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# Detachable Web-Based Learning Framework to Overcome Immature ICT Infrastructure Toward Smart Education

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**ABSTRACT** Amid the recent disease outbreaks that have been spreading across the world, the education systems in every country have witnessed a dramatic transformation. In particular, the situation has promoted online learning on an unprecedented scale, with classes being held virtually on digital platforms. This vital transformation is a major challenge in developing countries where information infrastructure for remote learning is lacking. Inspired by these observations, this study first investigated the obstacles in the way of the deployment of smart education systems (SESs) in developing countries from a technical perspective. Consequently, a detachable SES framework, named vSmartEdu, is proposed. The framework is based on a hybrid online/offline web-service model, which adopts a service-based architecture (SBA) design concept to develop smart classrooms. In particular, the online mode is activated for a web-based classroom if an Internet service is available. In contrast, the offline-version of the system is available in offline mode in packaged form, and is utilized when the Internet is not available in a local classroom. Finally, a prototype was deployed to collect feedback from learners and educators at various educational levels. The trial implementation and survey results concretely validate the feasibility and advantages of the proposed solution.

**INDEX TERMS** Adaptive learning, digital transformation, smart education system, virtual photoreality.

## I. INTRODUCTION

Online learning has experienced incredible growth as a promising method that enables education systems to overcome the critical impact of the ongoing coronavirus pandemic worldwide. Because of the social distancing requirements that have been implemented to prevent the spread of the disease, schools and universities were forced to immediately prioritize remote working and teaching [1]. This compulsory transformation significantly burdens the existing information and communications technology (ICT) infrastructure with heavy traffic, and has also resulted in a large number of concurrent service requests. Although various online education systems have been proposed recently to exploit the advantages of emerging technologies, such as mobile edge/cloud computing [2], [3], the Internet of Things (IoT) [4], and virtual/augmented reality [5], these efforts are possibly insufficient to respond to this surge in the demand for online learning because of time and financial constraints. To overcome these challenges, a flexible balanced solution is of vital necessity to manage the tradeoff between the technological aspects and costs related to serviceability in smart education systems (SESs).

Overcoming the aforementioned challenges is considered to be extremely critical for education systems in developing countries, where, unfortunately, ICT infrastructures have not yet matured in terms of service availability and system stability [6]. The difficulties are assessed from various perspectives, such as investigation procedures, human resources, affordability, deployment duration, backward compatibility,

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and open interoperability. Among these factors, the last four directly affect the SES design strategy, which is essential to quickly adapt the application to the changing situation, which in this case is the COVID-19 pandemic. Therefore, a flexible solution that considers both these factors is critical in developing countries to efficiently provide a scalable and elastic SES framework.

A recent literature review focusing on SES [7] showed that existing solutions have paid significant attention to the emerging advanced technologies to engage and support learners, educators, and administrators efficiently. From a technological perspective, existing approaches can be classified into five categories, which are based on assisted technologies, namely mobile applications, cloud computing, web environments, social networking, and virtual reality, including their variants and hybrid solutions. Although several improvements have been introduced to enhance user satisfaction, an analysis of the literature [6], [7] reveals two major problems with existing solutions. The first is that a comprehensive framework design that considers the technical aspects, including backward compatibility, open interoperability, scalability, elasticity, and self-government, has not yet been reported. The second problem is the immaturity of the supportive ICT infrastructures in terms of Internet service availability, heterogeneity of user devices, and local ICT infrastructure adaptability, none of which have yet been considered. In other words, existing solutions fail to completely address the aforementioned challenges SESs would have to overcome in developing countries.

Inspired by the above observations, this paper proposes an adaptive SES framework, named vSmartEdu, which was built by adopting a service-based architecture (SBA) design to develop smart classrooms. Our contributions can be summarized as follows.

- First, we conducted an investigation to identify the technical difficulties associated with SES deployment in response to the current disease outbreaks in developing countries. At the same time, related work was surveyed to reveal their advantages and shortcomings in a challenging context. We established the immaturity of the ICT infrastructure to be a near insurmountable obstacle that negatively impacts the implementation of online learning platforms, especially in developing countries and rural areas; however, the ways to overcome this obstacle have not yet received attention.
- Second, we proposed vSmartEdu, which is a hybrid online/offline web-based modular framework that employs an SBA design to address the challenges. In particular, the system functions are represented by discrete modules of functionality that can be accessed via a common communication bus. The online mode is activated for a web-based classroom if an Internet service is available, whereas a standalone local classroom is packaged to deliver an offline learning environment in the absence of Internet access. A synchronization function is used to manage the task of bridging between the online and offline modes.
- Third, we developed and implemented a prototype of vSmartEdu using virtual photoreality technology to validate the feasibility and advantages of the proposed solution. The real-life observations demonstrated the successful deployment of vSmartEdu and user satisfaction in various scenarios. Finally, the discussion, conclusion, and future work are documented to conclude this paper.

## II. REVIEW OF CUTTING-EDGE SOLUTIONS

The role of information technologies in the development of modern learning environments is indispensable for an SES. Multiple SES aspects and functions can benefit from the advantages of emerging technologies, such as mobile applications, web-based access, virtual reality, the IoT, social networking, cloud computing, machine learning, and blockchains, as illustrated in Figure 1. Obviously, the first four technologies directly affect the service experiences with the user devices and the external peripherals, whereas the last four technologies are dedicated to improving the system performance and extending the system features. It is worth noting that these technologies can be utilized to complement each other in hybrid solutions.

