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Towards a quality model of technical aspects for mobile learning services: An empirical investigation

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ABSTRACT

Quality issues are commonly reported following the development of mobile learning applications. To evaluate and increase the chance of the successful development of new mobile learning products, the adoption of a complete and well-defined set of technical quality aspects for mobile learning development and their adoption in the education environment are proposed. This work describes a model that captures most abstract and generic technical aspects of mobile learning service quality, including availability, fast response times, flexibility, scalability, usability, maintainability, functionality, functionality, reliability, connectivity, performance, user interface and security. A set of technical quality aspects was developed following a literature study focussing on standards and guidelines for learning and mobile application software quality. The presented case studies point to a set of contextual technical quality factors that influence the choice of mobile learning application. The findings also indicate that there are causal relationships between learner satisfaction and the overall proposed model technical quality aspects. The model has a positive impact on overall learning process outcomes by evaluating the technical aspects while maintaining the quality of mobile learning delivered. The model components purportedly affect learning outcomes by assessing and improving the acceptability to stakeholders of the technical aspects of mobile learning.

1. Introduction

Virtual and electronic worlds are receiving increased global attention in wide range of applications in business, government, education and social media (Zhang, Zhang, de Pablos, & Sun, 2014; Zhang, de Pablos, Zhu, 2012). In a range of educational environments, learning normally consists of students' interactions with their instructors, who are responsible for providing learners with quality learning content. The rapid diffusion of ICT and its deployment in learning processes has led to a massive improvement in the quality of learning using several learning techniques. In particular, mobile computing technologies have enhanced learning performance and provided new activities for active learning, utilising the advantages of mobility and wireless technologies. This supports the establishment of a learning environment in which knowledge may be obtained at any time irrespective of geographical location (Alzahrani, Alalwan, & Sarrab, 2014; Sarrab, 2014).

The use of mobile devices as learning tools to facilitate the learning process is often seen as a conceivable key solution to some of the challenges currently faced by students, teachers and education providers in general. The use of mobile wireless technologies as a learning tool in education is the most recently developed approach to learning in educational environments. Since mobile learning (M-learning) materials are delivered using wired or wireless Internet, they are information-oriented services and products. All service divisions should thus have service quality characteristics that specifically fit its criteria and features (Al-Mushasha & Shahizan, 2009). It is well-known in learning environments that service quality and stakeholder satisfaction are the key factors for a successful learning process. Service quality in M-learning is used to denote the general perception of how good the M-learning application in terms of software and mobile application quality, while M-learning application quality attributes are used to acknowledge that application quality comprises many different attributes, for example performance, reliability, usability and security. M-learning application service quality does not need to be

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perfect but rather needs to answer the question of "How much less than perfect is sufficient?" There is no adequate answer to such a question, whereas a specific answer needs to consider the context in which it is being asked. However, the Quper model helps in answering this question by describing a relationship between the quality level, the costs and benefits (Regnell, Berntsson, & Olsson, 2008). Researchers and developers in the field of ICT have proposed five dimensions to measure the service quality provided, including reliability, responsiveness, assurance represented in knowledge, empathy and tangibles, such as equipment, facilities and personnel appearance (Al-Mushasha & Shahizan, 2009; Khan, Al-Shihi, Al-khanjari, & Sarrab, 2015; Pitt, Watson, & Kavan, 1995). Despite extensive research into M-learning, there are no complete and well-defined technical aspects of M-learning service quality in the education environment. The set of technical aspects of M-learning service quality proposed in the model is based on a literature study, mobile application software quality standards and relevant guidelines. This study presents the results from case studies that examined the application of the proposed model in four different M-learning applications. The main objective of this study is to determine which technical quality aspects aid the development and adoption of M-learning services in the education environment. In particular, this study aims to identify the most relevant technical quality aspects for M-learning services that motivate learners, instructors, learning providers and decision-makers in developing, selecting or adopting M-learning in the education environment. This research draws on a background study and usage experience to understand all possible characteristics of technical M-learning service quality. To achieve the objective of this research, it was necessary to investigate the components of the proposed model in different M-learning applications empirically.

2. Software quality

The quality of M-learning products is described from the perspective of software quality characteristics. Many well-known standards and quality characteristic systems exist, such as ISO 9126 (Standards Collection, 1994) and (ISO, 2005), which outline several characteristics of software applications. Given the large amount of information available, time restrictions and the cost of the software application development process, it was decided to focus on the characteristics of high-quality mobile learning applications. This set of software quality criteria is defined by selecting the significant characteristics set for the software product analysed software and the technical and nontechnical quality characteristics of the M-learning application. Several factors can influence software quality in general. However, in the case of the M-learning software application, the situation is more complex due to the particularities of the process, particularly those derived from the information technology field. In mobile learning applications, many technical and nontechnical aspects might influence the overall quality of the final product. In multi-national and cross-cultural virtual classes, learners' cultural values have significant impacts on knowledge sharing process (Zhang, de Pablos, Xu, 2014; Zhang, Vogel, Zhou, 2012). The nontechnical aspects include pedagogical, social and economic factors. The approach to mobile learning quality should take into consideration the fact that the mobile learning process is educational as well as technical. The technical aspects thus include a range of factors that might influence the quality of mobile learning product. Ignoring technical and nontechnical aspects risks making the final results concerning the quality of mobile learning application less accurate. Furthermore, the objectives of the mobile learning application development process would be affected and significant resources would be used in less important areas. Mobile learning application producers aim to maximise general quality levels, with a greater focus on improving the characteristics that are considered to be critical. However, the level of stakeholder satisfaction with mobile learning applications plays a major role in increasing the quality of the final product. Whilst it is entirely based on using different types of mobile technologies to deliver educational and learning materials, its evaluation means more than the evaluation of a book or other traditional resources. The quality of mobile learning application is in this sense influenced by the quality of the content and by the way in which teachers manipulate the learning material and its delivery to learners through mobile technologies (Pocatilu & Boja, 2009).

3. Technical quality model

Software engineering comprises many different software quality models. The most common approach to representations of software quality present a hierarchy of quality attributes, such as McCall's quality model (McCall, Richards, & Waiters, 1977), Boehm's quality model (Boehm, Brown, & Lipow, 1976; Boehm, Brown, Kaspar, 1978) and ISO 9126 (ISO9126, 2001). However, all these quality models have been criticised for containing several deficiencies. The main complaints about ISO 9126 are insufficient or absent detailed quality aspects and inadequate information about measuring the defined quality aspect. (see Fig. 1).

