An architecture for e-learning infrastructures on a national level: a case study of the Afghanistan Research and Education Network

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Abstract: National Research and Education Networks (NRENs) are for sharing resources among member organisations. NRENs play an important role in e-learning activities as they enable cross-organisational communication. Heterogeneous infrastructures used for e-learning are a challenge for system design, data integrity, and interoperability. This paper proposes an NREN e-learning reference architecture and affiliated NREN e-learning design patterns that consider communication, reliable access, a collaboration and interoperability between e-learning infrastructures. Research exists about different architectures including traditional e-learning systems, service-oriented cloud computing such as the service-oriented architecture (SOA) adaptations for education systems, e-learning systems and a service-oriented cloud computing architecture (SOCCA). However, no research has been carried out for NREN e-learning architectures. For deeper insight, we investigate in this paper an e-learning architecture based on the Afghanistan Research and Education Network (AfgREN). The reference e-learning architecture based on AfgREN provides guidance for the rapid development of different e-learning services and learning-analytical infrastructure for Afghanistan.

Keywords: reference model; architecture pattern; NREN e-learning; standard; reference architecture; MDE; ATAM; learning analytics; e-governance.


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1 Introduction

This paper is about an NREN e-learning architecture and we design a cross-organisational e-learning architecture based on national network infrastructures. National Research and Education Networks (NRENs) provide high-speed connection, data repository centres, software and hardware sharing facilities and national, regional and global collaborations. Currently, around 120 NRENs operate worldwide. They have some regional collaboration via the regional NRENs such as GEANT (Hazlinsky et al., 2014) in Europe, NORDUNET (Graham and Sundblad, 2014) in the Scandinavian region, CLARA (Villalon and Hermosa, 2016) in Latin America, CKLN (Fryer, 2012) in The Caribbean, and TEIN (Llyod et al., 2014) in Asia, Ubuntunet (Mbale et al., 2012) in East and South Africa, WACREN (Wara and Singh, 2015) in Central Africa, and ASREN (Mulhanga et al., 2016) in the Mediterranean region connecting the Arab States.

E-learning is one of the new learning platforms for gaining knowledge at universities and other educational institutions. The main purpose of e-learning systems is to utilise knowledge and skills of educators in such a way that educational e-learning services can be provided anywhere and anytime without the limitation of time and space. Additionally, many tools exist for managing courses and learning activities (Islam, 2016).

The quality of e-learning depends on the content and infrastructure that is available for users, such as infrastructures for the course and content delivery, the effectiveness of delivery, interactivity, and personalisation of e-learning courses (Sarrab et al., 2016). Each component of e-learning has its own role and effect on the quality of services. The e-learning platform is one of the components that is very important for the delivery of content to a learner. There are different e-learning platforms including learning
management systems (LMS), course management system (CMS), virtual learning environment (VLE) (Costa et al., 2012). Some examples of LMS such as Moodle (Benta et al., 2014) provide many capabilities like the interaction between teacher and students, feedback, conversation, and networking, etc. The blackboard e-learning environment (Zenker et al., 2011; Henrich and Attebury, 2012) supports training, testing, and grading of online assignments. There are also WiKi environments for the collaboration to develop in e-learning systems (De Wever et al., 2011), and blogs (Deng and Yuen, 2011). A blog is an interactive portal for teachers and students, while the content of blogs is mostly posted by students. Blogs are interactive and reflective tools used by students and teachers to share their knowledge with a group, one to one, or publicly.

Current e-learning platforms mostly focus on the theoretical content and the evaluation of students based on their theoretical knowledge, Robles-Gomez et al. (2011) proposes a client-server e-learning architecture to provide more practical knowledge for students. Client-server-based platforms, composed of a web server, a storage server and LMS (Islam, 2016), offer e-learning services via the internet. Thus, the network layer of such e-learning architectures is very important.

The existing and evolving NRENs provide a good opportunity for e-learning implementation in academic organisations in most countries. Many e-learning architectures already exist using service-oriented architecture (SOA) adaptations for educational systems (Kaur, 2011). The latter are distributed educational systems that function via web-based applications. The components of the application layer of e-learning systems, including web interface, authentication, and related services, are the main explored aspects in this approach. An e-learning system based on a cloud architecture proposed by Arora et al. (2013) considers three layers of architecture, including an infrastructure layer as a physical host pool, software resource layer as a unified interface for e-learning developers, and a resource management layer.

Our literature review demonstrates that researchers of e-learning architectures (Robles-Gomez et al., 2011; Arora et al., 2013; Palanivel and Kuppuswami, 2014) mostly consider application development, access mechanisms, learning management tools and database engineering. However, e-learning resources need to be shared across organisations on the national level, and therefore, national network infrastructures need to be used. National e-learning architectures prevent data duplication, guarantee security and relevant collaboration flexibility, while existing e-learning architectures using public networks are vulnerable to many network attacks. Furthermore, the implementation of diverse e-learning applications in a single education organisation tackles the problems of integration and interoperability. Still, many problems (Juue and Daryapurkar, 2014) exist in e-learning architectures based on public cloud computing such as loss of data, change of data, and unauthorised access to data (Palanivel and Kuppuswami, 2014).

