6

Multi-Device Design in Contexts of Interchange and Task Migration

Rodrigo de Oliveira, Heloísa Vieira da Rocha
State University of Campinas (UNICAMP)
Brazil

1. Introduction

With the miniaturization of digital components and the vast technological development of the past years, society has remarked the redefinition of "personal computers" by the advent of modern mobile devices. Together with the innovation brought by these handhelds, there was also the challenge to develop multi-device interfaces for today's desktop applications. While some created mobile interfaces from scratch to get the best from the devices, others looked for automatic adaptations to reduce the load imposed to the designer. In both cases, the user wasn't the focus anymore, resulting interfaces so different from each other to the point of compromising usability when performing the same task on many devices.

The proposal described in this chapter claims that there is no multi-device approach capable to provide full usability in every context because the user may choose only one interface to access the application or interchange its use via many devices. In the first case, the user learns to perform tasks with only one device, which makes relevant an approach that takes advantage of its resources and solves its limitations. In the second, the user already knows one of the available interfaces, which generates an expectation for the others. Therefore, it is necessary to combine approaches with different goals and suit the user according to the appropriate context.

In this sense, we propose multi-device design via the maintenance of a Consistency Priorities hierarchy defined in three levels. The first two levels give support to the user's expectation in order to guarantee easiness of learning/remembering and safety in contexts of interchange (prone to task execution with different devices) and task migration (starting tasks with one device and finishing with another). On the other side, the third level provides task personalization according to the user's interest towards higher efficiency and satisfaction of use with a specific device.

We evaluated this proposal by means of a controlled experiment in which an e-learning desktop application was taken as a reference to design three pocket PC interfaces using different approaches: (1) *Direct Migration* to maintain exactly the same layout of the desktop interface; (2) *Linear Transformation* to personalize and adequate the desktop interface to the handheld; (3) and *Overview* applying the first two levels of the Consistency Priorities hierarchy. All participants executed common tasks using each of the three mentioned interfaces.

The subjective evaluation results pointed the Overview approach as the best to maintain the user's mental model by preserving easiness, efficiency and safety of use for inter-device interaction. Additionally, both efficacy (task result accuracy) and efficiency (task average execution time) were the same or even better with this approach. On the other hand, users revealed their preference for the task personalization present in the Linear approach. This result gives support to our proposal, corroborating that the efficacy generated by the first two levels of the Consistency Priorities hierarchy (task perception and execution) should be combined with the third level of personalization. This could be done by letting designers create interface patterns and make them available to users during interaction. Such combination should guarantee usability while constantly accessing one application through the same device or in contexts of interchange and task migration.
This chapter is structured as follows: First, we review some relevant previous work in the area of multi-device design. Then, we describe our proposal and outline supportive theories in multidisciplinary fields. The implementation of these ideas are exemplified and evaluated in the next sections. Finally, we present our conclusions and future directions of research.

2. Related Work

Multi-device design has been addressed in many ways focusing the transition between desktop and mobile interfaces. Generally, this process involves automatic or manual transformations to remove images, reduce sizes, summarize texts, adapt orientation or restructure the whole information to better suit the handheld characteristics. In order to understand the collection of proposals presented recently in this research field, we suggest a division based in four categories: Hypertext Structure, Universal Controller, Adaptive Interface and Layout Consistency.
The *Hypertext Structure* category includes interfaces that outline the structure of related web pages using hypertext. This proposal has been implemented with automatic approaches that create hyperlinks matching the web site structure in a tree-based view. This way, users may first explore the document at high-level and only then visualize details about the information of interest. This visualization technique has proven to be useful in cases of limited bandwidth and processor power. First prototypes were developed for desktop browsing, like WebMap (Dömel, 1995) and WebTOC (Nation et al., 1997), and improved towards the mobile context with projects such as WebTwig (Jones et al., 1999) and Power Browser (Buyukkokten et al., 2000). Other proposals applied these ideas not only to one web site, but also to a set of them belonging to the news context (Banerjee et al., 2003).
The *Universal Controller* category envisions a totally different perspective for multi-device design, adapting handhelds' functionalities to exploit services discovered while entering new environments (*e.g.* controlling of lights, projector, stereo, *etc.*). Examples of this category include the architecture proposed by Hodes et al. (1997) and the ICrafter framework (Ponnekanti et al., 2001), both adequate to rigid ubiquitous environments. On the other hand, the PUC system (Nichols et al., 2002) has a more flexible structure for the mobile context by engaging in a two-way communication with everyday appliances, first downloading a specification of the functions and then translating protocols to automatically create remote control interfaces. Follow-on work had major upgrades in efficacy and efficiency whenever users had to execute tasks using interfaces consistent with their previous experience (Nichols et al., 2007).

The *Adaptive Interface* might be the most predominant category considering its vast number of proposals implemented using model-based design. The methodology builds specifications from an abstract declarative model of how the interface should behave and then automatically generate concrete user interfaces based on such model. Eisenstein et al. (2000) proposed techniques to help designers with the modeling process of platform, presentation and task structure. Lin (2005) also targeted the designers by creating a tool called Damask, which enables the design sketching using patterns optimized for each target device. Many authors implemented prototypes to automatically generate interfaces based in the abstract models (Bergman et al., 2002; Mori et al., 2003; Coninx et al., 2003; Gajos & Weld, 2004). Model extraction from already made applications was also addressed for the web domain (Gaeremynck et al., 2003) and graphical user interface reverse engineering (Santo & Zimeo, 2007). Although the adaptive interface category reduces the heavy load imposed to the developer, the generated interfaces can't guarantee a smooth inter-device transition in contexts of interchange and task migration, which have been considered the primary concern by many authors (Denis & Karsenty, 2004; Florins et al., 2004; Pyla et al. 2006). In fact, the experiments realized with adaptive interfaces tend to focus only on the automatic interface generation efficacy instead of horizontal usability issues.
At last, the *Layout Consistency* category is based on Overview transformations that preserve visual characteristics of the desktop layout. Some of the most used visualization techniques include the fisheye (Baudish et al., 2004), thumbnail (Milic-Frayling & Sommerer, 2002; MacKay et al., 2004; Lam & Baudisch, 2005) and focus + context (Roto et al., 2006). These proposals have revealed better easiness, efficiency, safety and satisfaction of use when compared to other automatic transformations, such as the Direct Migration and the Single Column. However, designers still need a well established theoretical model to guide them towards constructing these interfaces with better usability for multi-device contexts. The following sections describe our user-centered approach that addresses this issue for contexts of interchange and task migration.

3. User-Centered Multi-Device Design

3.1 Mental Model Update Cycle

Norman (1988) proposed a seven stage action model of how people execute tasks. Although it can't be considered a complete psychological theory (stages are not discrete, nor necessarily sequential and most behavior does not go through all stages), the main human cognitive processes involved are well highlighted, like *attention* to world objects, *decision making* to execute actions, *perception* of produced effects, *memory* analysis to interpret the world state and *learning* of final results. Fig. 1 adapts this model to a simplified version that focus on the user's mental model update stage.

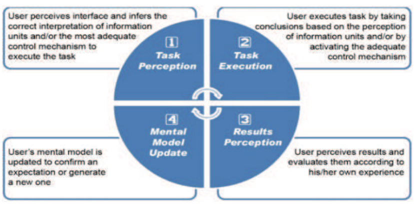


Fig. 1. – User's mental model update cycle to execute tasks using computer interfaces.

