DESIGNING A SOFTWARE ARCHITECTURE FOR AN INTERACTIVE WEB-BASED ASSESSMENT TOOL FOR SMART BASIC EDUCATION SCHOOLS IN ENUGU STATE

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Abstract

The study designed and evaluated a software architecture for an Interactive Web-Based Assessment Tool (IWBAT) intended for integration into smart basic education schools in Enugu State, Nigeria. Specifically, the study identified the software requirements for the proposed IWBAT, determined appropriate software architectural components, and evaluated the suitability of the resulting architectural design. The study adopted a Design Science Research approach complemented by expert evaluation. Researcher-developed instruments, namely the Interactive Web-Based Assessment Expert Questionnaire and the Software Architecture Validation Questionnaire, were used to collect data from software experts and ICT compliant teachers, who were purposively selected. Data were analyzed using mean and standard deviation. The findings revealed that all identified software requirements were considered necessary for the development of the IWBAT (Overall Mean = 3.77), while the proposed architectural components were rated as highly appropriate (Overall Mean = 3.71). Furthermore, the overall architectural design was adjudged appropriate to a high extent (Overall Mean = 4.33), particularly in terms of requirement representation, interoperability, scalability, system availability, and support for online examinations. The study concludes that the proposed software architecture provides a robust framework for developing secure, scalable, and maintainable interactive assessment systems capable of supporting smart basic education schools in Enugu state, Nigeria. It was recommended that educational authorities adopt architecture-driven approaches in developing digital assessment platforms and that future studies validate the proposed architecture through real-world implementation and usability evaluation.

Keywords: Assessment, Digital Assessment, Interactive Web-based Assessment Tool, Software Architecture, Smart Basic Education School

Introduction

The integration of Information and Communication Technology (ICT) into education has transformed the delivery of teaching, learning, and assessment worldwide (UNESCO, 2023; OECD, 2021). This transformation has redefined educational practices by facilitating digital access to instructional resources, promoting learner-centred pedagogies, and enabling institutions to leverage technology for efficient academic management and evidence-based decision-making. One significant outcome of this transformation is the emergence of smart schools, which represent a paradigm shift from conventional educational systems to

technology-enabled environments where digital infrastructure, intelligent learning resources, and interconnected platforms facilitate effective instructional delivery and administrative processes (Zhu, Yu, & Riezebos, 2016).

Within these technology-enhanced environments, assessment occupies a central position because it provides evidence of learners' achievement, informs instructional decisions, and supports educational accountability (Black & Wiliam, 2018). Assessment is the systematic process of collecting, analysing, and interpreting information about learners' knowledge, skills, attitudes, and performance to inform educational decisions and improve learning outcomes (Brown & Knight, 1994). Beyond measuring academic attainment, assessment serves as a mechanism for monitoring learning progress, diagnosing instructional needs, providing formative feedback, and evaluating the effectiveness of educational interventions. As educational institutions increasingly adopt digital technologies, traditional assessment methods are being complemented or replaced by technology-driven approaches, particularly web-based assessment.

Web-based assessment refers to the use of internet technologies and web platforms to design, administer, deliver, score, and provide feedback on assessments electronically (Bennett, 2002). Consequently, assessment systems deployed in smart schools must be efficient, interactive, scalable, secure, and capable of providing timely feedback to learners and educators (Redecker & Johannessen, 2013). Web-based assessment systems are particularly suited to smart school environments because they enable real-time monitoring of learners' progress, automated scoring, immediate feedback, secure storage of assessment records, and flexible access irrespective of geographical location (Alruwais, Wills, & Wald, 2018). By leveraging networked technologies, these systems also support data-driven instructional planning and facilitate continuous improvement in teaching and learning.

The increasing demand for learner engagement has led to the evolution of Interactive Web-Based Assessment Tools (IWBAT), which extend beyond conventional electronic testing by embedding interactive features into the assessment process. An Interactive Web-Based Assessment Tool (IWBAT) is defined as a web-enabled assessment platform that facilitates dynamic interactions among learners, instructors, assessment content, and digital resources through real-time communication and automated processing mechanisms. Unlike conventional Computer-Based Testing (CBT) systems that merely digitize paper examinations, IWBAT supports multimedia integration, adaptive questioning, instant feedback, collaborative interactions, personalized learning experiences, and seamless communication with learning management systems (Redecker & Johannessen, 2013). These capabilities transform

assessment from a static measurement exercise into an interactive learning process that promotes continuous engagement and reflection.