Since NRENs exist in many countries and provide national private cloud and high-speed communication between education- and research organisations, research needs to focus on e-learning architectures and on creating a cooperative architecture that facilitates the integration and interoperability in e-learning systems. The quantity of data in the field of education and academic increases day by day. Processing, storing, and analysing large datasets are a concern in the field of learning analytics. Learning analytics is the measurement, collection, analysis and reporting of data about a learner and the related context (Chatti et al., 2012). An e-learning architecture based on NREN supports learning analytics at the national level, it is storage, processing, and analysis. The input
data is educational and research data to achieve a higher performance with respect to interoperability, integrity, and security of data (Saay and Norta, 2016).

In this paper, we address this gap by answering the research question of how to systematically create an architecture for an NREN e-learning infrastructure. The specific focus is on the process-aware communication layer and related e-learning patterns. To achieve a reduction of complexity, we create a separation of concerns by deducing the following sub-research questions. What development methodology is suitable for the NREN e-learning architecture? What are the identified steps of creating a standard architecture and a concrete architecture? What are the differentiating aspects of our NREN e-learning architecture as compared to other e-learning platforms?

In Saay et al. (2016b), we propose a general tentative standard e-learning architecture that specifies collaboration between different NRENs, while in this paper we also give the results of a scenario-based evaluation. This paper presents an NREN e-learning architecture that provides guidance for the rapid development of national e-learning collaboration and for the implementation of e-learning systems in NRENs. Additionally, patterns are considered as parts of standard architectures that enable the development of a best practice and the analysis of differences between existing systems.

The paper is organised as follows. Section 2 discusses e-learning infrastructures with the roles of NRENs and an e-Testing architecture based on the requirements of NREN. Section 3 focuses on the NREN development methodology and explores creating steps of architectures. Section 4 describes applicable NREN e-learning architectural patterns and affiliated styles and patterns. Section 5 evaluates the NREN e-learning architecture and Section 6 discusses related work. Finally, Section 7 concludes the paper together with suggestions for future work.

2 E-learning infrastructure and NREN roles: common practice

Learning models in schools and universities are divided the following way. A traditional model is the face-to-face teaching model where the presence of students in class is required. The electronic model involves information technology such as internet resources, communication resource, and computer-based testing to enhance the teaching quality. The open model requires students use open resources for self-learning and they do not restrict students to any assessment and presence of them in class. Among the e-learning model, the following three models are more popular: web-based instruction e-learning in which most of the communication between teachers and students are based on web applications (Yanuschik et al., 2015).

Using proper architecture in e-learning is important because it affects directly the quality and accessibility of an e-learning system. Consequently, certain traditional infrastructures and cloud computing infrastructures (Masud, 2012) are used in e-learning systems, and each of them has its own architecture. Cloud computing is a computer-based infrastructure that provides computation and storage resources as a service. Alongside traditional e-learning systems, using cloud computing infrastructures is one of the efficient ways of e-learning implementations in countries that have reliable, inexpensive, and sustainable internet (Caminero et al., 2011).
Due to the growing demand for e-learning and the application of various e-learning architectures in the educational field, a scalable and cooperative e-learning architecture approach is needed to provide more integrity and interoperability between different e-learning systems. Cloud computing is an approach that enables the provision of software-as-a-service (SaaS), platform-as-a-service (PaaS) and infrastructure-as-a-service (IaaS). An e-learning customer can access services on cloud remotely through the internet and use them without any additional software and hardware installation (Arora and Sharma, 2013). Other research efforts propose SOA to provide good quality of e-learning services and to support the collaboration and integration of e-learning platforms (Palanivel and Kuppuswami, 2014; Kaur, 2011). Several architectures already exist, or are being proposed based on SOA. For example, the service-oriented cloud computing architecture for personalised e-learning systems (SOCCAPES) (Palanivel and Kuppuswami, 2014) comprises a demand layer, supply layer, and delivery layer and uses SOA to provide adaptive learning environments and a single interface for learners that facilitates collaboration. In SOCCAPES, cloud computing enables an increase of storage capacity, better service-deployment efficiency and a higher level of security. In addition, SOCCAPES provides more scalability, and an optimised management environment through virtualisation. However, cloud computing is a relatively new technology where security, privacy, and technical development remain open research issues.