Dromey's quality model (Dromey, 1996) proposes the action definition that is required to achieve the desired quality level, instead of describing the quality approach itself. This approach will provide developers with concrete actions that will reach the preferred quality level. Grohmann, Hofer, and Martin (2005) argue that M-learning quality aspects can be divided into two main parts: technological and service quality aspects. M-learning technologies are concerned with limited battery life, small screen size,

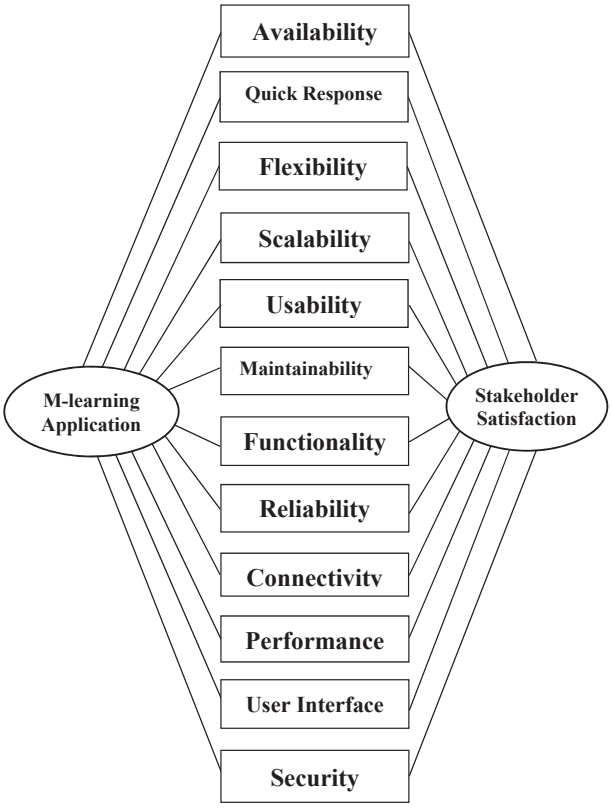

Fig. 1. Proposed technical quality model.

performance and unreliable network connections. In contrast, M-learning services are mostly concerned with providing access to learning resources, critical institution services and support services. The proposed technical quality aspects model is based on the DeLone and McLean information system success model was used as a useful approach for evaluating the organisational abilities of Information System (Delone & McLean, 2005). The DeLone and McLean model has been modified to cover a wide range of system features and has been used as open source software selection for adoption based on software quality characteristics (Sarrab & Rehman, 2014a, 2014b). A set of technical quality aspects was developed following a literature study focussing on standards and guidelines, technical reports, online technical articles, software documentation and user manuals, feedback of domains experts, official discussion forums and usage experience for learning and mobile application software quality. This work concerns a model that captures most abstract and generic technical aspects of M-learning service quality, such as availability, quick response, flexibility, scalability, usability, maintainability, functionality, reliability, connectivity, performance, user interface and security. This model is twofold:

- Development of new M-learning application.
- Evaluation of existing application.

3.1. Availability

The use of M-learning applications in education provides learners with easy access to appropriate information and multimedia content. The increased use of mobile devices to access M-learning materials allows instructors use a range of learning materials. The availability of mobile technologies has increased the number of adopters as learners are exposed to M-learning environments that can provide better and effective learning opportunities. Learners can access the required information irrespective of time and location in a way that supports just-in-time learning, in which the user can retrieve stored information when and where it is needed in any environment. Learners can access such materials via smartphones, PDAs, laptops, tablets, palmtops or MP3 players (Kumar, 2013; Sarrab & Elbasir, 2015a, 2015b). The universal availability and ease of use of mobile devices makes them a viable and exciting option for learning. Instructors are more reachable and knowledge is more available in M-learning as learners can interact with their instructors or peers in the form of synchronous or asynchronous communication. M-learning provides learners with broader access to knowledge and experts, for example librarians and instructors, than would be available through traditional learning programs. To enhance the accessibility for learners and to produce more engaging presentations of resources, activities and tasks, instructors can introduce new technological approaches to provide a better M-learning experience (Ally, 2009; Elmorshidy, 2012). M-learning ensures that learning is based on reliable tasks that engage learners in exploration and inquiry, which should provide opportunities for social discourse. A vast array of resources that allow learning tasks to be built on data capture, location-awareness and collaborative working are available. M-learning encourages flexibility and allows people to participate in learning opportunities irrespective of age, gender, group or geography. M-learning content should be of a minimum acceptable quality and the interaction with course content and multimedia materials as well as communication with the instructors and learners should function adequately using mobile devices. To meet these requirements, mobile applications should create separate instances of the content and should not use the same content that is available for computer-based applications (Ally, 2009; Sarrab, Alzahrani, Alalwan, & Alfarraj, 2014). The increasing availability and potential of mobile technologies merit an exploration of the possible ways in which M-learning can enhance the learning experience by utilising electronically available and reusable M-learning materials. The extensive availability and use of mobile devices for learning have provided institutions with unique opportunities to deliver education to their students through M-learning applications. M-learning can extend the available resources for both learning and information seeking for all users. The ready availability of knowledge and content is the key reason for the use of mobile devices in academic and communication purpose. The availability of mobile technologies presents opportunities for new types of learning delivery (Economides, 2009; Franklin, 2011).

3.2. Quick response

M-learning considers response time as a critical factor in stakeholder satisfaction with collaborative learning. M-learning applications should provide quick responses to learners' requests. Response time refers to the time taken to attend to a learner's question or comments by the system. Instant communication is very important in M-learning in order to make the learning process more exciting on the basis of location and the response time. A slow response time will undermine the learning process. Any delay in responding to learners' requests and communication should be avoided. M-learning should enable instructors to understand and respond to systemic challenges in offering support to learners for an effective learning experience (Rachel, Stephen, Judith, & Axel, 2006; Saipunidzam, Ibrahim, & Shakirah, 2010). Learners expect an immediate response from their mobile device. Contextual ideas and response time should also be considered in the design of M-learning modules. M-learning can improve interaction between learners by giving them the chance to communicate their ideas by texting or responding to surveys through their mobile devices, which leads to improved participation. Location and response time are crucial factors in supporting the success of academic interaction and learner satisfaction, with instructors easily able to facilitate online courses and respond to individual learners' queries irrespective of time and location (Alzaabi, Berri, & Zemerly, 2010; Corbeil, 2007; Jacob & Issac, 2008). M-learning designers should develop learning activities to accommodate various learning styles, as different learners respond, perceive and interact to learning situations in different ways. M-learning should respond to learners' requests without any delay in the processing, storing and communication of data. If the learner does not receive the required information within the expected time frame, this may result in lower engagement in learning. Using the Short Message Service (SMS) facility, M-learning enables prompt responses and interactions between learners to build a positive attitude towards learning. The design of M-learning applications depends on how learners respond and use the devices to build new knowledge (Ally, 2007).

