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Requirements of Mobile Learning Applications

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Abstract: Mobile learning is gaining high momentum and popularity. In order to develop effective mobile learning applications (MLAs), it is important to consider quality requirements. The MLAs should satisfy the learner's needs while enhancing the learning quality. This paper presents a framework for MLAs requirements, where the mobile learner performs an educational activity supported by context aware adaptations. It presents and analyzes four requirements' dimensions: educational, socio-cultural, economical and technical. Either the teacher, or the learner himself, or the system will select the appropriate parameters for the particular learner at the particular situation.

Keywords: context, educational requirements, human-computer interaction, mobile learning, quality, usability.

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1. Introduction

Currently, e-learning is widely accepted in education (Ahn *et al.*, 2005; Sun *et al.*, 2006), employee skills improvement (Beck *et al.,* 2004), vocational training (Huang *et al.*, 2006), knowledge sharing (Liu and Chen, 2006) among others. The combination of handheld computing and wireless communication with electronic measurement and control provides an enormous potential for education in areas of science and technology (Milrad *et al.*, 2004). It is recognized that the integration of mobile devices, wireless communication and networking technologies into the education environment could enhance the learning (Weiser, 1998; Vasiliou and Economides, 2007). Mobile devices enable the teacher and students to utilize computing power anytime and anywhere (Economides and Nikolaou, 2007). They can even be used for testing the students on the move (Triantafillou et al, 2007). Using the Internet and wireless technologies they interconnect with other computing devices seamlessly.

Recent empirical studies have suggested the advantages of using wireless technologies and mobile devices in learning environments, including enhanced availability and accessibility of information networks (Gay *et al.*, 2001). Just-in-time and situated learning provides many educational benefits (Goodyear, 2000). The usage of PDAs (Personal Digital Assistants) in field studies can increase student motivation and outcome-based appropriate assessment opportunities (de Crom and de Jager, 2005). Inquiry learning processes can be successfully integrated into daily school work (Mattila and Fordel, 2005). A pupil may outline his or her thoughts on the current topic, collect information and observations from the surroundings and report the findings in the network-learning environment.

Evaluation of a general architecture of a mobile Web-based distance learning service for interactive outdoor learning confirmed the adequacy of the approach (Roccetti at al., 2001). Teachers and students showed positive attitudes towards the acceptability, affordability and functionalities of a mobile system that provides news, help, classified ads, academic, financial, library and account services to both teachers and students (Chen and Kinshuk, 2005). Teachers could monitor web-based learning activities as well as help learners to efficiently promote learning interests and performance (Chen *et al.*, 2005). Also, students with PDAs explored woody plants in the school garden, and they became more interested in learning (Lai *et al.*, 2005). Students readily engaged with a participatory simulation about the spread of a virus (Collella, 2000). They successfully collaborated to answer the relevant questions and found it to be a rewarding and stimulating experience. Mobile technologies have been also used for language learning (Kadyte, 2003; Thornton and Houser, 2004; Collins, 2005; Shih, 2005).

Handheld-centric classroom supported: ready-at-hand writing, increased motivation, collaboration and document sharing, instant feedback, learning-in-context, managing multiple resources, ongoing assessment, progress monitoring, parent involvement, and communication (Norris and Soloway, 2004). Context in mobile learning has been investigated in several studies (Lonsdale *et al*., 2003; Nyiri, 2002; Lai *et al*., 2005).

Wireless Internet learning devices will likely become available in the same price range as today's Palm devices, and include short-range wireless networking (Roschelle and Pea, 2002). These technologies will support students working towards shared understanding in groups, thus building joint representations of their knowledge. An e-learning platform for mobile students allowed guided discussions, team activities, information access information and communication anytime, anywhere and from arbitrary device types (Hummel *et al.*, 2002). Interactivity (e.g. brainstorming, a quiz, voting) on mobile devices is important in mobile learning (Dawabi *et al.*, 2003). Mobile learning has also been adopted by mobile professionals using 3rd Generation cellular networks to deliver mobile high quality multimedia (Hardless *et al.*, 2001). Handheld computers were used as tools to aid in research, alternatives to paper-based tasks, group collaboration activities by students at four different Michigan schools (Curtis *et al*., 2002).

Mobile learning would be used to collect on-site instant data as well as real-time working experience in business learning (Seng and Lin, 2004). Handheld PC could also be used as data collection, management, and analysis tools (Spinuzzi, 2003). Students used handheld-based probes to collect and analyze data in real time and compared it instantaneously with data from different locations (Milrad *et al.*, 2004). This experiment augmented inquiry-based investigations with real-time data and visualizations, which in turn increased the students' engagement. Characteristics of mobile communication for e-learning and requirements for mobile e-learning platforms were discussed in (Kurbel and Hilker, 2002). A business perspective was also considered for adopting m-learning (Petrova, 2007).

The exponential increase of the research and development on mobile learning applications (MLAs) is due to the promising freedom from traditional class restrictions. Despite this delirium, little work exists on developing a common framework for evaluating the quality of these MLAs. Quality includes the characteristics of the MLAs that bear on their ability to satisfy the student's needs. Usability and student satisfaction are extremely important for effective MLAs. Evaluation of MLAs is needed to justify the investment and select the most appropriate ones. It is important to evaluate the quality of MLA in various contexts of use. For example, does the MLA motivate the learner? Does it provide accurate knowledge? Does it support collaboration? Is it reliable? Is it easy to use on transit? Is it effective? Does it adapt to the learner and the environment?

