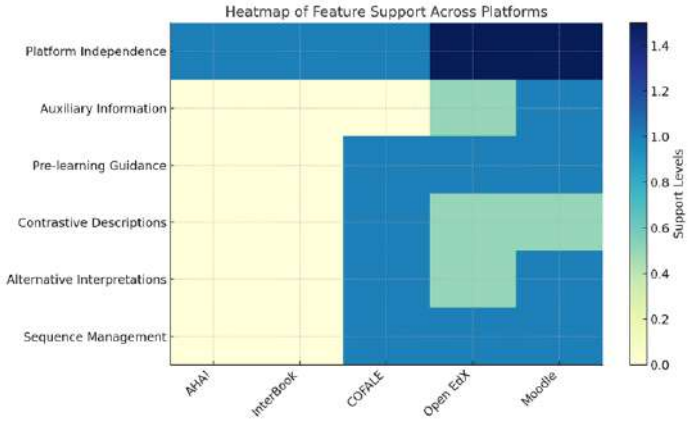

Figure 5. Heatmap for Feature Level Support across Platform

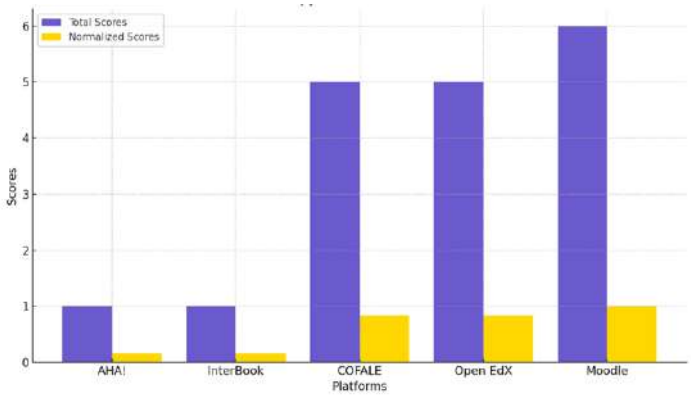

Figure 6. Platform support scores across features

Moodle leads, followed by Open EdX and COFALE, with AHA! and InterBook at the same level.

4.2 Adaptive Navigation

4.2.1 Feature-by-Platform Matrix

First translate the support levels into a numerical matrix

4.2.2 Heatmap for support levels Adaptive Navigation

4.2.3 Aggregate Scores

Sum up the numerical values for each platform

AHA! : 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 0.0

InterBook : 1.0 + 1.0 + 0.0 + 1.0 + 0.0 = 3.0

COFALE : 1.0 + 1.0 + 1.0 + 1.0 + 1.0 = 5.0

Open Edx : 1.0 + 1.0 + 1.0 + 0.5 + 1.0 = 4.5

Moodle : 1.0 + 1.0 + 1.0 + 1.0 + 1.0 = 5.0

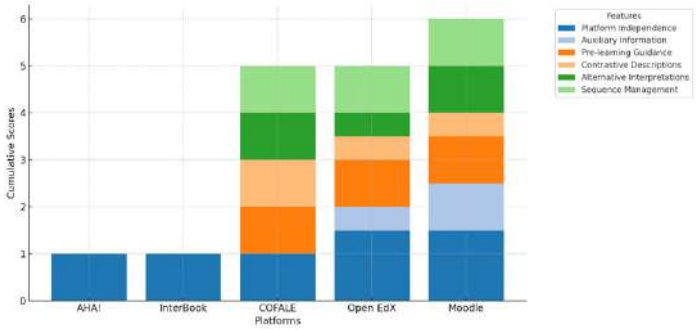

Figure 7. Cumulative scores support platform

Features of Framework	AHA!	InterBook	COFALE	Open Edx	Moodle
Global guidance	0.0	1.0	1.0	1.0	1.0
Local guidance	0.0	1.0	1.0	1.0	1.0
Holistic Context Clarity	0.0	0.0	1.0	1.0	1.0
Activity-level Context	0.0	1.0	1.0	0.5	1.0
Tailored View Control	0.0	0.0	1.0	1.0	1.0