3.2 Consistency Priorities

According to the mental model update cycle presented in Fig. 1, the user's first step is to infer what should be the appropriate action towards the goal and, only then, actually execute it. This inductive inference based reasoning process usually contrasts the interface perception (*e.g.* visual, auditory, tactile, *etc.*) with the user's previous experience (mental model). As a result, a particular decision making is drawn according to the user's judgment, increasing the possibility to achieve the desired goal. However, when the system presents similar situations leading by inference to different conclusions, it is likely that the user will make mistakes and store ambiguous information in his/her mental model (forth stage). In order to avoid this, we propose that the application's interfaces should preserve the same perceptual characteristics (which constitute the inference process input) and have a consistent behavior in which one task can be executed following the same actions' flow on different devices maintaining the richness of the distinct interaction types involved. This proposal can be structured in the following Consistency Priorities:

1. *Task Perception:* Inter-device perceptual constancy[1] preserving size, shape and color of every control mechanism and information unit relevant to the task. Also, their relative localization within the interface should be maintained. If relevant differences are found between devices considering their:
   - *sizes*, interface should be adapted maintaining visibility;
   - *shapes*, interface should be adapted maintaining visibility and mapping;
   - *colors*, interface should be adapted maintaining visibility, mapping and feedback.

   Additionally, if the interaction types are incompatible (*e.g.* speech and graphical pointing interfaces), each control mechanism perception and its relative localization should be mapped to demand attention of the correspondent human sense;
2. *Task Execution:* Inter-device consistency of the actions' flow required to execute each user's task. If the control mechanisms had to be adapted by the task perception priority, the actions' flow should be preserved in a logic perspective to maintain the task model structure under a different implementation of the modeled interactions.

By adapting to the user's previous experience, the Consistency Priorities hierarchy shall contribute to multi-device design guaranteeing easiness of learning, remembering and safety of use in contexts of interchange and task migration. However, some users could choose only one device to access the application, thus reducing the concern with his/her experience. Additionally, the varied nature of these devices may restrict the application's executable tasks set, thus compromising efficiency and satisfaction of use with the first two consistency levels. We suggest a third consistency priority to balance the usability attributes:

3. *Task Personalization:* Ability to change both levels of task perception and execution according to the user's preferences and context of use. The goal is to achieve the best design which is the configuration that the user expects. In this sense, we encourage the development of interface patterns at the users' convenience. This priority is related to the personally consistent design concept (Nichols, 2006, p.86), but with an active position for the user. As a result, efficiency and satisfaction are guaranteed to both experts and novices, avoiding the downsides of consistent design (Grudin, 1989).

---

[1] Denotes the tendency of animals and humans to see familiar objects as having standard shape, size and colour regardless of changes in angle of perspective, distance, or lighting. Impression tends to conform to the object as it is or is assumed to be, rather than to the actual stimulus.

4. Applying the Consistency Priorities Approach

The implementation of this approach must be understood in the same context as the original application's design process. In this sense, Fig. 2 highlights the steps required in the lifecycle model towards applying the Consistency Priorities.

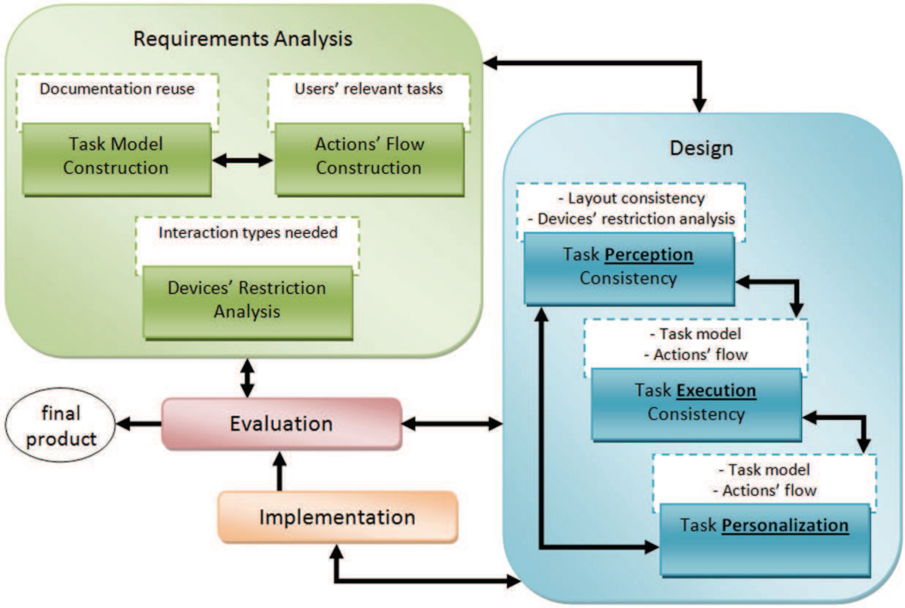


Fig. 2. – Interaction design lifecycle model adapted from Sharp et al. (2007) to focus on the Consistency Priorities implementation steps.

According to Fig. 2, the Interaction Design process can be divided in four main stages: Requirements Analysis, Design, Implementation and Evaluation. Moreover, the Consistency Priorities approach can be embedded in the model, reinforcing the importance of iteration. Pragmatically, we suggest applying this methodology by taking the following steps:

1. *Task Model Construction:* Representation of the user's tasks defined in high level, interaction tasks required to execute such user's tasks, their sequential steps and information units present on the interface;
2. *Actions' Flow Construction:* Description of the user's cognitive effort on relevant tasks concerning perception, execution and memory storage/retrieval activities;
3. *Devices' Restriction Analysis:* Comparison of the application access devices to identify relevant restrictions. This procedure is important to reveal the main design principles to be accounted on the next phase;
4. *Consistency Priorities Implementation:* Design of alternative interfaces following the three priorities of the consistencies hierarchy (perception, execution and personalization).

In order to ease the transition between theory and practice, this section presents an example applying the Consistency Priorities to design a pocket PC interface for a desktop application. Following, we present the chosen application, the task model elaborated for one of its tools, the actions' flow identification process, the restriction analysis for the target devices, and the implementation of two mobile interfaces adequate to different contexts (task migration and sole device access).

4.1 Application Domain

We chose Distance Learning to be the application's domain for this example due to its potential for dissemination and the availability of human resources to conduct experiments. Moreover, the application chosen was the TelEduc[2], an open-source e-learning environment used by more than 3000 institutions around the world, among schools, faculties, universities and companies. Fig. 3 shows a screen from this system designed for desktop.

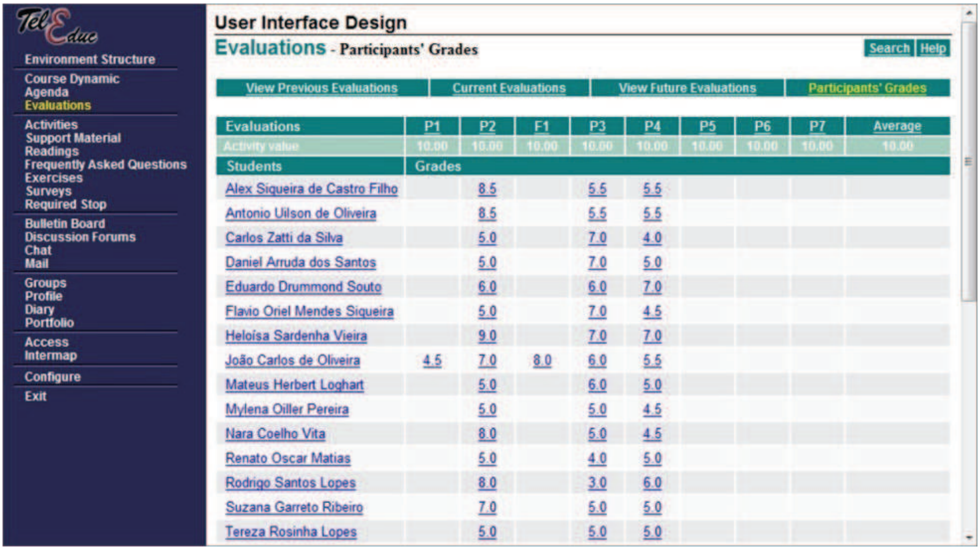


Fig. 3. – Example of a TelEduc screen with the students' grades in each evaluation.