In this paper, we investigate the requirements for MLAs. For the technical requirements, we are inspired by the ISO/IEC 9126 standard for software quality which we also extend. By establishing and maintaining standards, institutions can more effectively reengineer their learning programmes to deliver high quality online education (Haugen and Behling, 2006). In addition, we consider the educational, economical and socio-cultural requirements. We have incorporated ideas from various research areas on pedagogical theories, adaptive learning (Economides, 2006), usability, human-computer interaction, mobile applications, quality standards, and software and system design. In the next section 2, we describe the stages of mobile learning adaptations. In section 3, we describe the mobile learning requirements. Finally, in section 4, we conclude and suggest further research directions.

2. Stages of mobile learning adaptations

We consider that in mobile learning "the mobile learner performs an *Educational Activity* supported by *Adaptations* which are based on *Learner's State, Educational Activities, Devices and Environment's Awareness*". The learner may have physical (pragmatic reality via mobility), virtual (augmented reality via the device) and collaborative (synchronous or asynchronous) educational experiences at any place and time. These educational experiences may be formal or informal. The learner learns autonomously or collaboratively useful knowledge that makes sense to him. He is supported by a smart "device". This device may be handheld (mobile phone, PDA, smart phone, palm PC, pocket PC, pen tablet PC, tablet PC, etc.), wearable or holographic (keyboard, screen, etc.).

The states of the learner, his device, the educational activities, and the environment are time varying. They are changing over time influencing and influenced by each other.

The mobile learning application (MLA) receives measurements on various parameters about the learner (e.g. his performance, location, deadlines), his devices (e.g. speed, memory, protocols), and the environment (e.g. weather, networks, resources). It also has information about the educational activities. Then, it estimates and infers about the true state of the learner, his devices and the environment. Based on this state estimation, it decides to adapt various parameters (e.g. its educational content, presentation, difficulty level). Finally, it implements these adaptations and evaluates the results.

So, we consider as stages of the mobile learning the following:

1. Monitoring, Sensing, Detection, Tracking and Measurement of the learner, devices and environment.
2. Estimation, Prediction and Inference of the learner's, devices, and environment's states.
3. Adaptation.
4. Implementation of the Adaptations.
5. Evaluation & Assessment of the Adaptations' Implementation.

In order to successfully design, develop and evaluate such diverse MLAs, we need to describe requirements. The next section deals with this.

3. Mobile learning requirements

In this Section, we present the mobile learning requirements along four dimensions: A) Pedagogical, B) Socio-Cultural, C) Economical and D) Technical. We develop this framework based on personal experience on developing and evaluating e-learning applications, input from colleagues, the ISO 9126 software quality standard and the literature on evaluation of human-computer interaction, e-learning, e-commerce, and mobile learning applications. Next, we analyze each one of these dimensions:

A. Pedagogical requirements

The Pedagogical requirements are categorized into the following areas: 1) Learning theories, 2) Instructional Design models, 3) Content Quality, 4) Content Comprehensiveness & Completeness, 5) Content Presentation, 6) Content Organization, 7) Student Support & Feedback, and 8) Control (Chart 1).

(Insert Chart 1 about here)

Regarding the *Learning theories*, various learning and didactic theories (e.g. constructivism, behaviorism, cognitivism, social learning) should be incorporated into the MLA. For example, based on constructivist learning, there should be projects which require that the learners collaboratively construct an educational object. Also, based on situated learning, there should be additional educational material when the learner approaches a specific location (e.g. museum artifact).

Regarding the *Instructional Design models*, various instructional design models (e.g. analyze, design, develop, implement, evaluate) should be included into the MLA. For example, there should be exercises on evaluation and comparison of various theories so that the learners' evaluation abilities are enhanced.

Regarding the *Content Quality*, it should be valid, trustworthy, and accurate. It should be based on currently acceptable theories that will survive for a long time. It should be useful and appropriate for the indented educational objectives, ages and level of learners. It should objectively present a variety of "points of view" without discriminating with respect to age, gender, race, religious, political ideas etc. It should provide experiential opportunities based on pragmatic cases. It should also motivate the learner.

Regarding the *Content Comprehensive & Completeness*, it should cover all main topics, ideas and key points at all levels, at the right quantity for mobile learning (restrictions due to screen size, memory etc.).

Regarding the *Content Presentation*, it should be based on a variety of media (e.g. text, picture, image, graphs, diagrams, audio, video, immersion) of high quality (e.g. resolution, number of colors, refresh rate, sound fidelity, mono or stereo sound). There should be the right mix of media objects at the appropriate positions in the content.

Regarding the *Content Organization*, it should be simple, modular and flexible. There should be a variety of alternative content's organizations for different learners (e.g. sequential vs. random learner) and situations. It should be easy to navigate providing many navigation tools (e.g. Table, Map, Directories). Its structure should be intuitive, logical and appropriate for the learners (e.g. age) and the educational activities. There should be few navigation levels (i.e. small tree depth) in order the learner not to be lost. The sequencing among the modules should be proper and important topics should have priority.

Regarding the *Student Support & Feedback*, the MLA should support the learner and react to his actions at the right quantity at the right moment. The feedback would aim at informing (e.g. advising on content, helping on assessment, guiding or navigation, supporting on collaboration, notifying on events and activities), alerting (e.g. reminding on deadlines, warning on danger), or motivating (e.g. attracting learner's attention, stimulating, challenging, provoking, building confidence, assuring, encouraging, praising, relaxing) the learner. There should exist a variety of support facilities (e.g. searching, communication, collaboration, sharing, glossary, dictionary, FAQ, bibliography, references, links, help, documentation).