Table 2. Frameworks Comparison for Adaptive Navigation

4.3 Normalized Scores

Normalize the scores to a range of [0, 1] using the maximum score (5.0)

$$\text{AHA!} : \frac{0.0}{5.0} = 0.0, \quad \text{InterBook} : \frac{3.0}{5.0} = 0.6$$

$$\text{COFALE} : \frac{5.0}{5.0} = 1.0, \quad \text{Open Edx} : \frac{4.5}{5.0} = 0.9, \quad \text{Moodle} : \frac{5.0}{5.0} = 1.0$$

The comparative hierarchy is:

$$N(\text{Moodle}) = N(\text{COFALE}) > N(\text{Open Edx}) > N(\text{InterBook}) > N(\text{AHA!}) \tag{2}$$

Moodle and COFALE tie for the lead, Open EdX is next, with InterBook and AHA! following.

4.4 Communication Support

4.4.1 Feature-by-Platform Matrix

Here data is encoded into a matrix M.

Features of Framework	AHA!	InterBook	COFALE	Open Edx	Moodle
Messaging	0.0	0.0	0.0	1.5	0.5
Forums	0.0	0.0	1.0	1.5	1.0
Real-time collaboration	0.0	0.0	0.5	0.5	0.5
Notification	0.0	0.0	1.0	1.5	1.5

Table 3. Frameworks Comparison for Adaptive Navigation

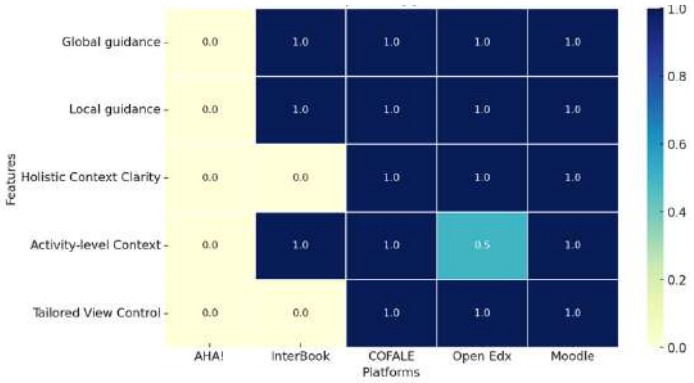

Figure 8. Heatmap of support levels Adaptive navigation

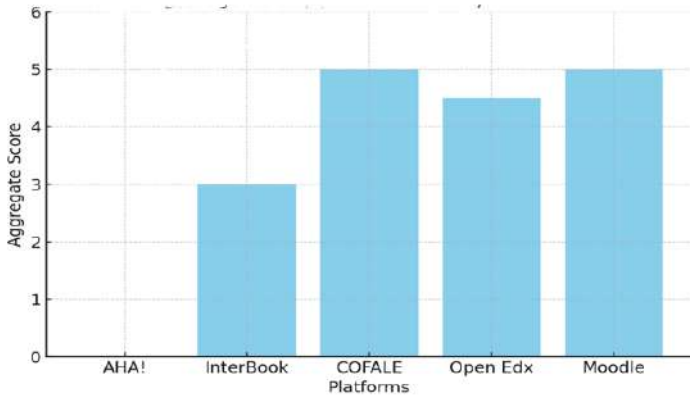

Figure 9. Aggregate support scores by platform

4.4.2 Feature support level across platform

4.4.3 Aggregate Scores

To compute the total support for each platform, sum the scores across all features

$$T(\text{AHA!}) = 0.0, \quad T(\text{InterBook}) = 0.0, \quad T(\text{COFALE}) = 2.0$$
$$T(\text{Open Edx}) = 5.0, \quad T(\text{Moodle}) = 3.0$$

