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Modular Web-based Learning Model to Address Underdeveloped ICT Infrastructure for Smart E-learning Education System

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Abstract

Advancements in Information and Communication Technology (ICT) enhance learning and instructional practices, generating chances for novel techniques and tools while simultaneously transforming the learning model. Historically, smart education models mostly consisted of qualitative investigations that delineated the conceptual structure and its implications for the Smart E-learning Education System (SEES). While these theoretically organized SEES can enhance student learning, facilitate peer and instructor communication, and improve teaching practices—thereby aiding in the comprehension of the status of learners and needs and offering real-time synchronous/asynchronous guidance—many qualitative investigations conducted in the past lack empirical evidence to substantiate the prioritization of E-Learning scheduling. This research first examined the technological barriers to implementing the SEES in developing nations. As a result, the suggested framework for the SEES based on underdeveloped ICT has been introduced. The system utilizes an integrated online/offline Web-Based Learning Model (WLM) incorporating a

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Service-oriented Architecture (SA) architecture to create SEES. The online mode is enabled for a WLM when an internet connection is accessible. The offline variant of the system is provided in a packed format and is used when Internet access is unavailable in an isolated classroom. A working example was launched to get input from learners and instructors across diverse educational levels. The trial installation and survey results confirm the viability and benefits of the suggested system.

Keywords: Information and Communication Technology, Web-Based Learning Model, Smart E-learning, Education, Service-oriented Architecture.

1 Overview of ICT and Smart E-Learning

ICT has been used in learning to enhance productivity and educational outputs in the twenty-first-century E-learning environment inside the Internet of Things (IoT) framework. Instructors, including professors, lecturers, instructors, and teachers, may use audio, video, visual aids, and literary resources via computers to prepare lessons and give interactive presentations online, independent of live classroom interaction. Within the framework of dynamic instructional pedagogy, educators and faculty members may provide multimedia content in an engaging, participative, and omnipresent synchronized digital space. Synchronous demonstrations save significant energy and time while enhancing efficiency in digital learning environments. Furthermore, interactive presentations are engaging to see, listen to, and study, particularly the audio and video elements, 3-D simulation environments, and optical illusions that make lectures very impactful (Bailey, 2020). The integration of computers in E-learning will enhance the educational landscape of the 21st century by eliminating monotony in dynamic instruction and learning activity (Min & Atan, 2024). The use of ICT in educational institutions will further influence technical breakthroughs and the methods of digital learning and instruction. Recently, ICT has experienced significant advancements in all areas of human management, integrating various media for immersive participation while completely tackling all facets of contemporary ubiquitous education and learning in a significant pedagogical achievement (Chen et al., 2020).

Currently, ICT is at the forefront of study and development, significantly advancing education through modern innovations that enhance the accessibility of contemporary technological tools, including mobile phones, personal computers (PCs), and personal digital assistants (PDAs), all of which positively influence information shift (Ruzibaeva et al., 2024; Hernández et al., 2024). Advancements in science and engineering have highlighted the essential elements of the digital society concerning data management, often known as ICTs. Computer innovations have impacted the lives of all learners in Nigeria, Africa, and the whole globe, even those residing in the most distant areas of the planet. It is undeniable that computers, mobile technology, and the internet have profoundly dominated the lives of normal students in the academic environment of the 21st century, whether at the postgraduate or undergraduate level (Jahnke & Liebscher, 2020).

The researchers examined the use of technological advances in instruction and education from a global educational viewpoint, focusing on 21st-century online learning design on the internet and computing (Gao, 2024). Numerous schools and universities globally have used E-learning platforms to enhance learning availability, regardless of geographical constraints and the location of e-learners (Matthew et al., 2020). The COVID-19 pandemic resulted in the closure of college and university campuses, highlighting the technological importance of the E-learning development framework. This shift provided numerous advantages, including enhanced learning and knowledge dissemination, improved access to educational curricula, cost efficiency, and the widespread use of computing platforms for digital education and sharing ideas (Prabhath et al., 2022). Modern E-learning applications, such as Zoom, are highly sophisticated, adaptable, dynamic, and adaptable, providing a well-organized learning atmosphere available to electronic learners in a configurable setting for widespread and synchronous data exchange (Kurbanazarova et al., 2024). The contemporary creative educational tools anticipated in the twenty-first century, including E-learning, blended instruction, online education, mobile learning (m-learning), virtual instruction, and e-libraries, have afforded members of scientific communities—such as faculty members, lecturers, trainers, professors, researchers, and students—the opportunity to gain, cultivate, and sustain essential digital competencies without impediments (Alduaij et al., 2024).