Regarding the *Control*, various Control levels among the learner, the teacher and the system should be possible. For example, the learner may have the option to overtake control over the educational activity ignoring any suggestions of the system. Also, various educational tools should be provided to the learner and the teacher (e.g. content designing, creating, and organizing; learner monitoring, instructing, tutoring, evaluating, and recording) to use without requiring to know programming.

B. Social-Cultural requirements

The Socio-Cultural requirements are categorized into the following areas: 1) Acceptability, 2) Social Interaction methods, 3) Sociability, 4) Attitude, 5) Visibility & Observability, 6) Trust, Privacy & Intellectual Property, and 7) Fashion (Chart 2).

(Insert Chart 2 about here)

Regarding *Acceptability*, the MLA should be open to various social, cultural, racial, political, and religious values and ideas. It should not discriminate with respect to age, gender or health issues. It should support the value of tolerance and learning.

Regarding the *Social Interaction methods,* the MLA should support various Social Interaction and Communication modes and styles (e.g. formal – informal, visual - oral), communication flexibility and multilingualism (e.g. using translators).

Regarding *Sociability,* it should promote and support the learner in socialization, active participation, relationships development, cooperation, sharing, friendship, mutual understanding, and responsibility. It should support the social cohesion and collaboration.

Regarding *Attitude*, it should enhance the learner's self-efficacy, self-esteem, confidence, and commitment. It should motivate the learner to learn.

Regarding *Visibility & Observability*, there should be no secret activities occurring. All data, activities, decisions and applications should be visible and available to the learner whenever he requests them. For example, there should be no secret monitoring and recording of the learner's transactions.

Regarding *Trust, Privacy & Intellectual Property,* the learner should trust it that none will have access to his data, records, activities, results, achievements etc. without his authorization. His privacy and intellectual property should be assured.

Regarding Fashion, the MLA can not ignore the current socio-cultural trend. So, it should be "trendy".

C. Economical requirements

The Economical requirements are categorized into the following areas: 1) Various Costs & Economic Feasibility, 2) Cost-Effectiveness, and 3) Service Level Agreement (Chart 3).

(Insert Chart 3 about here)

Regarding its *Various Costs & Economic Feasibility,* the costs at various stages of the MLA's lifetime should be kept low. So, the costs of developing or buying, operating, repairing, upgrading and replacing it should be low. All costs during the MLA's lifetime should be considered together. It should be economically feasible to implement and operate the MLA. There also possible health (e.g. addiction, eye problems), environmental and quietus (termination) costs and risks that should be considered.

Regarding its *Cost-Effectiveness*, the MLA should achieve the intended results and benefits at the lowest possible cost compared with alternative applications with the same intended results. The achieved benefits (e.g. improved learner's learning, satisfaction, abilities) should surpass its costs.

Regarding its *Contracts*, there should be various types of Contracts, SLA (Service Level Agreement) or Licenses to choose from. For example, a diversification may be respect to the number of participants, the content quantity, the features, etc. Important parameters to consider are their flexibility, duration, visibility, awareness, discounts (e.g. with respect to the number of users, number of courses) and guarantees.

D. Technical requirements

For the Technical requirements, we are inspired by the ISO/IEC 9126 standard for software quality. This standard defines six software characteristics: Functionality, Reliability, Usability, Efficiency, Maintainability, and Portability.

In this paper, we consider the following 8 technical areas: User Interface, Functionality, Awareness, Adaptation, Reliability & Maintainability, Efficiency & Performance, Connectivity, and Security (Chart 4).

(Insert Chart 4 about here)

D1. User Interface

The requirements for the User Interface are categorized into the following areas: 1) Usability, 2) Layout & Organization, 3) Media, 4) Navigation & Orientation, 5) Effectiveness, 6) Accessibility, 7) Help, and 8) Personalization (Chart 5).

(Insert Chart 5 about here)

Regarding its *Usability,* it should be easy to understand, learn, remember and use its functions. It should be simple and convenient to operate (e.g. minimum number of clicks to find and display information, minimum number of scrolls to display information). It should neither distract nor cognitively overload the learner. Rather, it should attract the learner's attention and focus.

Regarding its *Layout & Organization*, it should be simple and intuitive to use. Its design should be aesthetically attractive, pleasant and fun to use. The background, menus, toolbars, buttons, icons etc. should be simple and rational. They should appear in a consistent and uniform way. The number of menu levels and choices per level should be appropriate.

Regarding its *Media,* various media types (e.g. text, audio, video, immersion) of high quality and fidelity should be supported. They should appear at the right mix and position. For example, audio guidance is a suitable interactive method for mobile learning.

Regarding its *Navigation & Orientation*, it should be easy, simple and intuitive to navigate. They should be accurate and consistent. There should be alternative ways of navigation (e.g. shortcuts) with proper number of levels. It should offer many navigation & orientation facilities (e.g. sitemap, index, next, previous, home, exit, undo, redo, history trail, prediction, save, print).

Regarding its *Effectiveness*, it should provide useful, appropriate and meaningful means to increase the user productivity.

Regarding its *Accessibility*, it should be as usable as possibly by as many people as possible regardless of age, ability or situation. It should support various languages and modes of communication. It should support persons with special needs (e.g. screen magnification/ zooming, speech-to-text and text-to-speech translation).