Some distinguishing characteristics of IWBAT include ubiquitous access through internet-enabled devices, automated result processing, scalability for large numbers of users, integration of multimedia learning objects, adaptive assessment capabilities, and continuous monitoring of learner progress. These systems reduce administrative workload, improve examination integrity, enhance accessibility, and facilitate data-driven educational decision-making (Nicol & Macfarlane-Dick, 2006). Furthermore, advances in cloud computing, database technologies, and web development have enabled educational institutions to deploy assessment platforms that integrate seamlessly with broader digital learning ecosystems (Mell & Grance, 2011; Pressman & Maxim, 2020). Despite these technological advances, the adoption of interactive web-based assessment systems remains relatively limited in many developing countries, including Nigeria, where assessment practices continue to be dominated by traditional or basic computer-based approaches.

In Nigeria, efforts toward educational digitalization have accelerated in recent years through various government initiatives aimed at integrating ICT into teaching and learning. One notable development is the establishment of smart basic education schools designed to prepare learners for participation in an increasingly knowledge-driven and technology-oriented society. Smart basic education schools are technology-enhanced educational institutions that leverage digital infrastructure, intelligent learning systems, internet connectivity, interactive instructional resources, and data-driven management practices to improve teaching, learning, assessment, and school administration (Zhu, Yu, & Riezebos, 2016). According to UNESCO (2023), smart schools utilize emerging technologies to create learner-centred environments that promote collaboration, creativity, critical thinking, and personalized learning experiences. These schools are characterized by smart classrooms equipped with digital devices, ubiquitous internet access, interactive learning platforms, cloud-based educational resources, technology-supported assessment systems, real-time monitoring of learning activities, and integrated administrative management systems (Hwang, 2014; Zhu et al., 2016).

The Government of Enugu State has demonstrated commitment to this educational transformation through the establishment of 260 smart schools across its seventeen Local Government Areas (Nnadozie et al., 2024). The initiative seeks to provide digital classrooms, internet connectivity, and modern instructional technologies capable of supporting twenty-first-century teaching and learning. However, while considerable investments have been directed toward classroom technologies and instructional infrastructure, comparatively little

attention has been given to the development of context-specific digital assessment systems capable of complementing these smart learning environments.

Existing assessment practices in many Nigerian schools continue to rely heavily on conventional paper-and-pencil examinations or standalone computer-based testing applications that primarily digitize traditional examination processes without providing comprehensive interactive functionalities (Ayo et al., 2007; Oye et al., 2012). Although commercially available Learning Management Systems and assessment platforms exist, many are proprietary, expensive to customize, inadequately aligned with local curricular requirements, or developed without sufficient consideration for the infrastructural realities of public basic education institutions in developing countries (Andersson & Grönlund, 2009; Unwin, 2009; UNESCO, 2023). Previous studies have considered some perceived challenges of the smart schools (Agwu et al., 2024; Nnadozie et al., 2024) without paying attention to one of the major rudiments of a smart school, the connective architecture for assessment and feedback, which is capable of bringing out the smart in the school. Consequently, smart school administrators may struggle to deploy assessment systems that simultaneously satisfy requirements relating to usability, maintainability, security, scalability, interoperability, and contextual relevance.

From a software developer's perspective, the effectiveness of any digital assessment platform depends fundamentally on its underlying software or system architecture. Software architecture is defined by Bass et al. (2022) as the structure or structures of a software system comprising software elements, the externally visible properties of those elements, and the relationships among them. Similarly, the International Organization for Standardization (ISO/IEC/IEEE 42010, 2022) defines software architecture as the fundamental concepts or properties of a system embodied in its elements, relationships, and the principles guiding its design and evolution. Accordingly, system architecture represents the conceptual blueprint that governs how software components are organised, interact, communicate, and evolve to satisfy both functional and non-functional requirements. A carefully designed architecture improves modularity, facilitates maintenance, enhances scalability, supports future upgrades, improves reliability, and minimizes implementation risks (Pressman & Maxim, 2020; Bass et al., 2022). Conversely, poorly designed architectures frequently result in systems that are difficult to maintain, vulnerable to security threats, and incapable of adapting to changing educational requirements.