Mobile-based e-learning is another e-learning technology and the most recent improvement in learning systems. However, the quality of mobile-based e-learning is an open issue. Furthermore, mobile learning is a new e-learning method, and researchers have not yet sufficiently studied the non-functional quality attributes and the technical perspective of mobile-based e-learning (Sarrab et al., 2016).

2.1 E-testing architecture based on AfgREN

Based on the proposed architecture, we consider university entrance e-testing for Afghanistan as a part of e-learning architecture. We analyse the functional- and non-functional requirements for the proposed architecture. Still, the existing university entrance exam does not satisfy the requirements for nationwide e-Testing. Interoperability, integrity and security are always a concern in e-Testing systems. The university entrance exam in Afghanistan is an example of nationwide testing, where ca. 250,000 students from all schools of the country participate (MoHE, 2016).

We complete the requirement analysis by using Requirements Bazaar (Renzel et al., 2013). The latter is a web-based application with Web 2.0 to allow users add requirements and vote for requirements and quality attributes. Requirements Bazaar solves the problem of communication between the user and the system developer (Nussbaumer et al., 2014). Requirements Bazaar is not limited to data collection, the collected data, quality attributes, and collected votes also can be used later for the evaluation of the designed architecture. In the design science research method, after collecting the requirements, the researcher can design the artefact method or process.

2.2 Requirements

We divide the requirement of the application in two main parts including functional and non-functional requirements, we use Requirements Bazaar for requirements gathering,
communication, and negotiation with the customer. A functional requirement describes the function of a system and its components, while non-functional requirements define the quality of system performance (Norta et al., 2014). Following is the list of e-testing application functional requirements:

- support and handle large amount of data
- support data entry for student testing candidates
- generate forms for registration
- sending notification to students through e-mail and SMS
- generate exam cards and attendance sheets
- match the answer sheet to answer keys for acquiring the result
- allocate succeeding students to faculties
- generate reports and validate the final result

Non-functional requirements:

We list the non-functional requirements below and we explain them in Section 5.1. Security, performance, scalability, availability, reliability, maintainability, manageability, data Integrity, usability, and interoperability are the main non-functional requirements in this paper.

3 Methodology

In this section, we analyse relevant research methods to choose one for this research. The process of the NREN architecture development and the NREN e-learning reference model are also discussed in this section. A methodology is a process of work that describes how the task should be completed in a systematic way. A research methodology is a science of studying how research is conducted. It is also defined as the study of methods by which knowledge is gained and the aim of a research methodology is to provide a work plan for research (Kumar, 2011).

There are several methods for the development of system architecture. Action-design science (Sein et al., 2011) is applicable as an experimental method for system development. However, action-design science is more related to a running and live system and for organisations that develop systems in an evolutionary way. Action-design science is used in two variations:

1. addressing an organisational problem by intervention and evaluating a specific activity
2. constructing and evaluating an IT artefact to address a series of problems in an organisation.

Since we do not have ongoing NREN e-learning development projects available and this method is too dependent on the target organisation, we consider action-design science an unsuitable research method for this paper.
The experimental research (Cao et al., 2012) is another research method that can be applied in information technology studies. The purpose of experimental research is to investigate cause-and-effect relationships among variables. The experimental research involves several working groups, including an experimental group and a control group. The result of research from all groups also can be different based on experimental environment.

The experimental research method has a more definite procedure than other methods. It starts with the research problem. Then it is determined whether experimental methods apply and the independent and dependent variables are specified. The experimental research method involves specifying tentative hypotheses, determining the measures to be applied, pausing to consider the potential success experiment, identifying the intervening variables, stating formally the research hypotheses, designing the experiment, estimating the potential success of the experiment, conducting the study as planned, analysing the collected data, and finally preparing a research report. Social and technical components are combined on NREN e-learning because we considered experimental research not an appropriate method in this research.

The case study research method (Runeson et al., 2012) provides a deep understanding of certain natural phenomena. The method can also bring with it a change in the area that is studied. According to Yin, there are four types of cases: the single case, multiple cases, the embedded case and the holistic case (Leitner and Strauss, 2008). The four types of the case study can also be combined, based on the researcher’s need (Verner and Abdullah, 2012). The case study research is not only useful for the emulation and observation of a system but also for explaining and exploring certain phenomena of a real system setting. The case study method applies a descriptive method, an exploratory method, and an explanatory method. We considered case study also not an appropriate method in this research because the NREN e-learning architecture needs a rigorous design of architecture and evaluation of it.

According to the cross study cited in Vaishnavi and Kuechler (2010), design-science research is applicable in many different fields, including architecture, engineering, education, psychology, and fine arts. The design science research method is applied to designing artefacts in a relevant and rigorous way. In recent years, design-science research has become a popular research method in the field of information systems. Researchers can also use design science for designing and evaluating sociotechnical artefacts that can be real artefacts or designs of theories (Drechsler, 2015). E-learning is a sociotechnical system that comprises more than one technical system. A sociotechnical system in an e-learning context is an information technology system that has an ongoing social process implementation, usually articulation work that is needed for IT activities. It considers the context of IT and the social use (Sorrentino and Virili, 2003). Therefore, we consider design-science research as the most suitable method for architectural design in this research.