Regarding its *Help,* it should offer various forms and tools to support the user. The search engine should provide complete, accurate and relevant results. There should be various and useful directories and indexes. There should be schedulers, dictionaries, FAQ, etc.

Regarding its *Personalization*, it should be aware of the user and the environment, predicting any changes and actions, and be tailored to the individual user. For the same conditions similar personalization should be achieved. The responses to any change should be transparent to the user, immediate and effective. For example, if there is not adequate daylight then the screen may lighten. The user may have various levels of control over it.

D2. Functionality

The requirements for the Functionality are categorized into the following areas: 1) Variety, 2) Quality, and 3) Interactivity, Communication & Collaboration (Chart 6).

(Insert Chart 6 about here)

Regarding its *Variety* of functions, the MLA should offer many features to deal with various situations. These features should cover as many as possible cases. For example, it should support mobility almost anywhere (e.g. deep canyons, high mountains, out-of-sight communication), for large coverage areas, at any mobility speed.

Regarding its *Quality*, the functions should be useful and suitable for the educational objectives, the learner and the situation. They should be simple and self-explanatory. They should provide to the learner flexibility and convenience at the right moment. For example, if a 10Mbps link is unavailable, the next best link is accessed. They should be not only innovative but also mature and stable. They should be autonomous and self-contained. Multiple functions should be able to run concurrently with no interference among them. Their operation should be transparent and invisible to the learner. Finally, it should anticipate the learner's needs or future actions and support them.

Regarding its *Interactivity, Communication & Collaboration*, it should offer various communication modes (e.g. synchronous or asynchronous; user-to-device or user-to-user; one-to-one, one-to-many, many-to-one). Synchronization and coordination among media, features, applications, devices and networks are also very important.

D3. Awareness

The MLA should know information about the following areas: 1) Learner's State, 2) Device, 3) Activities, 4) Teams, and 5) Environment (Chart 7). Then it is adapted according to this information.

(Insert Chart 7 about here)

Regarding the *Learner's State*, the MLA should be aware of the learner's cognitive, social, affective, conational and physical state. The parameters that describe the learner's state can be declared by the learner himself, or can be estimated by his answers to appropriate questionnaires, or can be measured by devices. Research on affective computing manages to recognize and measure emotions using sensors, such as body-worn accelerometers, rubber and fabric electrodes, miniature cameras and microphones, and garment or accessory-type devices, along with pattern recognition algorithms of facial expressions from video or/and vocal expressions or of stress patterns from thermal imagery of the face and other physiological measures (Picard, 1997; Klein *et al.* 1999; Bickmore and Picard, 2004). Recognition (81% accuracy) of eight emotional states of a human given four physiological signals has been achieved (Picard at al., 2001). For example, it should know whether he is visual or verbal; concrete or abstract; explorer or assimilator; active or passive; happy or sad; enthusiastic or bored; motivated or discouraged, etc. It should know his demographics, age, gender, language, nationality, history, and religion. It should know his background, education, profession, experiences, and skills. It should know his objectives, aims, expectations, plans, interests, and preferences. It should know his abilities, proficiencies, strengths, weaknesses, performance, and achievements. It should also be aware of his current availability status and duration, current location (GPS and altitude) and his mobility pattern. It should be aware of his speed and duration on every section of his route, where he stopped and for how long, what is the reason of moving (e.g. wondering, traveling to reach a destination, looking for something) and what restrictions exist. For example, it is important to know if the learner has the strength and will to walk further, if he is scared or enjoys the educational activity.

Regarding the *Device*, the MLA should know every moment what is the available processing power, free memory capacity, remaining battery lifetime, and the input/ output capabilities.

Regarding the *Activities*, the MLA should know the status of the active applications and activities, their objective, their participants, their duration, their pricing, resources and tools consumed, being used and remaining, as well as their achievements. It should be aware of who else is sensing, tracking and collecting information about the learner. It should be aware of the various security restrictions on the learner awareness states and resources imposed by the learners or the system. Also, time awareness issues are extremely important. For example, it should know the learner's deadlines, time availability, scheduled activities (e.g. meetings, events, classes, homework, projects, exams, to-do-lists), bookings, reservations, etc.

Regarding the *Teams*, the MLA should know information about the teams where the learner belongs. It should be aware of the number of members in each team, the roles of its members, the relationships of its members, the state for each member, the communication/ interaction among the members, and the activities of each team.

Regarding the *Environment*, the MLA should be aware of the terrain, the weather, the available infrastructure and resources. More explicitly, it should be know if the learner is moving in an urban, rural, wilderness, desert area, if he is on land, sea or air, etc. Awareness and prediction of the weather (e.g. temperature, humidity, wind speed and direction, atmospheric pressure), the light and noise conditions are also important. Available hardware (e.g. networks), software (e.g. databases), services (e.g. health) and other (e.g. gas station) resources in the learner's system and vicinity (real or virtual) are also essential to be known. It should also have information about the network's coverage, connectivity and technology (e.g. GSM, GPRS, UMTS, IEEE 802.11, IrDA, Bluetooth, WiMax, Microwave, and Satellite). For example, Bluetooth (Davidrajuh, 2007) and MANETs (Mobile Ad hoc Networks) (Vasiliou and Economides, 2007) have been proposed for m-learning. The network's performance QoS (quality of service) and reliability measures (e.g. available bandwidth, average packet delay, packet delivery ratio) are also necessary to be known. Finally, information about other persons in the neighborhood is also useful. For example, how many neighbors exist, what are their states, roles, relationships, interactions and activities.