3.3. Flexibility

M-learning applications should be flexible, adaptable to any of the learning environments and delivered across multiple platforms. M-learning enhances learning flexibility by enabling learning to be more personalised and learner-centred. M-learning technologies should be technically flexible and easily customisable to include both technical and non-technical features (Madjarov & Boucelma, 2011; Zhang, Wang, de Pablos, Tang, & Yan, 2015). The integration of learning management systems and student assessment software into M-learning applications

facilitates easy course management. M-learning applications are designed to support in-app downloads of PDFs, audio files and other learning materials to enable learners to learn offline to enhance learning flexibility. The creation of interactive media-rich content, better delivery platforms and emerging technology standards facilitates the compatibility and reusability of M-learning services (Ally, 2007; Dye and Rekkedal, May 15th-16th 2008). M-learning applications use a modular structuring of learning objects in which Extensible Markup Language (XML) is used as a tool for data processing and storage. This allows the learning content to be classified hierarchically and structured at the desired level of granularity in order to adjust to different mobile devices, contexts and situations (Madjarov & Boucelma, 2011; She, Zhang, Wang, & de Pablos, 2014). The instructional support materials allow developers to use a large set of tools to deliver content in various formats. Re-usable learning objects, learning activities and software are created by instructional designers and published within a common repository, together with their description by learning technology specifications and standards. Learners and instructors can search this repository to retrieve access and to share learning objects with other learners and the community (Huang, Hsiao, Tang, & Lien, 2014). The pervasive nature of mobile devices makes them adaptable to any learning management system by modifying the source code to suit the needs of mobility (Dye and Rekkedal, May 15th-16th 2008; Rachel, Stephen, Judith, Axel, 2006). Organising the adaptation and personalisation issues in M-learning allows mobile devices to provide an environment that accommodates the individual preferences and needs of learners irrespective of time and location (Economides, 2009; Pollara & Broussard, 2011). M-learning facilitates the use of technologies such as asynchronous device communication and enables pre-produced video, audio and printed materials to be accessed anytime and anywhere (Dye and Rekkedal, May 15th-16th 2008). The appropriate tools should be implemented and differentiated according to the targeted learners and the required learning outcome. The ability to install and run mobile applications on any mobile device that is adaptable to specified environments is the critical factor influencing the success of the design and development of m-learning (Sarrab, Al-Shihi, & Rehman, 2013; Parsons and Ryu).

3.4. Scalability

Scalability refers to the ability of an M-learning application to accommodate changes made to the system. The M-learning platform should manage the published and targeted distribution of multiple types of content to mobile devices and ensure that the application can handle additional content and an increasing number of users in the future (Wingkvist, 2009). If the M-learning application is to be scalable, it should match the pre-set requirements at the development stage. The application should adapt to the learning process as regards context change. It should accommodate the changing environment with a new class of learning applications that can adapt to dynamic learning situations accordingly (Wang, 2004). In order to achieve scalability, M-learning applications should consider the need to manage a large amount of data, allow a large number of users to access the application at the same time, provide an instant connection to learners from various locations, provide high-quality services and applications and satisfy learner's objectives (Wang, 2004). Scalability concerns involve planning what to change and considering how these changes will affect the initiative. M-learning applications should be able to handle growing amounts of information and additional features (Economides, 2009). M-learning applications should use a user-friendly and interactive graphical user interface (GUI) built using an object-oriented approach to enable it to be easily modified to incorporate newly added features. The scalability feature makes it easier for the M-learning application to update outdated or inaccurate sections more easily and provides customisation and personalisation of the application to provide a better learning experience (Wingkvist, 2009; Wang, 2004). M-learning applications that utilise the learning context should adapt to the learning process with respect to context change (Issa and Al-Bahadili). The application may be either refined or extended to gradually improve the handling of complex issues as the scope of the system is extended. The scalability of M-learning applications indicates how well it can be extended to suit certain needs. It should be sufficiently scalable to support the needs of a number of different disciplines, each with different teaching methods and technical solutions (Pollara & Broussard, 2011; Alabbadi, 2011). M-learning applications should exploit the changing environment of a new class of learning applications that can adapt to dynamic learning situations accordingly (Sarrab et al., 2013; Parsons and Ryu).

3.5. Usability

Usability in M-learning is defined as the qualitative characteristics that determine the most effective way of utilising the user interface. It deals with the extent to which the M-learning application can be used to achieve specified goals in an effective, efficient and satisfactory manner in a specified context of use (Wishart & Green, 2009). In order to enhance usability, preferential attention should be given to the functional and non-functional requirements of M-learning applications (Traxler & Wishart, 2011; Abdalha, 2013; Seong, 2006) including technical and nontechnical aspects. The learning interface should be simple and easy to operate by different age groups to ensure improved usability of the application. Usability guidelines require a measurement mechanism to be used to monitor, understand and improve the software processes as well as the mobile application (Rabi, Semi, & Hector, 2012; Freitas, Filho, & Barbosa, 2013; Hussain & Ferneley, 2008). Issues such as low performance, screen size, limited memory, poor display resolution and storage capacity, support for a limited number of file types, a lack of data input capability and the use of different platforms and operating systems of mobile devices all affect the usability of M-learning applications. The attributes used in measuring the usability of M-learning applications are learnability, efficiency, adjustability, reliability, simplicity, and memorability, readability, learning performance, errors and satisfaction (Fetaji et al.,; Hujainah et al.,). M-learning applications should be fast and have a vision-friendly display. The physical characteristics of mobile devices should be considered when designing the interface and design elements such as navigation should be considered to enable the user to access the required information easily without any delay (Harrison, Flood, & Duce, 2013). The ISO usability guidelines describe usability criteria in terms of three attributes: effectiveness in terms of the accuracy and completeness with which users achieve specified goals; efficiency in terms of resources expended in relation to accuracy and completeness and satisfaction, with reference to positive attitudes towards the use of the product (Fetaji et al.,; Chiu, Hsiang, & Sun, 2005). Developers should ensure that the M-learning applications designed are highly related to contextual use and have the ability to adapt and be sensitive to the surroundings (Rabi et al., 2012) and considers social virtual world strategies that impact long-term user commitment (Zhang, de Pablos, Wang, et al., 2014). Issues such as small screen size, poor connectivity and limited input modalities play a key role in the usability of M-learning applications.

3.6. Maintainability

The maintainability of M-learning applications is concerned with the application's ability to undergo modifications (including corrections, improvements or adaptation of the system to environmental changes) in requirements and functional specifications (AL-Mukhtar & Sami, 2014). The rapid changes in technology in the area of M-learning and learners' increasing requirement for continuously updated material, easy system modifications and enhancements make maintainability an important quality factor to be considered. To support application maintainability, a modular design has been devised that integrates constituent modules and provides a full-fledged M-learning system (Papanikolaou & Mavromoustakos, 2006). The crucial features related to maintaining M-Learning applications are analysability, changeability, stability, testability and maintainability (Hamdeh & Hamdan, 2010). Analysability is concerned with the effort needed to diagnose the failure of the application and identify the features that need to be modified. Changeability concerns the amount of effort needed for modification and application error elimination. Stability concerns the application's tolerance regarding the unpredicted effects of modification. Testability refers to the way in which modification is validated. Maintainability compliance refers to the exploration of the capability of M-learning applications to meet regulations and standards relating to maintainability (AL-Mukhtar & Sami, 2014). M-learning applications should use a layered architecture appropriate for mobile devices that improves reusability and maintainability. Multiple layers can be located on mobile devices depending on the application type. In order to improve the reusability and maintainability of M-learning applications, the concept of layers is used. M-learning applications should deal with the authenticity of actions and maintain events logs for later debugging or maintainability. As m-learning applications work on different mobile platforms, more effort is required to manage and maintain the application (Erturk, 2013; Boja & Andrian, 2011). Error detection and correction in M-learning applications should be easy and prevent the reoccurrence of these errors. The configuration and upgrading of the system should be made simple and easy. The application must be designed with easy future maintenance in mind. A clear and well-documented M-learning application will enable different individuals to be able to perform maintenance (Pocatilu, Doinea, & Ciurea, 2010; Pocatilu, 2013).

