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Evaluation of Handheld Devices for Mobile Learning

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Abstract- Many educational organizations start using handheld devices for learning. The aim of this paper is to identify the current status of handheld devices and their appropriateness for mobile learning. First, it presents handheld devices requirements for mobile learning. Then it presents a framework for evaluating handheld devices in relation to mobile learning. It evaluates current handheld devices using the evaluation criteria and records the state of the art. Finally, it identifies the strengths and weaknesses of current handheld devices and suggests technical specifications appropriate for mobile learning.

Keywords: communications, evaluation, handheld device, mobile device, mobile learning, requirements, usability, quality, technical specifications.

1. INTRODUCTION

Recently, there is a huge market of handheld devices. According to Gartner [1], the worldwide PDA (Personal Digital Assistants) market (excluding smart-phones) reached a record 14.9 million units shipped in 2005, up 19% from 2004. Research In Motion (RIM) became the No. 1 PDA vendor based on worldwide shipments in 2005 as it accounted for 21.4 % of total shipments. Its shipments in 2005 (3.19 million PDAs) increased 47% from 2004. Palm shipped 2.77 million PDAs in 2005, down 25 % from 2004 shipments. Microsoft Windows CE was the No. 1 PDA operating system (OS) in 2005 as 7.05 million PDAs were loaded with the OS, up 33% from 2004 shipments of 5.28 million units. Palm OS PDA shipments declined 34% to 2.96 million units in 2005.

However, there is a shift from standalone handhelds to converged smart mobile devices. According to Canalys [2], the smart mobile devices market increased 105% from the second quarter of 2004 to that of 2005 (12 million devices in Q2 2005) and 75% from the third quarter of 2004 to that of 2005 (13 million devices in Q3 2005). The most popular OS was Symbian (62.8%). Standalone handheld shipments fall 18%, while converged devices more than double in volume. Leader Nokia ships record 7.1 million smart phones, up 142% year-on-year. Particularly successful were its 3G Symbian Series 60 based smart phones, including the Nokia 6680, 6630, N90 and N70.

According to Yahoo! [3] there are 2 billion mobile phone users around the world. China's mobile phone market, already the world's biggest, has passed 400 million users (Xinhua News Agency - Associated Press, February 23, 2006). The wireless industry association, CTIA, estimates that there are approximately 204 million cellular phone users in the United States.

Currently, there are about 5 million mobile e-mail users in U.S. [4]. However, there will be 100 million mobile e-mail users in four years according to Dave Grannan, general manager of mobile E-mail at Nokia's Mobility Solutions. Also, Yankee Group [5] predicts the US consumer Internet telephony market will explode from 130,000 subscribers at the end of 2003 to 17.5 million subscribers in 2008. Internet connectivity at 19.2 Kbps via mobile phones is widely available. So, there is a major spreading towards mobile Internet. A handheld device with Internet connectivity will make available to the user Internet applications such as email, chat, Web, search, VoIP (Voice over Internet Protocol) etc.

Although various names (e.g. PDAs, Pocket PCs, Palmtops, Smart-phones, etc.) exist to describe various types of handheld devices, this paper aims at investigating handheld devices that would be appropriate for mobile learning. In this paper, the term handheld device means a device that can be easily carried by a student and has the following multimedia functionalities: i) information and knowledge access, process and storage, ii) communication (synchronous and asynchronous), iii) entertainment and amusement (e.g. games, music, video, radio, TV, etc.), and iv) organisation and management (e.g. scheduling, planning, calendar, address book, calculator, etc.).

Using these handheld devices, the users can confront any situation as it happens instead of postponing it until they reach their office, home, school etc. This real-time situation confrontation let them solve problems as they happen. However, it also puts a stress on them, since they ought to be continually alert. So, is it better to take care of various business and social obligations and through out the day, rather than batching all the messages and responding later upon returning to one's workstation [6]? In addition, the handheld devices can be used in education. Many pilot programs in education investigate the educational value of handheld devices. They can aid in research, support collaborative activities and increase student to student interaction [7]. Surveys showed that students preferred using handhelds PCs over other alternatives, such as raising their hands [8]. Furthermore, handheld devices appear to be very suitable for accessing information (reading e-mail, checking stock quotes and news headlines), especially when the user is seeking to fill a time slot that would otherwise be lost (during a short bus ride, while waiting in a line) [6]. Surely, the handheld devices have enough advantages, especially against the Laptop PCs. Laptop PCs require a lap or surface to operate properly, they are relatively bulky and obtrusive, they take much longer to boot and consequently must be left on so that they will be ready to use and they typically have short battery life [9]. Currently, for certain reasons (availability, acceptance, network connectivity and price) handhelds appear to be a straightforward solution for mobile applications [10]. Despite all these advantages, there are also many disadvantages which arise exclusively from their size. Trying to reduce the dimensions of the handheld devices, the manufacturers decreased their usability (e.g. small screen size), availability (e.g. battery lifetime), and performance (e.g. low processing speed). However, they are still cheaper than the Laptop PCs. Age or stage in life seemed to influence the manner in which the mobile device users balanced the expenses and convenience associated with mobility [6]. In the sequence, this paper will examine the characteristics of the handheld devices and the requirements in order to support mobile learning. Section 2 presents requirements of handheld devices in order to support mobile learning. Section 3 presents an evaluation framework with specific criteria that handheld devices should support.

Section 4 presents the evaluation results of current handheld devices. Section 5 concludes about the appropriateness of current handheld devices and suggests the requirements for handheld devices appropriate for mobile learning.

2. EVALUATION FRAMEWORK

As it was described in the Introduction, there are many types of handheld devices in the market. Having presented the handheld devices requirements for mobile learning, we proceed to develop an evaluation framework. This framework will contain criteria for evaluating various handheld devices.

First, we define three evaluation areas: 1) Usability, 2) Technical, and 3) Functional (Figure 1). Then for each evaluation area, we define specific criteria. Finally, we perform the evaluation of various handheld devices to determine the extent to which they satisfy these evaluation criteria.