D4. Adaptation

After becoming complete aware of the situation, the MLA adapts its features to the awareness state. In order to be successful, the adaptation should satisfy the following requirements areas: 1) Variety of adaptation, 2) Awareness Parameters, 3) Usefulness, 4) Transparency, 5) Accuracy, 6) Consistency, 7) Flexibility, and 8) Speed (Chart 8).

(Insert Chart 8 about here)

Regarding the *Variety of adaptation*, various parameters of the MLA's educational, socio-cultural, economical and technological context should be adapted according to the awareness parameters. For example, the educational content, organization, presentation, navigation, feedback, and assessment should be tailored to the learner's state, performance and achievements. The socio-cultural context of conversation (e.g. formal or informal) among a learner and a teacher is tailored to their state. The economical context of operation (e.g. economical or expensive communication lines) is tailored to the need for low or high communication quality. Transmitting a video through a low bandwidth network may require decreasing the video's quality, changing the image size, resolution, or number of colors.

Only these parts of the MLA that change are down/up-loaded, e.g. the content of a frame. Adapting the content to a small screen handheld may require abstract viewing (instead of the whole page) or stretch text.

Regarding the *Awareness Parameters*, the Adaptation should be based on various awareness parameters (see Section D3). Being completely aware of the situation, the adaptations would be better.

Regarding *Usefulness*, the adaptations should be useful and appropriate for the given situation. They should effectively support the learner and the educational activities.

Regarding *Transparency*, the adaptation should be transparent and invisible to the learner. He should not be bothered unless he would like to select the adaptations by himself.

Regarding *Accuracy*, the adaptations should be correct, accurate and precise.

Regarding *Consistency*, similar awareness state should produce similar adaptation results.

Regarding *Flexibility*, the adaptation should be flexible and adjustable. If an exact match cannot be found an approximation should be given. Also, there should be prioritization among the parameters' importance in case of constraints or conflicts.

Regarding the Speed, the faster the adaptations the better the operation.

D5. Reliability & Maintainability

The requirements for the Reliability & Maintainability are categorized into the following areas: 1) Error Free, 2) Error Recognition & Prevention, 3) Fault Tolerance & Recoverability, 4) Availability, 5) Installation easiness, 6) Maintenance easiness, 7) Reconfiguration easiness, 7) Upgrade easiness (Chart 9).

(Insert Chart 9 about here)

Regarding its *Error Free,* the MLA operation should be correct and accurate with no errors (faults). It should correctly sense, estimate, and adapt according to the awareness parameters. Its operation should be consistent and similar states should be treated similarly. For example, learners at the same performance level should be taken assessments at the same difficulty level.

Regarding its *Error Recognition & Prevention*, the MLA should continuously monitor its state. It should be easy and fast to analyze and test its state. If an error or fault happens, it should recognize its existence and its source. Then, it should make correct diagnosis of the error. It should also prevent errors that may occur, for example measurement errors due to "noise" or interference.

Regarding its *Fault Tolerance & Recoverability*, any errors that cannot be prevented should be easily repaired with minimum effort and resources at the minimum time. The MLA should be able to continue valid operation in case of fault or failure of some of its parts. The repair should be transparent to the learners. No data or other useful resources should be lost in case of error. No data discrepancies should occur due to hardware faults (e.g. power off, communication disconnection). The duration and the cost of the interruption should be minimal. It should handle any unexpected case and should resist to malicious attacks. It should not be stacked in a deadlock situation. Its operation should be stable and consistent with minimal transient phenomena.

Regarding its *Availability*, the MLA should always be available in any environment. It should survive at most extreme situations keeping on its integrity.

Regarding its *easiness of Installation*, it should be easy and fast to install at any appropriate device or system.

Regarding its *easiness of Maintenance*, it should need minimal effort and time to maintain its efficient operation.

Regarding its *easiness of Reconfiguration*, it should be easy, unproblematic and fast to reconfigure or replace parts in case of changes in its scope and operation. Self-tuning would be appreciated.

Regarding its *easiness of Upgrade*, it should be easy and fast to revise and upgrade it.

D6. Efficiency & Performance

The requirements for the Efficiency & Performance are categorized into the following areas: 1) Responsiveness, 2) Communication Bandwidth (BW), 3) Memory Storage, 4) Energy Consumption, 5) Input, and 6) Output (Chart 10).

(Insert Chart 10 about here)

Regarding its *Responsiveness*, its response to a change (learner's action, environment's change, etc.) should be fast and appropriate. For example, when the system detects that the learner enters a specific area a message is transmitted to him immediately. There should be no delays in responding to the learner's requests and communications. The learner should not notice any delays. The delay of processing, storing, communicating data should be smaller than the threshold for efficient application deployment. For example, the delay of transmitting voice should be smaller than a threshold. Also, the processing unit should be utilized efficiently.

Regarding its *Communication Bandwidth*, the MLA should utilize the BW efficiently. Also, in case of not available enough BW, it should adjust its operation to the available BW.

Regarding its *Memory Storage,* the MLA should utilize it efficiently. Memory management techniques may be used to increase the performance.

Regarding its *Energy Consumption*, the MLA should not consume a lot of energy. Energy conservations techniques may be applied to save energy when no activity is taken place. It is important to have long energy autonomy in mobile learning.

Regarding its *Input,* the MLA should accept data and services efficiently. It should utilize the input devices in the best possible way. For example, the quality of the transmitted audio packets should be the best possible for the available BW.