4.4.4 Normalized Scores

Normalize the scores to a range of 0–1 for easier comparison

Here is a function $N(x)$ that takes the name of a platform as input and returns its corresponding value:

$$N(x) = \begin{cases} 0.0 & \text{if } x = \text{AHA!} \\ 0.0 & \text{if } x = \text{InterBook} \\ 0.5 & \text{if } x = \text{COFALE} \\ 1.0 & \text{if } x = \text{Open EdX} \\ 0.7 & \text{if } x = \text{Moodle} \end{cases}$$

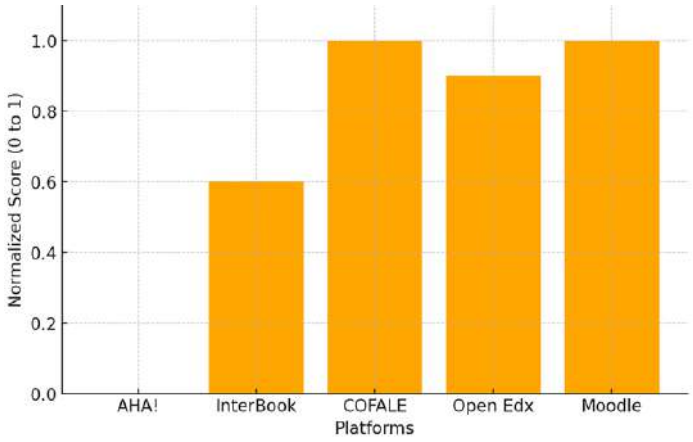

Figure 10. Normalized Support Scores by Platform

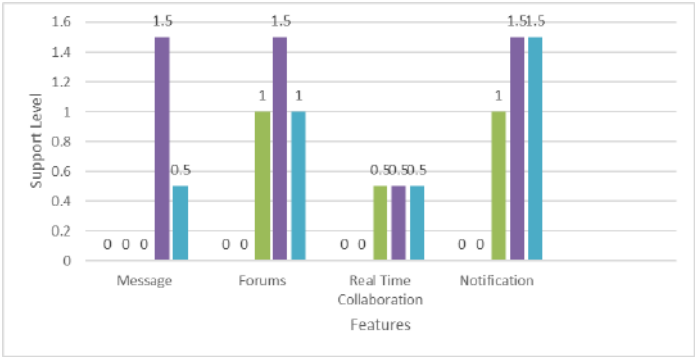

Figure 11. Feature support level across platform

4.4.5 Comparative Analysis

$$N(\text{Open Edx}) > N(\text{Moodle}) > N(\text{COFALE}) > N(\text{AHA!}) = N(\text{InterBook}) \quad (3)$$

Open EdX is highest, followed by Moodle, COFALE, and the tied AHA! and InterBook.

4.5 Framework Support Level Comparison Results

In the first analysis, Moodle ranks the highest, followed by Open EdX, COFALE, and both AHA! and InterBook, which are tied at the lowest level. In the second analysis, Moodle and COFALE share the highest value, with Open EdX coming next, followed by InterBook, and AHA! at the bottom. In the third analysis, Open EdX takes the lead, followed by Moodle, COFALE, and both AHA! and InterBook, which are tied at the lowest rank.

The three analyses highlight varying rankings among frameworks, Moodle and Open EdX alternate as leaders, with COFALE consistently in third. AHA! and InterBook remain tied at the bottom across all analyses, showing limited support compared to the top contenders.

