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Learning object design considerations for small-screen handheld devices

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Abstract

The key limitation of handheld technology for the delivery of learning objects is the small screen that is available for effective display. The smallness of the screen not only adversely affects the clarity, but it also negatively impacts on the acceptance and integration of this potentially useful technology in education. Handheld devices are likely to change further in size in the future with consumer demand for less bulky but more powerful devices. This exploratory study investigated characteristics of effective design of learning objects on such devices. This paper reports upon user response to learning object design possibilities and provides a set of recommendations to guide improved utility and future research.

Keywords: Handheld devices; Learning objects; Mobile learning; Small-screen design

1. Introduction

Handheld portable digital devices nowadays often include wireless network connectivity, with extensions such as a mobile phone, Bluetooth connections, a camera and a variety of add-on hardware and software. These handheld mobile-enabled devices are sometime called Personal Digital Assistants (PDAs), Pocket PCs, "smartphones" (Keegan, 2004), "wearables" (Sharples, 2000), "communicators" or "mobile multimedia machines" (Attewell, 2005). As the number of these devices increases, Attewell (2005) suggests that this technology will become inextricably part of the "digital life" for many individuals around the world. The technology also offers a spectrum of educational opportunities and new options for student-technology partnerships in learning. Empowered with interactive multimedia presentational capabilities, handheld technology permits the delivery of a range of digital material such as video, audio, graphics and integrated media. If appropriately designed for the context, educationally useful interactive multimedia digital material like learning objects can be effectively delivered to students at any time, inside and outside of classrooms.

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Studies report a variety of issues in relation to use of handheld technologies in education contexts. For example, use of handhelds during classes, enabling teachers and students to share files (Ray, 2002); allowing students to ask anonymous questions, answer polls, and give teachers feedback (Ratto, Shapiro, Truong, & Griswold, 2003); delivering an intelligent tutoring system (Kazi, 2005); delivering quizzes (Segall, Doolen, & Porter, 2005); disseminating information and collecting data during field trips (So, 2004); supporting students' inquiries (Clyde, 2004; Sharples, Corlett, & Westmancott, 2002); supporting computer collaborative learning (Roschelle & Pea, 2002; Zurita & Nussbaum, 2004); improving literacy and numeracy for disadvantaged young adults (Attewell, 2005); and as a personal technology for lifelong learning (Sharples, 2000). However, the research literature about the effective design of educationally useful material for delivery via handheld technology is extremely limited, rather as the preceding list indicates, the existing studies are focused more on supporting the general efficacy of the technology in educational contexts.

The current typical dimension of a screen area of a handheld device is about 3.5 in. (9 cm) with a resolution of 320 by 240 pixels. Further development in this technology may involve a possible reduction in physical size of screen area. For example, the new models of O2, Dipod and HP mobile-enabled handheld devices have screen size of about 2.7 in. (7 cm). Recent studies have pointed to potential limitations of such screen sizes for effective presentation of information. Albers and Kim (2001) highlight three specific issues that affect user access to information via handheld devices: (a) users' reading of text of a handheld computer screen is more difficult than on paper, (b) presenting graphical information is limited in the size and complexity of image, and (c) challenges for interactivity are increased due to the lack of keyboard and mouse and also the screen size limits space for interactive elements to be displayed.

Educational studies show that a number of pedagogical and technological issues need to be addressed if handheld technology is to be effectively applied in learning (Clyde, 2004). Sharples et al. (2002) have called for studies to explore how handheld devices might more effectively support teaching and learning and especially their multimedia presentational capabilities, from a technical perspective it is possible to deliver a range of learning objects and other educational materials. Bradley, Haynes, and Boyle (2006) suggest that these devices offer increased flexibility for students to access and use learning objects. However, at this stage there are very limited guidelines suggesting effective design considerations for learning objects when presented via handheld devices, however the challenge is mainly related to the size of the screen (Luchini, Quintana, & Soloway, 2004). In current practice, learning objects are often simply downloaded from computers to handheld devices rather than designed to ‘‘fit’’ appropriately the constraints and affordances of the technology. A learning object designed for a small screen is likely to be effective when presented on a larger display area, but, unlikely to work in the reverse direction. This paper addresses this void by suggesting some design strategies which emerged from our engagement in discussions with a number of educational professionals and user interface evaluation of a number of learning objects with students in schools.

2. Small screen of the handheld devices and proposed solutions for improved design of information

Current research effort in design is concerned with text, in particular, text compression, formatting, scrolling, and to a limited extent with graphics (usually scaling). Little has been published about integrated multimedia displays. It would appear that the implicit assumption that is often made is that information is largely about text. Kim and Albers (2001) suggest that there is not only a lack of appropriate design guidelines for information via handheld devices, but the current guidelines are either based on software design guidelines, that is, they target software rather than information designers, or they simply assume handheld devices to be miniature computer monitors. Elsewhere the same authors (Albers & Kim, 2001) suggest that information design for handhelds must be informed by a new understanding of small screen usability, and the ‘‘limited real estate’’. Thus optimizing it remains the primary concern for information designers.