Model-driven engineering (MDE), is a domain-specific modelling language to formalise the application structure, behaviour and the requirements of systems in a specific domain. It also facilitates analysing specific aspects of models and imposes domain performance checking to detect errors before commencing a development life cycle (Schmidt, 2006). A model is an abstraction of a system that is under study or targeted for application system development in the future (Da Silva, 2015).

The MDE-method is used for architectural development to implement a stepwise specification process and to check occurring errors prior to implementation. This
approach facilitates a deep understanding of the implications of using design patterns and architectural styles that are used to ensure the high quality of design. There are also other methods to analyse systems, for example, performance analyses, availability, and review for modifications. In this research, the term architecture refers to a sociotechnical system and its components and relationships, as well as the development and structuring that is used by an organisation. To specify a method, the specification and roles of an organisation need to be explained.

We additionally plan to use the architecture trade-off analysis method (ATAM) (Kazman et al., 2000) for evaluating and analysing in a qualitative and empirical way the e-learning architecture with the related functional and non-functional requirements in our next research paper. ATAM is mostly used for exploring the use of best-practice architectural styles for quality attributes of architecture and for the evaluation of existing systems. ATAM also helps to modify an architecture, or supports integration work with new systems. The purpose of ATAM is to identify risks that emerge because of architectural design decisions and to mitigate those risks in future efforts for modelling and prototypes. Our goal of using ATAM in this research is to elicit the communication factors that affect the quality of e-learning architectures and to consider the factors for reference in NREN e-learning architectures. Figure 1 explains that domain knowledge, patterns, reference architecture and a standard architecture are the prerequisites for establishing a high-quality concrete architecture that is very context-specific.

![Figure 1](image)

We design the development process of the architecture in accordance with Figure 1. For more clarification and in order to show a method for architectural development, it demonstrates a method for architecture development where we start from a reference architecture as a general guideline for NRENs. As the second step, we design a standard architecture for NRENs e-learning, and finally, a concrete NREN e-learning architecture for Afghanistan Research and Education Network (AfgREN).

4 NREN architecture and affiliated patterns

An architecture is a description of components, functions, and connections among functional components that comprise an overall system (Castelan et al., 2014). To design
an architecture, the architectural domain, conceptual knowledge about architectures and relevant styles and patterns of architecture need to be studied thoroughly.

A pattern provides a solution on an architectural level and it serves as a guideline for developing a high-quality specification of new systems, while it provides a reusable process. There are two types of patterns, namely design patterns and architectural patterns. Architectural patterns present the best practice for specifying an architectural infrastructure of systems, whereas design patterns focus on the functionality of systems (Hussein et al., 2010). Thus, a standard architecture for a domain such as e-learning NRENs results from analysing the used reference models that must be incorporated, and the related architectural patterns in order to provide a concrete high-quality architecture (Fernandez, 2013). For example, a concrete and very context-specific architecture is the AfgREN.

Figure 2 The NREN e-learning architecture pattern adapted from Norta et al. (2014)

We adapt the so-called eSourcing Reference Architecture eSRA (Norta et al., 2014), and it shows a three-layer style that comprises an external-, conceptual-, and internal layer. On the external layer, an eLearning_Exchange component is replicated into each respective e-learning concrete architecture, i.e., in Figure 2, we assume that AfgREN, Nangarhar University, and Balkh University (BU) engage in a national e-learning NREN with their own respective concrete architectures.

The eLearning_Exchange component is present in all concrete architectures, and they synchronise each other during setup and enactment time of an e-learning exchange. Inside the eLearning_Exchange component, there resides a façade component to shield a respective national e-learning platform from cyber security threats that may arise from other national e-learning platforms. Furthermore, there is a component to facilitate the national setup of a collaboration agreement for which we assume each concrete architecture is driven by process-aware services. Thus, the eLearning_Exchange component also contains a component for distributed e-learning process enactment. Finally, the eLearning_Exchange component includes a rules engine that supports the
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distributed e-learning process enactment engine in, e.g., deciding the rules attached to or branches of an e-learning process. To enable the setup phase of an e-learning collaboration, a trusted third party exists in the middle in the form of an eLearning_Broker component. The latter facilitates the rapid matching of e-learning needs with requests. Such a matching is possible by using advanced algorithms and recommendation systems. The concrete architecture in Figure 2 with the labels AfgREN, NU and BU all share the same three-layer style. NU and BU only show the external layer component due to space limitation.