4.2 Task Model

Building the task model is the first step of this methodology and its relevance is due to the fact that it describes interactive systems in terms of tasks needed to be executed towards the users' goals. Hence, the multi-device design process gains support to generate consistent interfaces directing the designers' focus to the system's requirements and behavior instead of implementation details for each platform. No specific notation is required, as long as the chosen language is able to model:

- User's tasks defined in high level;
- Interaction tasks required to execute the user's tasks;
- Sequential steps for the interaction tasks;
- Interface elements or information units present in the interaction.

[2] http://teleduc.nied.unicamp.br/teleduc

One way to start building this model is to considering each user's task and investigate every interaction needed to conclude them. Another way follows the reverse flow, describing all the interaction possibilities in each screen and growing the task model tree level by level until all functionalities were explored. Fig. 4 shows an example of the model built for the TelEduc's Evaluation tool using this latter approach under the ConcurTaskTree notation (Paternò et al., 1997). The result is a task model tree describing all the interaction tasks available on the screens related to this tool and is of great importance for this methodology's further steps, particularly for the Consistency Priorities implementation phase.

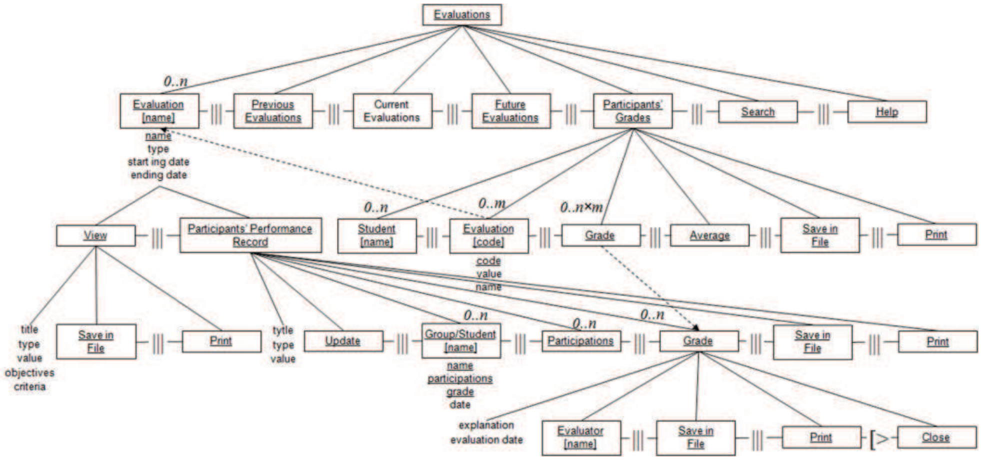


Fig. 4. – Task model of the TelEduc's Evaluation tool using the ConcurTaskTree notation with two extensions: (1) multiplicity in associations to avoid redundancy and (2) explicit declaration of interface elements (*e.g.* attributes like *name*, *type*, *starting date* and *ending date* present on the evaluations' screen with multiple interaction tasks called *Evaluation[name]*).

4.3 Actions' Flow

In this step, the actions' flow for each relevant task to the user should be specified. Again, it isn't necessary to use any specific notation, but it is of great interest to consider the activities listed in the user's mental model update cycle (see section 3.1). We suggest using the following terms:

- **perceive:** effort applied during the interval between searching the object of interest (control mechanism or information unit) and finding it. Every human sense might be involved in this search. Perception must be stored in memory in case the individual needs to use it after the interruption of its finding (see "**store**" below);
- **execute:** effort applied during the interval between decision making and activation of the perceived control mechanism;
- **store:** effort applied for temporary storage in short-term memory.

The actions' flow specification considering these activities assists in the process of task personalization (third level of the Consistency Priorities hierarchy) in which the designer will be concerned with choosing the user's most relevant tasks for their simplification towards better execution efficiency and satisfaction of use. Table 1 presents some examples of actions' flow specified for the TelEduc's Evaluation tool.

User's Task	Actions' Flow
Check evaluation's criteria (evaluation=*y*)	1. **execute perceive** Evaluations 2. **execute perceive** Evaluation[name=*y*] 3. **execute perceive** View 4. **return perceive** criteria
Check student's grade in evaluation (student=*x*; evaluation=*y*)	1. **execute perceive** Evaluations 2. **execute perceive** Participants' Grades 3. *c* **store perceive** Evaluation[name=*y*] 4. *aval* **store perceive** Evaluation[code=*c*] 5. *stud* **store perceive** Student[name=*x*] 6. **return perceive** Grade(*stud*, *aval*)
Check highest grade from the *n* students in evaluation *y*.	1. **execute perceive** Evaluations 2. **execute perceive** Participants' Grades 3. *c* **store perceive** Evaluation[name=*y*] 4. *aval* **store perceive** Evaluation[code=*c*] 5. for each Grade in *aval*'s column 5.1. *temp* **store perceive** Grade(*aval*) 5.2. if *temp* > *highest*, then *highest* **store** *temp* 6. **return** *highest*

Table 1. Example of user's tasks and corresponding actions' flow for the Evaluation tool.

4.4 Devices' Restriction Analysis

This step identifies main differences among target devices considering three attributes pointed by the perceptual constancy principle as the most relevant, *i.e.* size, shape and color. Although other attributes could also lead to ambiguous or erroneous perceptions when drastically changed (*e.g.* light, distance, weight, size, fluidity, flexibility, opacity, *etc.*), we expect that these three characteristics can model most devices in order to guide implementation of the task perception consistency priority.

In this sense, Table 2 presents concise comparative descriptions for a desktop, pocket PC and smartphone input/output (I/O) devices.

Device	Attribute	Desktop	Pocket PC	Smartphone	Relevance
Display	Color	24-bit	16/24-bit	16/24-bit	low
	Size	15", 800x600 pixels	3.5", 240x320 pixels	2", 240x320 pixels	high
	Shape	4:3	3:4 / 4:3	3:4 / 4:3	high/none
Keyboard	Color	variable	variable	variable	none
	Size	40cm/10cm	4.8cm/4cm	4cm/5cm	high
	Shape	QWERTY (hand adapted)	virtual QWERTY (pointing device adapted)	numeric/ QWERTY (thumb adapted)	medium

Table 2. Comparison among I/O devices of a standard desktop, pocket PC and smartphone.

According to Table 2, both input and output devices of a standard desktop have relevant differences in size compared to those available for the pocket PC and smartphone. Also, the pocket PC rotation on the palm of the hand to adjust its orientation regarding the desktop display has undesirable ergonomic implications, pointing the shape as another perceptual attribute to be considered for the interface adaptation. Thus, we expect to focus on visibility and mapping during the Consistency Priorities implementation for these target devices.

4.5 Implementation

Task Perception and Task Execution
The task perception consistency aims to preserve size, shape, color and relative localization of control mechanisms and information units available on interfaces. On the other side, the task execution consistency demands the same actions' flow to execute the user's tasks. A useful baseline to start implementing these consistency priorities is the Direct Migration approach, which consists of the desktop interface presented on the handheld device without any adaptation. According to the results obtained with the devices' restriction analysis in section 4.4, *size* and *shape* were the attributes with the most relevant differences between target devices, indicating that *visibility* and *mapping* shall be the design principles to focus on this consistency level (see section 3.2). The violation of these principles in the Direct Migration can be perceived by the intense interaction required with both vertical and horizontal scrolling to access information throughout the interface. If tasks are not visible, many usability attributes can be compromised, like utility, efficiency and safety of use.

