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Evaluation of Handheld Devices for Mobile Learning*

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Many educational organizations have started 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, this presents a framework for evaluating handheld devices in relation to mobile learning. Then, it evaluates current handheld devices using the evaluation criteria and records of 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

INTRODUCTION

A HUGE MARKET FOR HANDHELD DEVICES has come into being recently. 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 in 2005 as 7.05 million PDAs were loaded with it, 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 fell 18%, while converged devices more than doubled in volume. Leader Nokia shipped a 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, 23 February 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 the US [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 e-mail, 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, we focus here on handheld devices that would be appropriate for mobile learning. For us, 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.),
iv) organization and management (e.g. scheduling, planning, calendar, address book, calculator, etc.).

With these handheld devices, users can confront any situation as it happens instead of postponing it

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until they reach their office, home, school, etc. This real-time confrontation lets 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 throughout the day, rather than batching all the messages and responding later on returning to one's workstation [6]. In addition, the handheld devices can be used in education. Many pilot programmes in education investigate the educational value of handheld devices. They can aid research, support collaborative activities and increase student to student interaction [7]. Surveys show that students prefer 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 queue) [6]. Surely, handheld devices have enough advantages, especially compared with Laptop PCs. These 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 Laptop PCs. Age or stage in life seem to influence the manner in which mobile device users balanced the expense and convenience associated with mobility [6].

EVALUATION FRAMEWORK

Mobile learning poses some challenges for the design and development of appropriate handheld devices. Every student will have to carry such a device in order to organize and manage educational activities, perform educational tasks, access and process educational material, as well as communicate and collaborate with classmates and teachers. The most important requirement is that these devices should support the student wherever located while on move or at rest. This means that the student should be able to communicate (synchronously and asynchronously) with other students and teachers as well as with other devices via voice and data (text, photo, audio, video etc.). In addition, these devices should support access, processing, storage and playing of educational material. As mentioned above, there are many types of handheld devices on the market. To evaluate the diversity, we need to develop an evaluation framework.

First, we define three evaluation areas:

1) Usability,
2) Technical,
3) Functional (Fig. 1).