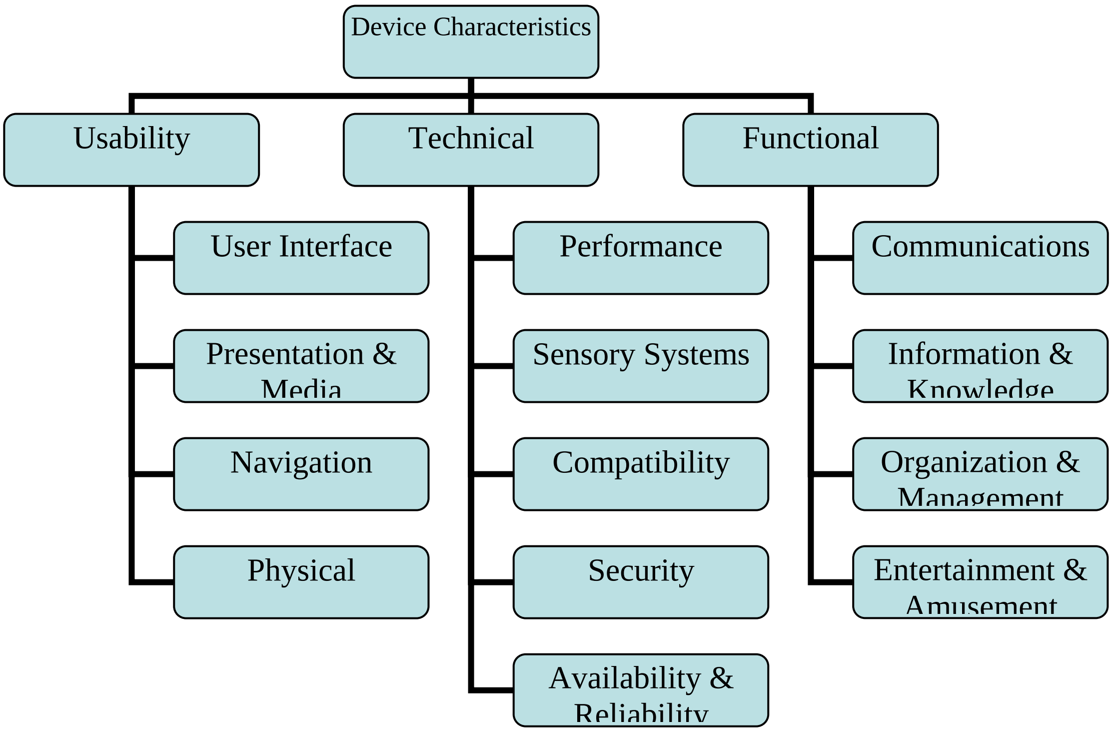


Figure 1. Handheld device characteristics.

Let describe briefly these three evaluation areas:

1) Usability: it is related to the easiness of understanding, learning, remembering and using the device and its tools. It should be easy to carry the device, to use its interface, to read and write text, to communicate with others, to record and play audio and video, to organize emails, messages, songs, photos, to navigate and oriented in its content, etc. (Table 2).

2) Technical: it is related to the device's performance, connectivity, compatibility, security and reliability. The device should have high processing power, large available memory, and ability to run various software formats. It should have long battery autonomy and easy battery recharging. It should support various communication protocols and networks without serious restrictions on distance and

bandwidth. It should also secure the content and communications against theft or malicious changes (Table 3).

3) Functional: it is related to the quantity and quality of the available features, functions and tools of the device. It should support tools for synchronous and asynchronous communication, as well as for information access, processing, storage, organization and playing (Table 4).

Next, we further analyze these areas.

3.1. Usability

The user-interface comprises the means by which the student interacts with the handheld device (Table 2).

USABILITY CRITERIA

1. USER-INTERFACE
   - Appropriate and effective layout
   - Simple and easy to use menus, toolbars, buttons etc.
   - Multiple languages
   - Personalization, various versions
   - Accommodation, special needs persons consideration
2. PRESENTATION & MEDIA
   - Easy to read, write, draw, record (photo, audio, video etc.), play, print
   - Variety of media support (text, diagrams, maps, photos, sound, video etc.)
   - Quality and fidelity of multimedia
3. NAVIGATION
   - Simple and easy structure/organization
   - Effective and easy organization of files
   - Effective and easy organization of tools and functions
   - Simple and easy navigation
   - Shortcuts available
   - Return to home from everywhere
   - Help from everywhere
   - Search from everywhere
   - No broken and missing links
   - Simple and consistent orientation everywhere
   - Table of contents
   - Directories for email addresses, telephone numbers, urls, radio stations, TV stations, etc.
   - Directories for emails, sms, mms, calls, files, photos, songs, etc.
4. PHYSICAL
   - Size
   - Weight
   - Design, Aesthetics, “Trendy”

Table 2. Handheld devices usability criteria.

Since, the student should use the handheld device in any situation even while he is moving, he should be able to easily use it to accomplish his educational tasks. So, the interface layout, the menus, toolbars, buttons, etc. should facilitate the device's usage. It needs to make it easier for normal people to use not just for techno geeks [6]. Designers of contemporary handheld devices have tried to make them as simple as possible, sometimes supporting touch-screen or having shortcut buttons for some functions. Simultaneously, handhelds devices should be friendly to persons with special needs giving them the opportunity to participate in all educational activities. For example, a converter text-to-voice or/and voice-to-text will be very useful for them. Also, different students have different needs, interests, desires, learning styles, abilities, etc. It would be useful the handheld device to be personalized according to every student's state and/or the particular educational activity. So, the student should be able to set up his personal profile, or to adapt the handheld device according to the educational activity. These setting changes and control should be done via a control panel. For example, a user of a device with Symbian operating system can organise different profiles about how his device will ring or he can change the layout, the toolbars or other settings according to his needs.

The presentation of the information is straight connected to the user-interface. The ability to show multimedia applications as well as the quality of the pictures, audio, video, etc. is important. However, streamlining the presentation to make the most essential information and tools highly accessible on screen is often accomplished by reducing the functionality of the tool [12]. Also, the flexibility of the graphical presentation depends on the operating system of the handheld device. Every operating system has its way to present the information on screen. For instance, the web browsers often automatically remove graphics and summarize text to reduce the amount of time users spend looking for specific information [12]. The graphical presentation displays current state action and results, through feedback mechanisms such as echoing input text and formatting rubber-banding, wire-frame outlines, progress bars, highlighting changes in a document, listing sent messages and so on [13]. On the other hand, if the student finds that the graphics and the sounds are not helpful for him, it would be nice for the student to have the ability to customize the presentation. For example, the Listen System provides audio presentations according to the location and the profile of the visitor in the art exhibition. The operating systems give this ability to the student through some preset profiles or allow him to customize his own profile. For instance, Symbian handheld devices have some ready-to-use themes, but also the user can customize most of them. The presentation and structure of the toolbars, menus and applications is also important. So, we consider the following criteria in relation to the presentation: multimedia variety, fidelity and clarity of the multimedia, personalization of the multimedia (e.g. user may select the graphics and sounds), etc.