Regarding its *Output*, the MLA should provide data and services efficiently. It should utilize the output devices in the best possible way. For example, the quality of the displayed images should be the best possible for the available screen size and resolution, energy, etc.

D7. Connectivity

The requirements for Connectivity are categorized into the following areas: 1) Openness, 2) Standards Conformance, 3) Portability, 4) Transparency, 5) Scalability, 6) Variety, and 7) Autonomy (Chart 11).

(Insert Chart 11 about here)

Regarding, its *Openness*, it should be advisable to adhere to open architectures.

Regarding its *Standards Conformance*, the MLA should comply with international standards. It should be compatible and easy to work together with other standard-based applications, data format, databases, devices, networks, platforms, etc.

Regarding its *Variety of connectivity*, it should support as many different data and systems as possible. For example, it would support various multimedia format (e.g. Tivo, WMN, DivX, MPEG, AVI, RealMedia), operating systems (OS) (e.g. Window Mobile, Palm OS, Symbian OS), devices, browsers, communication protocols (e.g. IEEE 802.11x, GPRS- General Packet Radio Service, UMTS- Universal Mobile Telecommunication System).

Regarding its *Portability*, the MLA should easily import from and export to other systems data and services. Also, the whole MLA as well its modules should be easily reused by other systems.

Regarding its *Transparency*, its operation should be transparent to the learner. The modules of the MLA should be seamlessly integrated. The MLA should be harmonious interconnected with other applications. It should concurrently operate with other applications without any interference. All data and services exchange among the applications should be done without any learner's effort and worry.

Regarding its *Scalability*, it should be easy to increase the number of supported learners, data, mobility patterns, areas, and services. It should be easy to extend and expand the MLA. It should be easy to add or remove modules, features and services.

Regarding its *Autonomy*, the MLA should require minimum resources and extra hardware and software (e.g. plug-ins) to operate.

D8. Security

The requirements for Security are categorized into the following areas: 1) Security Completeness, 2) Security Levels, 3) Privacy, and 4) Security Control (Chart 12).

(Insert Chart 12 about here)

Regarding its *Security Completeness*, the MLA should incorporate current, updated security technologies (e.g. firewalls, access control, authorization, authentication, certification, encryption, cryptography, tunneling, anti-virus, anti-spam, anti-spy). These security technologies should completely protect the access, storage and communication of the data and applications. For example, security protocols (e.g. Baltimore Cyber Trust Root, GTE Cyber Trust Global Root, RSA Data Security, Testing ACS Root, Thawte Premium Sever CA, Thawte Server Ca, VeriSign Class 1, 2, 3 ,4 Public Primary Certification Authority) protect some current handheld devices.

Regarding its *Security Levels*, it should support multiple levels of security for different users and resources. It should ensure that legitimate users are able to perform what they are allowed to do.

Regarding its *Privacy*, it should support the user's confidentiality, anonymity, privacy and trust. No unauthorized person will have access to the user's data, work and results. Also, he should be able to hide his identity.

Regarding its *Security Control,* the user should have control over his data, applications and resources. He should control what personal information (e.g. his identity, his position, his test score) would be available to others.

4. Conclusions

In order to maximize the utility of a mobile learning application (MLAs), it is important to consider all critical factors that affect its quality. This paper is a first step towards providing insights on key areas of MLAs. The learner should be at the core of the MLAs. Every effort should be made to support the learner in gaining the most from quality learning. The learner should achieve the specified educational objectives with accuracy and completeness, being satisfied and using the resources efficiently. This paper describes requirements for student-centred MLAs.

It is not an easy task to define requirements, since they involve a lot of complexity. It is not possible to provide specific metrics that satisfy all possible MLAs for all possible users, devices, activities and environments. In order to cope with this complexity, this paper provides requirements for a general MLA at an abstract level. This paper extends the ISO/IEC 9126 standard for software quality to incorporate pedagogical, socio-cultural and economical requirements. Each of these general dimensions is decomposed into specific areas. Each specific area is further analyzed.

These requirements may help in the design and development of MLAs. New features and opportunities may be discovered, risks and obstacles may be avoided. They may also facilitate the testing of the MLA's reliable and efficient operation. They may be useful in determining the strengths and advantages, as well as the limitations, disadvantages, ambiguities and drawbacks of the MLA. They may also assist educational organizations to reliably evaluate and compare various MLA in order to select the most appropriate for a given educational scenario and objective. They may serve as guidelines for the successful adoption of suitable MLA to satisfy the learners' needs considering not only technical but also educational, socio-cultural and economical perspectives. Incorporating in the education MLAs that support such requirements may enhance the learning and satisfaction of the students. They may help to increase the students' engagement, motivation, learning, proficiency, and abilities.

This paper is a first attempt to address important parameters that affect the utility of a MLA. Further research may investigate particular metrics for every parameter for a specific MLA. For example, the response time should be less than 100 msec. Although ISO/IEC 9126 is a standard currently used in the software industry, the development of a specific MLA based on all proposed requirements would be desirable. Then it would be possible to validate its usefulness and determine flaws, weak, overlooked and missing issues. Current limitations on the accuracy of positioning systems, the devices' battery lifetime, the devices' screen size, the input and output methods, the devices' reaction speed would be addressed. Furthermore, it may happen that not all requirements would be concurrently satisfied for a particular MLA. Then, priorities among the requirements should be assigned.