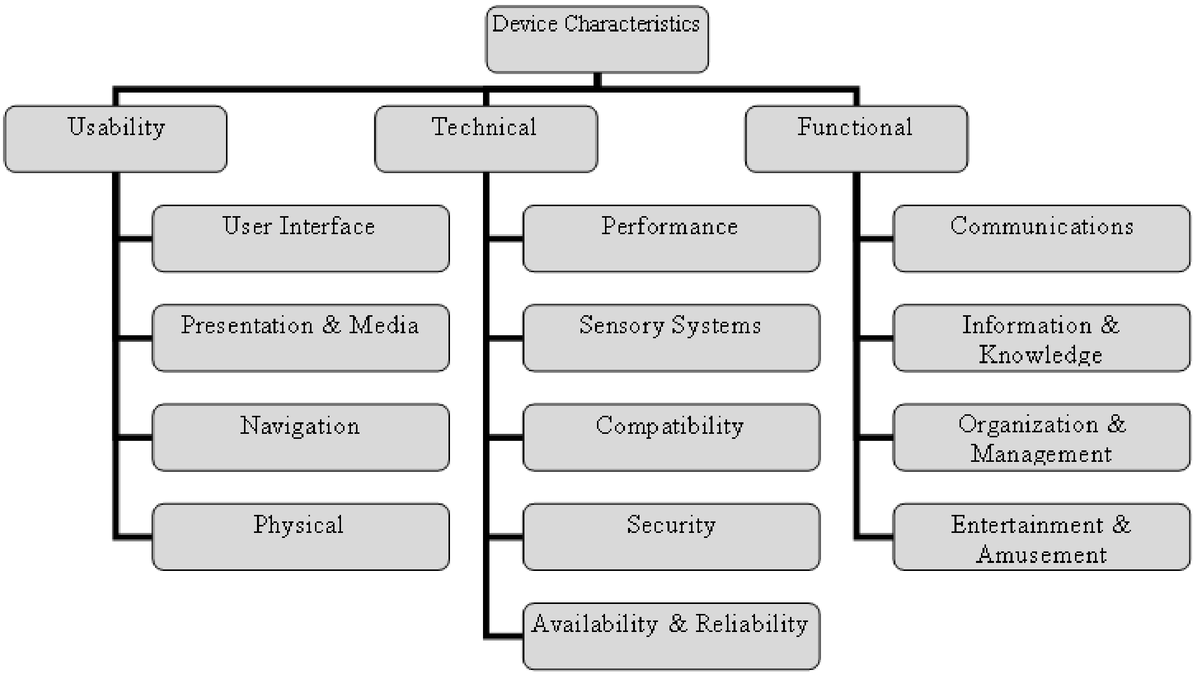

Fig. 1. Handheld device characteristics.

Table 1. Usability criteria

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. Technical criteria

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

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.

Let describe briefly these three evaluation areas:

1) Usability: 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 e-mails, messages, songs, photos, to navigate and be orientated into its content, etc. (Table 1)
2) Technical: 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 2).
3) Functional: is related to the quantity and quality of the available features, functions and tools. It should support tools for synchronous and asynchronous communication, as well as for information access, processing, storage, organization and playing (Table 3).

Next, we further analyse these areas.

Usability

The user-interface comprises the means by which a student interacts with the handheld device (Table 1). Since, the handheld device should be usable in any situation even while the student is moving, it should make it easy to accomplish educational tasks [11]. So, the interface layout, the menus, toolbars, buttons, etc. should facilitate usage. It needs to make it easier for normal people 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. Equally, handhelds 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. Also, different students have different needs, interests, desires, learning styles, abilities, etc. It would be useful for a

Table 3. Functional criteria

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

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 a personal profile, or to adapt the handheld device according to 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 organize different profiles about how the device will ring or the layout, toolbars or other settings can be changed according to needs.

The presentation of information is 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 information on screen. For instance, 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 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, it would be handy 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 through 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. The operating system of a handheld device plays a significant role in enabling navigation. It needs to enable easy navigation without the student spending time.

We must analyse 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 in navigating the menu and submenus, making it easier to find the target file or tool immediately. In contrast to Pocket PCs, Smart phones do not support touch-screen but give the student a five-direction pad as an alternative way to navigate. Using this, a student can go up, down, left or right in the Smart-phone menu and select an application or enter a submenu by pushing 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. So, there is the need for a search engine which enables the student to navigate from anywhere in a handheld's menu. Moreover, the student should be able to return to the home page from everywhere in one step. For example, devices with Symbian operating system have a 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 handheld devices, there is not much scope for innovatory navigation.

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

Technical

Technical specifications are the keystone of a device (Table 2). 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,
8) Connectivity and Communications.

Let's further analyse these.

The processor 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

Memory usually means an operating system stored in ROM (read-only memory) and the RAM (random access memory) 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].

Expandable memory is useful when the storage memory is insufficient in the form of 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).

Display should be at least 240x320-pixel resolution and support colours 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 handheld devices [10]. Screen space is at premium, 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].

Input devices usually 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, text can be entered either by 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 a microphone, sensors, bar code scanner, 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 per cent this year' [16].

Output requires speakers, players (audio, photo and video).

Expansion cards are a necessary addition to memory cards in the form of communication cards (e.g. Wi-Fi, Bluetooth), as well as cards for digital cameras, FM tuners, bar-code scanners, GPS (Global Positioning System), etc.

Handheld devices should support alternative ways of connecting to and communicating with other devices [15, 17]. 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. at a distance ofless than 10 m. 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 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 prerecorded audio (at 8 Kbps). Other future wireless technologies include UMTS (Universal Mobile Telecommunications Systems), EDGE (Enhanced Data rates for GSM Evolution), HSDPA (High-Speed Downlink Packet Access), etc.