The SEES predominantly rely on the internet structures as the conduit for information; however, the internet and its frameworks have regrettably evolved into a new category of malicious activities, including cybercrime, cyber-terrorism, eavesdropping, and spying. Consequently, information within the e-learning environment traverses the internet protocol cyberspace, rendering it perpetually vulnerable to security threats due to SEES's dispersed, open, and highly interdependent nature (Oni et al., 2019). The expansion of ICT and the increased incidence of online crimes in the 21st century's digital learning setting are critical factors in informing post-COVID-19 educational investments in E-learning.

This research presents a framework for the SEES based on undeveloped ICT inspired by the abovementioned findings. The system employs a unified online/offline WLM that integrates an SA architecture to develop SEES.

2 Literature Survey

"Smart" denotes intellect, insight, efficiency, and competence. Consequently, SEES denotes a learning medium that empowers learners to think critically, operate efficiently, and resolve issues adeptly. Consequently, smart schools strive to create an intelligent atmosphere for education focused on students, offering individualized and flexible educational services, along with interactive and collaborative technologies that are readily available. Smart learning is "the efficient and cohesive use of ICT to attain educational results via suitable pedagogical approaches." Authors in (Kwet & Prinsloo, 2020) previously defined smart education as implementing intelligent devices to offer intelligent surroundings, deliver tailored learning services, enhance intelligent teaching, and enable learners to cultivate intelligent skills. It has orientation, enhanced value, enhanced cognitive quality, and increased potential for action.

The concept of "E-learning" encompasses various interpretations and designations due to the evolution of instructional tools, including WLM, training, virtual education, and remote learning (Tangirov et al., 2021). Fundamentally, all these terms refer to computer and network technology utilization in educational contexts, encompassing both synchronous and asynchronous learning modalities. WLM involves storing educational information on CD-ROM or disk for individual study via personal computers. Internet-based learning encompasses any educational activities employing ICT, including but not limited to learning via web pages, electronic mail, uploading files, discussion boards, and proprietary systems. Online learning often denotes educational activities delivered via web pages or network technologies.

E-learning, or digital learning, refers to educational activities that use various technologies. The novel communication method and ample learning materials, facilitating a new pedagogical approach, will transform the function of educators in conventional instruction and the dynamics between instructors and students, thus altering the educational framework and the essence of education (Melki & Bouzid, 2023). It may include several educational activities like online learning, computer-aided instruction, online instruction, and digital collaborative learning. Consequently, digital learning (E-Learning) pertains to education and instruction online or in other electronic mediums. It fully utilizes the educational atmosphere of contemporary ICT, including an innovative interaction mechanism and abundant resources to provide a novel approach to learning (García-Tudela et al., 2021).

It comprises six pertinent factors. The success of the suggested E-learning platform is contingent upon many layers of the idea. The literature identifies the primary requirements as including smart classroom functionality, technologically dependent learning systems (IoT, Metaverse), teaching monitoring systems, and conceptual aspects of smart instruction (Chang et al., 2022; Huang et al., 2021). A smart classroom's functions may be individualized instruction for individuals, wireless technology, optimization of teaching resources, and collaborative learning among students. The ICT-based educational system may be categorized as education via gaming, electronic community, and dependable wireless connectivity (Huang et al., 2019). The teaching evaluation system comprises cyberspace protection, system information backup, academic achievement rate, and educational focus detection (Geng, 2024). The conceptual components of smart learning may be categorized into intelligent learners, intelligent teaching methods, ergonomics, and instructional analytics (Budhrani et al., 2018).