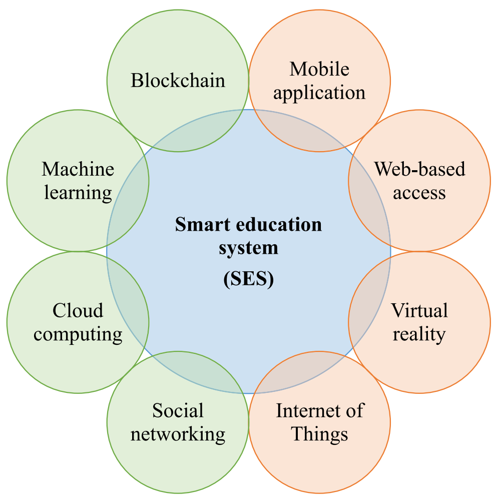



**FIGURE 1. Classification of cutting-edge SES solutions from a technological perspective.**

### A. SERVICE-EXPERIENCE AWARENESS

Mobile applications and devices have been widely utilized for online learning across multiple subjects, as reviewed in [8]. The review revealed that the portability, ubiquity, multifunctionality, and popularity of mobile technologies have significantly assisted SES to achieve learner satisfaction. For instance, Kobayashi *et al.* [9] introduced a mobile education framework that automatically transforms the original information contents into multi-aspect information that can be displayed on screens with different sizes and resolutions.

The mobile platform offers an efficient approach to manage the teaching resources and academic achievements of online learners. To support mobile education, web-based technology [10] was exploited to offer standard, open, and flexible data delivery protocols for remote access by using built-in web browsers on mobile user devices. Moreover, any updates and upgrades on the system performance and functions can be conducted centrally by the web server in the cloud, and are accessible to users. On the other hand, mutual data exchange procedures were developed and exploited by Cornetta *et al.* [11] and Shapsough and Zualkernan [12], who employed IoT information from peripheral components, such as cameras and sensors, to enrich the teaching materials in the central system. The proposed frameworks enable multiple laboratories in different geolocations to share and collaborate with respect to learning practices in real time. To improve the learner's engagement, three-dimensional (3D) object models and virtual reality technologies can be used to render an interactive learning environment [13], [14]. In these learning frameworks, teaching objects are presented in 3D scenarios, where learners can adjust the view angles as well as anatomize the objects to view the components they constructed.

From the perspective of service-experience awareness, most studies have exploited advanced technologies to improve learners' experiences from multiple viewpoints such as comfortability, functionality, visualization, and interactiveness. However, these studies did not focus on the need for adaption to uncertain changes in the working environment and infrastructure. Importantly, the ICT infrastructure would need to adequately support the applied technologies as expected to prevent the system from encountering service interruption problems.

### B. SYSTEM-PERFORMANCE AWARENESS

In terms of system-performance awareness, cloud-computing technology has been widely utilized to facilitate SES with a central client-server model. Empowered by cloud computing, computationally intensive SES services can operate with high performance, stability, and scalability [15], [16]. In this context, the latest SES services enable additional functions to be implemented, such as social networking, context-aware adaptation, and advanced machine learning for data analyses and service recommendations. Pensabe-Rodriguez *et al.* [17] conducted a usability assessment based on a field study with 6 professors and 48 students to evaluate context-aware learning systems. The results showed that 82.4% of users were satisfied with the services offered by the systems, especially the messaging service. On the other hand, Khanal *et al.* [18] investigated the engagement of learners with machine learning based on e-learning systems. They showed that machine-learning techniques not only improve the service quality but also the system performance in terms of course recommendations, learner evaluation, and content management. Considering the fact that collaborative knowledge generation, predictions, fusion, storage, and sharing are performed by multitier computing capabilities from the edge to the cloud, Guo *et al.* focused on security for online education in [19]. To secure the environment for sensitive and personal data exchange in online learning, emerging blockchain technology was exploited. Every service request and response transaction is validated, tracked, and recorded in the blockchain platform for data integrity protection.

The aforementioned studies introduced high-end advantages for system performance by applying recent cutting-edge technologies. This approach was observed to improve the system performance significantly. However, the literature does not offer flexible solutions that consider both immature ICT infrastructures and heterogeneous user devices for system design, which represents the situation in developing countries. A containerized modular framework is needed to adapt to different situations and the specific requirements of the working environments.

## III. RESEARCH QUESTIONS AND METHODOLOGY

Motivated by the aforementioned analysis of related work, this study was designed to address the following research questions:

1) **RQ#1:** *To what extent does the immaturity of the ICT infrastructure impact the SES development?*
2) **RQ#2:** *Considering the immaturity of the ICT infrastructure in developing countries, what would constitute an effective online learning solution that can be deployed quickly to overcome the negative effects of disease outbreaks?*
3) **RQ#3:** *Does our proposed framework satisfy the needs of learners and educators at different education levels within various teaching subjects?*

The methodology we employed to address the research questions is as follows:

1) We first investigated the difficulties presented by an immature ICT infrastructure with respect to SES deployment, and motivated by the findings, we considered selecting the appropriate technology and developing an efficient approach.
2) As a result, our approach combines cloud computing, a web-based service, and containerization technologies within an SBA design concept for the online learning framework.
3) Then, the framework applicability is verified by trial implementation for different education levels within various learning subjects. A questionnaire survey was conducted to gather feedback on the system performance metrics from learners and educators.