When referring to navigation in a Desktop or a Laptop PC we mean a process in which we browse throughout files, applications and tools using the mouse and the keyboard. It is nearly the same for handheld devices too. However, handheld device navigation should be even easier for the mobile student. "We can open windows, pull down menus, drag the scrollbar to inspect contents and so forth" [13] even without using a mouse or keyboard. So, there is a challenge. How handheld devices can enhance navigation that Desktop and Laptop PCs tried hard to achieve? The operating system of the handheld device plays a significant role in enabling navigation. It needs to enable easy navigation without the student spending his time. We must analyze and deconstruct the most common activities to identify the salient tasks and determine which ones should be included in device software [12]. For example, instead of including a flowchart that describes the activity process but does not provide functionality, a navigation menu might be used to provide both the functionality for moving between workspaces and the process scaffolding that makes the overall work process visible [12]. On the other hand, a Desktop or a Laptop PC might be designed to support many components, for example, of a scientific research process whereas a handheld tool might only be designed to support one task such as gathering data from field experiments [12]. However, some handheld devices, especially Pocket PCs, solve the navigation problem combining the mouse and the keyboard in one device, the touch-screen. The touch-screen facilitates the student to navigate the menu and sub-menus easier finding the target file or tool immediately. In contrast to Pocket PCs, Smart-phones do not support touch-screen but give to the student a five-direction pad as an alternative way to navigate. Using this five-direction pad a student can go up, down, left or right in the Smart-phone menu and select an application or enter a sub-menu by pushing inside the pad. Also, sometimes handheld devices need to embody additional buttons for specific tools so as the student can have a quick access to them. It sounds very simple, but the problem is that a student sometimes has to navigate the whole menu until he finds what he is looking for. So, there is the need to offer help and search engine enabling the student to use them from everywhere in handhelds' menus. Moreover, the student should be able to return to the home page from everywhere within one step. For example, devices with Symbian operating system have the five-direction pad, as well as two or three additional buttons for specific moves (back, properties and exit). However, due to the small dimensions of the handheld devices, there are not many things to do with respect to the navigation.

The optimal dimensions and weight are closely associated with the situations where they used. For example, the optimal size of a device used when wandering is different than that used when visiting or travelling [6]. Furthermore, the student likes to have a nice and trendy designed handheld device. Many people believe that handheld devices like other personal things should have their own style, representing a part of user's personality. In addition, they expect that their handheld device is composed from qualitative, reliable and durable materials, in order to use it without worries.

3.2. Technical

The technical specifications comprise the keystone of the device (Table 3).

TECHNICAL CRITERIA

1. PERFORMANCE
   - Processor
   - RAM
   - Expansion Storage
   - Communication technologies (Bluetooth, Wi-Fi, GPS, Telephony, GPRS, Infrared IrDA)

2. SENSORY SYSTEMS
   - Display screen
   - Audio, Photo and Video recorder and player
   - Microphone and speakers
   - Touch screen, Keyboard, direction pad
   - RFID sensors, smart card reader, data probes, bar code reader, scanner, etc.
   - GPS navigators

3. COMPATIBILITY • Support open source software • Operating systems • Browsers • Variety multimedia format support 4. SECURITY • Security Certificates • Encryption, Cryptography • Anti-spam, anti-virus etc. • Password • Touch-screen or Keyboard lock • Block incoming/outgoing 5. AVAILABILITY, RELIABILITY, & MAINTAINABILITY • Battery lifetime autonomy • Error free • Easy recovery in case of error • Easy upgrade, updated, online • User technical support and documentation

Table 3. Handheld devices technical criteria.

A high performance device can support many tools and give the ability to the student to perform many functions. The most important parameters include the following: 1) Processor, 2) Memory, 3) Expandable memory, 4) Display, 5) Input, 6) Output, 7) Expansion cards, and 8) Connectivity and Communications. Let further analyse these.

1) Processor: it is the heart of the device. The more powerful it is the faster its operation. However, it should consume low power. So, it should support multiple power modes (run, idle, sleep and deep sleep), frequency and voltage adjustment

2) Memory: usually, the operating system is stored in ROM (read-only memory) and the RAM (random access memory) is used as temporary processor memory and file storage space. The minimum requirement is 16MB of memory. However, 128 MB or 256 MB will be useful for MP3 playback, games, etc. For instance, small operating memory means a small buffer and small buffer means low data gathering and analysis tools in observational research [9, 11].

3) Expandable memory: when the storage memory is insufficient, it would be useful to have available slots for adding external memory. Large files, MP3, video files, etc. are stored on memory cards like CompactFlash, and MMC/SDIO (MultiMedia Card/ Secure Digital Input Output).

4) Display: it should have at least 240x320-pixel resolution and support colors for easier reading due to the high contrast ratio. A high-resolution display can be used for viewing photos and video. Nevertheless, there are many problems with the screen size. For example, there is the “partial” view principle due to the physical size restriction of the handheld devices [10]. Screen space is at premium in handheld devices’ tools, but designers must find a balance between including enough scaffolds to support the learning activity and not including so many elements that the interface becomes unusable [12]. The constraints of the device screens can make it difficult for learners to organize and visualize their work particularly when artifacts are scattered

across multiple workspaces or when viewing the workspace requires extensive scrolling [12].

5) Input: the usual input devices are the five-way navigator, keyboard and scroll wheel or thumb. Also, the student can use a stylus or pen to activate buttons or menu choices on a touch-screen. Then, he can enter text either typing on a virtual keyboard, or free writing and using handwriting recognition software (e.g. Graffiti, Block Recognizer, Letter Recognizer, Transcriber). Other input devices include, microphone, sensors, bar code scanning, optical reader, audio and video recorders. “By the last quarter of 2004 about 75 percent of mobile phones in Japan were camera phones and it is expected this number will saturate at around 75-85 percent this year” [16].

6) Output: speakers, players (audio, photo and video).

7) Expansion cards: in addition to memory cards, there is need for communication cards (e.g. Wi-Fi, Bluetooth), as well as cards for digital cameras, FM tuners, bar-code scanners, GPS (Global Positioning System), etc.