3.7. Functionality

The functionality of an M-learning application refers to the capability of the application to provide functions that meet stated and implied needs under specified conditions (Little, 2013). The application must include all features that are necessary to provide an improved learning experience. These include accuracy, suitability, compliance, interoperability and privacy, and must be taken into account during the design of an M-learning application. These functionalities are implemented according to requirements. The instructor should be able to control the implementation of these functions in the areas of privacy and code reusability. (Hamdeh & Hamdan, 2010). Functionality can be characterised into a number of sub-criteria, including accuracy and concerns about the capability of the M-learning application to provide appropriate results and information. Suitability and concerns about the ability of M-learning applications to provide appropriate functionalities to fulfil learners' needs must also be considered. Compliance refers to the need to develop M-learning applications in accordance with established guidelines and specifications. Interoperability refers to the interaction with other specified applications. Privacy is concerned with the capacity to protect information and data from unauthorised users (Little, 2013). M-learning applications should make use of functions such as barcode reading, GPS and augmented reality, where information about learner location is added on screen automatically (Katja, 2014). The functionalities in M-learning applications are aimed at increasing activation and enabling robust and operational interaction (Motiwalla, 2007). These functionality requirements are categorised into three areas (Ali, Ouda, & Fernando, 2012). Variety requires M-learning applications to offer various functions that can be used according to the requirements of the learner. Quality means that M-learning applications should be simple and that the input should be easy inserted and simplified by using location aware functions. There should be a well-designed interface with appropriate colours and font sizes. Interactivity is concerned with quick and simple interactions among stakeholders (Motiwalla, 2007; Pachler, 2010). Learners should be able to use the application for synchronous and asynchronous communication. Since lectures are streamed live, access to the application for both learners and instructors is possible (Ali et al., 2012). The functionalities of M-learning technology can be improved by the addition of existing courses with value-added features such as alerts, personalised agents or communication aids as well as access to interaction or discussion utilities that help learners convert their dead-time to productive activities (Pereira & Rodrigues, 2013; Vavoula and Karagiannidis, 2005).

3.8. Reliability

Reliability refers to the M-learning application's consistency in performing according to the specifications in different environments. The application should perform its intended functions and operations without experiencing failure (namely a system crash). M-learning applications should be reliable, with high processing power, battery life, robustness, performance and accuracy. The number of users, connectivity, configuration, time and place of use or data access should not affect them (Kitnav & Davcev, 2012; Sarrab, Alzahrani, Alalwan, & Alfarraj, 2015). Users should be able to recognise, diagnose and recover from errors (Harrison et al., 2013). M-learning applications should overcome issues such as fault tolerance, crash frequency, recoverability and maturity in order to improve the reliability of the system. Sensitive data, such as student details, grades and exams, should be protected and correctly recovered. The application should correctly sense, estimate, and make adaptations according to requirements. M-learning applications should maintain a specified level of performance in case of software faults and keep crashes to a minimum. Reliable wireless networking technologies prevent the degradation in performance of M-learning applications, allowing users to access the application with minimum blocking, disconnection, delays or loss of data (Hamdeh & Hamdan, 2010). Increasing data capacity should be handled at high speeds, supporting a growing network of users while providing support for critical applications and delivering converged services and solutions (Leung & Chan, 2013). Learners must be able to access M-learning applications, even under varying degrees of network failure (Ghadirli & Rastgarpour, 2013). A reliable M-learning application can both increase the battery life of mobile devices and improve the working memory and processing capacity of the application through reduced hardware dependency, increased consistency and efficiency, thus, making intelligent learning possible irrespective of time and location (Meskini & Capretz, 2013; Somani & Vaidya, 1997). Reliability includes fault tolerance, which can be achieved by keeping a backup component that can immediately take its place with no loss of service (Uzunboylu & Ozdamli, 2011). The crash frequency is concerned with the amount of crashes that occur over a period of time. M-learning applications should perform without any hardware or

software crashes. Recoverability concerns restoring the lost data or functions through back-up. The maturity of the application and its performance should be accessed throughout the lifecycle from concept development, through design, and ultimately to the operational deployment of the application. (Motiwalla, 2007; Lin, 2004).

3.9. Performance and efficiency

The success of M-learning applications depends on the commitment to performance and efficiency enhancement. The application response-time performance must be fast enough to satisfy user needs. Long waiting times are likely to result in reduced interest from learners, de-motivation and boredom, leading to unwillingness to use such applications. Applications should have increased capabilities and performance in terms of CPU power, memory usage and connectivity. A user-friendly user interface and usable interaction with the M-learning application can enhance the learning process (Seong, 2006; Keegan & Mileva, 2010). Learners expect the application to run in an efficient manner when utilising an M-Learning environment that integrates a wide range of technologies in terms of components such as content, information component and user interface. Applications should provide fast access to the information with a good network speed (Hamdeh & Hamdan, 2010). The key issues influencing the performance of various M-learning applications are interference (which leads to high loss rates due to radio transmission), low bandwidth (low transmission rates), high delays (delays may range from hundreds of milliseconds to seconds), lower security (the radio interface is at risk of attack), frequent disconnections (cell interference, limited cell capacity or lack of network coverage may lead to frequent disconnections). The performance and efficiency of the application can be enhanced with the examination of different application states, multi-tasking support, limiting the power of the device, energy efficiency and memory management (Hamdeh & Hamdan, 2010; Dochev & Hristov, 2006).

M-learning application performance and efficiency can be broken down into responsiveness, communication bandwidth, memory storage and energy consumption. Responsiveness refers to the need of learners for an immediate response from their mobile device. Reduced loading time makes it easier for users to interact with, share and bookmark content, which leads to more flexibility and greater adaptability. There should be no delay in interaction between learners and instructors. Any delay in processing, storing or communicating data should be kept to a minimum. In terms of communication bandwidth, the bandwidth must be utilised efficiently without any interference. M-learning applications should allow the use of multimedia content. The program and data space requirements should be minimised by optimising software and removing any unnecessary features. Memory allocations must be monitored carefully to avoid running out of memory and to free all memory allocations for exiting processes to prevent memory leaks. Finally, as energy consumption is an overriding concern in M-learning applications, developers should be aware of and use the low power system features that are available to them (Motiwalla, 2007; Haag, 2013).