Mobile apps and gadgets have been extensively used for online education across several areas, as examined in (Bano et al., 2018). The analysis indicated that the flexibility, accessibility, multifunctionality, and attractiveness of handheld devices have contributed significantly to SEES in attaining student fulfillment. Authors in (Pham et al., 2021) developed a mobile education system that autonomously converts original material into multi-faceted information suitable for presentation on displays of varying sizes and resolutions. To enhance learners' participation, 3D models and virtual reality techniques may create a dynamic educational setting (Abichandani et al., 2019). In these educational frameworks, instructional objects are shown in three-dimensional settings, allowing learners to modify the viewing angles and dissect the items to examine their created components.

The research revealed significant improvements in system performance via advanced technology. This method was noted to enhance system performance considerably. The literature lacks adaptable solutions that address both underdeveloped ICT infrastructures and diverse user devices in system design, reflecting the circumstances in emerging nations. A flexible containerized architecture is required to accommodate various circumstances and the particular demands of the work settings.

3 Materials and Methods

To address the above-described challenges, the SEES framework is founded on three technological pillars: (i) cloud computing (CC) for resource provisioning, (ii) software architecture design, and (iii) WLM connectivity for user engagement. The CC technology, in combination with the fundamental infrastructure virtualization, provides a stable and elastic environment for deploying a SEES. The SEES architecture may dynamically modify the limit of specific functions as needed without requiring physical resource modification.

The SA design approach is a contemporary software design paradigm in which each function is encapsulated as a service, accessible externally and autonomously over a shared transmission channel, referred to as a common data bus (CDB). By implementing the SA design, the SEES framework enhances control and upkeep processes through actively adjustable workflows, allowing for flexible scaling, extension, addition, removal, and containment of system functions. The WLM approach provides user-friendly interfaces and connections, facilitating convenient access methods. Most functional upgrades in the centralized system do not need configuration alterations on individual devices.

This technology operates independently from regional operating systems and is compatible with diverse displays and accessories.

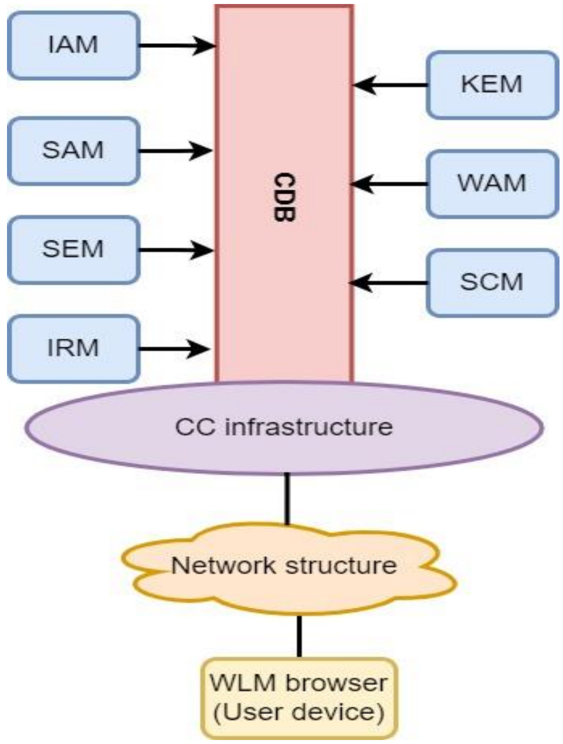

Figure 1: SEES-WLM Framework Using SA Architecture Design

System Architecture

The SEES architecture has the following seven services, which serve as operational modules, interacting via established communication methods on a CDB (Figure 1). The seven primary services of SEES are enumerated in the following order:

1) Identification and Authentication Module (IAM)

The IAM implements two security measures before providing user accessibility to system operations and materials. The authentication procedure verifies the user's identification by comparing the evidence submitted by the user with the data recorded in the system library. The pairing procedure is conducted asynchronously via the public key management method to provide reliable authentication. Upon user identification, the authorization module ascertains the user's credentials. The system library is queried for the user's service account to delineate the services and assets to which the user has access rights. Specifically, we delineate four user categories inside the SEES framework: students, teachers, managers, and executives, each possessing distinct classes.