8) Connectivity and Communications: handheld devices should support alternative ways of connecting to and communicating with other devices. Most popular short range wireless connections are Bluetooth, IrDA and Wi-Fi (IEEE 802.11). For long distances, the device can use cellular networks.

i) Bluetooth: handheld devices that support Bluetooth can communicate directly with other Bluetooth-enabled devices such as phones, desktop PCs, printers, etc. ar a distance less than 10m. Only two devices can communicate each time.

ii) Infrared (IR): it offers low-bandwidth data transfer between nearby devices (closer than 10 m). There should be a clear line of sight between the devices since the signals cannot travel through clothing and other barriers. For instance, students can aim their palms at the infrared printer in the room so as to print out a hard copy for themselves or the teacher [7].

iii) Wireless LAN (Local Area Network): a Wi-Fi-enabled handheld can connect directly to the Internet at high speeds. It needs to be less than 100 m from an access point (hot spot) in order to connect. Wi-Fi achieves longer range without limits on how many users can be connected together at the same time. However, Wi-Fi consumes a lot of power. The 802.11b can achieve throughput at 5.9 Mbps over TCP(transmission Control Protocol) and 7.1 Mbps over UDP (User Datagram Protocol). The 802.11a achieves a throughput of 20Mbps (with a maximum raw data rate of 54 Mbps). The IEEE 802.11g achieves a throughput of 24.7 Mbps (with a maximum raw data rate of 54 Mbps). The future 802.11n is expected to reach a theoretical 540 Mbps.

iv) Wireless WAN (Wide Area Network): devices with cell phone capabilities can communicate via cellular networks over long distances. Using wireless networks could extend the range of classroom scenarios and process to be served and make the results “directly portable” within the classroom but also between different locations [10]. “Whether students are at home, in the classroom or beside a river, they can get what they need right when they need” [7]. The network allows students to go online and find information from whenever they are in the school area or whenever they are outside science data or in the cafeteria discussing questions over lunch [7]. But if the student needs more freedom, handheld devices should support technologies like GPS, mobile telephony and GPRS (General Packet Radio Service). GPRS supports data transmission rates at 30-80 Kbps (with a theoretical maximum of 171.2 Kbps). It is able to support text, images and low quality pre-recorded audio (at 8Kbps).

Also, GPS technology may help the orientation of a student at outdoors. It can "show" him his current location and facilitate his route towards a destination. So, it is useful for a student who wants to discover and explore new places without getting lost. However, GPS does not generally work indoors or underground and is problematic in built-up urban environments or in poor weather [19].

Currently, a major problem is related to the inability of different devices to communicate among themselves due to different standards. For example, digital cameras and high-resolution displays may follow common technical specifications but not the same operating system. So, devices with different operating systems may be unable to exchange files or be synchronized. Currently, there are five operating systems (OS):

- Windows Mobile (Pocket PC), owned by Microsoft.
- Palm OS, owned by Palm Inc.
- Symbian OS, owned by Panasonic, Nokia, Samsung, Siemens and Sony Ericsson.
- BlackBerry, owned by Research in Motion.
- Linux-based (GPIE, OPIE/Qtopia), free.

Furthermore, the devices may even do not support the same multimedia formats (eg. Tivo, WMN, DivX, MPEG, AVI, RealMedia). So, the student is constrained to use converters in order to communicate with others. In addition, sometimes an operating system does not support a new program causing many problems to the user [9]. Of course, it would be nice that every program to run on every operating system, but this is almost unreachable. Open source software aims at this direction.

It is also imperative that the handheld device assures the student's secure information access, storage, and communication. The student will send and receive a variety of information types through a variety of channels. So, he should be sure that none will use his device and the stored information without his authorization. Also, none will intercept his transmitted information without his agreement. Encryption and cryptography would support secure interactions among handheld devices or handhelds and other devices. The device should support all necessary security protocols that guarantee safe operation and communication. For instance, a Symbian-based device supports the following security protocols: Baltimore Cyber Trust Root, Baltimore Cyber Trust Root, GTE Cyber Trust Global Root, RSA Data Security, Testing ACS Root, Thawte Premium Server CA, Thawte Server CA, and VeriSign Class 1,2,3,4 Public Primary Certification Authority.

Additionally, handheld devices face the risk of getting a virus via Internet or another communicating device. Therefore, it is absolutely necessary for an antivirus program to have been installed to protect the device's software from virus attacks. Also, there should be a support-site where a handheld device can be connected and download updates for new viruses. Moreover, a student should have the ability to control the incoming and the outgoing calls. Finally, a student wants to protect his device from accidental or unauthorized use. He should have the capability to lock the touch-screen or the keyboard and in some cases to give passwords if he wants to make new adjustments.

Finally, the student needs to rely on the device's availability and reliability. The lifetime of the battery is a very important parameter. The battery lifetime is measured both on standby and during processing (e.g. talking, watching video, playing game). Of course, the device should operate consuming low energy. On some models, there is also the risk of losing data if the battery is completely exhausted. Rechargeable batteries (lithium ion, nickel cadmium, or nickel metal hydride) comprise the best option. Another option for sunny places is devices based on solar energy. Another restriction comes from the small size of the handheld devices. Their small size requires small batteries. However, small batteries do not last for long time. So, either new batteries technology with higher autonomy should be developed or the energy consumption should be reduced. The device should operate without any problems even after hard usage in unfriendly environments (e.g. water, sand, dust, temperature, etc.) for long time. The operation should be error-free. In case of errors, the student should be able to recover his data and continue from that point. Also, the manufacturer should offer technical support for damage repairs, replacements, add-ons, upgrades, etc.

3.3. Functional

The available features, functions and tools in the device will help the student to perform various educational activities. They can be classified into four categories: i) communications tools, ii) information and knowledge processing tools, iii) organization and management tools, and iv) entertainment and amusement tools (Table 4).

FUNCTIONAL CRITERIA

1. COMMUNICATIONS
- Phone
- E-mail
- Web
- Chat
- Video conference
- Fax
- SMS
- MMS
- T.V.
- Downloading

2. INFORMATION & KNOWLEDGE
- Recorder
- Editor and office applications
- Calculator
- Drawing
- Playing audio
- Playing video
- Viewing photos
- Converter text-to-voice or/and voice-to-text
- Sharing files
- Dictionary, Translator

3. ORGANIZATION & MANAGEMENT
- Calendar
- Clock
- Agenda
- Database management system
- Organizer, Planner, Reminder, Alerting, etc.

4. ENTERTAINMENT & AMUSEMENT • Playing games • Playing music and movies

Table 4. Handheld devices functional criteria.

Using 3G (3rd Generation) mobile telephony the student can easily participate in a conversation, send a video-message, or download a song from almost anywhere. A short message service can facilitate group interaction by providing a context-aware environment with shared calendars, documents and events anytime and anywhere [14]. Moreover, during class, students can interact with the instructor via a message server allowing them to ask questions or request clarification without interrupting the flow of the lecture [14]. A short message service can also be used by instructors. Many instructors frequently stop their lectures to ask the class a question. If the instructor asks a multiple-choice question, students could use handheld devices to answer and the instructor could easily keep track of who is answering and get a bar graph of the results [18]. Mobile text messaging is suitable when short messages are exchanged. Current constraints with respect to the device, especially the nature of the keyboard, made it virtually infeasible to participle in high volume exchange [6]. The collaboration support will, in both cases (classroom and outdoor), be an integral port allowing the students to exchange their ideas and hypothesis peer-to-peer between the handheld devices and project them on the electronic whiteboard to initiate a classroom discussion about specific solutions [10].