Details are presented in the following sections.

## IV. DIFFICULTY ANALYSIS IN SES DEVELOPMENT

Although the use of digital technology in education systems has exploded during the past few decades, developing countries have been unable to participate in this occurrence; however, they are experiencing growing demand for online learning classrooms in the context of the emerging coronavirus pandemic [1], [20]. Various technical and infrastructural difficulties must be overcome when an SES is developed, including the following major problems.

- *Immature network infrastructure:* The network infrastructure in developing countries typically consists of asynchronously and discretely deployed parts in response to local and regional requirements and installations [21]. Specifically, a significant number of under-serviced areas exist with respect to the availability of the Internet or stable Internet connections.
- *Inadequate digital facilities:* Digital facilities include user devices, displays, speakers, and cameras, all of which are available in different qualities, quantities, technologies, and conditions. These facilities require significant efforts to allow them to interoperate smoothly and stably. Moreover, maintenance and troubleshooting of these facilities present an additional challenge [22], [23].
- *Unsupportive backend environment:* The core ICT infrastructure lacks comprehensive networking, computing, and storage environments for a large-scale and hierarchical software system implementation [24]. This unsupportive backend environment limits the capacities and capabilities of the software system to offer high quality of service (QoS) to end-users.
- *Weak information sharing platform:* The information sharing platform defines facilities to manage, organize, and distribute knowledge, information, and data across multiple systems and applications synchronously [22], [23]. Two major functions of information sharing are common database centralization and communication channels, which are typically unaligned with the ICT infrastructure design in developing countries.
- *Heterogeneous frontend medium:* The front end access media are heterogeneous with different transmission technologies, such as copper, coaxial, and optical cables as well as (low speed) mobile and Wi-Fi accessibility [24]. This presents a more critical problem in rural and remote areas with low population densities.
- *Poor management and maintenance:* The management and maintenance services are poorly supported owing to the lack of human resources and financial plans for post-deployment. Moreover, collaboration among repair service partners is too weak to address system-level issues [25].

Based on the above analyses, backward compatibility, open interoperability, scalability, elasticity, and self-government are identified as mandatory capabilities toward the success of adaptive SES development in developing countries.

## V. vSmartEdu FRAMEWORK

Motivated by the above observations, this paper proposes vSmartEdu, which is a hybrid online/offline web-based framework that adopts an SBA design. The technological approach, system architecture, and operational procedures comprising vSmartEdu are described in this section.

### A. TECHNOLOGICAL APPROACH

To overcome the aforementioned difficulties, the vSmartEdu framework is built on the basis of three technology pillars: (*i*) cloud computing for infrastructure preparation, (*ii*) SBA design for software system development, and (*iii*) web-based access for user interaction.

- The cloud computing technology, which exists in conjunction with the underlying infrastructure virtualization, offers a convenient environment to deploy an SES stably and elastically. Accordingly, the vSmartEdu framework can dynamically adjust the capacity of the individual functions on demand without physical resource reconfiguration.
- The SBA design strategy is a modern software design model where each function is packaged as a service that can be accessed remotely and independently via a common transmission medium, also known as a common information bus (CIB) [26]. By adopting the SBA design, the vSmartEdu framework facilitates the management and maintenance processes with dynamically reconfigurable workflows and makes it easy to scale, extend, add, remove, and contain the system functions flexibly.
- The web-based approach presents user-friendly interfaces and interactions and offers a convenient access method. Most functional updates in the central system do not require any configuration changes in the user devices. Moreover, this technology is independent of local operating systems, and it adapts well to various displays and peripherals.

### B. SYSTEM ARCHITECTURE

The vSmartEdu framework consists of seven services, which are the functional modules, and they interact using predefined communication protocols on a CIB (Figure 2). The seven major services of vSmartEdu are as follows:

*1) Authentication and authorization function (AAF):* The AAF provides two security steps before granting a user access to the system functions and resources. First, the authentication function confirms the user identity by matching the evidence provided by the user with the user information stored in the system repository. The matching process is asynchronously performed using the public key infrastructure approach to ensure trustful authentication. Once the user is identified, the authorization function verifies the user's permissions. Here, the service profile of the user is sought in the system repository to specify the functions and resources the user is permitted to access. In particular, we define four user groups in the vSmartEdu framework, including learners, educators, managers, and administrators, each of which has a different class of permissions.