The assumption that information design is simply about text minimization has led some researchers and developers to explore possibilities for a system to automatically examine (using artificial intelligence) text of an informational resource that may have been initially designed for presentation on a personal computer. Then the task becomes an exercise to trim the information down by selecting only important parts and concatenating them together for presentation. Such a system would also reduce any associated graphical elements to a size that fits into a small screen. Albers and Kim (2001) use term ‘‘web clipping’’ to indicate application of these approaches in trimming web pages for presentations in small screens. Some software firms such as Opera and Spyglass took this idea seriously and invested into development of browser and server-side applications with small-screen rendering capabilities. Lee and Bahn (2005) referred to such systems as automatic and extractive compression systems. These applications reformat web pages for display on mobile phones. Although Lee and Bahn continued to research automatic and extractive compression systems, they acknowledged that this research is not new and it has been conducted in various forms since the late 1950s. From this approach derives a paradox: new emerging technologies are being explored using the older research approaches and associated thinking in place. While this thinking might be appropriate in the context of design and redesign of text-based information where the content can be summarized and presented on small screens without loss of meaning, Kim and Albers (2001) warn that reducing information to small chunks presents a risk of "fragmenting ideas to smaller-than-meaningful grains, which would then take more effort to reconstruct to the point of being understandable" (p. 2). Albers and Kim (2001) also suggest it might be difficult to find "a point when compressing information distorts the information's meaning?" (p. 48).

Researchers have explored the use of scrolling and dragging information to increase the amount of content effectively presented on a small screen. Jones, Buchanan, and Thimbleby (2003) investigated a group of users' information search strategies and found that screen size is the factor that most adversely affects information finding and results in reduced performance and satisfaction. In order to deal with this problem, they recommend pre-processing of pages for better usability on a small screen, and that this might be adopted for vertical rather than horizontal scrolling. One proposed alternative to scrolling is to present a "hierarchical view of the web site that can be interactively expanded... to enable users to identify useful areas of the site before final document selection is made" (Jones et al., 2003,p. 480). Such a strategy appears to be widely adopted by news reporting web sites designed for handheld delivery where new articles are presented as titles and summaries that users can examine before deciding to go to the entire content of the article.

Albers and Kim (2001) foresaw potential problems with scrolling but at the same time they questioned how it might be possible to present information in ways that do not require users to plumb more than three levels deep. One suggested solution is to allow the user to drag up and down the entire screen with a stylus pen. Albers and Kim also point out that users are likely to be reluctant to follow links on the small screen unless they are certain that on the linked screen they will access the sought information. They claim that their research suggests that users prefer to click rather than scroll, but, users would also prefer to scroll than to click on a questionable link.

Another proposed alternative is to format text in way that provides "meta-knowledge" view of the information. For example, large text might indicate links to more important information while brighter text colours might indicate more recently published information. Jones, Marsden, Mohd-Nasir, Boone, and Buchanan (1999) suggest that scrolling can be reduced by placing navigational features in the fixed place near the top of presented resource, and by placing key information at the top. Overall, studies appear to concur in their suggestion that scrolling on a small screen should be avoided or at least minimized.

Any discussion related to researching the design of information for handheld delivery should be sensitive to context and the tasks in which this information becomes effectively useful. Albers and Kim (2001) suggest that design of information should not be considered in isolation from the context and that "designers must orchestrate the way the text and graphics work together to help the user make meaning of complex information, and this must be done within the context of the task at hand" (p. 51). Similarly for Rettig (2002), design for small screens is not just about screen size but it must include consideration of context and task. Rettig recommended that designers should also consider input devices and the fact that people often do something else while using handheld devices (divided attention).

3. Small screen of the handheld devices and learning objects

Bradley et al. (2006) conducted two case studies to explore design and delivery of learning objects via handled devices. During the design stage they understood that text legibility and the nature of interaction represented limitations on design possibilities for available display area. One strategy chosen to partially overcome this limitation was to design learning objects for full screen presentation rather than for presentation in a browser window. When presented in a browser window, the top and bottom areas of the screen are occupied by the standard controls and this reduces available display space. When designing learning objects for students to use on handheld devices, Bradley et al. concluded that although user interactivity does not appear to be affected, screen size continues to present a design challenge. They recommend greater use of audio over text to compensate for the limited text display. Although this study represents an important step towards better understanding the design of educational material, its key limitation rests on how learning objects were defined, namely, "small, self-contained resources that focus on one learning objective". This limited view raises challenges when reviewing the complex range and the many disagreements that exist in the literature on learning objects.

Learning objects are perhaps better described in more general terms as representations designed to afford educational use. They reside in digital repositories, ready to be located and utilized by those involved in educational activities (e.g., teachers and students). These representations might be displays of: key concepts from the discipline, represented in visual and often interactive ways (conceptual models); educationally useful information (information objects) and data (contextual representation objects) that can be useful in the context of developing disciplinary-specific thinking, culture of practice, spirit of inquiry, or theoretical knowledge and information work. Learning objects also support; the presentation of small, instructional sequences; delivering encapsulated descriptions of some aspects of subject matter (presentation objects); providing opportunity for practice (practice objects); and simulate key equipment, tools and processes from a discipline to enable the development of a deep understanding of artifacts used in a culture of practice (simulation objects) (for a more complete explanation of the classification, see Churchill, 2006).