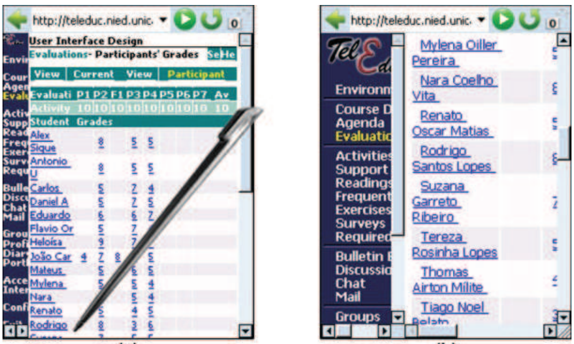
A common solution to adapt desktop interfaces to the pocket PC screen is the Single Column feature, which is able to analyze and partition the web page structure presenting its content without the horizontal scrolling. However, this proposal can violate many task perception consistency requirements by changing relative localization of side menus and content area, losing visibility of the user's tasks and generating ambiguities on semantic mapping by reorganizing information units. These side effects are due to the fact that Single Column considers only the *shape* as an attribute with relevant difference between target devices. Therefore, we must also consider adaptations on *size*.

Among the information visualization techniques focusing on this attribute, we highlight the focus+context and the thumbnail (reduced replica of the desktop interface). Belonging to the latter, Smartview (Milic-Frayling & Sommerer, 2002) and Gateway (MacKay et al., 2004) are examples of proposals that let users first scan the thumbnail and then explore regions of interest. The main advantage is that visual mapping remains consistent with the user's previous experience, but the zoom-out rate makes content unreadable, as it can be noticed comparing Fig. 3 and Fig. 5a. In order to support visibility, the Gateway prototype presents readable texts of the thumbnail regions touched by the user, overlapping the readable region on the thumbnail (see Fig. 5b). However, data comparison tasks on the same interface might demand excessive memorization, besides the additional touch interaction for multiple regions of the same thumbnail. Also, mapping of table structures can be compromised as readable columns will be shown one at a time, losing the correlation between lines and columns.

(a) (b)

Fig. 5. – Example of the Gateway proposal applied for the TelEduc's participants' grades screen (see Fig. 3). In (a), a reduced non-functional replica of the desktop page; in (b), the TelEduc's side menu overlapped on the thumbnail after touching its region in (a).

We argue that these problems arise because only the attribute size was considered for adaptation. According to the devices' restriction analysis, both size and shape shall be adapted, thus requiring special focus on the visibility and mapping design principles. In this sense, the Summary Thumbnail (Lam & Baudisch, 2005) proposes a more adequate solution by improving the latter prototypes with text font increase and content summarization for the thumbnail. Fig. 6 shows an example of this adaptation for the TelEduc.



(a) (b)

Fig. 6. – Example of the Summary Thumbnail proposal applied for the TelEduc's participants' grades screen (see Fig. 3). In (a), a reduced functional replica of the desktop page with readable and summarized texts; in (b), the detailed view of the region touched by the user's pen (full text and real size images as in the Direct Migration approach).

The interface presented in Fig. 6a reveals good similarity to its desktop equivalent (see Fig. 3) and also enhances the thumbnail legibility obtained with the Gateway (see Fig. 5a). Still, Summary Thumbnail fails to preserve mapping and consistency on task execution.
The mapping failure can be verified in the summarization of links "View Previous Evaluations" and "View Future Evaluations", resulting in two labels called "View" (menu

on top of Fig. 6a). This was due to the automatic summarization process, which crops characters from right to left until text fits within the available space. This methodology might lead to other unexpected results, especially for languages in which adjectives come after nouns (*e.g.* Portuguese, Spanish). This problem could be fixed using a conversion table built statically by the designers and containing every control mechanism label related to its most appropriate summarized form (non-hyperlink texts could still be summarized using the right to left cropping approach). A more dynamic solution could be based on a domain oriented summarization approach that would rip terms not relevant to the given page (low frequency on the page and high frequency in the database) and preserve only the important ones (high frequency on the page and low frequency in the database).

The task execution inconsistency comes from the ability to activate any navigation structure by pointing over it directly on the thumbnail. As the user needs to perform the same action to reveal its full text on the detailed view before deciding if that's the appropriate hyperlink to activate, there will always be an interaction ambiguity. This problem can be fixed substituting the Direct Migration detailed view by an overlapped window (thus avoiding many inconsistencies of such method as presented before) and eliminating the navigation ambiguity with a non-functional thumbnail. In this case, navigation could be provided by activating the full text hyperlink in the detailed view. This way, task execution remains consistent[3] by always revealing the detailed view whenever the user touches the thumbnail. Fig. 7 shows an example of how these adaptations can be implemented to preserve the first two levels of the Consistency Priorities hierarchy.

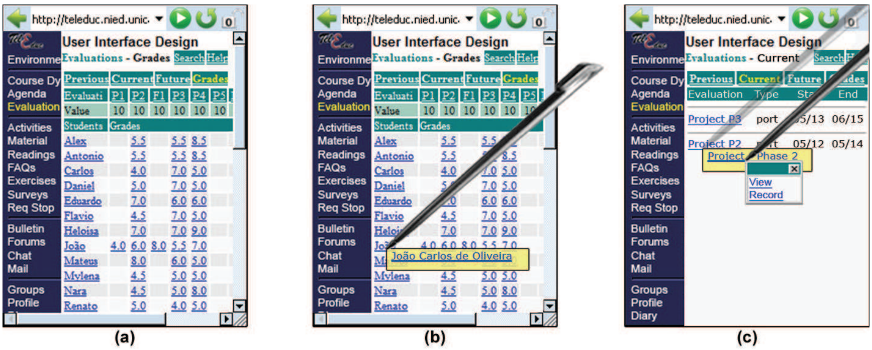


Fig. 7. – Example of the Consistency Priorities (first two levels) applied to the TelEduc's participants' grades screen (see Fig. 3). In (a), the Summary Thumbnail approach adapted to preserve visibility and mapping principles; in (b), the detailed view overlapped on the thumbnail avoiding context loss while switching views; and in (c), an example of navigation by activating the hyperlink inside the detailed view.

[3] Although task execution claims the interface to be consistent with both task model and actions' flow developed in sections 4.2 and 4.3, we argue that these changes to the Summary Thumbnail (including an extra interaction with the hyperlink inside the detailed view) don't break consistency at this level because it constitutes a new approach for handheld navigation. The concept implies that every object activated by the user reveals a detailed view with full text for summarized texts or real-size images for reduced images; but if the object is a hyperlink, an additional activation is required to actually follow the hyperlink (see Fig. 7c). Therefore, we state that the task model wasn't changed, but the navigation concept implicit on its tree nodes.

Task Personalization

This third level of the Consistency Priorities hierarchy focuses on users that won't access the application in contexts of interchange and task migration. In other words, they plan to access the application using only one device. Therefore, the concern with consistency in the first two levels of the hierarchy loses its relevance for this group of users. In this case, we suggest personalizing the interface with an active position for the user during interaction, which can be implemented in two ways:

- *Customization:* Ability to change perceptual aspects of control mechanisms' (*e.g.* enlarge fonts, shrink side menu, change structures' attributes like shape, color, *etc.*) and to reorganize information (*e.g.* hide images, menu items, table columns; add shortcuts; reveal full texts and/or descriptions; *etc.*);

- *Pre-built Interface Patterns:* Design of alternative interfaces with improved efficiency for tasks considered more relevant to a group of users. The original task model must be adapted towards reducing the actions' flow for such tasks, which could be done by removing leaf nodes, sub trees, or via a hierarchical rearrangement of child nodes as a result of their parent removal. The users' choice over pre-built interface patterns can be implemented by checking their profile on first interactions with the application.