The device should offer a variety of communications tools like email, SMS (short messaging service), MMS (multimedia messaging service), phone, fax, videoconferencing, chat, newsgroups, etc., as well as access to information via Web, radio, TV etc. Web chat, newsgroups and e-mail systems are examples of distributed educational information technologies that support communication among students [14]. Also, the student should be able to download, record, store and play various multimedia files (e.g. photos, songs, video clips). Office type software should be available for word processing, making presentation, drawing, spreadsheets, etc. Tools that help him to organize his time, activities, files, contacts, etc. are useful. For instance, a student may need to keep a calendar for scheduling observations, an address book for contacts, a set of notes for interview questions, a list of administrative tasks to accomplish and so forth [8]. For example, a student holding a Symbian-based device is able to use time clock, calendar, notes, address book, contacts, calculator, converter, recorder, internet and e-mail through GPRS, SMS, MMS, fax and, sometimes, TV streaming (especially in 3G-technology devices). Users expect anytime/anywhere communication with information systems and enjoy a one-to-many relationship with the devices they use [14]. A student can also use his device to play educational games either autonomously or with others. Finally, handheld devices can be used as alternative devices in other uses. For example, a handheld device can be used as a laser pointer in PowerPoint presentations, or as a remote controller to control and scroll windows on a PC while recharging in a cradle beside the keyboard [18].

4. EVALUATION RESULTS & DISCUSSION

Having defined the evaluation framework, we proceed to evaluate the current state of the handheld devices. We have searched in the market and found 148 handheld devices by various manufacturers (Appendix). Our aim is to record the current state of available handheld devices and identify whether they meet the requirements for efficient mobile learning.

Most manufacturers try to develop simple and easy to use interfaces with clear layouts and friendly menus. They aim to facilitate the user in daily operations. The user interfaces support menu (bar, pop-up, pull-down, list etc.), buttons (push, hyperlink, radio, check, etc.), icons etc. Also, a student can tailor his device to his preference using various profiles. However, almost all devices ignore the persons with special needs.

The presentation of multimedia depends on the size and technology of the screen. Pocket PCs have bigger displays than Smart-phones. So, it is easier to look on and use the screens of Pocket PCs. Also, the screen resolution is higher in Pocket PCs, so the multimedia could have better fidelity. Also, a student can use a great variety of media, for example, pictures, sound, videos, diagrams, etc. by installing the appropriate program. Liquid-crystal display (LCD) is a good choice. Also, transflective thin-film transistor (TFT) screens perform best indoors and outdoors, due to their reflective properties, which cause sunlight to bounce off the screen.

Navigation depends on the device operating system. Icons are used for displaying the different categories of tools in the basic menu, while icons, files and specific tools are displayed in sub-menus. The student has the ability to return home from everywhere in handheld’s menus by using only one button. Also, the student can create shortcuts to his favourite tools and functionalities for quick access. In Windows Mobile O.S. and Symbian O.S., there are displayed windows for properties, options, help and search. Most Smart-phones have navigation-pad and keyboard for navigation and typing. On the contrary, Pocket PCs have touch-screen and navigation-pad, and only a few of them support keyboard for typing. It was found that **59%** of the devices support touch-screen, and almost all have five-navigation pad for alternative navigation and buttons for specific tools. Finally, all devices offer help and the student can use it from everywhere.

The technical specifications comprise the heart of handhelds. The following Figures 2-9 show the current state of the devices’ technical specifications.

Figure 2 shows the distribution of various Operating Systems among current devices. Windows Mobile O.S. is the most popular and is supported by 85 devices, Palm O.S. by 33 devices, Symbian O.S. by 19 devices, and Black Berry Desktop Software by 11 devices.

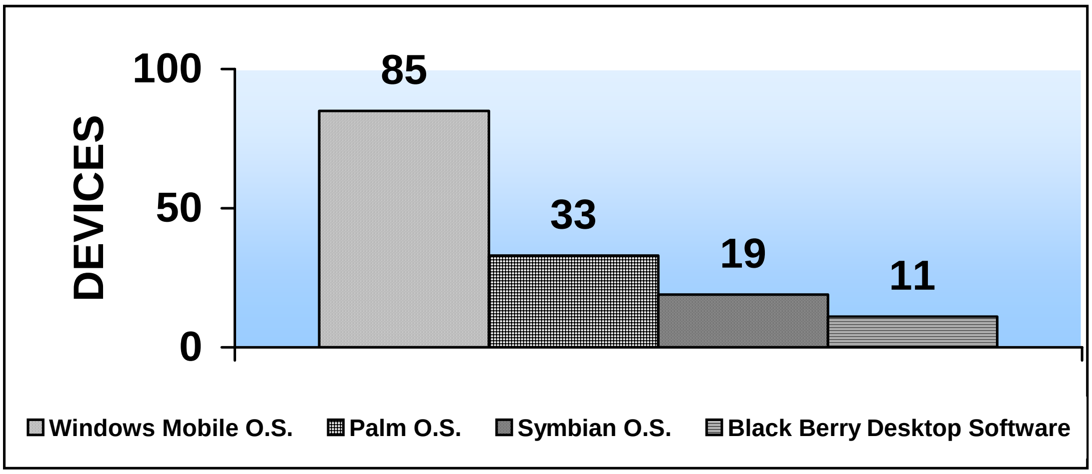


Figure 2. Operating Systems distribution.

Figure 3 shows the CPU speed for 118 devices. It was not possible to find the CPU speed for 30 devices by Nokia, Blackberry and Sony-Ericsson. Palm OS devices use a variety of processors from Intel, Motorola, Sony, and Texas Instruments and are available with maximum clock speeds of between 127MHz and 400MHz. Windows Mobile for Pocket PC devices use StrongARM or XScale processors with maximum clock speeds of between 200MHz and 624MHz. There is a variety of CPU speeds among the devices. The majority of them run on 100-200 MHz (38 devices) and 300-400 MHz (37 devices). An interesting remark is that there are 22 devices that run faster than 400 MHz.

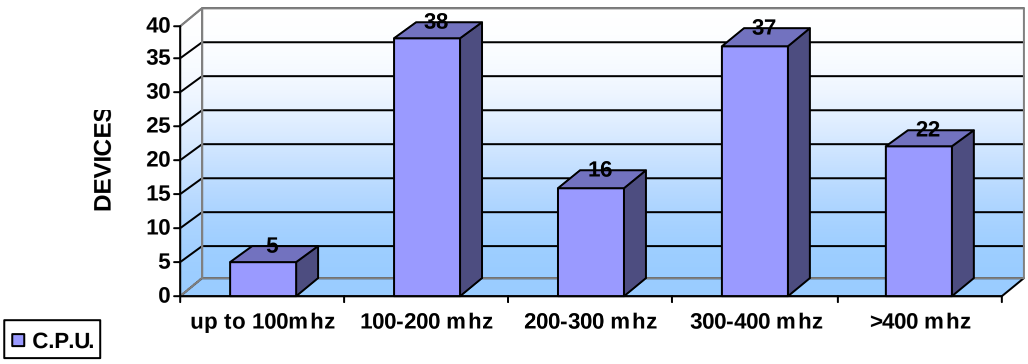


Figure 3. CPU Speed distribution (there were no information for 30 devices).