Focusing on the fully depicted layers in AfgREN. The Conceptual-Layer comprises an e-Learning_Setup_Support component in which e-learning services are composed collaboratively in a crowd-sourcing way. The e-learning services in each concrete architecture are process-aware and have rules to attach and link to rich multi-media content. Additionally, the Translator-component converts heterogeneous data formats between the external- and the internal layer. The latter contains a Legacy-Management component in which local process enactment engines orchestrate information technology infrastructure that is wrapped as a web-service.

The NREN e-learning architecture with embedded concrete national e-learning architectures can be projected to a cloud environment. The NREN as such could be maintained as a totally public cloud into which a respective national e-learning platform may join as a national community cloud, which yields in its composition a hybrid cloud.

Affiliated styles and patterns

For the NREN e-learning architecture in Figure 2, we adopt the set of styles and patterns that are also part of eSRA (Norta et al., 2014). Thus, a layering style for the domains of respective national e-learning system structures components into groups at a particular level of abstraction. These abstraction layers are the external collaboration layer, the conceptual layer, and the internal layer to manage and orchestrate legacy systems. The layers assure that there is only communication with each adjacent layer.

The eLearning_Broker component uses a publish/subscribe style in which publishers submit new e-learning services and all subscribers receive a notification automatically. The notifier forms the central component of a star topology where the publishers and subscribers are the leaves. The advantage of this style in a multi-party collaboration environment with large numbers of potential e-learning service consumers and providers is enhanced system performance because of reduced communication overhead and an enhancement of flexibility and integrability of additional national e-learning platforms.

For the remaining way of data management, the NREN employs an abstract-data-repository style. This style keeps the e-learning service consumers and providers of shared data from having knowledge of each other’s existence, if they wish so, and of the details of their respective internal implementations. In addition, using a layering style and interposing an intermediary protocol between the producer and consumers of shared e-learning services also realises the abstract data repository style. The abstract data repository style requires an abstract interface to the data repository that further reduces the coupling between the data producers and consumers. A whole-part pattern aggregates the parts of an e-learning collaboration. Dedicated components exist on the external and internal layer in the form of the global and local process-enactment- and rules engine.
The broker-pattern in NREN is the *eLearning_Broker* component between the domains of collaborating parties. A broker is a separate component that interacts with the remainder of the architecture. Its purpose is the redirection and bundling of communication with many collaborating parties. Hence, since the broker pattern stops parties from having to find, contact and investigate every potential collaborating party separately, it affects performance positively.

The *eLearning_Exchange* component comprises a façade pattern that is a unified interface and offers to a collaborating counterpart access to a set of interfaces of a subsystem, namely the replicated components of the external layer. Hence, this supports the interoperability between e-learning parties and enhances the security in a collaboration as it shields the legacy systems behind the façade of the external-layer.

On the conceptual-layer of NREN, a pipes-and-filters pattern facilitates establishing communication channels between the external and the internal-layer via the conceptual-layer. This pattern provides a structure for processing streams of heterogeneous data while filter components encapsulate each processing step. Hence, data passes through pipes between adjacent filters from the external layer to the internal layer and vice versa.

### 5 Evaluation

The results of the ATAM workshops help us to design a tentative concrete architecture. ATAM has four main phases: scenario and requirement gathering, architectural view and scenario realisation, attribute model building and analyses, the trade-off of architecture. The following steps are based on the four phases of ATAM including scenario and requirement gathering, architecture views and scenario realisation, attribute model building and analyses, and trade-offs.

For the remainder we first explain in Section 5.1 is the scenarios based evaluation on the *e-Testing* as part of e-learning architecture. In Section 5.2, we explore the relevant environment for *e-Testing* scenarios. In Section 5.3, we compare the NREN e-learning architecture to e-learning architectures based on cloud computing. For the comparison, we considering security, interoperability, scalability and performance. The detailed questions, attributes, sensitive points and trade-offs can be found in Table 1.

#### 5.1 Scenario-based architecture evaluation

In this section, we consider an *e-Testing* architecture based on AfgREN (Saay et al., 2016a) as a scenario. Currently, existing examination systems in Afghanistan do not cooperate with each other, which causes duplication of data. Furthermore, the registration process of the universities’ entrance exam, the validation of students’ certificates and the examination process take too much time. The results are not acceptable for the examined. Our proposed architecture that we evaluated in six ATAM workshops and for which we consider *e-Testing* as a scenario, addresses the problem of such a long process. In this proposed architecture, organisations exchange the required documents in a secure way. *E-Testing* always involves sensitive data, and using a public network for *e-Testing* is a
big risk. However, using AfgREN as the infrastructure of e-learning and e-Testing has the following benefits, high privacy, and security: AfgREN is a national network that is owned and managed by academic organisations and based on their developed rules and policies. They can develop any required rules and policy by themselves.