Moreover, despite the increasing interest in web-based educational assessment, extant literature has predominantly emphasized implementation outcomes, usability evaluation, learner satisfaction, e-assessment effectiveness, and technology adoption of existing platforms

(Alruwais et al., 2018; Baleni, 2015; Isaias, Issa, & Kommers, 2022). Comparatively few studies have systematically examined the architectural design principles underpinning interactive assessment systems, particularly within the context of smart basic education schools in Nigeria. Available Nigerian studies have focused largely on the development or deployment of computer-based testing systems rather than architecture-driven frameworks for smart-school assessment environments (Ayo et al., 2007; Oye et al., 2012). Furthermore, existing studies rarely integrate software requirement specifications with architectural modelling and expert validation to produce context-sensitive assessment frameworks suitable for public basic education institutions. This indicates a significant knowledge gap in the design of scalable and sustainable assessment infrastructures capable of supporting Nigeria's emerging smart school ecosystem, beginning with Enugu State.

Hence, this study seeks to design and validate an architecture for an Interactive Web-Based Assessment Tool (IWBAT) intended for integration into smart basic education schools in Enugu State, Nigeria. By grounding the proposed architecture in empirically derived software requirement specifications and subjecting it to expert validation, the study aims to provide a scalable, maintainable, and contextually relevant framework capable of supporting secure, interactive, and efficient assessment practices within smart basic education schools.

Purpose of the Study

The purpose of this study is to design and validate an architecture for an Interactive Web-Based Assessment Tool (IWBAT) suitable for deployment in smart basic education schools in Enugu State, Nigeria. Specifically, the study sought to determine the:

1. Software requirement specification for the IWBAT.
2. Software architecture components for the IWBAT based on the identified software requirements.
3. Extent to which the proposed architectural design is appropriate for the development of the IWBAT.

Research Questions

The following research questions guided the study:

1. What are the software requirement specifications for the development of an IWBAT for smart basic education schools in Enugu State, Nigeria?
2. Which software architecture component is appropriate for the development of an IWBAT based on the identified software requirements?

3. To what extent is the proposed architectural design appropriate for the development of an IWBAT for smart basic education schools in Enugu State, Nigeria?

Methodology

Research Design

This study adopted a Design Research Science approach complemented by a descriptive survey approach for expert validation. Design Science Research is appropriate because it focuses on the creation and evaluation of technological artefacts intended to solve identified practical problems (Brown, 1992). The architectural framework developed in this study constituted the primary research artefact and was produced through iterative processes involving requirement elicitation, architectural modelling, expert evaluation, refinement, and validation. The study followed three major phases: software requirement specification in phase I, architectural design and modelling in phase II, and expert validation of the proposed architecture in phase III.

Area of the Study

The study was conducted in Enugu State, Nigeria, where the government has initiated the implementation of 260 smart basic education schools equipped with digital teaching and learning facilities. Enugu state's ongoing investment in educational technology provides an appropriate context for developing an architecture for interactive web-based assessment systems.

Population of the Study and Sampling Technique

The population for this study covered 859 participants, comprising 2 software architects from the ICT Department of the Pilot Smart Green School in **Owo, Nkanu East LGA.** 17 ICT-compliant teachers served as experts, who used the software to assess the 840 pupils drawn from the pilot Smart Green School in **Owo. This school was** among the already completed smart schools at the time of conducting this study.

To complete the three phases involved in this study, a purposive sampling technique was used to select 19 participants, comprising 2 software architects and 17 ICT-compliant teachers. The rationale for this was supported by Cresswell (2012), who asserted that to learn or understand an essential phenomenon, a researcher can select individuals to serve that particular purpose.

Instrument for Data Collection

Two questionnaire instruments were used for data collection in this study. The researchers developed the instruments following a thorough literature review, stakeholder consultation, system requirements and the expected performance requirements of the software architecture. The instruments are the Interactive Web-Based Assessment Expert Questionnaire (IWBAEQ) and the Software Architecture Validation Questionnaire (SAVQ).