Figure 4 shows the distribution of the RAM sizes used by the devices. Most devices use 64 MB (56 devices), followed by 32MB (36 devices). Small memories up to 16MB are used by 29 devices, while large memories of 128MB are used by 27 devices.

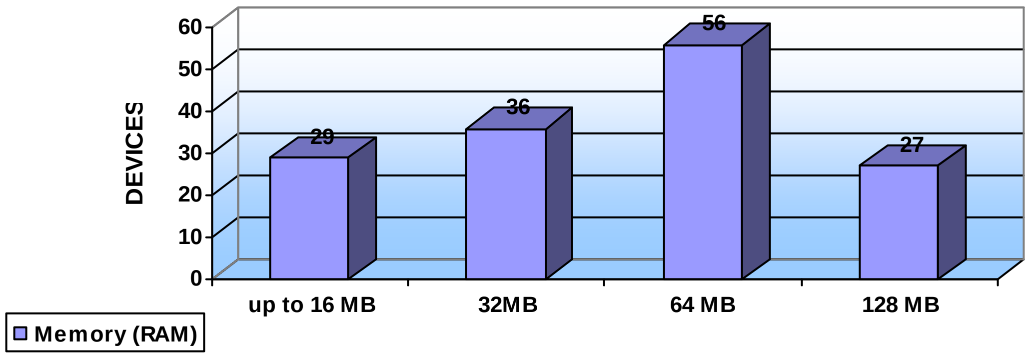


Figure 4. RAM distribution.

Figure 5 shows the distribution of the devices' screen size. There are three main clusters regarding the screen size. Most devices employ screen size 3.5" (56 devices), 20 devices have screen size 2.8", and 38 devices have screen size 2.2". There are also 14 devices with screen size 4".

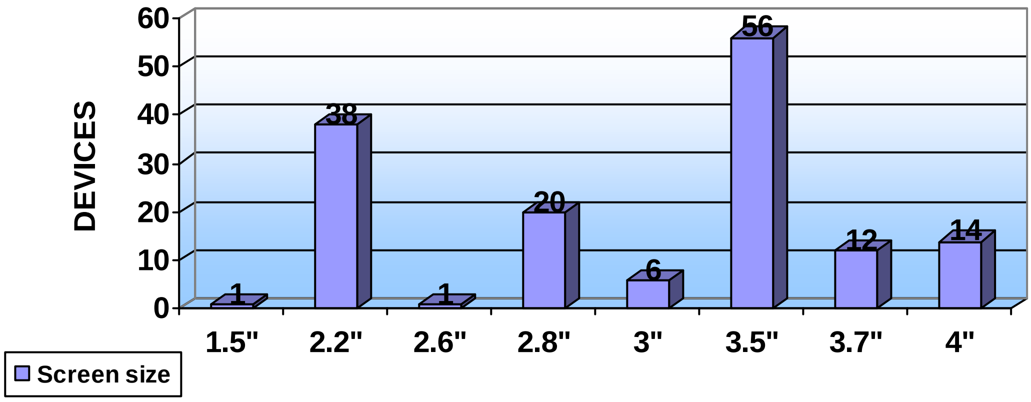


Figure 5. Screen size distribution.

Figure 6 shows the distribution of the devices' screen resolution. Most devices use screen resolution 240*320 (59 devices). Few devices use less than 240*320 (49 devices), and even fewer more than 240*320 (40 devices).

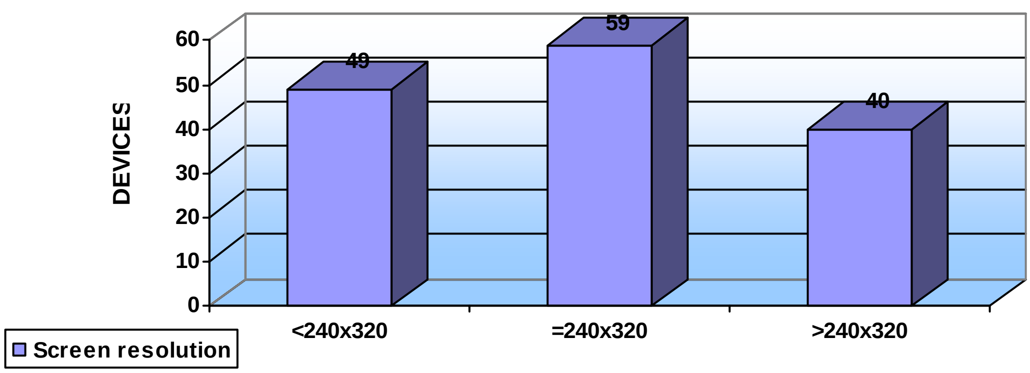


Figure 6. Screen resolution distribution.

Figure 7 shows the distribution of the available colors on the devices' screens. It is clear that most devices support 6500 colors (128 devices). This agreement among various manufacturers is interesting. It seems that they agree that 65000 colors are appropriate for effective presentation.

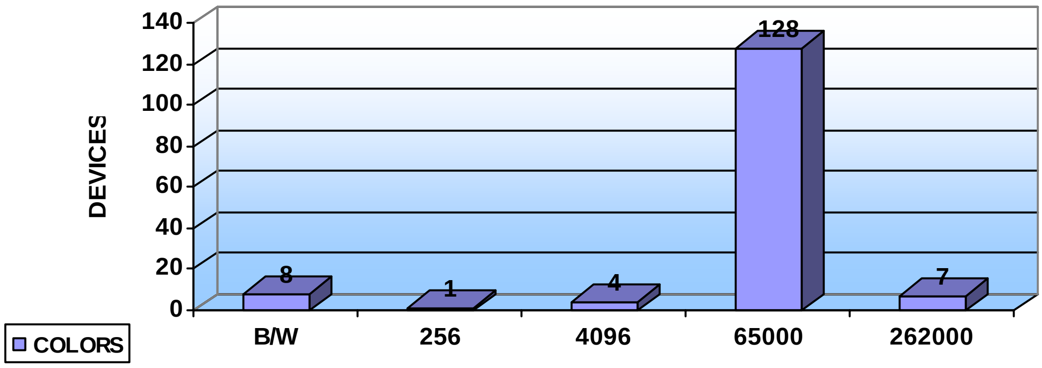


Figure 7. Number of colors distribution.