While some presentation objects from this classification might be in the form of learning objects defined by Bradley et al. (2006), a more immediate question that emerges from this classification—what types of learning objects are best for handheld screen display.

For a learning object to be cognitively engaging and practically useful, their design must leverage not just text and/or audio but more importantly visualization and interactivity, where text is used for labeling, pointers and short content messages only when necessary. Tufte (1983, 1990) suggests that visuals can communicate complex ideas with clarity, precision, efficiency and convey the most ideas in the quickest time in the small space. De Jong et al. (1998) use the term "modality" to describe particular forms of expression such as text, animations, diagrams, graphs, algebraic notions, formulae, tables and real-life observation (video). Van Someren, Boshuizen, de Jong, and Reimann (1998) suggest that multimodality supports learning by allowing learners to learn by exploring and linking different modalities, and that educational representations should be developed to utilize this opportunity. Similarly Mayer (2003) suggests that multiple representations facilitate learning employing different modalities that are encoded and organized in different mental models leading to deeper understandings. For Tufte (1990) interactivity made possible by contemporary technology significantly expands the representational power of visual displays. Fraser (1999) suggests that capabilities of contemporary technology provide a unique opportunity for communication of concepts to learners through what he labels as representational pedagogical models. Fraser claims that "in the past, we relied on words, diagrams, equations, and gesticulations to build those models piece by piece in the minds of the students... we now have a new tool—not one that replaces the older ones, but one that greatly extends them: interactive computer visualization".

Further considerations relate to suggestion by Albers and Kim (2001) that context and task should inform design. Thus "what types of task work best for educational applications of learning objects via handheld devices?" Initial anecdotal evidence from our earlier studies suggests that conceptual models and to some extent information objects are the most appropriate types of learning objects for handheld delivery.

An information object can be an effective strategy for packaging multimodal, educationally relevant information using tables, matrixes, mind maps, illustrations, formulas, pictures, animations, videos, diagrams, 3D models. Interactivity, such as buttons, clickable hot-spots, roll-over areas, sliders, text-entries and drag-and-drops supports the organization of the information space to support learners exploring information, changing modalities, manipulating parameters or configuring options and observing changes in information. Overall, the facilitate manipulating the information students are accessing through the interface (raw information might reside within an information object, or in a database). Interactivity and modalities allow large quantities of information to be represented efficiently, and made available for display in a relatively small screen space. Thus an information object is not for students learning about a topic by systematically consuming embedded messages, the better idea is to provide useful as students engage in learning tasks.

Conceptual models are learning objects that represent one or the linkage of two or more related concepts or ideas, usually in an interactive and visual way. Earlier research with visual educational material has introduced the conceptual model (Mayer, 1989). Mayer suggests that these improve the ability of learners to transfer their learning to solve new problems, because learners have constructed useful conceptual structures that they are able to mentally manipulate when needed. Due to limitations of traditional non-interactive technologies and tools, these conceptual models were largely undifferentiated from print-based diagrams, images, drawings and charts. With handheld digital technologies, we have tools that enable us to add critical interactivity and modality dimensions to the design of conceptual models.

Best practice in user-centered design of learning objects for educational applications on handhelds may be summarized from the literature as

- text needs to be kept short and formatted in a way that provides meta-knowledge about information,
- images should be reduced in size but not beyond the point of becoming meaningless—Albers and Kim (2001) also recommend to minimize or avoid use of graphics and images for decorative purposes as they might unnecessary occupy already limited screen space,
- scrolling should be avoided,
- learning objects should be designed for a full screen presentation, and
- greater use of other modalities (in particular visuals) and interactivity over text should be employed as means of maximizing amount of educationally useful information presented on a single screen.

Rettig (2002) proposed one additional useful recommendation for design of information for small screens when he suggested that designers should storyboard their prototypes on small pieces of paper that reassemble the physical size of a screen of a handheld device. These recommendations from the literature were taken into consideration in the current study of design of learning objects for handheld devices.

4. A study of design of learning objects for small screens

In the initial stage of the study, a number of educational professionals who had previously used handheld technology for personal and educational purposes, were interviewed. Ten such individuals were identified across a number of educational institutions in Hong Kong who subsequently accepted an invitation to participate as respondents. The interviews were conducted in a semi-structured manner and began by asking the respondent to outline his or her prior experience with handheld technology. The interview progressed to discussion in relation to the small screen and this was facilitated by a handheld device (O2 XDA model) and small selection of learning objects from the Learnactivity web site (see http://ww.learnactivity.com/lo/). These learning objects were originally developed for computer-based delivery over the Internet and were downloaded into the handheld device for the purpose of this study. The respondents were encouraged to interact with the learning objects, which were selected to also permit demonstration of various modalities (e.g., text, visuals, audio) and different kinds of interaction (e.g., buttons, hot-spots, sliders, text-entry boxes) in order to facilitate discussion leading to an understanding of possibilities for dealing with the challenges of a small display area. Ideas about possible contexts for educational applications of these learning objects were also explored with the respondents. Interviews and development of understandings were greatly facilitated by the interviewer's knowledge and extensive experience with the design of educational multimedia material. During the interview, the researcher was able to comprehend suggestions and concerns by participants, and to immediately speculate and table possible design solutions for discussion.