Also, GPS technology may help the orientation of a student out of doors. It can 'show' a current location and facilitate a 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):

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

On top of which, the devices may not even support the same multimedia formats (e.g. 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 convenient if every program ran 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 of secure information access, storage and communication. The student will send and receive a variety of information types through a variety of channels. So, the privacy and integrity of stored information is essential. Also, no one should be able to intercept transmitted information without previous 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 the Internet or another communicating device. Therefore, it is absolutely necessary for an antivirus program to have been installed to protect the device's software. Also, there should be a support site where a handheld device can be connected and updates downloaded for protection against new viruses. Moreover, a student should have the ability to control incoming and the outgoing calls and have protection against accidental or unauthorized use by, for example, being able to lock the touch-screen or the keyboard and in some cases give passwords. Finally, the student needs to rely on the device's availability and reliability. The lifetime of the battery is a very important parameter. Battery life is measured both on standby and during processing (e.g. talking, watching video, playing game). Of course, the device should consume minimal energy. On some models, there is a risk of losing data if the battery is completely exhausted. Rechargeable batteries (lithium ion, nickel cadmium, or nickel metal hydride) are the best option. Another option for sunny places is empowerment by solar energy. Another restriction comes from the small size of handheld devices which, it might be assumed, requires them to use small batteries. However, small batteries do not last for a long time. So, either new battery technology with higher autonomy should be developed or energy consumption should be reduced. The device should operate without any problems even after hard usage in unfriendly environments (e.g. water, sand, dust, heat, etc.) for a long time. The operation should be error-free. In case of errors, the student should be able to recover data and continue from that point. And the manufacturer should offer technical support for damage repairs, replacements, add-ons, upgrades, etc.

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,
iv) entertainment and amusement tools (Table 3).

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 impossible to participle in high-volume exchange [6]. The collaboration support will, in both cases (classroom and outdoor), be an integral part allowing the students to exchange their ideas and hypotheses 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 e-mail, 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 presentations, drawing, spreadsheets, etc. Tools that help students to organize their 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]. A student with 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 a device to play educational games either autonomously or with others [15, 17]. 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].

EVALUATION RESULTS AND DISCUSSION

Having defined the evaluation framework, we proceed to evaluate the current state of the handheld devices market. During 2005, we have searched the Greek market and found 148 handheld devices by various manufacturers.

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 a device to personal preference using various profiles. However, almost all devices ignore 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 submenus. The student is able to return home from everywhere in a handheld's menus by using only one button. Also, the student can create shortcuts to favourite tools and functionalities for quick access. In Windows Mobile O.S. and Symbian O.S., there

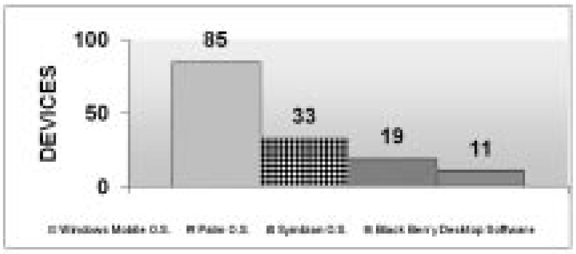

Fig. 2. Operating systems distribution.

are displayed windows for properties, options, help and search. Most smart phones have a navigation pad and keyboard for navigation and typing, whereas pocket PCs have a touch-screen and navigation pad, but only a few of them support a keyboard for typing. It was found that 59 per cent 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 which the student can access from everywhere.

The following Figs 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, BlackBerry Desktop Software by 11 devices.

Figure 3 shows the CPU speed for 118 devices. It was not possible to find the CPU speed for 30

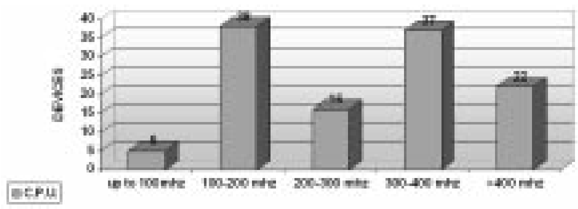

Fig. 3. CPU speed distribution.