5 CONCLUSION AND FUTURE WORK

This study shows that the comparison of AHA! InterBook, COFALE, Open edX, and Moodle reveals distinct strengths and weaknesses in their support for features critical to e-learning environments. All platforms are platform-independent, ensuring universal accessibility. However, when it comes to Adaptive Presentation and Adaptive Navigation, COFALE demonstrates robust capabilities, supporting features like Pre-learning Guidance, Contrastive

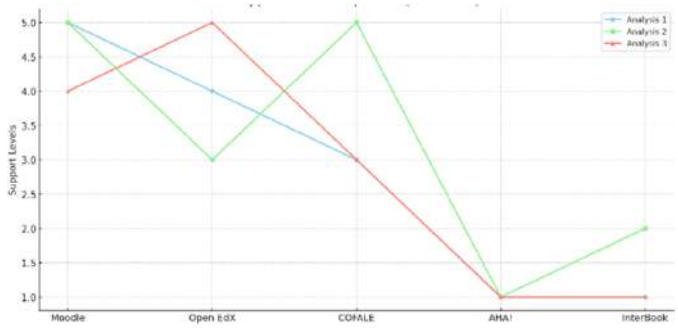

Figure 12. Support Level Platform Comparison

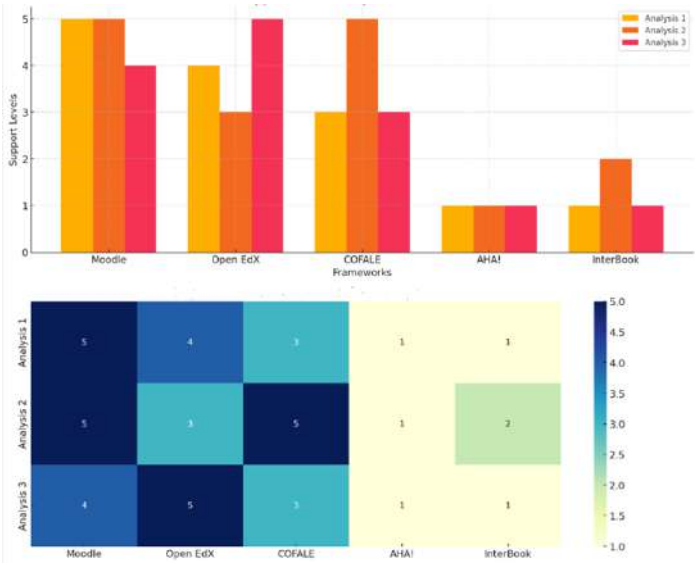

Figure 13. Support Level Comparison (Heatmap)

Descriptions, and Sequence Management, making it well-suited for personalized learning. Open edX and Moodle offer moderate support, often relying on plugins or customization to achieve advanced functionality, while AHA and InterBook show limited support, particularly in adaptive features.

In Communication Support, Open edX and Moodle stand out with built-in messaging, forums, and real-time collaboration tools. These platforms foster interactive and collaborative learning environments. COFALE provides basic communication features but lacks the sophistication required for dynamic collaboration. In contrast, AHA and InterBook fail to offer any significant communication tools, making them less viable for institutions that prioritize interaction and engagement.

Looking ahead, future development efforts should focus on enhancing adaptive and communication features across platforms. For AHA! And InterBook, the integration of adaptive presentation and navigation capabilities is essential to remain competitive. Platforms like COFALE could benefit from advancing their communication tools, while Open edX and Moodle should work toward reducing reliance on customization by integrating advanced adaptive features out of the box. Emphasizing interoperability with third-party tools, improving user-friendly customization interfaces, and incorporating AI-driven personalization and analytics are critical steps for all platforms. These advancements will ensure the platforms remain adaptable to the evolving needs of learners, educators,

and institutions, fostering more effective and engaging e-learning experiences

Author Contributions

Muhammad Kamran: Conceptualization, Methodology, Software uses **Binish Raza:** Data curation, Writing- Original draft preparation **Mr. Furrakh Shahzad:** Visualization, Investigation. **Muhammad Shoaib Kareem:** Software, Validation. **Kiran Naz:** Supervision.

Compliance with Ethical Standards

It is declared that all authors don't have any conflict of interest. It is also declared that this article does not contain any studies with human participants or animals performed by any of the authors. Furthermore, informed consent was obtained from all individual participants included in the study.

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