Following the interviews, a few learning objects were progressively (re)designed for implementation with a small group of students in schools. Macromedia Flash was selected as the tool for development of the learning objects as it supported rapid production of web-based interactive and visual material that could easily be deployed on handheld devices. It also supports vector-based graphics that offer visual clarity of graphical representations at different screen sizes. If designed with care, Flash files are small in size which enabled more reliable downloading and execution over the Internet on devices with slower processing power. Flash content

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is also easily integrated into other files such as web pages and presentation slides. These learning objects were deployed on four available handheld devices and these were taken for a test in one primary and one secondary school classroom. The students used learning objects in a context of inquiry-based tasks designed by their teachers in consultation with the researcher. During the two lessons, observations were recorded (including some video, audio and photos) and after the lessons, interviews were conducted with students in attempt to identify any further issue that may influence the design of the learning objects.

5. Recommendations for design of learning objects for handheld devices

This study thus led to articulation of a set of recommendations for the design of learning objects for delivery via handheld technology. The study results provided additional ideas for new strategies for interaction with resources delivered via this type of technology. Although at this stage these results are based largely upon case study evidence, design activity and isolated trails, there is opportunity for more comprehensive empirical studies to expand these proposals. In addition to creating further research opportunities, these recommendations might be useful to other designers of learning objects for delivery via handheld technologies and to people involved in planning the actual use of these resources by students. Some understanding of effective designs for small screens might inform the design of information for handheld delivery in fields other than education, such as, journalism and other fields concerned with design of information for handheld delivery.

5.1. Design for full screen presentation

Throughout our study, all the participants indicated preference for full screen presentation of information when accessing it via the handheld device. Internet-based material (we understand that learning objects should be developed for internet-based implementation) is usually delivered though web browsers. Full screen presentation of learning object increases amount of available space and this appears to create an improved user experience. Typically, this type of content is presented inside a browser window where certain portions of the screen are occupied with standard elements such as navigation buttons, menu items, etc. Computer-based browsers are equipped with capability to switch to full screen display of the content and this permits hiding of those elements while increasing amount of screen space for information display. This was not possible with an Internet browser for a handheld device. At the time of the study, we used Pocket PC Windows 2002 and in this context we were confronted with the technical challenge of how to present learning objects in full screen. We opted for third party software Handsmart FlashPack that permitted learning objects to be packaged (as Flash files) for full screen presentation. However, all new handheld devices arrive preinstalled with Windows Mobile 5 which supports browser capability to present content web-based a full screen and there is no longer need for third party software to be used.

5.2. Design for landscape presentation

Typically a screen of a handheld device is presented in portrait layout. This is different from most traditional devices, such as computers and television screens, and from many contemporary technologies such as screens in digital cameras and game consoles. Although the goal of a handheld device is to be comfortable to hold in a single hand (usually because it is reasonable to assume that the other hand is holding a stylus pen during interaction), participants in our study were unanimous that presentation of learning objects in a landscape position was preferred. From a design perspective, through our attempt to create relevant learning objects that explored design options, it appeared that the landscape screens also offered more flexibility. Perhaps, this mode of presentation was more comfortable as it replicates the presentation mode of other devices with which both participants and researchers felt more familiar in terms of common uses.

5.3. Minimize scrolling

The participants agreed with the literature and suggested that scrolling should be avoided or at least minimized. While several authors propose as an alternative, dragging the content presented on a screen (e.g., Albers & Kim, 2001), in this study the participants also treated this approach unfavorably. Some material that required dragging was presented to the participants who found this method of control uncomfortable. As emphasized earlier, learning objects should utilize visualization and interactivity and minimize amount of text presented on a screen. Scrolling is largely characteristic of navigation through text and long web pages. Considering that learning objects primarily utilize other kind of modalities, different methods should underline navigation, if any navigation is required. Often a learning object is designed such that everything is squeezed into a single representation presented on a single screen (or portion if it). Design practice has shown that large amounts of information can be organized and effectively presented in this way. However, this study identified another method that allows visual and interactive content to extend beyond the limits of the screen and this is discussed in Section 5.6.

5.4. Design for short contacts and task centeredness

A handheld device personally assists and supports an individual in his or her activities, e.g., conducting a business, making scientific inquiry, planning a trip, creating art, learning, on so on. Attention is often divided so that an individual might be undertaking some tasks simultaneously or in a variety of modalities when drawing on the assistance of handheld devices. This contact with device is purposeful and usually short in terms of time (e.g., checking calendar and tasks, calculating, viewing latest news headlines or stock market movement, capturing an image, or making a personal note). Applying this thinking to design of learning objects, they should be designed in a way that provides for learning task-centered information to be provided in a single action on a small screen. One of the general concerns of the participants was the impact of prolonged use of handheld-based learning objects on their health and in particular to possible eye-strain of students. A recent article in the Wall Street Journal (Spencer, 2006) speculates that the impact of a small screen device might have serious impact on an individual's eyesight. In evidence, the article described a case of a single individual who claimed to be experiencing problems, however, the article further details how this individual also used a handheld device to read the novel "The Da Vinci Code." Reading a novel over handheld device is an activity that is somewhat disconnected with any real world task, it requires continuous and prolonged perceptional concentration on a small screen area and rationally this seems likely to cause problems. An audio podcast would seem a much better match with the task and the affordances of a handheld device. Learning object design should be based upon a consideration that these representations are to be task-oriented where the main perceptual and conceptual effort is directed at the task rather than at the small screen or the device. Thus, learning objects act almost in a way that supplements learner's intelligence and supports their conceptual deficiencies using the affordances of the device at hand. Portable technology ensures learning objects are available to access and provides support at any time and anywhere whenever needed by the task demands.