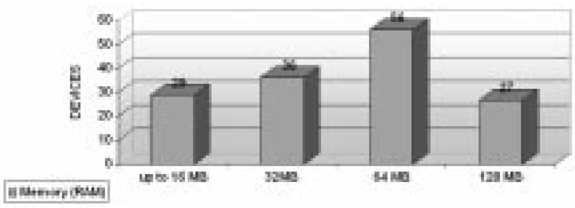

Fig. 4. RAM distribution.

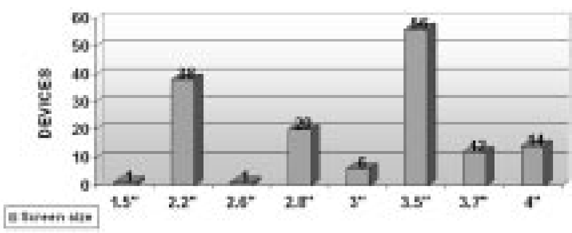

Fig. 5. Screen size distribution.

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 127 MHz and 400 MHz. Windows Mobile for Pocket PC devices use StrongARM or XScale processors with maximum clock speeds of between 200 MHz and 624 MHz. 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). Interestingly, there are 22 devices that run faster than 400 MHz.

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

Figure 5 shows the distribution of screen size. There are three main clusters. 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 6 shows the distribution of screen resolution. Most devices use screen resolution 240*320 (59 devices). Few use less than 240*320 (49 devices), and even fewer more than 240*320 (40 devices).

Figure 7 shows the distribution of available screen colours. Most devices support 6500 colours (128 devices). This agreement among various manufacturers is interesting. It seems that they

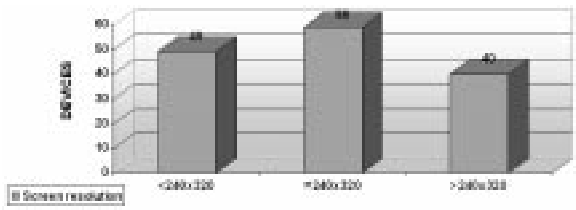

Fig. 6. Screen resolution distribution.

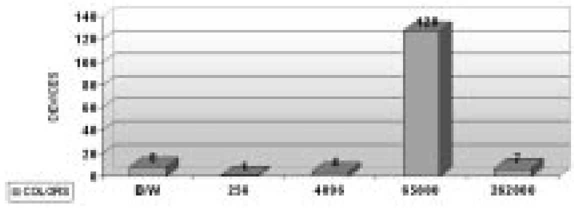

Fig. 7. Number of colours distribution.

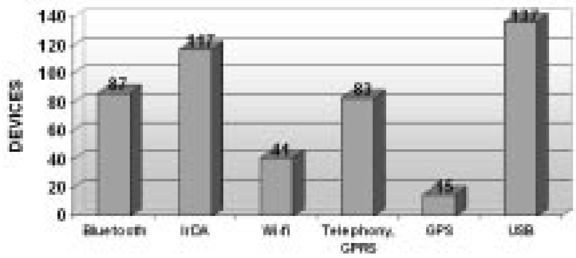

Fig. 8. Number of devices supporting communication technologies.

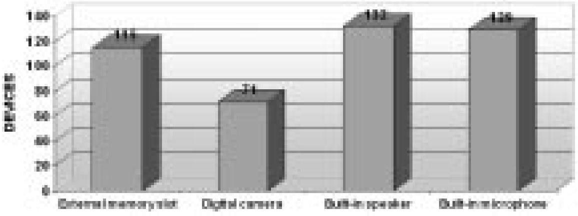

Fig. 9. Number of devices with extra capabilities.

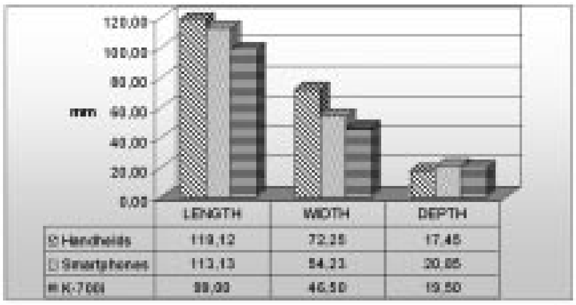

Fig. 10. Average dimensions of devices.

agree that 6500 colours are appropriate for effective presentation.