The customization approach demands higher motivation to be accessed during interaction, reason why we encourage designers to build interface patterns that will require less effort by the users and still delegate them an active role in design. This personalization can be exemplified for the TelEduc's Evaluation tool considering the task of checking the students' grade for a given evaluation *y* (see Table 1):

1. **execute perceive** <u>Evaluations</u>
2. **execute perceive** <u>Participants' Grades</u>
3. *c* **store perceive** <u>Evaluation</u>[name=*y*]
4. *aval* **store perceive** <u>Evaluation</u>[code=*c*]
5. *stud* **store perceive** <u>Student</u>[name=*x*]
6. **return perceive** <u>Grade</u>(*stud*, *aval*)

If this task was considered the most relevant to the mobile user, than it should be personalized to reduce complexity and improve efficiency. The first step is to identify changes imposed by the context of use that could simplify the way tasks are currently executed. In the given example, we could assume that the mobile user is not interested in comparing grades, but rather prefer having a faster way to access his/her personal information. This assumption reduces the actions' flow to four simpler steps:

1. **execute perceive** <u>Evaluations</u>
2. **execute perceive** <u>Participants' Grades</u>
3. *aval* **store perceive** <u>Evaluation</u>[name=*y*]
4. **return perceive** <u>Grade</u>(*aval*)

The newer actions' flow removes search and memorization tasks from two information units: the evaluation (which used to associate a code to the evaluation's name) and the student (which required the identification of the adequate row on the students grades table). Fig. 8 shows how these changes reflect on the original task model (see Fig. 4) and Fig. 9a shows the interface obtained with this personalization.

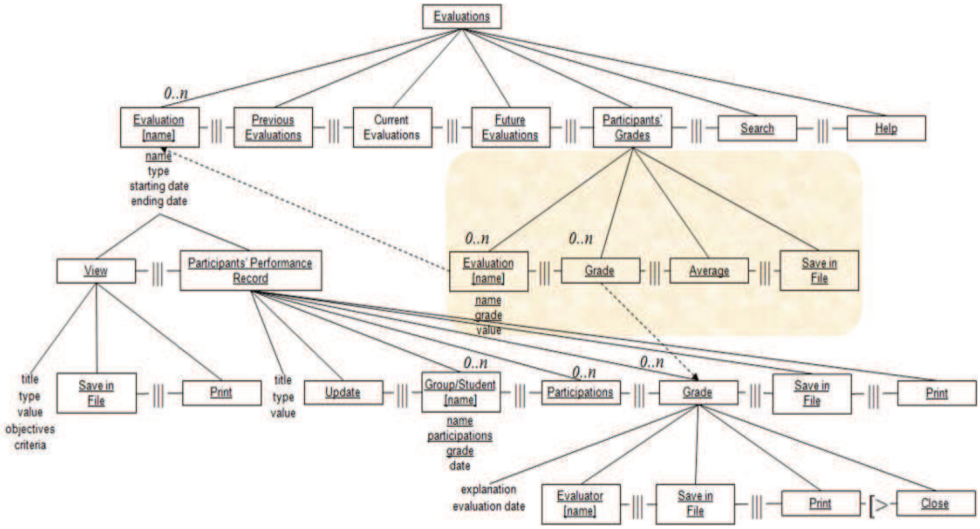


Fig. 8. – Personalization of the original task model (Fig. 4) for the TelEduc's Evaluation tool. The main focus was efficiency on the task of checking personal grades.

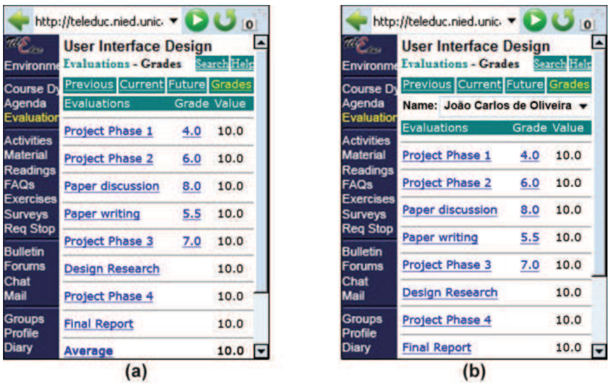


Fig. 9. – Interfaces obtained with the task personalization consistency priority for the TelEduc's Evaluation tool. While both screens consider the task of checking personal grades as the most relevant, in (a) the focus is restricted to the user, and in (b) grade comparison is enabled to balance interaction continuity and efficiency gain for the task.

As expected, the proposed interface for the mobile context described previously focus only on the user's personal information, thus preventing access to other students' grades (see Fig. 9a). However, many authors reinforced the idea that interaction continuity is a key element for multi-device design (Denis et al., 2004; Florins et al., 2004; Pyla et al., 2006; Hajdukiewicz, 2006). Hence, balancing interaction continuity and efficiency gain plays an important role in task personalization. Considering the TelEduc example, this could be done by preserving

the sub tree *Student[name]* (present in the original task model in Fig. 4) and implementing it as a choice structure, like a combo box (see Fig. 9b).
In this third consistency priority, almost every design decision conflicts with those taken in the previous levels. Basically, this happens due to the fact that task personalization means no compromise with the user's previous experience accessing the application via other devices. Additionally, if there isn't enough information to build personalized interface patterns, customization should be another important resource to enhance user experience.

5. Experiment

5.1 Domain, Application and Tasks

The motivation to choose Distance Learning as the experiment domain and TelEduc as the e-learning application was already presented in section 4.1. In order to choose one of its 21 tools as the experiment focus (*i.e.* agenda, evaluations, portfolio, *etc.*), we established the following requirements: the tool should have (1) higher access frequency in the computer science course taken by the population sample and (2) more relevant visualization information challenges for the desktop-handheld adaptation. While the first criterion was applied through an investigation of TelEduc's records, the second was based in the system's analysis, considering as challenges: the variable number of columns and rows inside tables, the need to show popup windows, the deeper menu hierarchy inside each tool and complex visual representations (*e.g.* graphs). Finally, the score combining both criteria for each tool revealed the Evaluations and the Portfolio as the most relevant ones. Therefore, the Evaluations tool was chosen to be the experiment focus because one of its challenges is very appropriate to highlight limitations in pocket PC's shape and size (*i.e.* the extensive matrix containing every students' grades on each test).

5.2 Participants

The experiment had 18 male computer science undergraduate students, ranging in age from 19 to 29 ($\bar{x} = 22$). They all had relevant experience with computers and the TelEduc e-learning system (used before in other seven courses in average). None had used it via a handheld, being their experience restricted to desktop/laptop/tablet PCs. When questioned about the devices they would like to use with TelEduc, only six showed interest in using more than one, which reveals an apparent indifference for task migration activities. On the other side, six subjects chose to access it solely by a desktop/laptop/tablet PC, pointing mobile interfaces as of the majority's interest to access the system (12 subjects). Participants were also questioned about their most frequent task with TelEduc's Evaluation tool. From a total of 15 answers, 12 indicated the checking of grades (two mentioning explicitly the comparison of grades) while three pointed the search for the evaluations' details.

5.3 Material

The experiment was conducted in a computer lab with wireless Internet connection and 18 tablet PCs available in individual desks. During evaluation, all the tablets remained laid or inclined on the desks and the pocket PC pen-based interaction was simulated by the tablet pen. Also, the pocket browser was reproduced in the tablet and equipments were connected to power outlets, which prevented interruptions by battery discharge.

5.4 Treatments and Procedures

The following treatments were applied to the experiment participants while executing a set of tasks to evaluate their effects and contribute to the investigation of the most appropriate multi-device design approach in a context of task migration:

- *Direct Migration:* Applied as a baseline, this treatment proposes a TelEduc pocket PC interface that is exactly like the desktop interface. Although consistency in task perception and execution is preserved, it can't guarantee usability principles like visibility, mapping and/or feedback (see Fig. 10a).