5.5. One step interaction

The design goal for a learning object should be to provide through visualization and interactivity all necessary information with a single display that fits the screen of the handheld device. Interactive elements (e.g., buttons, hot-spots, roll-overs, or sliders) when integrated in a learning object should provide immediate feedback to the learner. Single interactions, such as changing a position of a slider, should result in immediate updates on the screen presented in way that is perceptually and immediately noticeable in response to a learner's action. This can be achieved by visual effects such as text formatting, use of contrasting colours, and the flashing of prompts that are explained upon interaction. Audio effects can also capture user attention, although this might be less effective in noisy environments (unless we assume that the user has earphones). Visuals can also be adversely affected by environmental factors such as natural or artificial lighting, and reflections on the screen. However, an average user is likely to tilt the device or cover the screen by hand to prevent reflection and achieve better visual contact with the screen. Fig. 1 shows an example of a learning object designed in the context of our study that demonstrates this principle of "one step interaction". Limiting interaction for responses in this way would also be appropriate in the context of mobile network constraints.

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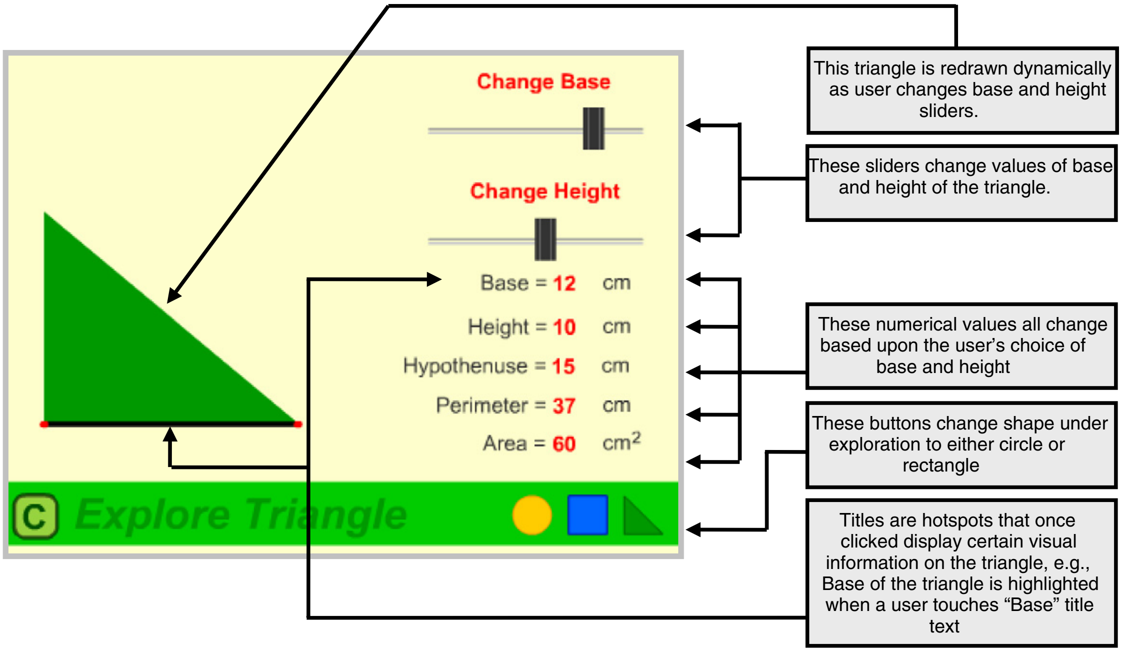

Fig. 1. "Shapes" learning object.

This learning object provides a conceptual model of a triangle. It can be reused in variety of tasks (developed by a teacher) that lead to the construction of a range of associated mathematical concepts from basic properties of a triangle to more complex trigonometric relationships. Students might also use the learning object as a reference conceptual model on their handheld device. This learning object allows a user to manipulate base or height of the triangle by dragging a corresponding slider. Manipulating either of the two parameters of the triangle (base or height) by dragging of slider will result in immediate update to the display in multiple modalities: the triangle will be redrawn in a corresponding size and the numerical information regarding associated parameters will be updated (such as the value of hypotenuse).

5.6. Zooming facility to enlarge display beyond the physical limits of the screen

From the literature, dragging of the screen was seen as more favorable and effective for a user than scrolling. In this study, we explored this possibility through redesign and use of a learning object *Pulley System*. This learning object is a conceptual model of mechanical transfer of power through a pulley system and was developed using Macromedia Flash. It allows students to manipulate a number of parameters (load, effort and the number of pulleys) to investigate the impact of the configuration on the pulley system. Exploring these relationships should lead to a deeper understanding of the key concepts encapsulated by the learning object. The understanding in the long run might be supported by perceptual impressions and the individual's cognitive ability to recreate relationships in their mind through their imagination. In educational applications, a teacher might create a task in which students are engaged in inquiry and exploration of the underlining relationships. Subsequently, this learning object might be a reference tool or an external cognitive mediator for students when challenged with relevant problems to solve.