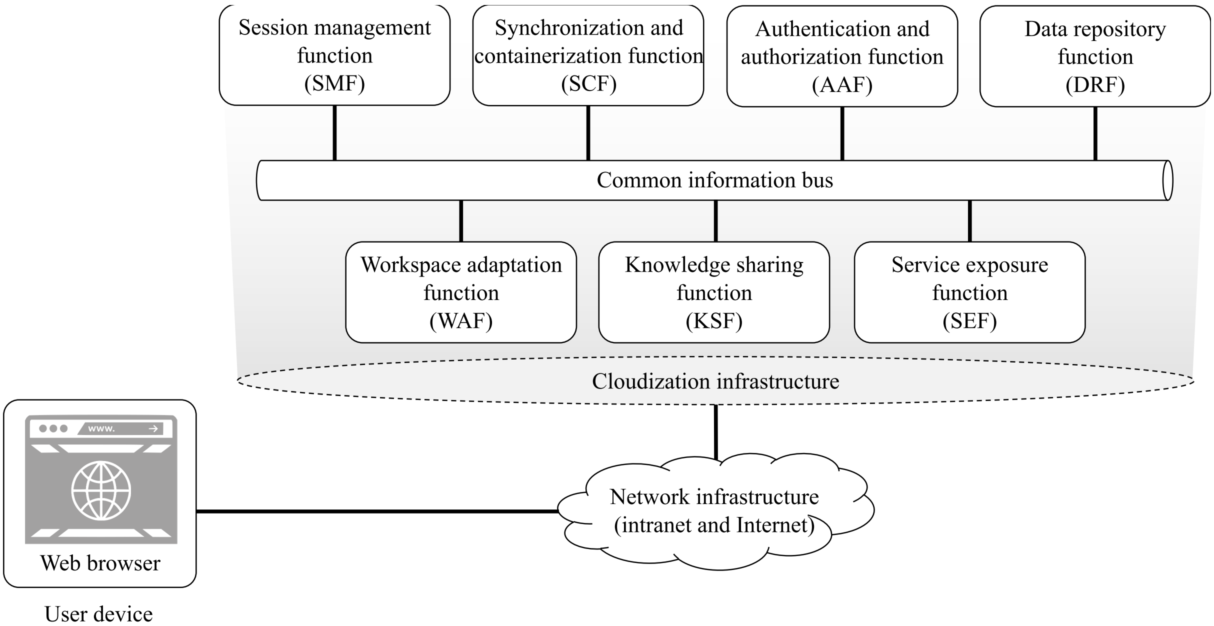



**FIGURE 2.** vSmartEdu web-based modular framework that adopts a service based architecture design.

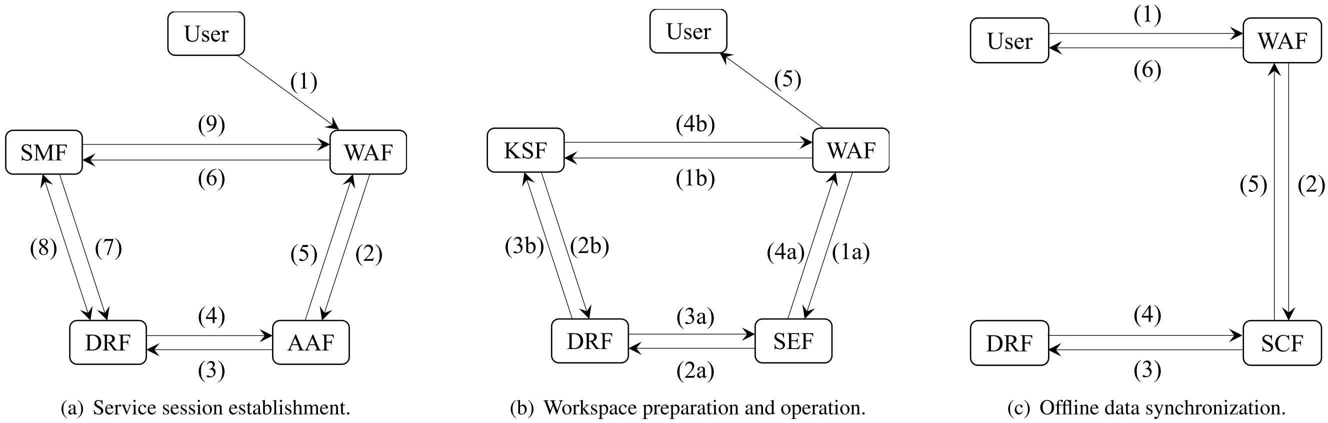
*2) Session management function (SMF):* The SMF is a fundamental element of the system, and is primarily responsible for establishing, modifying, suspending, and releasing the service sessions that are assigned to the authorized users. Depending on the requirements and interactions of the granted functions and the data for the user, the SMF manages the appropriate communication resources among them on the CIB to ensure smooth traffic flow throughout the vSmartEdu framework. Moreover, the SMF supports virtual private networking tunnels to enable users to access the framework via untrusted infrastructure, such as public Wi-Fi and the Internet. In addition, a session scheduling mechanism is activated as soon as the number of incoming requests exceeds the system serviceability capacity.

*3) Service exposure function (SEF):* The SEF facilitates open, robust, and flexible access to the system functions and capabilities. Native and third-party services interact with the system functions via standard interfaces and protocols provided by the SEF. Each system function is provided as a plug-in module along with its features, parameters, capacities, dependencies, and if possible special procedures. Prime examples of the system functions include but are not limited to classrooms, communication, practice, exams, scores, feedback, reports, user management, data management, and user interface adaptation. Depending on their permissions, users can select the desired functions to build their own workspaces. The user workspace configuration is saved and stored in the user profile repository.

*4) Data repository function (DRF):* Contrary to traditional data storage solutions, the vSmartEdu framework handles data independently by a dedicated system service, called the DRF. The DRF provides appropriate services to collect, manage, and store user datasets and system datasets for data analyses. Prime examples of these datasets are user identities, user profiles, user data, lecture materials, subject statistics, and system reports. The analyses include but are not limited to data cleaning, data fusion, data reorganization, and data transformation. The DRF responds to queries from other internal and external services by defining a standard set of commands and statements. In addition, a response scheduling mechanism is activated as soon as the number of incoming requests overloads the DRF capability. The DRF does not directly process the data. Instead, the DRF interacts with third-party data management tools and database structures such as MySQL, PostgreSQL, and MongoDB.