- *Linear Transformation:* A TelEduc pocket PC interface that adapts the desktop version to the handheld constraints, aiming efficiency in tasks of major interest to the user besides the preservation of task model characteristics. This approach loses consistency in task perception and keeps it partially for task execution, like many current approaches (*e.g.* most adaptive interfaces in the related work). Undesirable automatic transformation residues were avoided by manually designing the screens (see example in Fig. 10b).

- *Overview Transformation applying Consistency Priorities:* Adaptation of the TelEduc desktop interface for the pocket PC preserving the first two levels of the Consistency Priorities to focus in contexts of interchange and task migration (see Fig. 10c).

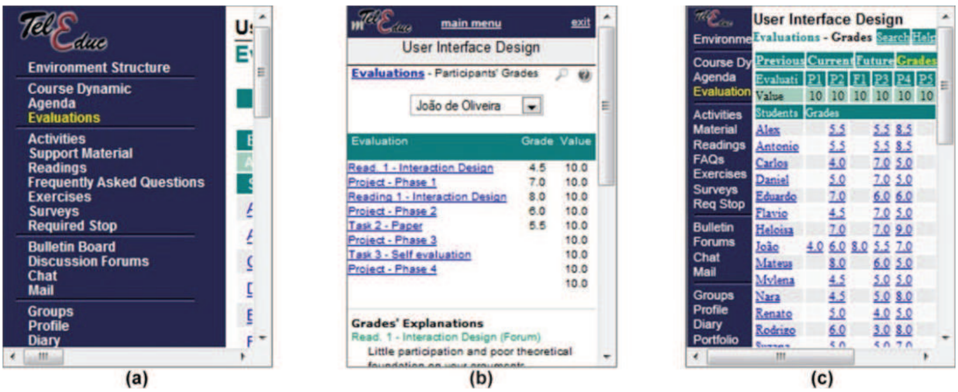


Fig. 10. – Experiment interfaces to visualize the TelEduc participants' grades using the three available treatments: (a) Direct Migration, (b) Linear Transformation and (c) Overview transformation applying Consistency Priorities.

Sample Partition

The 18 participants were fully distributed in six groups of three participants and each group followed a different treatments' application sequence, covering every possible combination. Thus, the residual effects of every treatment application over the other were balanced.

Studied Variables

In order to contrast pros and cons of each treatment applied in each task execution, we studied quantitative (execution time and task accuracy) and qualitative variables (easiness, efficiency and safety subjectively compared to the desktop interface). After finishing each task with the three approaches, users identified the best and the worst interfaces for that task. At last, after the execution of all tasks, they also filled a satisfaction questionnaire identifying their favorite interface and the reasons for that.

Tasks

Subjects had to execute a set of three tasks using each of the available interfaces (Direct Migration, Linear and Overview) in a context of task migration. Initially, the task description was presented and its execution process started on the TelEduc desktop interface to be further completed on the pocket PC simulator (the quantitative variables mentioned before were observed only during the pocket PC simulation). Tasks were chosen based on the subjects indication of the most frequently executed, in which 80% (12 subjects) said it was the checking of grades and 20% (three subjects) pointed the search for evaluations' details (*e.g.* date, criteria, *etc.*). Therefore, we implied that the checking of grades was the most relevant task, which led us to improve its efficiency in the Linear transformation approach (the grades matrix was replaced by a simpler table with only the user's grades, as shown in Fig. 10b). Table 3 compares actions' flow between treatments.

Steps	Treatments	
	Direct Migration/Overview	Linear
1	*c* **store perceive** <u>Evaluation</u>[name=*y*]	*aval* **store perceive** <u>Evaluation</u>[name=*y*]
2	*aval* **store perceive** <u>Evaluation</u>[code=*c*]	**return perceive** <u>Grade</u>(*aval*)
3	*stud* **store perceive** <u>Student</u>[name=*x*]	
4	**return perceive** <u>Grade</u>(*stud*, *aval*)	

Table 3. Task 1 actions' flow (*x*: student's name; *y*: evaluation's name).

We also wanted to investigate the implications of such improvement in related tasks, like the comparison of grades (two out of the 12 subjects explicitly mentioned it as the most frequently executed task). Thus, we created a second task in which subjects had to count the number of colleagues with a higher grade than his/her in a certain evaluation. While Task 1 should point the Linear interface as the most efficient due to its actions' flow simplification, Task 2 could help us investigate the implications of this consistency loss for a related task.

Finally, the third task was to go after the details of a certain evaluation (elected by three subjects as the most frequent task). As the second most executed task, a common scenario would be the user checking his/her grade in a certain evaluation and only then searching for details of the next evaluations to perform. In this sense, we implemented Task 3 with the same interface presented by the end of Task 1. This way, we provided both the adequate scenario according to the subjects' preferences (Task 3 stimulated by Task 1 or 2) and the means to investigate implications of a mental trace loss (incapacity to suppose the actions taken with device *x* to reach its current state due to a task migration started with device *y*).

Precautions with Tasks' Initial State

The following decisions were taken to make the task's initial state as real as possible and avoid particular cases that could benefit any of the evaluated treatments: (1) a standard user name was chosen to guarantee homogeneity for the subjects' search effort and also consider an average case for the user's name position inside the grades' matrix (Direct Migration and Overview transformation) and the combo box (Linear transformation); (2) evaluations and students' numbers, as well as the evaluations' names, were taken from a previous course; and (3) the students' grades in each evaluation were different to avoid users memorizing solutions with one treatment and reusing for the following.

5.5 Statistical Analysis

In order to adjust the residual effects in the task execution time continuous variable (due to the application of one treatment after the other), we opted for a parametric analysis of variance using latin square balanced for immediate residual effect (Cochran & Cox, 1992). The comparison between paired treatments was performed by the Tukey *post-hoc* test. As for the non-normal Likert scale discrete variables (easiness, efficiency and safety subjectively compared to the desktop TelEduc interface), the Friedman test was chosen according to its suitability for nonparametric analysis with three or more treatments and paired samples. Also, each pair of treatments was compared by the Wilcoxon signed rank test due to its adequacy on checking differences between medians of two groups with paired samples.

5.6 Results and Discussion

Task 1: User's Most Relevant Task

The checking of grades was considered the most executed task by 12 subjects out of 15 (not all the 18 subjects answered this question). Table 4 summarizes the observed data.

Observed Variables	Treatments		
	Direct Migration	Linear	Overview
Efficacy (task response accuracy)	18 (100%)	18 (100%)	18 (100%)
Efficiency (average execution time)*	50.93a	33.92b	45.32ab
Easiness compared to the TelEduc desktop*	3c	6a	4b
Efficiency compared to the TelEduc desktop*	2c	5a	4b
Safety compared to the TelEduc desktop**	3b	5a	4b
Best treatment's choice	0 (0%)	16 (89%)	2 (11%)
Worst treatment's choice	14 (78%)	1 (5%)	3 (17%)

* Treatments with different letters in the same line diverge significantly for $p < 0.05$

** Treatments with different letters in the same line diverge significantly for $p < 0.005$

Table 4. Task 1 results.

According to Table 4, all treatments had a perfect score for the task response accuracy, meaning that the consistency breaking, present in the Linear approach, didn't lead to errors. On the other side, although this approach has reduced considerably the required actions and their complex to perform the task, no significant difference was identified between its average execution time and the one obtained with the Overview treatment ($p < 0.05$). This result wasn't expected since the Linear transformation's major advantage is the efficiency gain by means of device oriented adaptations. Thus, *we conclude that executing a reduced number of simple non-expected actions can take as much time as a greater number of complex* *expected actions due to the user's mental model influence.* Although such conclusion is in agreement with the measured data, it can't be confirmed by the perceived data, which pointed the Linear approach as the most efficient one. This divergence can be explained by the fact that the efficiency subjective evaluation was realized after the task execution, when users eventually understood how to accomplish it. As the demanded cognitive adaptation wasn't relevant, users had the impression that an approach requiring a reduced number of simpler actions to perform the same task would take less time. We don't argue against this assumption (which is the reason why our proposal gives support to the third level of consistency on task personalization), but a context of task migration may prove the contrary, as verified by the measured efficiency.