A user can drag the two sliders in order to change quantitative values of the load to be lifted and the effort to be exerted to lift this load, or vice versa. These values are represented as numbers on the screen and this information was purposefully formatted in a slightly smaller font size to require an average user to use the magnifier to read the information on the small screen.

Experimentation began by using a standard feature of the Pocket PC Flash Player that supports magnification of the display beyond the physical limits of the screen. If the stylus pen is held against the screen for few seconds an option that allows magnifying is activated. The magnified display then becomes moveable. However, from casual demonstration and trialing with the participants, this possibility was not sufficiently explicit and was not employed by the average user. Thus in design, it is more appropriate to make this function more explicit via an interactive element on the main screen interface. To enable this redesign the new interface of the learning object included a button that would simply magnify the display to a larger size (see Fig. 2). This button also activated the feature that permits a user to drag the entire screen in any direction to access hidden areas of the display beyond the physical limits of the screen.

However, we discovered that this redesign was not optimal, participants did not always recognize the function so in a third redesign, the button that previously magnified the screen activated a moveable square that acted as a magnifying glass (see Fig. 3). The participant was able to move the rectangle to different areas of the display and to preview a magnified background of the area covered by it. In this new approach, the user was able to see the whole display and at the same time have access to magnification of the required information and this resulted in enthusiastic user endorsement.

However, this third approach solved only a limitation of the visual display but not aspects of the interactivity, such as the case when the user finds the sliders to be too small for effective manipulation. Interacting with the sliders inside of the magnifying rectangle was not possible and if the participants wanted to reposition them, they had to close magnifying rectangle, reposition the sliders, then open the magnifying rectangle and move it until the desired magnified part of the display becomes visible. This design worked against our proposed principle of "one step interaction", as a user was unable to see clearly and immediately the impact of their change of parameters.

This resulted in a fourth design which allowed the user to click on a button to magnify displayed learning objects beyond the limits of the physical screen while at the same time displaying small thumbnail view of the whole display in the top-left corner (see Fig. 4). This thumbnail served as a navigation area that contains another smaller movable rectangle. Moving the rectangle within the thumbnail would result in repositioning of the magnified display. This final approach was selected as most favorable by the participants and accordingly, based on this case study, we propose it as a suitable design. With introduction of new Windows Mobile 5 operating system for handheld devices a similar feature has been build into the presentation display of PowerPoint Mobile. This is in fact an endorsement for this fourth approach to design.

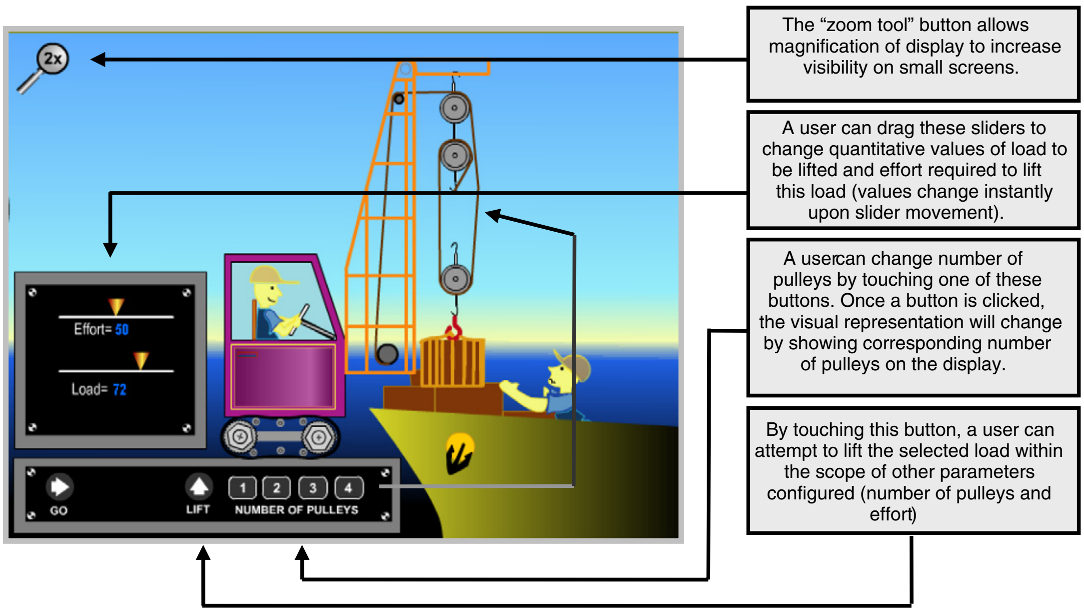

Fig. 2. *Pulley System* learning object with a button that magnifies the display.