Aside from the demographic variables, including area of specialization and years of experience, IWBAEQ has a total of 12 items eliciting information on the software requirements (5 items) and appropriateness of the Software Architecture for the IWBAT (7 items). It has five response options ranging from Not Required / Not Appropriate (1) to Highly Required / Highly Appropriate (5). On the other hand, SAVQ contained 20 items designed to assess expert perceptions regarding: completeness, modularity, scalability, maintainability, interoperability, security, usability, flexibility, and suitability of the proposed architecture. Responses were measured on a five-point Likert scale ranging from Very Low Extent (1) to Very High Extent (5).

Development Procedure

The architecture development followed an iterative process, outlined in three phases.

Phase I: Requirement Elicitation - Relevant stakeholders were consulted to identify user needs, system expectations, and operational constraints. Findings from literature and existing assessment systems were synthesized into a Software Requirement Specification document.

Phase II: Architectural Design - using the approved requirements specification, a high-level software architecture was developed employing a layered architecture pattern presented in component diagrams, sequence diagrams, and deployment diagrams, to illustrate system interactions.

Phase III: Expert Validation - The architectural design and accompanying documentation were presented to domain experts for independent evaluation using the System Architecture Validation Questionnaire. Recommendations received from reviewers were incorporated into the final architecture through iterative refinement.

Validation of the Instrument

The two questionnaires were face-validated by five experts: one in Educational Technology, one in Measurement and Evaluation, and one in Computer and Robotics Education, all from the University of Nigeria, Nsukka, and two software developers from

Tenece Professional Services Ltd, Enugu. The experts were asked to check the suitability of the Questionnaires for eliciting the information in line with requirements and the viability of the proposed system architecture for an IWBAT. Recommendations, suggestions and corrections from the experts were integrated into the final version of the instruments.

Reliability of the Instrument

The assessment of internal consistency of the instruments was conducted utilizing Cronbach's alpha. This approach was chosen due to its capacity to evaluate the reliability of the survey items. The reliability of the Expert Questionnaire and the System Architecture evaluation was ascertained through a trial testing process that involved 10 lecturers from the University of Nigeria, Nsukka, which is outside the area of the present study. However, the choice of the University of Nigeria, which does not possess identical characteristics, aligns with Nworgu (2015), who emphasized that when institutions with identical features are unavailable, those with comparable characteristics may be appropriately selected for research purposes, hence, it is essential to pilot test the instrument in multiple contexts. This process helps to identify potential issues and enhances the instrument's reliability across different settings. The reliability of the instrument was established using Cronbach's Alpha, yielding a coefficient of 0.87, indicating high internal consistency and suitability for data collection.

Data Collection & Analysis

Copies of the validated questionnaires were administered personally to selected experts. Participants independently reviewed the proposed architecture and completed the evaluation instruments. The Research Questions were answered using mean and standard deviation. The decision rule for Research Questions 1 & 2 were based on the cut-off point of 2.50, while Research Question 3 was determined using the mean score point of 3.50. Thus, decision rule: Mean $\geq$ 2.50 / 3.50 = Required / Appropriate / High Extent, and Mean < 3.50 = Not Required / Not Appropriate / Low Extent.

Results

Research Question 1:

What are the software requirement specifications for the development of an IWBAT for smart basic education schools in Enugu State, Nigeria?

The data for answering Research Question 1 is presented in Table 1.

Table 1: Mean Responses on the Software Requirement Specifications for the Development of Interactive Web-Based Assessment Tool (IWBAT)

S/No	Items	X	SD	Remarks
1	Web-based Assessment Software	3.98	0.16	Required
2	64 Bit Operating System	3.75	0.44	Required
3	32 Bit operating System	3.58	0.47	Required
4	PHP Software	3.69	0.47	Required
5	Database for creating User account	3.83	0.39	Required
	Overall mean	**3.77**	**0.46**	**Required**

The data presented in Table 1 indicate that all the identified software requirements were considered necessary for the development of the proposed Interactive Web-Based Assessment Tool. Specifically, web-based assessment software recorded the highest mean score ($\bar{x}$ = 3.98, SD = 0.16), followed by database support for user account creation ($\bar{x}$ = 3.83, SD = 0.39), a 64-bit operating system ($\bar{x}$ = 3.75, SD = 0.44), PHP software ($\bar{x}$ = 3.69, SD = 0.47), and a 32-bit operating system ($\bar{x}$ = 3.58, SD = 0.47). The overall mean of 3.77 (SD = 0.46) indicates consensus among respondents that these specifications constitute essential software requirements for developing the proposed IWBAT.