Another important observation concerns the seven point Likert scale, in which the number four means no difference between handheld and desktop interfaces for the evaluated attribute (*i.e.* easiness, efficiency or safety). In this sense, the Overview transformation was the only approach able to maintain median four for every attribute, besides the significant differences to the Linear transformation's results ($p < 0.05$). Thus, *we conclude that the interface proposed using the first two levels of Consistency Priorities preserved the user's mental model by attending to his/her expectations.* We are confident that such goal has more important implications to multi-device design in order to smooth the transition between devices in contexts of interchange and task migration.

Finally, the user's choice for the best interface confirmed that this task's optimization in the Linear transformation was the key to get the users satisfaction.

Task 2: A Variation of the User's Most Relevant Task

The comparison of grades was explicitly mentioned by two subjects out of the 12 voters of Task 1 as the most relevant task. In this sense, Task 2 demanded the count of students with a higher grade than the user's in a certain evaluation. Table 5 summarizes the observed data.

Observed Variables	Treatments		
	Direct Migration	Linear	Overview
Efficacy (task accuracy)	17 (94%)	3 (33%)	17 (94%)
Efficiency (average execution time)*	69.48a	75.28a	30.15b
Easiness compared to the TelEduc desktop*	2b	2b	4.5a
Efficiency compared to the TelEduc desktop**	2b	2b	4a
Safety compared to the TelEduc desktop**	2b	3ab	4a
Best treatment's choice	2 (11%)	2 (11%)	14 (78%)
Worst treatment's choice	6 (33%)	12 (68%)	0 (0%)

* Treatments with different letters in the same line diverge significantly for $p < 0.05$

** Treatments with different letters in the same line diverge significantly for $p < 0.007$

Table 5. Task 2 results.

According to Table 5, while 94% of the subjects realized Task 2 correctly with both Direct Migration and Overview approaches, only 33% did it using the Linear interface. This result exemplifies how an interface adaptation privileging a certain task and breaking consistency can lead to bad effects on related tasks. Also, task efficiency[4] revealed the same aggravating effect, pointing the Overview transformation as the fastest interface to accomplish Task 2. Perceived data confirmed these results, indicating that the Overview approach was the easiest and most efficient interface. Additionally, the Overview transformation was able to preserve the user's mental model, given that its medians were closer to four than the other treatment's medians. At last, the subjects' preference for the Overview approach and aversion for the Linear confirmed the importance of the task perception consistency priority, which concerns not only with the Perceptual Constancy attributes and relative localization, but also with the design principles compromised by the devices' relevant restrictions. Once again, efficiency was indicated as the major reason for this choice, followed by safety as a confirmation of the best efficacy in task accuracy.

Task 3: User's Secondary Interest Task

The search for evaluations' details was considered of secondary interest to the users (three voters out of 15), which led us set the Task 1 last screen as its initial stage. This kind of task execution as a consequence of others is a common scenario and its effects for multi-device design have great importance, especially in a task migration context. Table 6 presents the observed data.

Observed Variables	Treatments		
	Direct Migration	Linear	Overview
Efficacy (task accuracy)	17 (94%)	15 (84%)	17 (94%)
Efficiency (average execution time)*	24.07a	25.58a	12.39b
Easiness compared to the TelEduc desktop**	4ab	3b	4a
Efficiency compared to the TelEduc desktop*	3b	3ab	4a
Safety compared to the TelEduc desktop***	4a	3b	4a
Best treatment's choice	4 (22%)	4 (22%)	10 (56%)
Worst treatment's choice	8 (44%)	9 (50%)	1 (6%)

* Treatments with different letters in the same line diverge significantly for $p < 0.05$

** Treatments with different letters in the same line diverge for $p < 0.132$

*** Treatments with different letters in the same line diverge for $p < 0.158$

Table 6. Task 3 results.

According to Table 6, once again the Overview approach was able to overmatch the Linear transformation for every observed data. Both its measured values for efficacy and efficiency

[4] The experiment isolated task perception preventing users from activating any control mechanism inside any interface for all tasks (besides scroll bars). This procedure was crucial to identify that the Linear transformation's lower efficacy in Task 2 (33%) was due to a problem in the first stage of the user's mental model update cycle: hardness in identifying the need to switch students' names inside the combo box (see Fig. 10b). In order to guarantee a fair comparison between treatments for Task 2, we computed the following measures *for the Linear approach:* (1) the time taken by each subject to indicate the combo box activation as the first step to complete the task and (2) the smallest time to finish remaining steps (i.e. switch names inside the combo box, find and compare each grade with the user's grade, and count the total of greater grades). Thus, each subject's task execution time was a combination of both measures. Even benefitting the Linear approach with the increase of the smallest remaining time to each subject's partial time, Overview still proved to be more efficient.

were higher, indicating that users could perform the task faster and with better safety using an interface consistent to their previous experience. The Overview approach also overcame the efficiency obtained with the Direct Migration, indicating that the consistency on task perception shall be discussed together with the design principles compromised by the devices' relevant restrictions. Also, the subjective evaluation pointed the Overview as the best treatment to preserve the user's mental model by keeping a median four on every evaluated attribute under the seven point Likert scale. This might be the most important result for task migration contexts, in which perceptual changes could reduce devices' utility. Finally, the Overview interface was considered the best for Task 3 because of its efficiency. On the other side, the Linear transformation was the worst due to its layout differences compared to the TelEduc desktop interface, which confirms results from Task 2. These evaluations reveal the importance of consistency with the user's previous experience in order to address efficiency for multi-device applications.

User's Satisfaction

The last subjective evaluation aimed to compare interfaces by asking users to choose the one they liked most *despite the executed tasks* and to mention their reasons for that. Observed results highlight the importance of personalization: 12 subjects opted for the Linear approach; four chose Overview; and the remaining two decided for the Direct Migration.

As it can be noticed, although only the user's most relevant task had been improved with the Linear transformation (even without a significant difference to the Overview's average execution time), this approach was still considered the most attractive, contradicting some previous findings (MacKay et al., 2004; Lam & Baudisch, 2005; Roto et al., 2006). The main reason for such divergence is that our experiment didn't support comparisons to the Single Column automatic Linear transformation approach as on these authors' user studies. On the contrary, we decided to redesign TelEduc for the pocket PC to take the best from the device and also optimize the user's most relevant task. This way, we ended up with a more adapted and usable interface than the Single Column, in which no user-centered design decisions are taken. Thus, we argue that this experiment's design was able to make more fair comparisons because it took the best of each evaluated approach.