3.10. Connectivity

Mobile connectivity characteristics such as personalisation and geographical flexibility can be utilised in designing M-learning applications. Connectivity of M-learning applications improves collaboration through real-time or instant interactivity regardless of time and location (Pereira & Rodrigues, 2013). The selection of network connectivity infrastructure depends on the number of users, the need for range, connectivity and data access, the time and place of use, possible interference with other devices, security requirements and network configuration (Kitnav & Davcev, 2012). Learners can access information anytime and anywhere, using a rich and dynamic UI supported by a range of connectivity options (Pocatilu & Pocovnicu, 2010; Sarrab & Elgamel, 2013). Mobile device hardware and software provide various means of connectivity, including personal area networks (PANs), wide area networks (WANs), wireless local area networks (WLAN), synchronisation software, wireless fidelity (WiFi) and cellular connectivity. Common wireless technology standards used in M-learning include WiFi, infrared, Bluetooth, GSM and CDMA. The speed and quality of data transfer should be of an adequate standard (Liaw, Hatala, & Huang, 2010). The available communication networks for M-learning include satellites, mobile telephony, wireless local networks and personal ad-hoc networks. (Sarrab et al., 2015). The various connectivity standards that allow users to connect to other users, systems and information are often hindered by low bandwidth on wireless networks (Liaw et al., 2010; Tu, Sujo-Montes, Yen, Chan, & Blocher, 2012). Connectivity as a technical quality aspect may be classified into openness, portability, transparency, scalability and variety. In terms of openness, M-learning applications should adapt to open architecture. Learners should be able to create, share, and organise their personal learning in open network environments that allow social networking and collaborative activities that are open to public view. The device should be easily portable when connected to a network in order to facilitate tasks such as communication, data storage and video and audio recording. M-Learning applications should provide a transparent and seamless browsing experience of adaptive content. Transparent access to content, profile and result data, the cache transferred and data synchronised. In terms of scalability, the deployment of M-learning applications can be performed and scaled to meet user demands by flexible resource provisioning. It is easy to add and expand an application and service with little constraint on resource usage. A variety of different context elements, data, systems and multimedia types should be supported. The application must work on different operating systems, browsers and communication protocols (Huang, Hwang, & Chang, 2010).

3.11. User interface

The M-learning application user interface should include different features, such as ease of use, user satisfaction, attractiveness and learnability. When developing the user interface, designers should consider the type of users interacting with the application, special user requirements and functionalities of the application (Seong, 2006; Ali, Alrasheedi, Ouda, & Capretz, 2014). M-learning applications should be robust and of very high quality for wider acceptance of the system. The developer should minimise functionality in favour of a simple user interface that users can easily perceive and understand (Ali et al., 2014). M-learning applications should have a well-designed user interface to ensure improved adaptation of the application. Consistency across multiple platforms and devices should be maintained. The first main type of mobile user interface is the Graphical User Interface (GUI), in which the user's input information is accepted through various mobile computer keyboards or pointing methods that react to the screen. The GUI displays relevant information on the screen of mobile devices. In web-based user interfaces, a user request is accepted and transmitted to the web server. A response is received and the information displayed on the mobile device screen using a mobile web browser (Seong, 2006; Georgiev & Georgieva, 2009).

The stages involved in the development of a user interface for M-learning application include defining the functional

Table 1
Overview of case studies.

	Case 1	Case 2	Case 3	Case 4
Mobile learning (LMS)	Moodle Modular Object Oriented Dynamic Learning Environment	Blackboard Web Based Learning Management System	Schoology Course Management System	Edmodo Social Learning Platform

requirements of the user interface depending on the purpose and the needs of the users, development of the application navigation scheme, development of a prototype in the form of a simple interactive screen, which includes basic information text, graphics, audio and video, followed by testing the prototype with real users from different groups and making the necessary changes. (Ali et al., 2014). The requirements for the User Interface are categorised into: layout and organisation, media, navigation, accessibility, help and personalisation. The layout should be simple, easy to use and neatly organised with minimum functionalities and lower error rate. The user interface should support various media types, including audio, video and text. The navigation should be intuitive, located at the top or bottom of the screen, and should support work with mobile device keyboards. The elements should be visualised in the same way on mobile devices with different screen resolutions. Personalisation can be achieved via two adaptive approaches: a learning service that can adapt to learners' characteristics, such as learning styles, requirements, status, performances, preferences and profiles; or a learning service that can adapt to the context surrounding the learners (Ali et al., 2014; Georgiev & Georgieva, 2009).

3.12. Security

Security of M-learning applications can be defined as the process of achieving data confidentiality, integrity and availability by implementing controls such as authentication, authorisation, input validation and data protection. The security tools must be able to control and protect M-learning applications and content sharing (Kambourakis, 2013). It is also necessary to ensure the integrity, privacy and confidentiality of the data stored and transferred for the needs of the educational process. Mobile technology involves increased threats to system and data security and privacy as learners and instructors are permitted to use their own mobile devices to access resources and services. M-learning should therefore include mechanisms to support learner management of data, content copying, editing and downloading and safeguarding learner examination and assessment processes from attackers and impostors (Tsinakos & Ally, 2012). Mobile technologies provide several possibilities for learner information protection as well as safeguarding and administrating learners' sensitive data, which includes documented risks relating to Internet content and

Table 2
Technical aspects of the Moodle M-learning system.

Requirements	Scaling	Comments
Availability	5	Moodle is available in 237 countries across the world. More than a million teachers are registered on the platform. Over 70 million people use this platform in various countries. It is available in 95 languages. All checked-in Moodle code is made available, which allows users to update only the modules that have actually changed.
Quick response	4	Moodle provides feedback channels to respond to learners' needs in a timely manner. It allows faster data transmission on mobile devices.
Flexibility	4	Moodle is provided as free open-source software that can be used, modified and freely distributed under the terms of the GNU General Public License. Changes are tracked for the purpose of improving the software. Moodle uses portable software architecture and facilitates standard open-source components to allow installation on multiple platforms.
Scalability	5	Moodle has more tools for the learning environment and it is easy to incorporate multimedia elements and desired features. It provides easy code accessibility and supports more types of database in order to make it easy to use. Institutions and organisations can leverage Moodle to customise and extend features to suit any teaching and learning requirements.
Connectivity	3	In Moodle, learners must be connected online at all times to carry out the learning activities. The learning design accommodates a wide range of individual abilities, preferences, schedules and levels of connectivity. The current Moodle interface and other course resources are effective for online learners with fast Internet connections.
Efficiency and performance	4	Moodle helps to configure, monitor and fine-tune the virtual learning environment for maximum speed. Moodle is constantly updated to provide stable support. It has many features that are useful to potential students, such as easy installation, customisation of options and settings, good support, good educational tools and excellent documentation.
Reliability	5	Moodle runs without modification on Unix, Linux, Windows, Mac OS X, Netware and any other systems that support PHP. Moodle's technical team provides assistance for the installation and management of security systems and to locate and fix problems. Moodle allows learners to edit after posting, offers confirmation before sending assignments and warns when leaving the course site.
Functionality	5	Moodle can be operated by integrating or connecting with external systems, such as school affairs systems, content management systems and social networking systems. A useful optional Moodle module is a browser capability checker that helps students identify technological requirements at the beginning of a course and provides easy-to-find links to support services.
Usability	5	One of the strong points of Moodle is its ease of use. It allows teachers to make changes to create unique learning experiences. Moodle can be used on almost all servers that use PHP. Users can easily upgrade from one version to the next. Moodle makes the design and implementation of lesson plans easy and allows changes to the platform to be made to suit the learning setting.
Maintainability	4	Maintenance of Moodle software is minimal. Moodle can be easily installed and maintained whilst organising the learning activity factors. Moodle does not include company-based system maintenance or product support as part of its package. The technical team provides assistance to implement, upgrade and sustain the software.
User interface	4	The interface design of the Moodle application is too simple. There is information overload and confusing navigation layout design, including navigation icons and symbols that are poor and inconsistent. Users encountering this for the first time can experience confusion due to a lack of familiarity with the UI. However, the Moodle system interface can easily be modified by changing its background colors or adding photos to make the learning experience more visually pleasing.
Security	4	Moodle has set up a dedicated site to deal with security issues. Users are able to create content in Moodle either by using the resource editor or by uploading files. A number of settings are available to prevent misuse. Moodle is based on the LAMP platform, which has proven to be very secure if configured correctly. Moodle has the ability to track learners' progress and can be monitored by both teachers and learners. It stores user data into a cache that could subsequently be used by an attacker to launch an attack during the next session. The other security attacks that can occur in Moodle are session attack, design attack and user log-out or failure to close a session.