2) Session Administration Module (SAM)

The SAM is a critical system component, mainly tasked with initiating, altering, suspending, and terminating the service accounts allocated to authorized individuals. The SMF allocates suitable communication facilities among the permitted services and user information on the CDB, based on their needs and interactions, to provide seamless traffic flow inside the SEES framework. Additionally, the

SMF facilitates virtual personal networking pathways, allowing users to utilize the framework across insecure infrastructures, including free Wi-Fi and the Internet. A session planning mechanism is initiated when the volume of incoming requests surpasses the system's service capability.

3) Service Expose Module (SEM)

The SEM enables open, resilient, and adaptable utilization of system services and functionalities. Native and external services engage with the system operations using conventional interfaces and standards supplied by the SEF. Every system function is offered as an add-on module with its features, parameters, capabilities, dependencies, and specific processes where applicable. Prominent instances of the system operations include classrooms, interaction, practice, examinations, scoring, feedback, reporting, user administration, handling of data, and graphical interface customization. Users may choose the desired functionality to customize their workspaces based on access rights. The user workspace setup is preserved and maintained in the user account library.

4) Information Repository Module (IRM)

Inside the SEES architecture, data is managed autonomously using a specialized system service, which contrasts conventional data storage services. The IRM offers suitable services for collecting, managing, and storing user and system databases for data analysis. Notable instances of these datasets include user IDs, accounts of users, user information, instructional materials, topic statistics, and network statistics. The evaluations include data cleansing, merging data, data restructuring, and data conversion, among other processes. The IRM addresses inquiries from both inside and outside services by establishing a standardized set of instructions and assertions. A reaction scheduling process is initiated when the volume of requests received exceeds the capacity of the IRM. The IRM does not initially handle the information. The IRM communicates with external information management tools and database platforms.

5) Knowledge Exchange Module (KEM)

KEM offers resources and an environment enabling users to interact, discuss, exchange, and contribute official and unofficial data to the knowledge repository. Information may be sent in several forms, including text, audio, records of data, interactive media, and live streaming over public, team, and personal channels. According to the channel setup and authority arrangement, the KEM demands immediate or long-term memory from the IRM, where user-shared information is stored for potential reuse. The KEM is crucial in facilitating real-time interactions among students and between instructors and students, hence enhancing student involvement.

6) Workstation Adjustment Module (WAM)

It delivers online services to end users using an adaptive web interface like a workstation. The workstation layout dynamically adjusts to the user's screen dimensions, while the working environment functionalities are loaded according to the configurations from the user account databases saved in the IRM. Notwithstanding the adaptability, essential educational components, including classrooms, examinations, and assessments, remain obligatory in the workplace. Furthermore, user authority is linked to distinct groups of obligatory functions. For instance, educators' workplaces need examination reports, student administration, and instructional material leadership, whereas managers' workstations emphasize learning metrics and reviews.

7) Synchronize and Containerizing Module (SCM)

The SCM allows the SEES framework to function offline, facilitating assistance for a cohort of users (learners and educators) with local operating capacity independent of Internet connectivity. The containerizing encapsulates fundamental system functions with important settings files, archives, and requirements for educational activities, including classrooms, practicals, assessments, and evaluations. The user workstation setup includes limited features using loaded settings from individual profiles in offline configuration. The offline SEES package is deployable on microcomputers. When Internet connectivity is accessible, registered users, including educators, may upload localized information to the online SEES structure under the oversight of the synchronizing function.

Using the SA design, the web-based adaptable SEES framework may be regarded as a CC-native platform application due to its effective use of CC technologies and its surrounding context. The SEES system, being a native CC usage, can securely and efficiently interface with CC-native third-party solutions. The IRM module interfaces with third-party information management systems like MySQL, while the IAM and KEM may employ additional services from social media sites for authorization and instant communication functionalities. Furthermore, the Docker Engine could offer containerization capabilities for the SCM component.