*5) Knowledge sharing function (KSF):* The KSF provides facilities and an environment in which the users can interconnect, communicate, share, and contribute formal and informal information to the knowledge base. The information can be represented in various formats, such as text, voice, data files, multimedia, and live streams on public, group, and private channels. Depending on the channel configuration and the authority setup, the KSF requests either temporary or permanent memories from the DRF in which the information shared by the users is saved for possible reuse. The KSF plays key roles in supporting real-time interaction among learners and between learners and educators, and additionally improves learner engagement.

*6) Workspace adaptation function (WAF):* The WAF provides web services to the end users within a responsive web interface, such as a workspace. The workspace layout responsively adapts to the user display size and resolution, whereas the workspace functions are loaded following the configuration from the user profile databases stored in the



(a) Service session establishment. (b) Workspace preparation and operation. (c) Offline data synchronization.

**FIGURE 3. Three typical operational procedures in the vSmartEdu framework.**

DRF. Despite the flexible adaptation, the major learning functions, such as classrooms, exams, and scores, are mandatory in the workspace. Moreover, user authorities are associated with different sets of mandatory functions. For example, educators' workspaces require exam reports, learner management, and teaching material management, whereas managers' workspaces focus on learning statistics and reports.

*7) Synchronization and containerization function (SCF):* The SCF enables the vSmartEdu framework to be used in offline mode to support a group of users (learners and educators), with local operational capability regardless of whether Internet access is available. The containerization packages basic system services with the necessary configuration files, libraries, and dependencies for learning activities, such as classrooms, practices, exams, and scores. The user workspace configuration is equipped with these types of limited functions using the preloaded configurations from the user profiles in the offline mode. The offline vSmartEdu package can be deployed in microcomputers. Whenever Internet service is available, authorized users, such as educators, can upload the local data to the online vSmartEdu framework under the supervision of the synchronization function.

Adopting the SBA design, the web-based modular vSmartEdu framework can be considered as a cloud-native system application in the sense that the system efficiently exploits the advantages of cloud computing technology and its environment. As a native cloud application, the vSmartEdu framework can interact with cloud-native third-party services in a secure and tractable manner. In particular, the DRF module collaborates with external data management tools such as MySQL, whereas the AAF and KSF modules may utilize external services from social platforms for authentication and instant messaging features such as Google Sign-In/Facebook Login and Google Hangout/Facebook chat integration (https://developers.google.com and https://developers.facebook.com), respectively. In addition, the Docker Engine (https://www.docker.com) can be used to provide the SCF module with containerization ability.

### *C. OPERATIONAL PROCEDURES*

The vSmartEdu framework operates on the basis of three typical operational procedures: (*i*) service session establishment, (*ii*) workspace preparation and operation, and (*iii*) offline data synchronization. A flowchart of these procedures is illustrated in Figure 3.

*1) Service session establishment* procedure consists of nine actions (see Figure 3(a)).

- First, the user sends a service session request via a web browser to the vSmartEdu system, which is action (1). As a front-end representative of the system, the WAF collects the user request and asks the AAF to authenticate the user's identity and authorize the user's permission, which is action (2).
- In turn, the AAF executes the public key authentication protocol by using the private key information acquired from the DRF to verify the user identity, which is encrypted by the user's public key. If the authentication is successful, user permission is granted by the authorization based on the user profile registration in the DRF, which are actions (3) and (4).
- Consequently, the results are returned to the WAF, which is action (5). According to the user permission, the WAF requests the SMF to generate a new service session across all the granted system functions for the user, which is action (6).
- In response to the request, the SMF loads the user configuration files from the DRF, which are actions (7) and (8), to set up an appropriate service session and respond to the WAF, which is action (9). Finally, the WAF completes an end-to-end service path that satisfies the user request.

*2) Workspace preparation and operation* procedures are performed by the WAF to set up the desired workspace for the user (see Figure 3(b)).

- To this end, the WAF sends parallel requests to the SEF and the KSF referring to the user's configuration file, which are actions (1a) and (1b).