Table 3
Technical aspects of the Blackboard M-learning system.

Requirements	Scaling	Comments
Availability	5	Blackboard is available in 15 languages in 140 countries. Each release devotes time and resources to ensuring that Blackboard Learn can run on the latest operating systems, databases and browsers, with the objective of creating a system that is more manageable, stable and user-friendly. The Blackboard Mobile Learning Update module changes frequently as the technology evolves and will appear on Blackboard landing page when a student logs in to Blackboard.
Quick response	5	The Blackboard Student Response System (SRS) technology allows faculty to receive immediate feedback from students wirelessly with the use of mobile devices. The Blackboard Learn processing model, which is based on Web 2.0 and client-rich technologies, distributes the load between the client-side browser, the application and the database. Blackboard uses Turning Technologies software to engage students and provide them with instant feedback and to simplify user workflow.
Flexibility	4	Blackboard has native applications for Android, BlackBerry, HP webOS, and iOS-powered devices, which provides millions of students with full access to their course information. With the Blackboard Mobile Learn app, students and instructors can access documents in multiple formats, create threaded discussion posts, upload media as attachments to discussion boards and blogs, create content items within the course map, and comment on blogs and journals.
Scalability	4	Implementation engagements deploy a stable and scalable technology platform for Blackboard Learn and a foundation on which to build. Blackboard supports a flexible architecture that is configurable in accordance with installation requirements. It uses a scalable design that allows integration with student information systems and authentication protocols.
Connectivity	5	Blackboard provides 24/7 access to course materials and improved communication with instructors. Blackboard provides students with direct access to the instructor via discussion board posts and email. Learners are always connected to the necessary resources.
Efficiency and performance	4	The Blackboard architecture supports maximum performance and high service levels by providing a variety of deployment options, including a load-balancing application tier clustering and virtualisation. The Blackboard Performance Engineering team is responsible for refactoring under-performing areas of the application and verifying regression improvements based on optimisation. The application architecture and its flexible deployment options enable users to scale and optimise the performance and responsiveness of their Blackboard Learn deployment in various platforms.
Reliability	5	Blackboard reference architecture helps minimise IT complexity and maximise the overall learning experience. Its reliability is a result of its development by professionals who are paid to build an effective and efficient product, which makes it more responsive to resolving issues.
Functionality	4	Blackboard provides a number of learning tools, including an online discussion board, course content management, a course calendar, information announcements, electronic mail, reviews, auto-marked quizzes and exams, navigation tools, access control, grade maintenance and distribution and student progress tracking.
Usability	3	The most frequent problems encountered by students using Blackboard is difficulty in finding the targeted material and difficulties logging on to the system. Users can customise the application by assigning different colours to each course. This provides a quick visual representation of what each class content item is associated with.
Maintainability	4	Blackboard has an active technical support system dedicated to immediately fixing technical issues. The Blackboard CMS system provides an appropriate level of online assistance and explanation. IT department support staff are always available for consultation relating to Blackboard.
User interface	4	Blackboard's user interface allows for easier consumption, navigation, prioritisation and customisation of content. An important interface usability issue is the general organisation of course content and activities. The default Blackboard course organisation follows a form arrangement.
Security	5	Blackboard Mobile Learn securely transmits usernames and passwords over SSL and authenticates with the institution. Blackboard never saves a user's credentials on its servers. The Save Password option on a user's mobile device allows the user to save his or her login information on the secure storage space within the application. The Save Password option is only available for institutions using the native LDAP authentication scheme.

communication as well as portability. M-learning provides tight coupling of security and privacy with the learners' current situation, and calls for security and privacy policies that are able to offer advanced context-aware information control (Sun, Wang, Shen, & Zhang, 2015).

Learners' information is collected and shared either by using a centralised database controlled by one entity that processes and analyses the data, or by storing and processing the data where learners have better control (Pocatilu et al., 2010; Velev, 2014). Some security characteristics, such as authentication, network security and application security, can improve the mobility of M-learning applications (Pocatilu, 2010). Some recent and updated security technologies that can completely protect access, storage and communication must be integrated into M-learning applications. These technologies include access control, firewalls, identification, authentication, authorisation, cryptography and anti-virus protection. Data integrity in M-learning applications is concerned with protecting information from unauthorised changes. Files that remain open during device suspension and power failures may cause data integrity issues. Exception handling and retry logic should be included to ensure that file operations succeed. Transactions with SQL Server Mobile should be used to ensure data integrity in cases in which the mobile device loses power or connectivity (Sarrab & Bourdoucen, 2013). Privacy and confidentiality are concerned with protecting the information from unauthorised access. The privacy of the learner should be protected and clear feedback on the personal data collected, its storage location and who it is used by should be provided to the learner. Mobile technologies offer several possibilities for constant monitoring of the behaviour of learners and for protecting them by safeguarding and administering activities and collecting and evaluating personal data, such as information about user preferences and goals. Privacy is also closely related to biometric-based authentication schemes enforced by mobile devices, which include name, gender, birth data, address, credit card details, biometric characteristics, mobile phone number, email address, location data, IP address, IMEI, location data, service usage data, e-mail, call records, web-browsing log files and history and security credentials (Tsinakos & Ally, 2012). M-learning applications should allow users to control or filter information flow and interaction through mobile devices. Learners should be able to control the flow of information and to go back and forth between tasks without losing track of where they are. Users must have control over their data, application resources and any personal information (for example their identity, scores and mobile number) that is available to others (Sarrab & Bourdoucen, 2013; Hsu, 2012).

3.13. User satisfaction

From the perspective of learners and instructors, understanding stakeholder satisfaction with M-learning service providers is useful in helping education providers assess current and potential M-learning services. Previous research on ICT service quality could be applied to the understanding of M-learning service quality. M-

Table 4
Technical aspects of the Schoology M-learning system.