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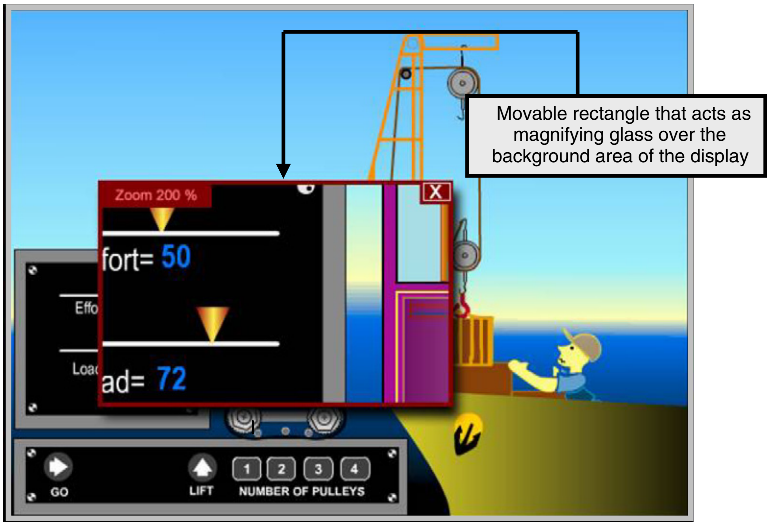

Fig. 3. Employing a moveable rectangle that acts as magnifying glass.

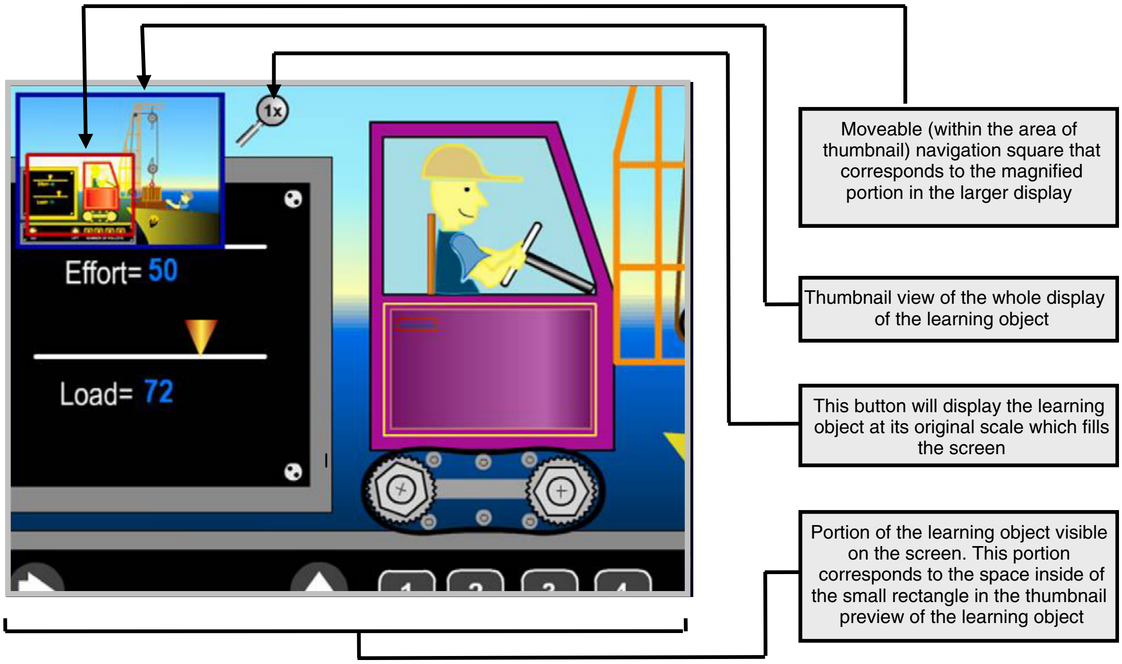

Fig. 4. Navigable thumbnail preview of the screen that allows focus on magnified areas.

5.7. Movable, collapsible, overlapping, semitransparent interactive panels

Our final effort concentrated on exploring design possibilities that utilize floating panels in order to maximize amount of information presented on a display. This focus emerged from the involvement with the participants as they suggested in relation to the *Pulley System* learning object that the sliders and buttons could be presented within a floating panel.

Rather than redesigning an existing object, we created a new learning object to increase the number available for potential further study. The final progressive result of our engagement was the *Parallel and Series Circuits* learning object presented in the Fig. 5.