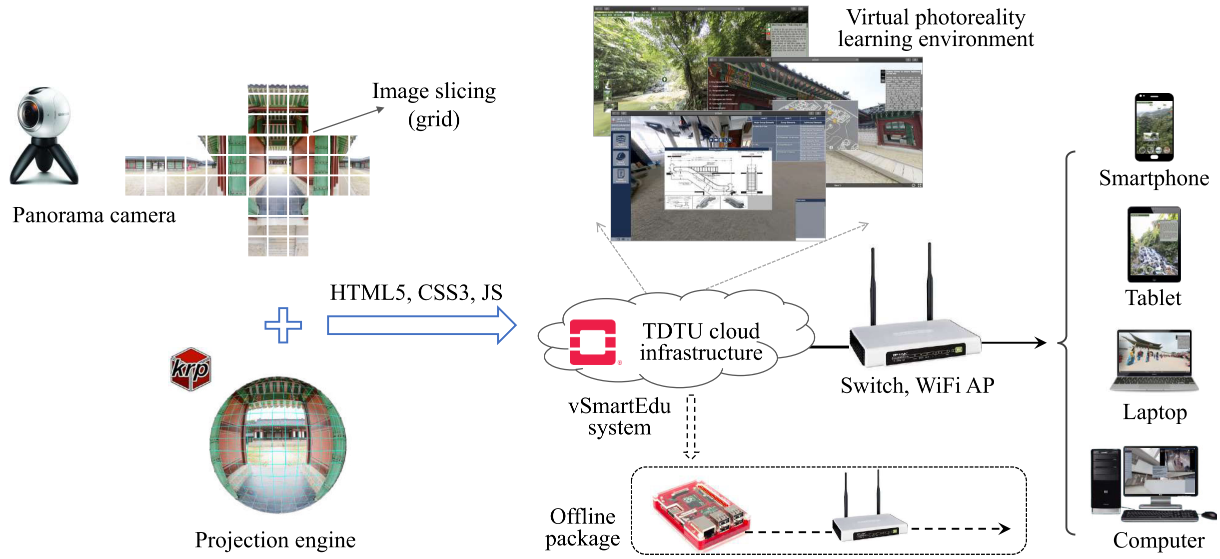



**FIGURE 4.** **vSmartEdu prototype development and deployment with various user devices.**

- Accordingly, the desired services are offered by the SEF, and the information sharing channels are allocated by the KSF. Hereafter, the continuous data flows are transferred along two paths, WAF-KSF-DRF and WAF-SEF-DRF, until the user terminates the service session, which includes action chains (2a)–(4a) and (2b)–(4b).
- At this point, the WAF completes the workspace preparation, and all the desired services are ready for user interaction, which is action (5).

*3) Offline data synchronization:* In the offline mode, the administrator generates an offline package from vSmartEdu to accommodate a specific group of learners and educators. This containerization is performed in response to a request from educators or managers. The local data generated from the learning operations are temporarily saved in the local computer during the offline mode.

- When the Internet is available, the authorized users, i.e., the educators and managers, connect to the vSmartEdu system and ask for a synchronization process, which includes actions (1) and (2) as shown in Figure 3(c).
- The SCF synchronizes the local data to the corresponding database and transfers the recent updates, which include new teaching materials, exams, evaluation policies, and software patches, to the offline package. This process comprises actions (3)–(6).

## VI. PROTOTYPE IMPLEMENTATION

Adopting the proposed vSmartEdu framework, we developed a vSmartEdu prototype using virtual photoreality (VP) technology to design an online learning environment. The VP refers to a computer-generated simulation that renders virtual reality from a panoramic photographic image that captures a view of the surrounding real environment. The VP technology was selected because of its technological advantages in terms of high popularity, independent containerization, high responsibility, and low costs with good learner engagement [27]–[29]. It is worth noting that the vSmartEdu framework model and design are independent of the technology selection. Figure 4 illustrates the vSmartEdu prototype development and deployment processes.

In system development, panoramic photographic images are used to capture real-world scenarios according to dedicated learning subjects and specific topics as the first step for material preparation. These images can be captured using either a single-shot 360 camera, such as Samsung Gear360 (https://www.samsung.com/global/galaxy/gear-360) or by using a stitching tool, such as Hugin software (http://hugin.sourceforge.net), to generate an image from multiple overlapping normal images. Panoramic images are presented in equirectangular and cubic formats. After collecting all the images that are required, the images are sliced into a grid of multiple pieces with the same dimensions. Based on the field of view of each image, these pieces are projected onto a spherical surface to simulate a virtual environment. In this prototype, we utilized the krpano projection engine (https://krpano.com) for this purpose. Consequently, to integrate the VP environment into the vSmartEdu system, the markup language HTML5 and the style sheet language CSS3 were used to develop the WAF web interface, whereas the remaining system functions and their interactions were built using the JavaScript language and Node.js (https://nodejs.org). The third-party MySQL database (https://www.mysql.com) was used for data management.

The prototype was deployed on a cloud server that was supervised by the cloud-computing infrastructure in the university intranet. In the cloud, MySQL was installed on a virtual machine. When the offline mode is activated, a Raspberry Pi board (https://www.raspberrypi.org) is used as a local microcomputer on which the offline mode package derived from the vSmartEdu system is installed. Other mobile devices with sufficient computational resources could be used in the place of the Raspberry Pi board. The offline package includes predefined WAF services and contents that are necessary for local learning subjects. Regarding the learning subjects, we implemented three classes at diverse educational levels, which included

- a primary education level science class with 27 students learning about natural exploration of a conservation forest in Tam Dao, Vietnam,
- a secondary education level history class with 36 students learning about the Gyeongbokgung Palace in South Korea,
- and a tertiary education level constructional engineering class with 54 students learning about construction safety by undertaking virtual field trips.

Various user device categories were accommodated, such as smartphones, tablets, laptops, and desktop computers. Every learner iteratively uses all these device categories to experience the learning subjects throughout the classes. On the other hand, offline modes are interleaved with online learning to simulate the case the Internet capability is temporarily unavailable.

## VII. EXPERIMENT ANALYSIS AND OBSERVATIONS

The advantages of the proposed system were comprehensively investigated by validating the evaluation criteria [30]–[33] based on the service experience, including 1) *comfortability* validates the extent to which users are comfortable when they use vSmartEdu to learn, 2) *functionality* focuses on the ease of use and the ease with which the learners can navigate the vSmartEdu functions during the lessons, 3) *visualization* reflects the way in which vSmartEdu can visualize the case study supporting the lessons, 4) *interactiveness* indicates whether users are able to interact with the vSmartEdu content by using their own various devices, and 5) *engagement* explains the way in which vSmartEdu motivates and engages the users with their learning to acquire knowledge and skills. Details of the structure and main content of the questionnaire are presented in Table 1. Regarding each evaluation criterion, 03 questions were designed to reveal users' opinions in online, offline, and hybrid modes, respectively. The feedback is collected via a popup form embedded in the software user interface.