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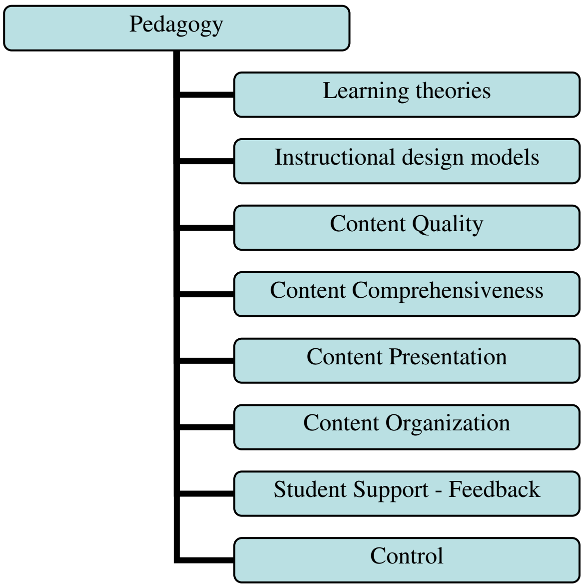

Chart 1: Pedagogical requirements.

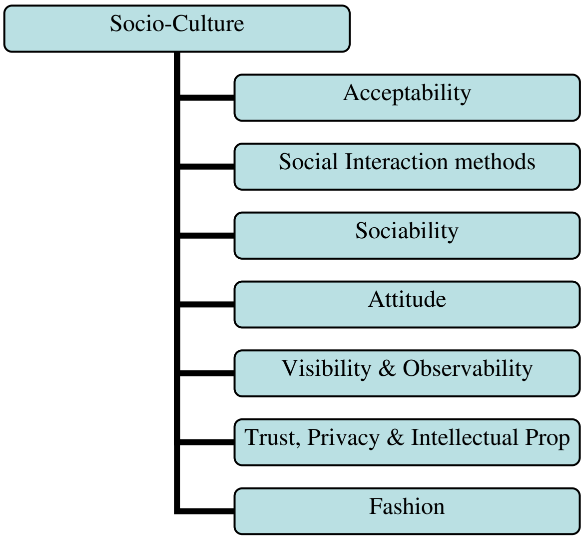

Chart 2: Socio-Cultural requirements.

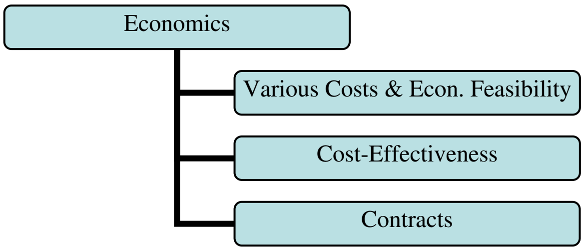

Chart 3: Economics requirements.

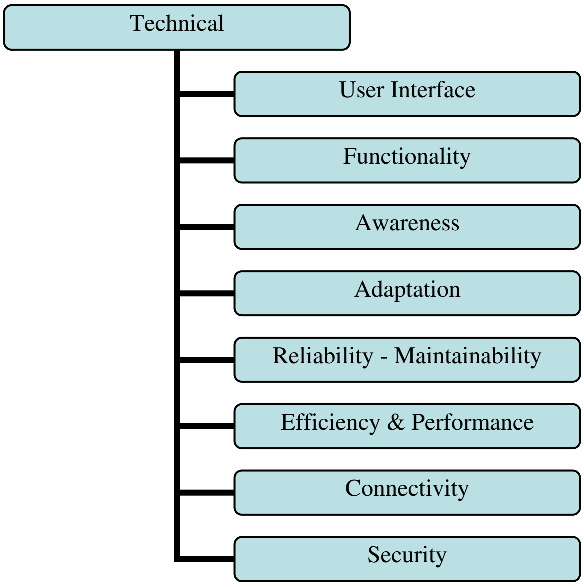

Chart 4: Technical requirements.

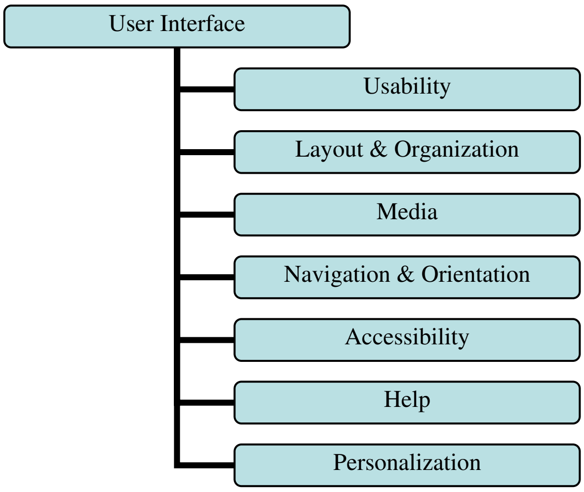

Chart 5: User Interface requirements.

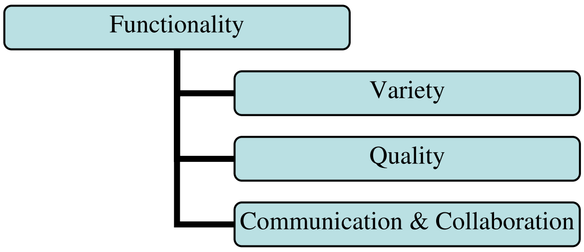

Chart 6: Functional requirements.