Requirements	Scaling	Comments
Availability	5	Schoology is used by seven million users in over 60,000 K-12 schools and universities around the world. Schoology is deployed as a cloud-based system and requires no software or specific hardware to support new institutional implementations. It is compatible with Firefox 3+, Internet Explorer 7+, Safari 3.1 + or Google Chrome.
Quick response	4	Schoology enables students and faculty to easily communicate, share resources, host collaborative groups and stay actively engaged from any device. Schoology meets the needs of all teaching styles.
Flexibility	5	Schoology can be implemented by a single teacher for their class, with no specialist technical expertise required to get started or sign up. Teachers can set up their own classes with Schoology, or multiple teachers can take advantage of free features. It allows lessons and coursework to be easily created, used and shared and manages academic material through a social networking interface that is similar to Facebook.
Scalability	5	Schoology is a hosted, subscription, cloud-based service that allows infinite scaling. Advanced access controls help institutions rapidly implement and constantly incorporate technologies, tools and features without interruption. Schoology is user-centric and scalable for any blended learning environment. Its API and developer platform allow third parties to create applications that extend Schoology's services.
Connectivity	5	Schoology allows an unlimited number of teachers and students to create accounts and use the system at no cost. An app store, in which students can pay to connect third-party apps, websites and programs to their platform, are available.
Efficiency & performance	4	Faster access to materials is provided. Teachers can easily create and update course materials. The interface is simple, similar to Facebook and easy to load. It allows faculty to monitor the amount of time students spend using Schoology. The resilience of the site has been increased by putting it behind a CDN that allows it to quickly scale up to handle any number of requests.
Reliability	4	Schoology has a help centre website that can answer users' queries. It provides guides for instructors, students, administrators and parents. It is easy to log in to the site and a technical team handles any issues with errors and loading time that are related to the system.
Functionality	4	Schoology also provides various instructional tools, including organisable lessons and self-paced learning, threaded discussion boards, micro-blogging, content migration and imports. Schoology manages the curriculum, assessments, grading and other classroom management tasks and also acts as a communication platform for educators and students in K-12 and higher education. Teachers can use Schoology to share material, facilitate discussions, post and grade quizzes, maintain schedules and to network with other educators.
Usability	5	It is an easy-to-use, easy-to-implement M-learning, classroom management, and social networking platform that improves learning through improved communication and collaboration and increased access to curriculum and supplemental content. Schoology was also selected on the merits of user experience and has been described as fun, intuitive and engaging.
Maintainability	4	Schoology adds resources that provide improved processes, monitoring, alerts, and a significantly improved uptime averaging 99.9%. In the case of content not being properly cached, Schoology deploys changes to correct the issue. High importance is attached to services to increase and expand high availability, ranging from code changes, new monitors and alerts to additional hardware purchases and implementation.
User interface	5	Schoology has a collaborative interface to boost student engagement and streamline curriculum management. Schoology's interface is much easier to navigate than that of other applications. Schoology's teacher dashboards and student interfaces are brighter and include clean icons. Its design is similar to that of Facebook, in which conversations take place, messages are sent, statuses are updated and information and other media are shared within a classroom network.
Security	4	Schoology is a very secure platform that is built using a cascading set of permissions and privacy settings. Only users with a username/email and password have access to the system. All data and information is controlled by a user's unique ID and role. Schoology integrates with AD/LDAP, any third party authentication service or even external accounts such as Google Apps. The simplest remote authentication involves a token based single-sign on. It maintains access logs of all user activity. These logs contain a timestamp, IP address, and username as well as a variety of other data that can be used in data analysis and tracking.

learning users do not just want a mobile device; rather, they seek a system that satisfies their M-learning services and above all demand service quality that leads to their satisfaction and a behavioural intention to use the service in future.

4. Case studies

To demonstrate the effectiveness and feasibility of the proposed model, four different and widely used M-learning platforms are selected in this study. The main objective of this study is to determine which technical quality aspects aid the development and adoption of M-learning services in the education environment. This research draws on a background study and usage experience to understand all possible characteristics of technical M-learning service quality. To achieve the objective of this research, it was necessary to investigate the components of the proposed model in different M-learning applications empirically. This section describes the four case studies considered in this empirical study. An overview of these case studies is presented in Table 1.

The MOODLE M-learning system is a free open source learning management system (MLE-Moodle) available on Android and iOS platforms. This system enables learners to access their required courses and to work virtually anywhere (Hsu, 2012; Hoda, 2013). Instructors can use MLE-Moodle to develop online courses or to improve their face-to-face classes with online components in which learners are able to access MLE-Moodle using variety of mobile devices. MLE-Moodle is an HTML5 web app that requires an internet connection to provide the best performance level, with some offline tasks (Muhsen, Maaita, Odah, & Nsour, 2013; Floyd, Schultz, & Fulton, 2014).

Blackboard M-learning is a mobile software application that is available for download and installation on mobile devices to support user access to different course features (Velev, 2014). The Blackboard M-learning system focuses on interactive teaching and mobile learning, offering learners and instructors access to the required materials, courses, and organisations on different platforms, including iOS and Android smartphones. Blackboard mobile solutions make it easy to implement M-learning systems that have the power to take learning and education steps further than expected (Beatty & Ulasewicz, 2006; Carvalho, Areal, & Silva, 2011).

Schoology is a learning management system available as a free native mobile app that extends learning beyond the limitations of the classroom. Schoology extends the CODiE-award-winning learning management system to Android, Apple and Kindle Fire mobile devices. Schoology has redefined the learning management system to offer online education as a collective effort and to increase the impact of all students involved in the education process. With a flexible collaborative interface, Schoology's robust M-learning apps empower engaging instruction and system-wide collaboration on any device (Schology, 2014).

Edmodo is an online and mobile social learning platform often described as a Facebook for education and learning providers.

Edmodo moves the learning process beyond the traditional classroom, offering a free, safe place in which instructors and learners can connect, interact, collaborate, share learning content and access learners' work in an online environment anytime and

Table 5
Technical aspects of the Edmodo M-learning system.