### A. SERVICE EXPERIENCE

As illustrated in Figure 5, all participants emphasized the importance of the service experience of vSmartEdu for effectively adapting the proposed learning method. Generally, the users in secondary education and tertiary education levels evaluated all the criteria for the service experience higher than those who were in primary education because of the large extent to which the lessons are enhanced by visual

**TABLE 1. Questionnaire structure and content sections.**

| No. | Contents | Evaluation |
|---|---|---|
| 1 | User information including education level, user type, and user device are collected automatically via the system after logging in. | – |
| 2 | 03 questions regarding the comfortability | Likert scale (1–5) |
| 3 | 03 questions regarding the functionality | Likert scale (1–5) |
| 4 | 03 questions regarding the visualization | Likert scale (1–5) |
| 5 | 03 questions regarding the interactiveness | Likert scale (1–5) |
| 6 | 03 questions regarding the engagement | Likert scale (1–5) |
| 7 | User expectations about system updates | Open comment |

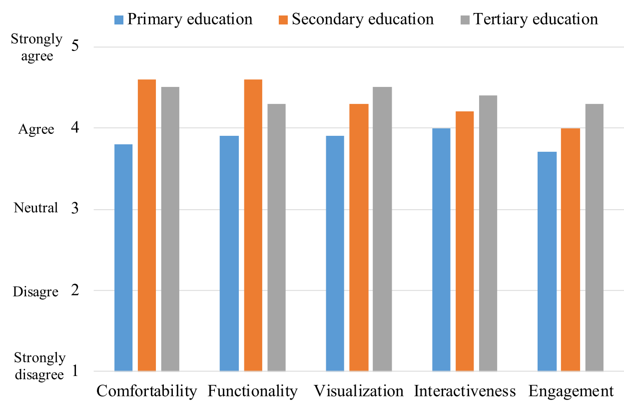



**FIGURE 5. Service experience assessments by different education levels.**

material. This is the reason the traditional primary education in schools usually provides pupils with interesting images, animations, and cartoons as complementary materials to the textbooks. Moreover, to ensure that the physical and mental development of the children is sustainable, certain schools and families have not allowed primary school pupils to spend too much time using smart devices, such as smartphones, tablets, and laptops every day. Thus, despite the prominent advantages, experiencing the vSmartEdu platform still does not offer a significant improvement at the primary education level. The secondary education participants allocated the highest scores to the comfort and functionality criteria, whereas the tertiary education participants rated the visualization, interactiveness, and engagement criteria the highest. Secondary school students are interested in the innovative vSmartEdu platform because of their high level of comfort with online learning, instead of the traditional white-board lectures, particularly considering the strict social distancing requirements that are currently in place because of the coronavirus pandemic. Furthermore, secondary school learners were impressed by the friendly interface designs that allowed them to use the vSmartEdu functions easily even though they were using vSmartEdu for the first time. Both the educators and students at universities emphasized that the computer-assisted visualization enhanced the lectures with the vSmartEdu platform, and that it played a crucial role in motivating learners to study difficult engineering subjects, which usually require case studies that visualize real-world experiences. The vSmartEdu platform enables the higher education students to easily interact by using zoom in/zoom out, navigation controls, and anatomize virtual objects and digital lessons that are designed to analyze difficult case studies. vSmartEdu thoroughly engages students in their learning to effectively obtain concrete knowledge.

From an operational perspective, Figure 6 shows a comparison among online, offline, and hybrid modes of the vSmartEdu frameworks on service experiences. Obviously, the online modes obtain the highest evaluations as all system functions and features are provided with the most updated information. While the offline modes were approximately assessed within *Agree* grades for all evaluation criteria. It is explained that even though the offline systems are packaged consisting of basic components such as predefined WAF services and contents, these materials provided significant facilities for e-learning while the Internet capability is temporarily unavailable. Indeed, evaluation results expose that a flexible combination of online and offline modes, i.e., the hybrid modes introduced by the vSmartEdu, mostly satisfies user requirements. In particular, 76% of the participants involved in the interview evaluated the online and hybrid modes with the same grades. Especially, since the visualization is consistently maintained, this criterion was evaluated equally in all modes. The observations illustrate that the vSmartEdu platform enables smooth learning experiences regardless of ICT infrastructure immaturity.

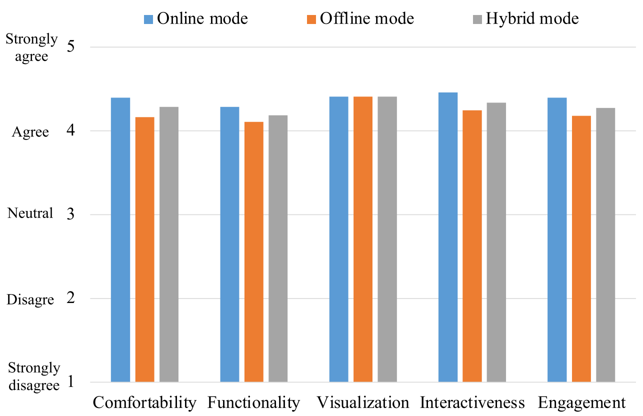



**FIGURE 6. Service experience assessments by different operational modes.**

To investigate the service experience evaluation that is based on the user group levels, Figure 7 provides the evaluation results of the educators and the learners after using the proposed vSmartEdu prototype. The learners strongly agreed that vSmartEdu visualizes the learning-supported case studies well, and it is very important for them to investigate and analyze difficult scenarios and examples provided by educators. Moreover, the learners stated that the highly interactive vSmartEdu interface is designed well and that it encourages user interaction, which therefore effectively engages