AfgREN provides many different controls including the user access control, the network access control, the devices access control and many different levels of control by the implementation of authentication, authorisation, and accounting (AAA) server. Energy and cost efficiency: to maintain and secure all information technology in all educational organisations needs much more energy and is too costly.

The following set of the non-functional requirements for the reference architecture we consider in the ATAM workshops.

Modifiability: an NREN e-learning architecture changes and adapts quickly and cost-effectively without a restriction to extensibility and the restructuring of software and hardware updates. Additionally, it harmonises inter-organisational heterogeneous system environments.

Interoperability: an NREN e-learning architecture must interoperate at runtime with other e-learning systems including cloud-based and other traditional e-learning architectures. It must interoperate without any restricted access or implementation.

Data integrity: an NREN e-learning architecture comprises separately developed and integrated components for which the interface protocols between the components must match. Hence, integrability between the components of the NREN e-learning architecture must be ensured in the reference architecture.

Next, we specify the system requirements for the NREN e-learning architecture that are discernible during runtime because their effectiveness is investigable during the setup and enactment of collaboration configurations.

Scalability refers to the ability of the NREN e-learning architecture to combine more than two collaborating parties into one configuration. Applicability states that an NREN e-learning architecture is instrumental for guiding the design of e-learning collaboration systems.

Performance: means that the computational and communicational strain is low in collaboration configurations for the setup and enactment phase. Hence, it is important to ensure that all phases of a collaboration are carried out within a desirable response time and without an exponential need for computing power.

Security is the protection of systems from theft or damage to hardware, software, and the information on the former, as well as from disruption or misdirection of the services they provide.

Accessibility and security: the NREN e-learning architecture is based on the three layers and the e-Learning Broker component provides different levels of access for NREN members. In practice, an Authentication Authorization and Accounting (AAA) server is used in this architecture to provide secure access for NREN members.

Collaboration: the NREN e-learning architecture is an infrastructure for collaboration between educational organisations. The NREN operates as a backbone for collaboration between NREN members and different e-learning services can be exchanged between members. For better clarification, we introduce the AfgREN and then we compare the NREN e-learning architecture with cloud-based e-learning.
5.2 Afghanistan Research and Educational Network

Public internet connection for Kabul University (KU) started in 2006 without any NREN. Considering the values of NREN, the Ministry of Higher Education of Afghanistan includes the establishment of the Afghanistan Research and Educational Network (AfREN) to their strategic plan. AfREN is for connecting public and private universities, higher education institutions, colleges, teaching hospitals, libraries, research and scientific centres to the global research community. AfREN is a new network that needs extensions and has to be made available to the entire target group.

Currently, AfREN provides some public services such as access to e-mail, video conferencing and web browsing. It also offers some academic services like access to digital libraries. The higher education management information system (HEMIS) and network management systems (NMS) are used in the AfREN.

We conduct eight workshops for studying AfREN with participants from the NRENs of Pakistan, Korea, Afghanistan, and some academic participants from Afghan universities, the University College of London (UCL), and from Germany. Our first three workshops focus on the notion of the NREN architecture and its services. The fourth and fifth workshop focuses on the coordination with stakeholders, the sixth AfREN workshop is about e-learning services, and the last two workshops address the issues related to the sustainability of AfREN.

In this research paper, for functional requirements and scenario realisation, we consider the exchange of data between AfREN members. Collaboration between the Ministry of Higher Education (MoHE), Ministry of Education (MoE), KU and BU, we consider as a scenario. MoHE and MoE both have Student Management Information Systems (SMIS), the profile of students, the exam result of students, the content of a digital library and the curriculum located on the external layer of the NRENe-learning architecture. These components are based on the Legacy Management of the internal layer of the AfREN architecture. The collaboration between the MoHE and the MoE is shown in Figure 3 as the process of data exchange between two ministries.

Figure 3 Inter-organisational collaboration in AfREN (see online version for colours)

MoHE needs to access data located in MoE to acquire the profiles of students for the university entrance exam. First, the e-Learning Broker sends a notification to AfREN members about the location of records of the student profiles. For example, HEMIS that has records of university students, databases of community colleges and the database of school students. The parties’ data is then available for exchange on the external layer of every concrete architecture. Figure 3 also shows that AfREN is a community cloud that provides IaaS, SaaS, and PaaS. Details of questions and Scenarios, quality-attribute tree, sensitive points and trade-offs are in Table 1.
5.3 **Comparison of NREN e-learning architecture with the existing e-learning architectures**

There are many traditional web-based e-learning (Riahi, 2015) architectures whose construction and maintenance are located in an interior or enterprise organisation. This causes several problems such as difficulties in finding additional investment and difficulties of development and extension of additional services. Additionally, service-oriented e-learning architectures based on cloud computing (Hajjej et al., 2015) exist that serve as new e-learning systems. Public cloud computing is also not sufficient for e-learning in education and academic organisations. In Figure 4, the concept map of e-learning architectures based on public cloud computing are analysed by considering scalability, interoperability, security and performance. Figure 4 shows that public cloud computing has good scalability because it supports optimisation, uses virtualisation and it is a guided system, while public cloud computing has limitations in interoperability, security, and performance. Details of Figure 4 show that shared infrastructures, using of public networks, maturity, data change, data loss, data ownership, hacking through public networks, data integration, and cloud policies, are the main limitations of public cloud computing.