4 Results and Discussion

The benefits of the system that is suggested were thoroughly examined by verifying the evaluation standards based on the service expertise, which includes: 1) convenience, assessing the degree of user convenience while utilizing SEES for learning; 2) functionality, emphasizing the simplicity of use and navigation of SEES features during lessons; 3) graphing, illustrating how SEES presents case studies that support the lessons; 4) interactivity, determining users' ability to participate with SEES content through various gadgets; and 5) engagement, elucidating how SEES inspires and captivates users in their pursuit of skills and expertise. For each assessment criterion, three questions have been developed to elicit users' views in online, offline, and mixed modes, respectively. Feedback is gathered using a popup form integrated into the program user experience.

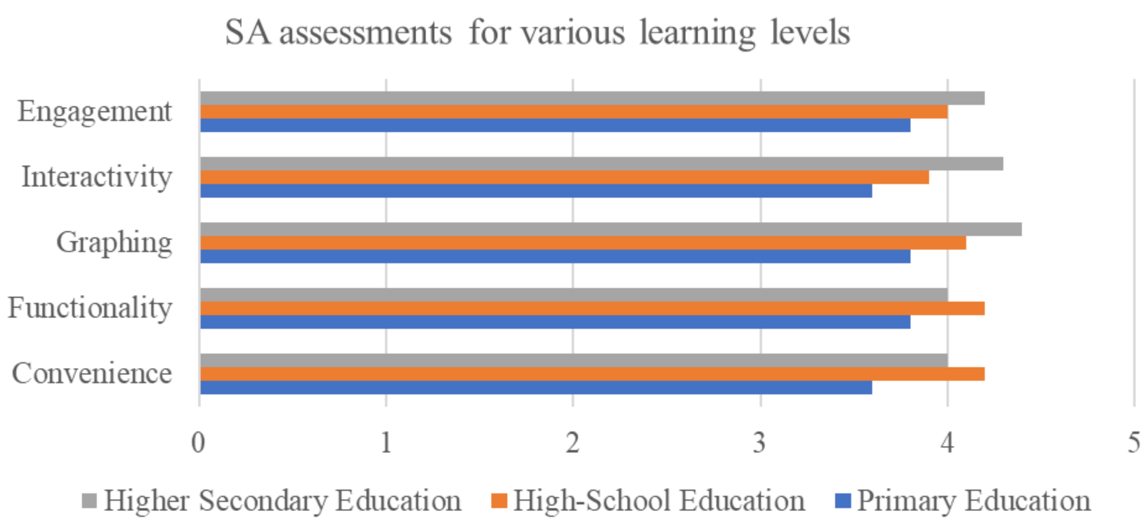

Figure 2: SA Evaluations of Several Educational Dimensions (Convenience, Functionality, Graphing, Interactivity, and Engagement) Across Three Educational Tiers in the SEES Framework

Figure 2 illustrates SA evaluations of several educational dimensions (Convenience, Functionality, Graphing, interaction, and Engagement) across three educational tiers: Primary Education (blue), High School Education (orange), and Higher Secondary Education (gray). The abovementioned elements are assessed using a Likert scale, wherein 1 signifies "strongly disagree", 2 signifies "disagree", 3 denotes "neutral", 4 signifies "agree", and 5 signifies "strongly agree."

The scores for Higher Secondary Education typically approach 4 (Agree) or exceed it significantly, reflecting substantial satisfaction in aspects such as Engagement and Functionality. High school education demonstrates reasonable satisfaction, with the majority of ratings about 4 (Agree), but significantly lower than that of higher secondary education. Elementary education often receives lower scores, ranging from 3 (Neutral) to 4 (Agree), indicating that children at the elementary level exhibit less satisfaction with elements such as Graphing and Interactivity. The evaluations indicate a correlation between rising educational levels and enhanced contentment.