Research Question 2:

Which software architecture component is appropriate for the development of an IWBAT based on the identified software requirements?

Data for answering research question 2 is presented in Table 2.

Table 2 shows that respondents rated all the proposed architectural components as highly appropriate for developing the IWBAT. Architectural flow diagrams and use-case views obtained the highest mean ratings ($\bar{x}$ = 3.80 each), followed by compatibility across web browsers ($\bar{x}$ = 3.72), quality verification and validation ($\bar{x}$ = 3.70), technical design ($\bar{x}$ = 3.65), high data security features ($\bar{x}$ = 3.64), and user interface design ($\bar{x}$ = 3.60). The overall mean score of 3.71 (SD = 0.46) suggests that respondents regarded the proposed architectural components as suitable foundations for the development of the system.

Table 2: Mean Responses on the Appropriate Software Architectural Component for IWBAT

S/N	Items	X	SD	Remarks
1	Architectural flow diagrams of the IWBAT	3.80	0.46	Highly Appropriate
2	User Interface Design of the IWBAT	3.60	0.44	Highly Appropriate
3	Use-Case View of the IWBAT	3.80	0.46	Highly Appropriate
4	Technical design of the IWBAT	3.65	0.46	Highly Appropriate
5	Quality verification and validation	3.70	0.46	Highly Appropriate
6	High data security features	3.64	0.41	Highly Appropriate
7	Compatibility across Web browsers	3.72	0.34	Highly Appropriate
	Overall Mean	**3.71**	**0.46**	Highly Appropriate

Research Question 3:

To what extent is the proposed software architectural design appropriate for the development of an IWBAT for smart basic education schools in Enugu State, Nigeria?

The data for answering Research Question 3 is presented in Table 3.

Table 3: Extent of Appropriateness of the Software Architecture for IWBAT

S/n	Item	Mean	SD	Remarks
1	The proposed architecture adequately represents all identified system requirements.	4.68	0.48	Very High Extent
2	The architecture clearly separates presentation, application, and database layers.	4.32	0.58	High Extent
3	The architecture promotes modular software development.	4.26	0.65	High Extent
4	The architecture supports maintainability.	4.32	0.67	High Extent
5	The architecture facilitates scalability.	4.37	0.60	High Extent
6	The architecture supports interoperability with other educational systems.	4.53	0.61	Very High Extent
7	The architecture provides adequate security mechanisms.	4.42	0.61	High Extent
8	The architecture supports role-based access control.	4.26	0.56	High Extent
9	The architecture ensures secure management of assessment data.	4.26	0.45	High Extent
10	The architecture supports efficient communication among system components.	4.21	0.63	High Extent
11	The architecture promotes efficient database management.	4.26	0.65	High Extent
12	The architecture supports automated result processing.	4.16	0.50	High Extent
13	The architecture can accommodate future functional enhancements.	4.11	0.57	High Extent
14	The architecture minimizes system complexity.	4.16	0.50	High Extent
15	The architecture supports high system availability.	4.63	0.60	Very High Extent

16	The architecture facilitates fault isolation and recovery.	4.32	0.48	High Extent
17	The architecture provides an appropriate framework for online examinations.	4.58	0.51	Very High Extent
18	The architecture supports integration with smart school infrastructure.	4.26	0.81	High Extent
19	The architecture adequately addresses usability considerations.	4.16	0.76	High Extent
20	Overall, the proposed architecture is appropriate for developing an Interactive Web-Based Assessment Tool for smart basic education schools in Nigeria.	4.32	0.58	High Extent
	Overall Mean	**4.33**	**0.36**	**High Extent**

Table 3 reveals that respondents perceived the proposed software architecture to be appropriate to a high extent. Three items attained a Very High Extent rating, namely the architecture's ability to adequately represent identified system requirements ($\bar{x}$ = 4.68), support high system availability ($\bar{x}$ = 4.63), and provide an appropriate framework for online examinations ($\bar{X}$ = 4.58). The architecture's support for interoperability with other educational systems also recorded a very high rating ($\bar{x}$ = 4.53). The remaining quality attributes, including modularity, maintainability, scalability, security, database management, usability, role-based access control, and future enhancement capability, were all rated to a High Extent, with mean scores ranging from 4.11 to 4.42. The overall mean score of 4.33 (SD = 0.36) demonstrates strong expert agreement that the proposed software architecture is highly appropriate for developing an Interactive Web-Based Assessment Tool for smart basic education schools in Enugu State.