Requirements	Scaling	Comments
Availability	5	Edmodo is one of the world's largest K-12 social learning platforms with over 20 million users. It provides students and teachers with a safe and easy way to connect and collaborate, offering a real-time platform to exchange ideas and share content, homework, grades and school notices. Edmodo is available in English, Spanish, Brazilian Portuguese and Japanese in 90 countries. It supports communication features and online digital storage.
Quick response	4	Edmodo facilitates the uploading, storing and sharing of learning resources in the form of courses, assessments, documents and manuals that complement students' in-class learning. In addition to the guides provided by Edmodo, an excellent support team is available. Edmodo's new search bar is more powerful than ever and makes it easy to find old posts, people to connect with and free standard aligned resources.
Flexibility	5	Edmodo stores an unlimited number of documents in its library (maximum file size 100 Mb), which can be shared with the groups using folders. The Edmodo Library is a tool for storing and managing uploaded documents in many file formats. These can be accessed and edited anywhere and at any time. Students can discuss topics relevant to their classes, share content and ideas with classmates, and complete assignments on this social learning network.
Scalability	4	Edmodo allows educators to harness the power of social media to enhance and customise the platform according to the needs of individual learners. Teachers can customise the classroom experience online and provide students with the necessary tools to collaborate in the classroom.
Connectivity	5	The platform is hosted by Edmodo in San Francisco, and is not able to be installed within individual networks. It is accessed using a web browser. Edmodo is accessible from any browser-compatible device, creating an anytime-anywhere learning environment. Edmodo enables a school or college to easily connect with the class and to instantly collaborate with them. It also serves as a document repository that allows students to gain access to relevant classroom materials 24/7 and to make EFL instruction a continuous process.
Efficiency and performance	5	Edmodo is very fast; it takes less than a minute to post onto the site. Teachers can also easily create and update course materials on their Edmodo site without the need for specialist programmers or designers. The content in their libraries is saved and can be used for multiple groups. It is quick to load and generally very reliable. The code system is clear and effective.
Reliability	4	Implementing the Edmodo login solution is simple and requires little development time. The Edmodo support team is highly responsive, offering both help and suggestions for new features.
Functionality	4	Edmodo gives teachers and students a secure and easy way to post class materials, share links and videos and access homework, grades and school notices. All forms of digital content, including blogs, links, pictures, video, documents and presentations can be stored and shared. Teachers can use Edmodo to send out quizzes and assignments, provide feedback, store and share content in the form of both files and links, maintain a class calendar, conduct polls and send notes and texts to individual students or to the entire class.
Usability	5	Edmodo is well-designed and should enable teachers who are proficient in the use of technology to set it up quickly. Files, photos, and videos can be directly imported to or exported from other iPad apps, making assignment allocation and submission very easy. Edmodo is structured around Facebook in both appearance and function, making it easy for students to adjust to using what they are already comfortable and familiar with. Edmodo can also be used as an peer–peer sharing space in which teachers can network and exchange ideas.
Maintainability	4	Edmodo's back end is substantial and serves all users, pushing frequent updates to content and tracking usage. There is proactive optimisation to ensure the scalability, efficiency and maintainability of the software.
User interface	5	The Edmodo interface resembles Facebook, which makes it instantly popular with students. The number of functions have been kept low to ensure simplicity. No installation on the server is required and there is no hosting interface. It is a social learning platform that offers greater media richness. Edmodo's new version offers a simplified interface and cross-device consistency, making teaching activities easier. The interface is clean, appealing to students and fairly easy to use and navigate.
Security	4	Edmodo allows only students who are invited and possess a unique six-digit code to join and interact with the specific class. It looks similar to Facebook, but is much more private and safe for learning environments as it allows only teachers to create and manage accounts. The interface security is ensured by the use of authentication codes.

Table 6
Evaluation of the applications studied in line with the model.

Dimension	Moodle	Blackboard	Schoology	Edmodo
Availability	5	5	5	5
Quick response	4	5	4	4
Flexibility	4	4	5	5
Scalability	5	4	5	4
Connectivity	3	5	5	5
Efficiency and performance	4	4	4	5
Reliability	5	5	4	4
Functionality	5	4	4	4
Usability	5	3	5	5
Maintainability	4	4	4	4
User interface	4	4	5	5
Security	4	5	4	4
Average	4.24	3.96	4.22	4.32

anywhere.

Edmodo attracts learners and instructors with a social element that resembles Facebook and its valuable learning applications. Designed by instructors, Edmodo enables exceptionally secure cloud-based collaboration. Instructors have full management and control and can limit learners to read-only status if desired (Al-Kathiri, 2014).

The selected mobile learning service platforms are scaled based on various, literature surveys, technical reports, tools documentations, research usage experience, and learners community feedback. The underlying system has gone through qualitative assessment process based on these resources and usage experiences. Then the qualitative assessment process converted to scale form for each model component. For the correct evaluation of these technical aspects, a score has been allocated to each aspect. Each technical aspect is scaled from 1 to 5, whereby score 1 is assigned for less important, score 3 is neutral, and score 5 is assigned to the most important technical aspect.

5. Discussion

Table 6 shows the changes in respondents' indications from different case studies with regards to a model that captures most abstract and generic technical aspects of mobile learning service quality, including availability, quick response, flexibility, scalability, usability, maintainability, functionality, functionality, reliability, connectivity, performance, user interface and security. Most respondents selected Moodle as the most important application from the four different case studies, which were conducted with a representative of the selected technical quality aspects in a cumulative exercise. An average of 4.24 out of five respondents preferred to use Moodle. In conclusion, analysis of the data as shown in Tables 2–5 showed that most of respondents asserted the importance of Moodle as the most important application by assessing all

model components and analysing stakeholders' satisfaction. However, the empirical case studies emphasised that a set of contextual technical quality factors affected the choice of mobile learning application. It was also observed that the application of the proposed technical quality model is twofold:

- Evaluation of the existing M-learning applications.
- Validation, showing the feasibility of the model.

5.1. Evaluation

The four applications were evaluated against the proposed technical quality model to show to what extent each the applications considered the non-functional technical quality characteristics. A summary of such an evaluation is shown in Table 6. As it is more difficult for an application to consider all technical quality characteristics, an average was computed for each of the technical quality characteristics and for each application. The overall average gives a general idea of each M-learning application.

5.2. Validation

The proposed model describes well the technical quality characteristics as non-functional requirements and is applicable to the most known M-learning applications. The column 'comment' in Tables 2–5 shows that all the applications are concerned with the concepts of the proposed model. This is supported by previous research that supports the necessity for M-learning applications to consider these technical quality characteristics alongside nontechnical quality characteristics and functional requirements mainly based on learning. Nevertheless, a model should consider other nontechnical quality characteristics, namely educational, pedagogical and social and business quality characteristics.

6. Conclusion

It is widely acknowledged that mobility and availability are the key barriers to the effective application of e-learning approaches. Whilst the advent and variety of mobile technologies could offer a means of removing these barriers, there is a lack of research that addresses different aspects of mobile learning service quality in the education environment. This study aimed to propose a quality model that captures the most abstract and generic technical aspects of mobile learning service quality. A set of technical quality aspects was developed from a literature study with a focus on learning standards and mobile application software quality and guidelines.

To demonstrate the feasibility of the proposed model, four different four case studies were conducted with the representative selected technical quality aspects in a cumulative exercise. This new non-functional technical quality mobile learning model examined the applications by assessing all model components and analysing stakeholders' satisfaction. The empirical case study investigation highlighted a set of contextual technical quality factors that influence the choice of mobile learning applications. The case studies show the feasibility of using the proposed model to evaluate existing mobile learning applications.

The findings also indicate that there are causal relationships between learner satisfaction and the overall technical quality aspects of the proposed model. The complexity of the quality management process for mobile learning arises from the intersection between different domains, including education, pedagogy, content management, software development and mobile technologies. Despite the resemblance to a software project, mobile learning development and evaluation processes are far more complex and require analysis of components from different fields. This has a further impact on the overall cost of the quality management process. The proposed quality model has a positive impact on overall learning process outcomes by evaluating the technical aspects while maintaining the quality of the mobile learning delivered. Future research could aim to offer a comprehensive and improved specification of the non-functional aspects, including both technical and nontechnical factors, with a shared ontology.

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