Figure 8 shows the available communication technologies supported by the devices. Bluetooth 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/she can move almost everywhere and still communicate with classmates and teachers.

Figure 9 shows the available extras on the devices. An 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.

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

Security 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 communication. In addition, the student can instal antivirus programs. A student with an Internet connection can download updates for new viruses or new antivirus programs. Finally, all devices enable the student to lock the touch-screen or the keyboard to avoid accidental or unauthorized use by setting a password or pushing

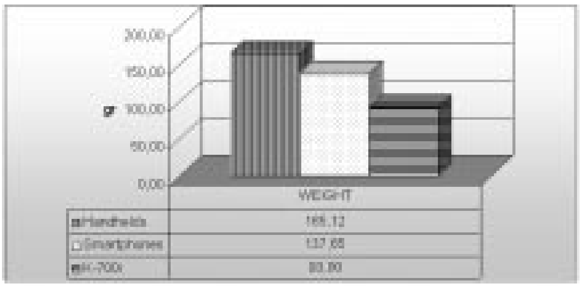

Fig. 11. Average weights of devices.

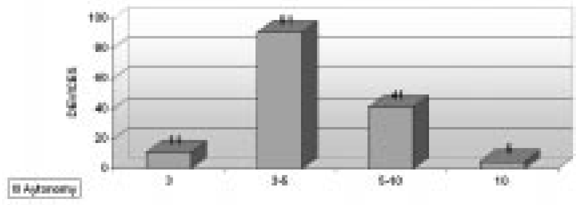

Fig. 12. Battery autonomy (in hours) distribution.

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, Fig. 12 shows the distribution of the devices' energy autonomy. Most devices run for 3–5 hours (91 devices). Few devices offer 5–10 hours (41 devices) and even fewer more than 10 hours (five devices). It is interesting that more than 65 per cent of the handheld devices have less than five hours autonomy, something which may cause problems to students who need to use them outdoors for a long period. Handhelds with more than five 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. Also, all manufacturers give one year warranty. Most manufacturers will replace the device if a problem appears within this period while some of them repair the device without any charge to the user. Finally, all manufacturers have an official Web site and service departments for assistance and information.

So, all handheld devices enable students to use various tools which are useful for educational activities. Particularly if the device supports telephony, and even better GPRS or 3G technology, the student has the opportunity to use the Internet to download files, send e-mail or send SMS, MMS and fax. However, only four devices support 3G communications, giving to the student the capability for video conferencing, higher downloading speeds, or even watching TV.

CONCLUSIONS

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 per cent) can be used as mobile phones and half of them have a 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 five hours autonomy which is problematic for outdoors learning. It is also important to support many expansion slots in order to add on functionality. It should support LAN connectivity (e.g. Bluetooth, Wi-Fi), WAN connectivity (e.g. GPRS, UMTS- Universal Mobile Telecommunications System, 4G), Internet connectivity (Web, e-mail, chat, etc.), GPS, as well as photo camera, expansion slots for extra memory (CompactFlash, Secure Digital, or MultiMediaCard memory cards), play back audio and video files (specially MP3, MPEG4).

Further attention should be paid to usability enhancements. The devices' small size imposes limitations on user friendliness. So, innovative methods should be invented to help students using the devices. Although existing technologies 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, barometric pressure, humidity meter), today's handheld devices do not incorporate them. Some of these features would be useful for mobile learning 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. In outdoors learning, the only free way of communication among students and teachers is by using handheld devices [15, 17]. Further research would investigate the educational advantages and disadvantages of using handheld devices from the pedagogical point of view. For example, there are issues related to the cheating possibilities or the distraction of playing games and Web surfing while an educational activity is taking place. There are also health concerns regarding the effect of electromagnetic radiation.

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