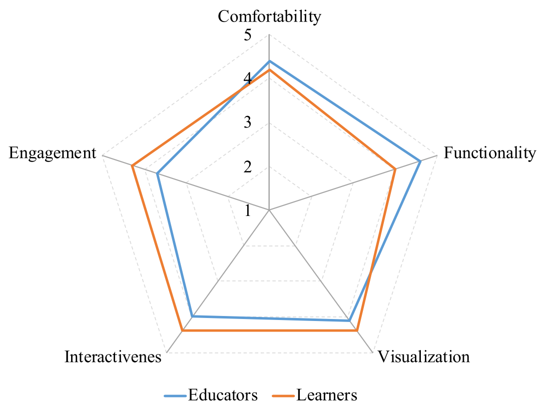



**FIGURE 7. Service experience assessments from a user group perspective.**

and motivates them to complete the lessons. The educators emphasized the importance of the functionality of vSmartEdu, which facilitates navigation. Furthermore, the educators also felt comfortable when using the vSmartEdu prototype and that it offered the better support for their teaching activities compared with the traditional lecture-based method. Moreover, the educators emphasized that the vSmartEdu platform supports online learning, enabling their students to learn anytime and anywhere.

The performance of the system was assessed by conducting an evaluation based on the use of various devices. The evaluation included users who were experienced in using the vSmartEdu prototype on smartphones, tablets, laptops, and desktop computers (Figure 8). The evaluation results confirmed that the vSmartEdu prototype can perform smoothly and effectively on all these devices. The outstanding system performance revealed that vSmartEdu could be easily adapted for an innovative education approach on various devices. In their survey responses, the users emphasized that vSmartEdu provided an innovative platform for learning at every education level. Despite the exceptional learning methods, which provide users with the ability to easily learn anywhere

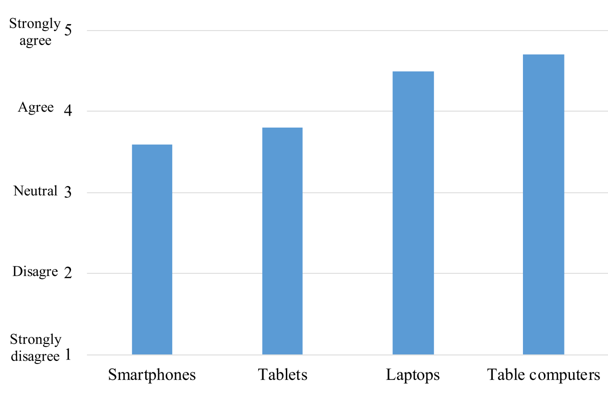



**FIGURE 8. Service experiences using different user device categories.**

at any time, smartphones and tablets did not perform as smoothly and effectively with vSmartEdu compared with laptops and desktop computers owing to the configuration limitations. This is because smartphones and tablets have small display screens, which adversely affects the user experience and makes it more difficult to learn the material that is being presented. Moreover, configuration limitations, such as the amount of RAM and the CPU, affect the vSmartEdu prototype and cause the system to perform less smoothly. The participants in the survey also agreed that the vSmartEdu system performed very well on laptops and desktop computers and these devices attracted the highest scores.

### B. USER COMMENTS

User comments were collected by posing an open question regarding their expectations about the system updates. Most of the comments start with user satisfaction with the current system, as shown in the above analyses. Their comments regarding the expectations on the next updates are classified into three categories:

- *Recommendation* – Both learners and educators agreed that it is necessary to include auto-recommendation of learning subjects and materials as revealed by 81% of the comments.
- *Subject* – In 79% of the comments, learners indicated that they enjoy more subjects and that crosslinks should exist among the subjects.
- *Immersiveness* – 64% of learners and educators requested more immersive environments such as game-based practices and tactile interactions.

Based on these observations, the vSmartEdu project was adjusted to reflect the user expectations in terms of the final deliverables in the second phase of the development.

## VIII. CONCLUDING REMARKS

In response to the exponential growth in the demand for online learning in developing countries, this paper proposes the vSmartEdu platform, which is a hybrid online/offline web-service education framework that adopts SBA design. The vSmartEdu framework consists of multiple independent modules of functionality that communicate via a common information bus. The SBA design facilitates system service containerization to provide system packages on demand in offline mode. The implementation and evaluation of the prototype revealed the feasibility and advantages of vSmartEdu for diverse education levels from multiple perspectives.

To popularize the vSmartEdu framework, further steps would involve investigating the requirements and expectations of different groups of learners and educators to adaptively optimize the system interface and interactions accordingly. Further, future work would need to consider integrating various learning technologies into the vSmartEdu framework, such as game-based, 3D classroom, intelligent response, and tactile interactions to extend the system features. In this regard, the system would need to (i) be upgraded to integrate machine-learning techniques for user behavior prediction and recommendation, (ii) apply the microservice approach for system functions, and (iii) be comprehensively evaluated with respect to its technical performance to measure its scalability and service availability in other possible scenarios with upgraded system performance, a larger number of users, and different teaching subjects.

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*(Quang-Dung Pham and Nhu-Ngoc Dao are co-first authors.)*

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