The infrastructure of a public cloud computing e-learning architecture is located in some public computing space and it is not an asset of any educational organisation. Finally, the analysis shows an NREN e-learning architecture provides a private-, or community cloud for educational organisations that is more secure, flexible, maintainable, and interoperable compared to other e-learning architectures. The architecture has high accessibility compared to traditional and public cloud-based e-learning architectures. While NRENs are responsible for user access control, they also collaborate with infrastructure that can extend the NREN e-learning architecture to other cloud-computing architectures. In that case, the point of presence of NRENs needs to be provided by a cloud-services provider (Suresh et al., 2015).

**Figure 4** Public cloud-based e-learning characteristics (see online version for colours)

With respect to learning analysis, NREN e-learning architecture helps to solve the following problems at the national level.

1. very large and hard to manage sets of e-learning systems content interaction data, system information data, personal- and academic data
while online learning has many benefits, it also causes the isolation of students from teachers and they experience technical problems. e-learning also comprises political concern, as students may not value a studious mentality enough in their national cultures (Ferguson, 2014).

For example, AfgREN supports the ministry of higher education and universities with strategy development as reports facilitate developing policies and strategy based on reliable digital data. To summarise this section, based on our evaluation, it illustrates that NREN e-learning architecture provides a nationwide, interoperable, extensible, maintainable, secure infrastructure with high-performance. Other e-learning architectures do not have those attributes, e.g., web-based traditional e-learning and e-learning based on cloud computing architecture.

Table 1  Summary of the quality attributes, questions, answers, implementation priorities and difficulties of an e-learning architecture based on AfgREN

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Quality attributes</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Does the architecture support adding new components? Yes L H</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does the architecture support adding new functions? Yes L H</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does the architecture support adding new collaboration parties? Yes L H</td>
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<td></td>
<td></td>
<td>Does the architecture support adding new hardware and new software? Yes L H</td>
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<td></td>
<td></td>
<td>Does legacy management system of collaboration parties allow for data exchange? Yes M L H</td>
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<tr>
<td></td>
<td></td>
<td>Does the architecture support data integration? Yes M L H</td>
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<td></td>
<td></td>
<td>Does the architecture have a verification system? Yes M L H</td>
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<tr>
<td></td>
<td></td>
<td>Does the architecture support exchange of heterogeneous data between collaboration parties? Yes L M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does the architecture response to the expected load? Yes L M</td>
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<td></td>
<td></td>
<td>Does the architecture support observability? Yes L M</td>
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<tr>
<td></td>
<td></td>
<td>Will customer learn using the architecture? Yes M L</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does the architecture support any error detection system? Yes M M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does the architecture support high speed media connection? Yes L M</td>
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<td></td>
<td></td>
<td>Does the architecture support a fast verification? Yes L H</td>
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<tr>
<td></td>
<td></td>
<td>Does the architecture support a fast response for brokering? Yes L M</td>
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<tr>
<td></td>
<td></td>
<td>Does the architecture provide a national learning analytical report? Yes L H</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does the architecture help for a technical collaboration? Yes L L</td>
</tr>
</tbody>
</table>
Table 1 shows a scenario-based evaluation that summarises the results of six ATAM workshops, including two workshops that include Requirements Bazaar. The participants of the workshops are policy makers, IT experts, the e-learning board, computer-science professors, NREN related experts and computer science students. We consider the e-Testing architecture based on AfgREN as a scenario in the respected evaluation method. In the ATAM workshops, after exploring the designed architecture and by considering the functional and non-functional requirements, we raise the quality-attribute questions. The votes and comments of the expert groups in Requirements Bazaar and answer of expert groups in the ATAM workshops are the result of this evaluation. After collecting the comments of target groups, we analysed and summarised them to yes or not. The quality attributes, questions, answers and the implementation difficulties and priorities are analysed and summarised in Table 1.

6 Discussion

One of the main problems of e-learning implementation is the lack of adequate e-learning infrastructure for which cloud computing is considered in many e-learning architectures as the future of e-learning systems. Riahi (2015) compare traditional e-learning systems...
with cloud-based e-learning, the delivery model, business model, access model, technical model, and acquisition model for that matter. Riahi proposes a cloud infrastructure for e-learning systems, although cloud-based e-learning infrastructures still need further investigations. The NREN e-learning architecture is a private or community cloud for educational organisations and uses the national infrastructure and acquisition model based on collaboration agreements. The NREN e-learning architecture is a further improvement and applicable in a cloud computing instantiation.