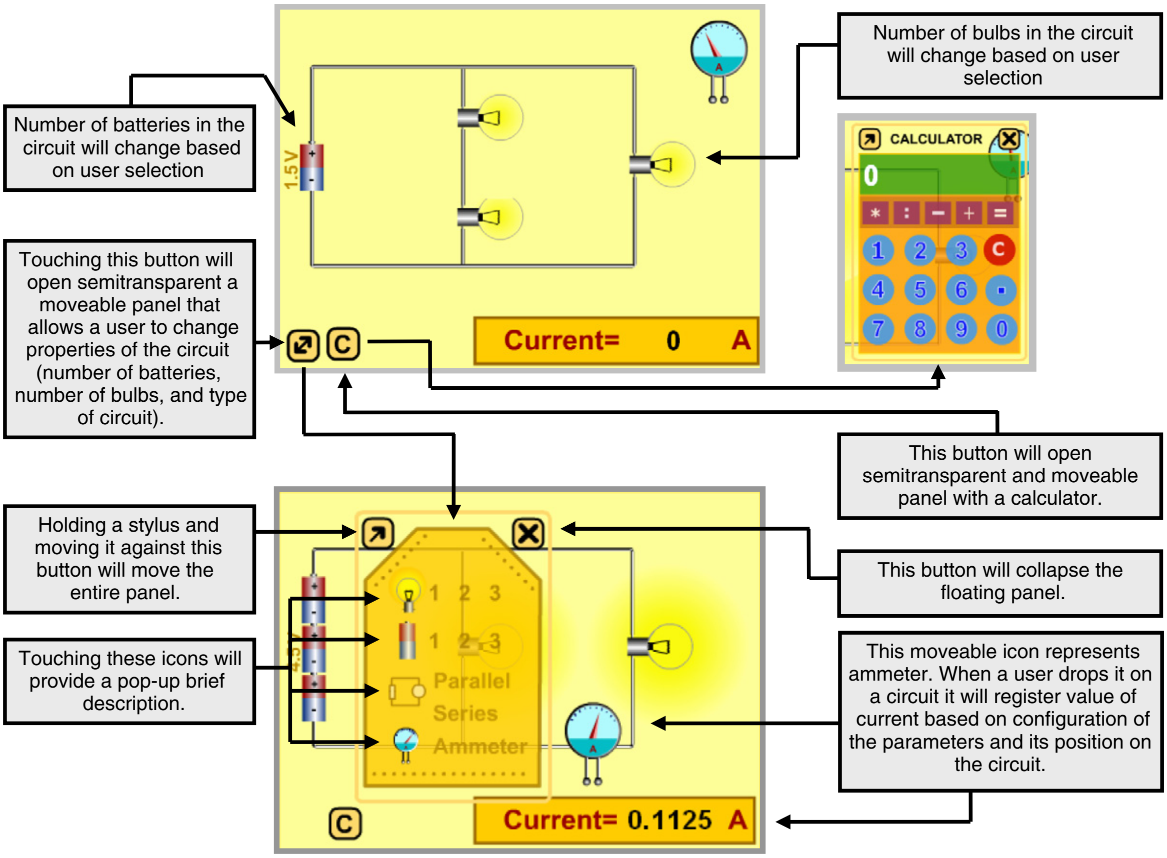

Fig. 5. Parallel and series circuit learning object.

Initial design contained a non-transparent floating panel that permitted a user to change the number of bulbs, number of batteries and type of circuit and it also provided a very brief description of these properties. The participants demonstrated discomfort in having to frequently move the panel in other to see what change had taken place on the circuit. Again this design worked against the principle of "one step interaction" as it was not always possible for a user to immediately "see" the outcome of their interaction with an interface element. Thus a design action taken at this stage was to make the floating panes semitransparent so that learners had limited visual contact with the information on the background. These designs received greater support and match the participants' experiences. At a later stage, the class teacher requested a panel with a calculator to enable the students to also calculate their final results.

5.8. Possible development of stylus pen interaction

One idea that surfaced through this exploration with the participants was the possibility of using a stylus pen to producing pressure upon the screen at a particular point. Arguing from a conceptual point of view, possible developments might focus on integrating electronics components into the stylus that might enable each of its ends to perform different interactive functions. One function might be a new standard feature that magnifies information.

6. Conclusion

The use of handheld devices has the potential to create more disruptive pedagogies (Hedberg, 2006). Empowered with interactive multimedia presentational capabilities, handheld technology permits the delivery

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of a range of digital material that if appropriately designed for the context and learning tasks can be effectively delivered to learning environments. The key limitation on handheld technology for the delivery of learning objects is the screen size. At this stage availability of relevant guidelines and a solid literature in relation to solution of this problem is very limited. Some recommendations from the literature that were taken into consideration in the current study of design of learning objects for handheld devices included issues such as appropriate text formatting, image reduction, avoiding scrolling, design for a full screen presentation, greater use of other modalities (in particular visuals), and interactivity over text. Some interesting ideas regarding effective design of information for small screens could have been possibly included experiences of professionals involved in the design of labels for small products (e.g., medications). We have developed some specific recommendations for design based upon several case studies with novice and expert users. These principles include: design for landscape and full screen presentation, design for one step interaction, minimize scrolling, design for short contact time, design to match the task, provide zooming capability to enlarge display beyond the physical limits of the screen, and design to include movable, collapsible, overlapping, semitransparent interactive panels.

Although we acknowledge importance of various technical issues in m-learning, for example, response time and reliability of delivery over mobile telephony networks, the primary focus of this paper remains to be design of educationally useful material for display. In the future it might be also important to establish specific design possibilities between various devices such as integrated PDA and mobile phone devices, compared with he more popular 3G mobile phones. Currently emerging 3G mobile phones appear to be increasing the size of their display area, so that in the future the difference between these technologies and the available display area appears to be blurring. We acknowledge one limitation of our experiments, we have not paid attention to use of audio as a mean of reducing the amount of information presented and voice-recognition possibilities for interaction with the device may be more useful in the future. Our initial assumption was that environmental factors as well as the personal profile of a user (e.g., linguistic background) might impact upon the possible options. Bluetooth enabled ear phone/microphone as well as flexible voice recognition software that can be trained by a user might be able to afford for interesting learning possibilities. However, more immediately studies should involve further exploration of contexts and tasks for pedagogically effective delivery of educational resources using these types of technologies.

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