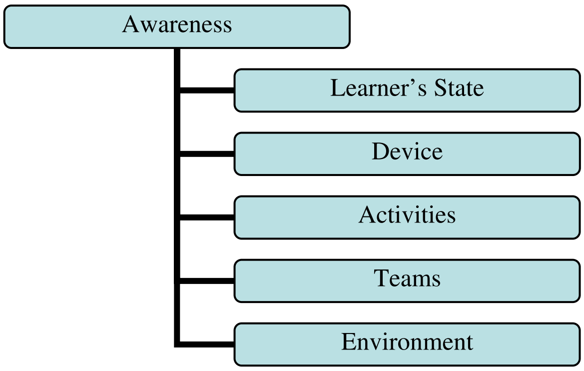

Chart 7: Awareness requirements.

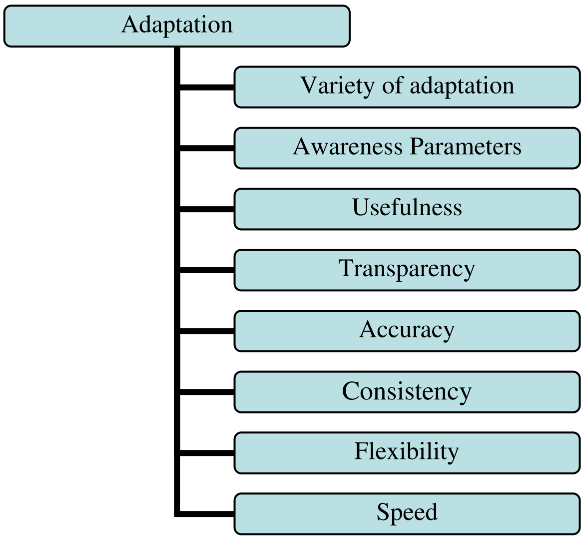

Chart 8: Adaptation requirements.

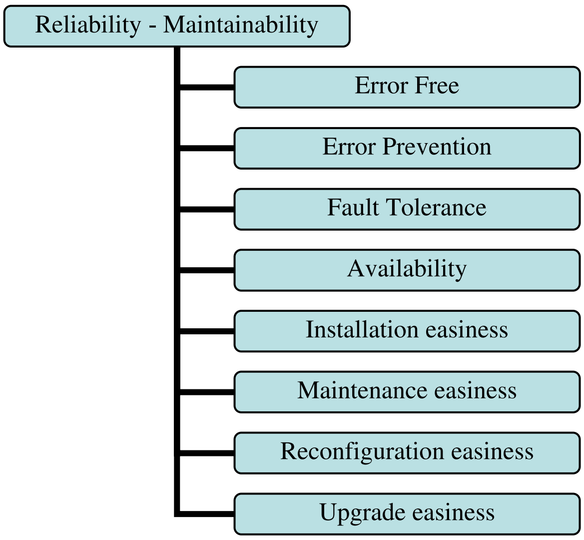

Chart 9: Reliability and Maintainability requirements.

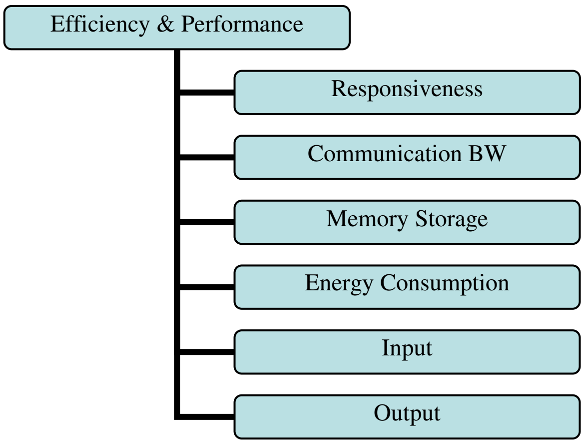

Chart 10: Efficiency and Performance requirements.

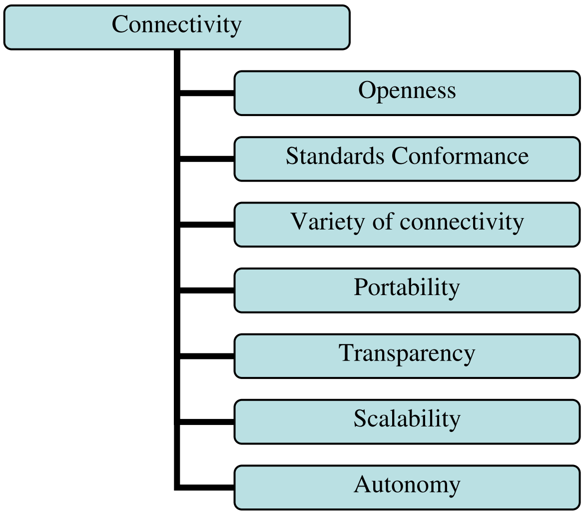

Chart 11: Connectivity requirements.

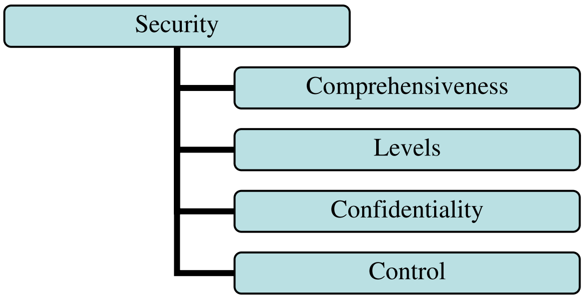

Chart 12: Security requirements.