Discussion

The study established that clearly defined software requirements constitute an indispensable foundation for developing an Interactive Web-Based Assessment Tool for smart basic education schools. Respondents identified web-based assessment software, operating system compatibility, PHP support, and database management as critical requirements. This finding agrees with the recommendation of Peng et al. (2021) on the assessment as a necessity for improved examination system. Likewise, that the IWBAT can be installed on a 64-bit and 32-bit system without malfunctioning, aligns with the assertion by Wressengger et al. (2016) that software solutions are to be compatible with both 64-bit and 32-bit computer systems. Thus, this finding reinforces the software principle that successful software products depend on comprehensive requirement elicitation before design and implementation. It also aligns with Pressman and Maxim's proposition that accurate requirement specification minimizes development risks and improves software quality.

The study further found that architectural flow diagrams, use-case modelling, technical design, user interface design, quality verification mechanisms, browser compatibility, and security features are highly appropriate architectural components for the proposed system. This finding highlights the importance of adopting a structured architecture-driven development process in educational software engineering. The result supports the argument of Bialy et al. (2017) that software architecture provides the structural blueprint through which functional and non-functional requirements are translated into maintainable and scalable software systems.

Another important finding is that the proposed architecture was judged to be appropriate to a high extent across multiple software quality dimensions. Experts particularly acknowledged its ability to represent system requirements, provide high system availability, support interoperability with other educational systems, and serve as an effective framework for online examinations. These results suggest that the architecture satisfies essential quality attributes expected of modern educational software, including modularity, scalability, maintainability, security, and extensibility. This aligns with the assertion made by Sanders & Stappers (2014) that the main objective of the development phase is to transform the system design, which was prototyped in the design Phase, into a functional system that fulfils the entire recorded system requirement.

The high ratings assigned to interoperability and scalability are especially noteworthy within the context of smart basic education schools. Smart schools require assessment systems capable of integrating with existing digital infrastructure while accommodating future technological advancements and increasing user populations. The findings therefore indicate that the proposed architecture provides a viable framework for supporting digital assessment within technology-enabled learning environments in Nigeria. Overall, the study demonstrates that architecture-driven design offers a systematic pathway for developing sustainable, secure, and context-sensitive assessment systems capable of supporting the ongoing digital transformation of basic education in Enugu State and potentially other regions of Nigeria.

Conclusion

The study designed and evaluated an architecture for an Interactive Web-Based Assessment Tool intended for deployment in smart basic education schools in Nigeria. The findings revealed that appropriate software requirements exist to support the development of the proposed system and that the identified architectural components are suitable for translating those requirements into a functional software framework. Expert evaluation further confirmed

that the proposed architecture possesses desirable software quality attributes, including modularity, scalability, interoperability, maintainability, security, and high availability.

The study therefore concludes that the proposed software architecture provides a robust and contextually relevant blueprint for developing an Interactive Web-Based Assessment Tool capable of supporting secure, efficient, and interactive assessment practices within emerging smart basic education schools in Nigeria.

Recommendations and Suggestions for Further Studies

Based on the findings of the study, the following recommendations are made:

1. Educational authorities should adopt architecture-driven approaches when developing or procuring digital assessment systems for smart schools to ensure scalability, maintainability, and long-term sustainability.
2. The Enugu State Ministry of Education should consider implementing the proposed architectural framework as a basis for developing standardized assessment platforms across its smart basic education schools.
3. Software developers should conduct comprehensive software requirement elicitation before designing educational assessment systems to ensure that both functional and non-functional user needs are adequately captured.
4. Future implementations of the proposed architecture should incorporate advanced capabilities such as adaptive testing, learning analytics, artificial intelligence-based performance prediction, and cloud-native deployment strategies.
5. Further studies should undertake pilot implementation and empirical testing of the proposed architecture in operational smart school environments to evaluate its real-world performance and user acceptance.

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