The SOCCAPES (Palanivel and Kuppuswami, 2014) is a cloud-based e-learning system that comprises a demand layer, supply layer and delivery layer using SOA to provide adaptive learning environments and a single interface for learners. In SOCCAPES, cloud computing enables an increase of storage capacity, better service-deployment efficiency and a better level of security. In addition, SOCCAPES provides more scalability, and an optimised management environment through virtualisation. Although SOCCAPES still uses a public cloud infrastructure, the user needs to buy services, while the NREN e-learning architecture is an asset for NREN members.

Ezenwoke et al. (2013) proposes a national education cloud for developing countries and considers Nigeria as a case study. Cloud services, cloud infrastructure, a control and management panel (CM panel) are considered as components of the proposed architecture (Ezenwoke et al., 2013). While the Nigerian Research and Education Network (NgREN) (Wara and Singh, 2015) already exists in Nigeria and can be used as a national cloud for education, they do not consider this as a national infrastructure. In the NREN e-learning architecture, we make an effort to use the existing national infrastructure since the NREN already exists and we integrate e-learning as part of this architecture.

Sarrab et al. (2016) make an effort for enhancing the accessibility of e-learning systems and they propose mobile-based e-learning. The latter is the most recent improvement in e-learning systems. Mobile learning is a new e-learning method for individual access and focuses on enhanced accessibility. Researchers have not yet sufficiently studied the non-functional quality attributes and the technical perspective of mobile-based e-learning (Sarrab et al., 2016). In the NREN e-learning architecture, our main focuses are quality attributes and accessibility as part of the quality attributes under consideration.

To conclude the discussion, the evaluation of e-learning architecture based on NRENs shows that our proposed architecture reduces the limitations that exist in other cloud computing systems. The NREN e-learning architecture provides high performance services and uses national infrastructures. While only academic and research organisations are members of NRENs, their strategies are overlapping because there is less security risk. Educational and academic organisations are using the same types of data because interoperability and data integration exist in the NREN e-learning architecture. At the same time, other cloud-computing solutions have challenges in security, high performance and interoperability (De Carvalho et al., 2017).
7 Conclusions

In this paper, we recognise the need for NREN systems to allow the national exchange of each e-learning services that can be extended across national borders. It also enables the exchange of e-learning services between NREN member organisations.

The paper explores suitable research process for the development of NREN e-learning architecture and the analysis reveals an existing gap for NREN e-learning systems. We demonstrate that design-science research is the most suitable method for studying an NREN since e-learning is a sociotechnical system where the human factor is very important. Based on the design-science method, we consider that the NREN-development approach must be rigorous and relevant to the application environment. MDE is used for the development process of the NREN e-learning architecture. We apply the ATAM for the evaluation of the proposed architecture.

With the help of qualitative interviews and literature reviews, and taking into consideration the commonalities and disparities between existing e-learning systems, we propose a top-down development process approach for architectural design. First, we consider eSRA (Norta et al., 2014) as reference architecture. Based on domain knowledge, styles and architecture patterns, we develop a standard architecture. Finally, based on the evaluation of standard architecture, we propose a tentative NREN e-learning concrete architecture in which the AfgREN e-learning architecture is evaluated and analysed. Affiliated architectural styles and patterns assure that the NREN has high utility.

Since the NREN e-learning architecture can be instantiated with cloud computing, we evaluate the proposed NREN e-learning architecture as a community cloud-computing solution by considering interoperability, accessibility and security, modifiability and performance. Thus, for developing countries such as Afghanistan, the NREN e-learning architecture is a good step for the integration of the traditional e-learning system together with a cloud-based e-learning architecture. The proposed NREN e-learning architecture provides a learning analytics infrastructure for countries and cross-border collaboration. Many different e-learning platforms and learning-management systems can be implemented based on the proposed architecture that supports learning analytics.

For future work, we aim to build a concrete NREN architecture that is deduced from the so-called eSourcing Reference Architecture eSRA. The planned prototype realises the affiliated relevant architectural styles that are layering, publish/subscribe and abstract data repository. The affiliated architectural patterns for the prototype are whole-part, broker, and façade. Furthermore, several additional directions for future work of this research exist

1. developing an e-learning platform based on the proposed e-learning architecture
2. developing a collaboration platform for data exchange between NRENs based on proposed architecture
3 technology infrastructure architecture
4 information architecture
5 application architecture
6 business architecture.

This research is ongoing and we also plan to explore how the principles of eSRA can be applied in other e-learning case studies.

References


An architecture for e-learning infrastructures on a national level


An architecture for e-learning infrastructures on a national level