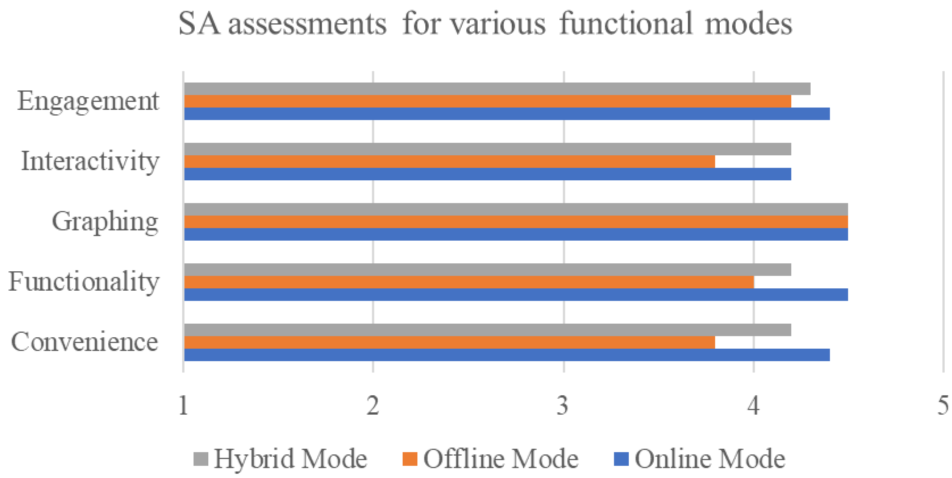

Figure 3: Evaluations of SA Experience Across Three Operating Modes (Online, Offline, and Hybrid) for Various Attributes in the SEES Framework

Figure 3 displays evaluations of SA experience across three operating modes (Online, Offline, and Hybrid) for various attributes, using a Likert scale where 1 signifies "Strongly Disagree" and 5 denotes "Strongly Agree." In general, Online Mode has the greatest ratings across most areas, with significant consensus in Convenience (4.4), Functionality (4.5), and Engagement (4.4). Hybrid mode strongly aligns, particularly in Convenience (4.2) and Interactivity (4.2), indicating comparable levels of pleasure. Offline mode often garners lower evaluations, especially in Convenience (3.8) and Interactivity (3.8), suggesting fewer positive experiences than other modes. All three modes exhibit agreement or good agreement in Graphing (4.5), indicating uniform satisfaction in this area across modalities.

User feedback was gathered by asking open-ended questions about their anticipations regarding system changes. Most comments indicate user satisfaction with the existing system, as shown in the preceding assessments. Their remarks about the anticipated improvements are categorized into three categories.

- Suggestion - A consensus among students and teachers indicates the need to include auto-recommendation for learning topics and resources, as shown by 82% of the feedback.
- Subject - In 80% of the responses, learners preferred a greater variety of subjects and advocated for interdisciplinary connections among them.

- Interactions - 63% of students and educators sought enhanced immersive settings, including game-based activities and physical interactions.

Given these insights, the SEES framework was modified to align with customer requirements for the final products produced in the subsequent implementation phase.

5 Conclusion

This study first investigated the technical obstacles to deploying the SEES in developing countries. The proposed structure for the SEES, based on undeveloped ICT, has been presented. The system employs a comprehensive online/offline Web-Based Learning Model (WLM) that integrates a Service-oriented Architecture (SA) to develop SEES. The online mode is activated for a WLM when an internet connection is available. The offline version of the system is supplied in a compressed file and is used when Internet connectivity is inaccessible in a secluded classroom.

An operational example was finally implemented to gather feedback from students and educators across several educational tiers. The trial installation and survey findings unequivocally validate the feasibility and advantages of the proposed technology. Results illustrate SA evaluations of several educational dimensions (Convenience, Functionality, Graphing, Interaction, and Engagement) across three educational tiers: Primary Education (blue), High School Education (orange), and Higher Secondary Education (gray). The characteristic elements are assessed using a Likert scale, wherein one signifies strongly disagree, and five signifies strongly agree. User feedback was gathered by asking open-ended questions about their anticipations regarding system changes. Most comments indicate user satisfaction with the existing system, as shown in the preceding assessments.

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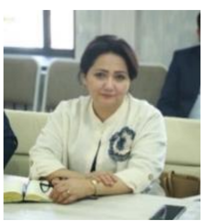

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