Figure 8 shows the available communication technologies supported by the devices. Bleutooth is supported by 87 devices, IrDA by 117 devices, Wi-Fi by 41 devices, GPRS by 83 devices, GPS by 15 devices and USB by 137 devices. It is important that most of the devices support a variety of communication methods. The ability to support GPRS frees the student of any location dependency. He can move almost everywhere and still communicate with his classmates and teachers.

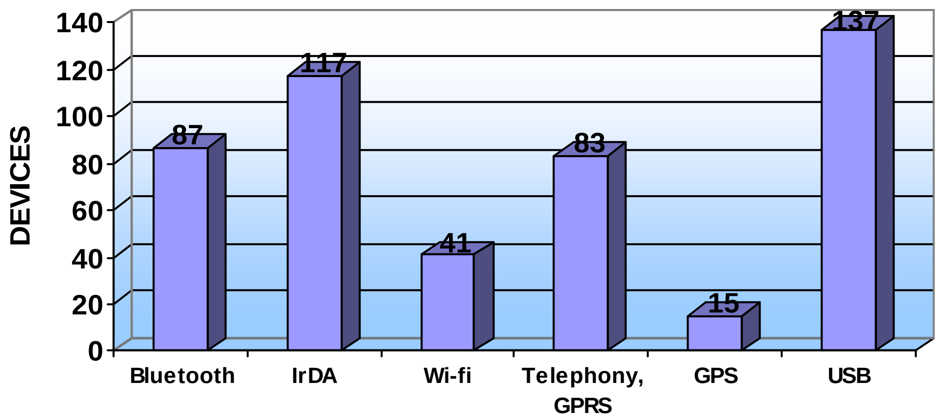


Figure 8. Number of devices supporting various Communication technologies.

Figure 9 shows the available extra capabilities on the devices. External memory slot is provided by 115 devices, digital camera by 71 devices, built-in-speaker by 132 devices and built-in-microphone by 129 devices. So, manufacturers recognize that voice communication and plenty of memory are essential components.

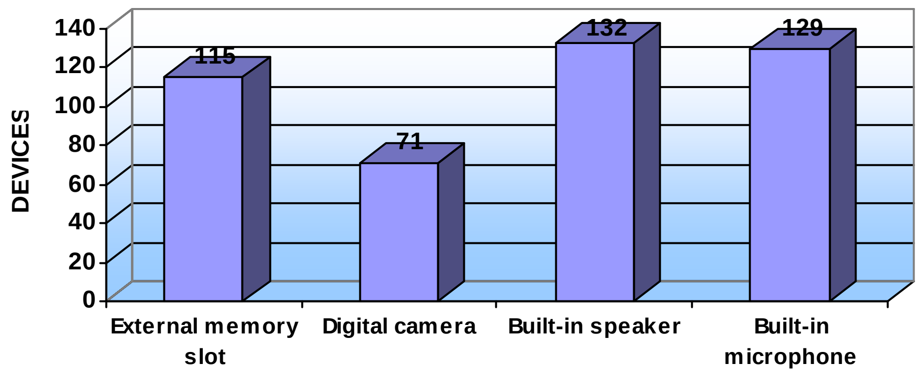
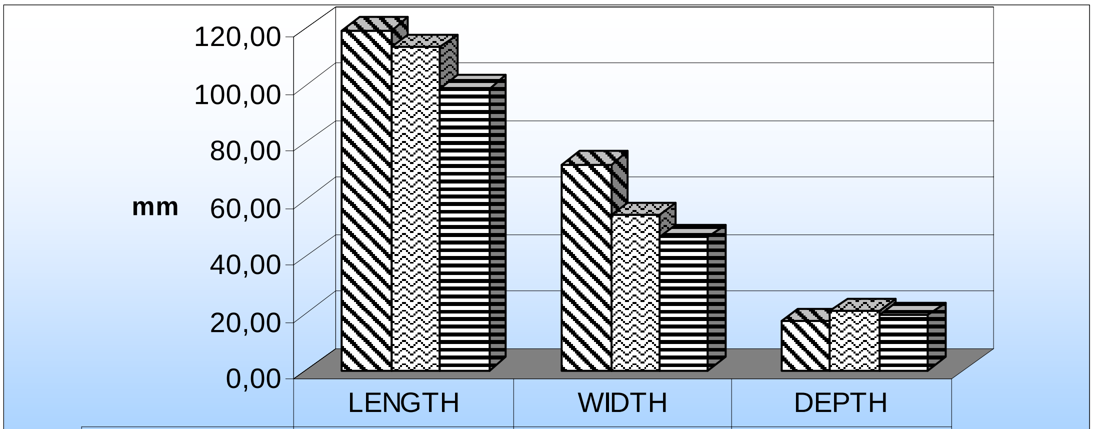


Figure 9. Number of devices with extra capabilities.

Finally, for a general idea about the dimensions and weight of handheld devices, we compare them to a common mobile phone, the Sony Ericsson K700i (Figures 10 and 11). Handhelds and smart-phones are a little bigger and heavier than this ordinary mobile phone. So, the students will not be loaded with too much extra weight and volume.



	LENGTH	WIDTH	DEPTH
Handhelds	119,12	72,25	17,45
Smartphones	113,13	54,23	20,85
K-700i	99,00	46,50	19,50

Figures 10. Average dimensions of devices.

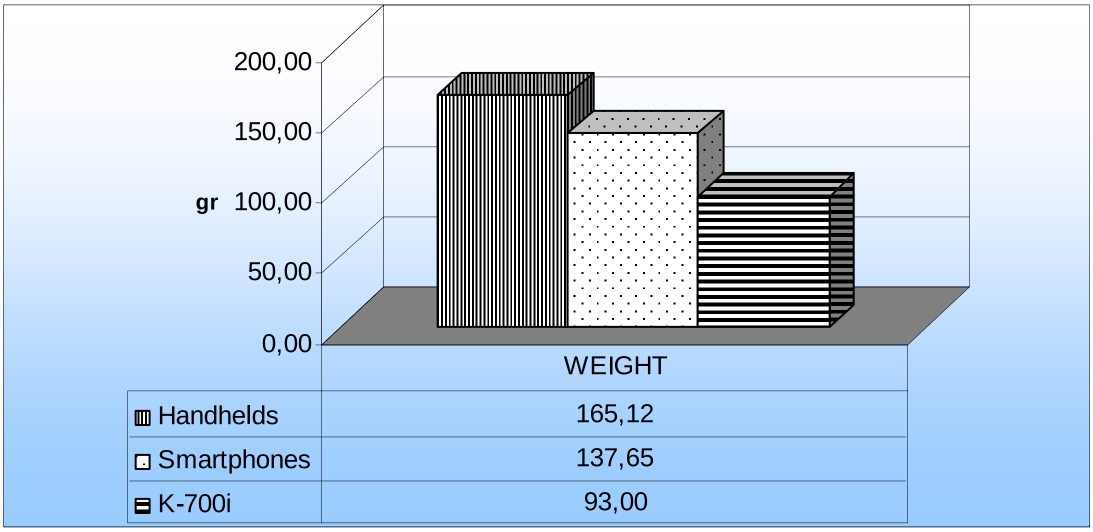


Figure 11. Average weights of devices.

Security is surely something that concerns all users. Handheld devices use various secure protocols for wireless connections giving the student a sense of safety and privacy. Secure protocols are, especially, useful in the Internet, Wi-Fi and Bluetooth connection as it is more difficult for the student to control the privacy of his communication. In addition, the student has the ability to install antivirus programs in order to protect the device from virus-attacks. If the student has an Internet connection, he can download updates for new viruses or new antivirus programs. Finally, all devices give the ability to the student to lock the touch-screen or the keyboard from accidental or unauthorized use by setting a password or pushing some buttons in the right order. A Nokia user can, for example, lock or unlock the keyboard, by using two buttons in the right order.

Regarding availability and reliability, Figure 12 shows the distribution of the devices' energy autonomy. Most devices have autonomy for 3-5 hours (91 devices). Few devices offer autonomy 5-10 hours (41 devices) and even fewer more than 10 hours (5 devices). It is interesting that more than 65% of the handheld devices have less than 5 hours autonomy, something which may cause problems to students who need to use them outdoors for a long period. Handhelds with more than 5 hours autonomy are more expensive and sometimes heavier. There are devices that have more than 10 hours autonomy, but they do not have enough features or they are low-powered devices. Also, all manufacturers give one year warranty. Most of the manufacturers replace the device with a new one if a problem appears within this period while some of them repair the device without any charge to the user. Finally, all manufacturers have official web site and official service-departments, which are ready to help the users with their device.

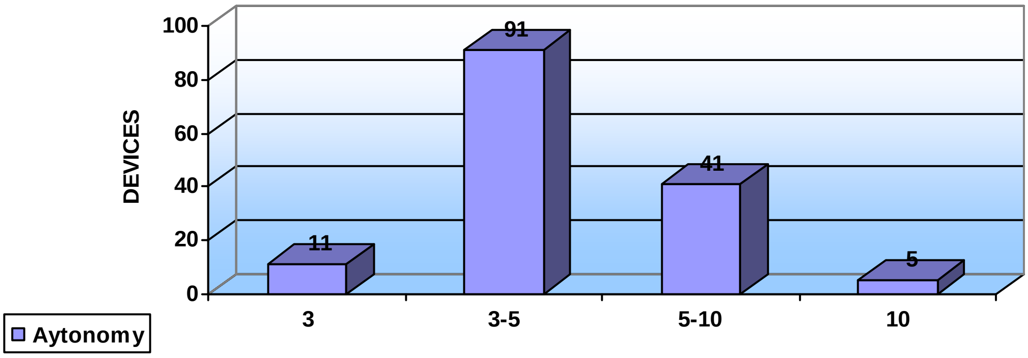


Figure 12. Battery Autonomy (in hours) distribution.

So, all handheld devices give the student the ability to use various tools useful for educational activities. Specially, if the device supports telephony, and even better GPRS or 3G technology, the student has the opportunity to use Internet, to download files, to send e-mail or to send SMS, MMS and fax. However, only four (**4**) devices support 3G communications, giving to the student the capability for video conference, higher downloading speeds, or even watching TV.

5. CONCLUSIONS

The current handheld devices can easily be carried and offer a variety of connectivity and communication technologies (Bluetooth, IrDA, Wi-Fi, GPRS, etc.). They support powerful processors and large memories with the ability to expand them. Most of them (90%) can be used as mobile phones and half of them have digital camera. However, there are still some problems to be solved like the limited screen size and readability, the battery autonomy, and compatibility issues. Most devices offer less than 5 hours autonomy which is problematic for outdoors learning. It is also important to support many expansion slots in order to add on functionality. Table 5 suggests device's technical specifications for mobile learning. It should support LAN connectivety (e.g. Bluetooth, Wi-Fi), WAN connectivity (e.g. GPRS, UMTS-Universal Mobile Telecommunications System), Internet connectivity (Web, email, chat, etc.), photo camera, expansion slots for extra memory (CompactFlash, Secure Digital, or MultiMediaCard memory cards), play back audio and video files (specially MP3, MPEG4), GPS. Such devices would support the requirements for mobile learning (Tables 1).

Hardware	***Specifications***
Processor	At least 400 MHz
RAM Memory	At least 64 MB, Recommended 512 MB
Hard Disk	At least 4 GB
Wireless LAN Connectivity	Bluetooth, IrDA, Wi-Fi
Wireless WAN	GSM 850/1800/1900 (Tri-Band), GPRS, UMTS, 3.5G
Display	At least 240*320 resolution, 6500 colors, Color transflective TFT with touchscreen
Input	5-way navigator, stylus, keyboard, touch-screen, scroll or thumb wheel, voice, GPS navigator, RFID reader, audio, photo and

	video recorder
Output	Speakers, audio, photo and video players (MP3, RealAudio, MPEG4)
Expansion	CompactFlash, SD, SDIO, MMC, Printer
Battery	Rechargeable Lithium-Ion or Solar, Long lifetime both on standby and under heavy processing

Table 5. Technical specifications for mobile learning.

Further attention should be taken for usability enhancements. The devices' small size enforces limitations on the devices' user friendliness. So, innovative methods should be invented to help the students using the devices. Although technologies exist to offer advanced features like user recognition (e.g. fingerprint, voice and face recognition), virtual reality, health monitoring (e.g. blood pressure, heart beats, body temperature), mobility metering (e.g. speed, distance, altitude), weather forecasting (e.g. temperature, barometer, humidity meter), the current handheld devices do not incorporate them. Some of these features would be useful for mobile learning at outdoors. For example, it would be helpful to support voice-based user-device interaction, 4G communication technologies, etc.

This study has investigated the suitability of handheld devices for mobile learning from the technical side. At outdoors learning, the only free way of communication among students and teachers is using handheld devices. Further research would investigate the educational advantages and disadvantages of using handheld devices from the educational and pedagogical side. For example, there are issues related to the cheating possibilities or the distraction by playing games and Web surfing while an educational activity is taking place. There also health concerns regarding the electromagnetic radiation. So, further research should investigate the effects of the power and transmission range on students.

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