After carefully analyzing the questionnaire's answers, we perceived that the better usability present in the users' most relevant task with the Linear transformation was the major factor for its subjects' preference, as indicated by the following comments:

> "*…I consider this linear interface more functional than the actual TelEduc.*" (Subject 1)
>
> "*...the linear approach makes activities easier than the TelEduc.*" (Subject 15)
>
> "*The linear interface would be good even for the TelEduc desktop!*" (Subject 15 about Task 1)

Considerations like these raise questions about the TelEduc's usability as if the decisions taken for the pocket PC should also have been taken for the desktop, confirming once again the importance of consistency between both interfaces. Still, we had to explain the reason why subjects were more satisfied with an approach that wasn't able to reveal advantages in practice for the executed tasks. In this sense, the following factors may have contributed:

- *Low-risk decisions:* Eight out of the 12 Linear approach electors weren't able to execute one or more tasks with accuracy using this approach. However, every Overview and Direct Migration voter executed the three tasks correctly. We believe that, if the application domain had involved high risk decisions, no error would have been tolerated (*e.g.* money transferring, management of chemical residues, operation of high-cost machines, *etc.*);

- *Indifference to multi-device access:* Although the demographic questionnaire had revealed that 12 out of 18 subjects were interested in using mobile interfaces for the TelEduc, only five also wanted to access the system via desktop, which characterizes indifference over the multi-device access and inadequacy of task migration contexts for the considered domain and/or sample. Thus, the third level of Consistency Priorities was more appropriated to guarantee personalization of relevant tasks. Some comments in favor of the Linear approach confirm this assumption:

  "*Because of fitting more information […] that I consider of my interest.*" (Subject 4)
  "*...presents information in a more objective and intelligible way*" (Subject 6)
  "*Structure directed to the student individually.*" (Subject 12)
  "*Because it shows individual information, less error inclined.*" (Subject 13)

As it can be noticed, although the Overview approach had been more adequate to execute tasks in general, subjects revealed a better satisfaction with the Linear transformation because of its task personalization. This observation corroborates that *the efficacy generated by the first two levels of the Consistency Priorities hierarchy concerning task perception and execution must be combined with the third level of personalization aiming better satisfaction and efficiency.* This combination may consider multiple use contexts by creating layout patterns to be chosen by the end user. This procedure can support both the sole and multi-device access in contexts of interchange and task migration.

6. Conclusion

The multi-device design methodology proposed in this chapter was based and supported by well established concepts from Philosophy and Psychology (definitions about logic and inductive reasoning), Connectionism laws (Thorndike, 1898), Cognitive learning theories (Hartley, 1998) and mental models (Young, 1983), as well as by recent findings from Neuroscience (Sohlberg & Mateer, 1989) and Human-Computer Interaction (MacKay et al., 2004; Lam & Baudisch, 2005; Roto et al., 2006; Hajdukiewicz, 2006). These theoretical foundations reinforce the hypothesis that interfaces of the same application must preserve perceptual characteristics and adopt a consistent behavior to execute tasks.

The experiment conducted on the Distance Learning domain also contributed with the following conclusions for multi-device design in contexts of task migration:

- *The Consistency Priorities (first two levels) preserve the user's mental model better than approaches maintaining full layout consistency (Direct Migration) or with a more dedicated design focus to the devices' characteristics (Linear):* This was verified via a subjective evaluation of the handheld interface built with our methodology, which revealed a significant similarity to the desktop version for easiness, efficiency and safety on tasks relevant to the users. This result was also significantly different to those obtained with the Direct Migration and Linear approaches, confirming their inability to attend the users' expectations;
- *The Consistency Priorities (first two levels) achieve similar efficacy and efficiency as the Linear's for tasks optimized in the latter:* Although the Linear interface was optimized for better efficiency with the user's most relevant task, our approach maintained similar efficacy and efficiency despite requiring more steps to execute. This fact reveals the

importance of consistency with the user's previous experience in contexts of task migration;

- *The Consistency Priorities (first two levels) enhance efficacy and efficiency compared to the Linear's for tasks not optimized in the latter:* Three times more subjects solved general tasks correctly using our approach contrasted to the Linear's and they took less than half of the Linear's time.

Although these results point the Consistency Priorities as a more adequate multi-device design approach for task migration, the Linear interface had higher preference by the subjects of the experiment due to its task personalization. This apparent contradiction can be explained by the fact that the experiment was realized in a context of task migration, but both the demographic questionnaire and the users' satisfaction evaluation made it clear that the sample wasn't interested in such context. Thus, while the first two levels of Consistency Priorities guaranteed better usability and preservation of the user's mental model, the personalization in the Linear approach had a great acceptance because the majority of the subjects preferred to access the application using only one device. This is in accordance with our initial claim that there is no multi-device approach capable to provide full usability in every context because the user may choose only one interface to access the application or interchange its use via many devices. Therefore, *it is necessary to combine approaches with different goals and suit the user according to the appropriate context.* In other words, *the efficacy generated by the first two levels of the Consistency Priorities hierarchy concerning task perception and execution must be combined with the third level of personalization aiming better satisfaction and efficiency.* This combination can be addressed with an active role for the user who shall specify the context of use in order to interact with the adequate interface pattern.

Results and implications obtained so far still leave open questions and draw lines of future research that might be pursued in follow-on work. Some of these questions are listed below:

- *Could the experiment results be extended to other domain applications besides e-learning?* We expect high-risk applications to reinforce our proposal of applying the first two levels of Consistency Priorities due to its better efficacy on task execution. Yet, applications with a restricted set of tasks and a clear demand for efficiency instead of accuracy may highlight the importance of personalization applied in the Linear approach. In both cases, combining approaches with different goals and suiting the user according to the appropriate context shall be perceived as a relevant design proposal;
- *Could the experiment results be extended to other samples?* The experiment's sample included only computer experts and even though the consistency in task perception and execution presented better results than the Linear approach (*e.g.* in Task 2, subjects didn't identify with good efficacy the need to switch students' names in the combo box of the Linear interface because this procedure wasn't in accordance with their previous experience). Thus, we expect that samples including computer novice users will highlight even more the importance of the first two levels of Consistency Priorities besides reducing the interest for task personalization (third level);
- *Could the experiment results be extended to contexts of sole device access?* If users first learn how to interact with a certain application using an interface *x* and only then opt for an interface *y*, we expect the transition between them to reveal similar results as those observed in our experiment. However, if users never need to accomplish any task with any of the application's interfaces besides with the only one they know, we expect

better results with the Linear transformation. Thus, we need to know how likely it is for users not to access an application using more than one available interface;

- *Once interfaces for task migration and sole device access were proposed, how could they be implemented by an automatic transformation approach in order to ease software maintenance?* We developed a prototype for contexts of interchange and task migration that automatically adapts the TelEduc desktop interface applying the decisions taken on the first two levels of the Consistency Priorities hierarchy. The adaptation process was similar to that described by Lam & Baudisch (2005), but including our proposed changes for text summarization, detailed view and also the ability to run the system with a pocket PC/smartphone web browser [5]. As for the sole device interface (applying also the third consistency priority), we didn't implement it for automatic adaptation because different types of personalization could make the adaptation very specific and vulnerable to small changes on the desktop interface;
- *How could the Consistency Priorities design process be automated?* The development of tools for task and actions' flow modeling integrated to the restriction analysis of target devices will be of great interest to both designer and developer. Most of all, the automatic identification of inconsistencies based on heuristics of interface analysis, and the solutions proposal based on the compromised design principles could dictate a new trend for the next generation of multi-device development environments.

We expect the arguments and conclusions presented herein to be useful as a support for user centered multi-device design. Thus, not only contexts of interchange and task migration shall be approached in a more adequate way, but also sole device access, in which users have an active role of personalization while choosing and/or customizing the interface.

7. References

Banavar, G.; Beck, J.; Gluzberg, E.; Munson, J.; Sussman, J. & Zukowski, D. (2000). Challenges: an application model for pervasive computing, *Proceedings of the 6th international conference on mobile computing and networking (MobiCom)*, pp. 266-274, ISBN 1-58113-197-6, Boston, MA, USA, August 2000, ACM Press.

Banerjee, S.; Gupta, A. & Basu, A. (2003). Online transcoding of web pages for mobile devices. *Proceedings of the 5th international conference on human-computer interaction with mobile devices and services (MobileHCI),* pp. 271-285, Udine, Italy, September 2003.

Baudisch, P.; Lee, B.; Hanna, L. (2004). Fishnet, a fisheye web browser with search term popouts: a comparative evaluation with overview and linear view. *Proceedings of the working conference on advanced visual interfaces (AVI),* pp. 133-140, ISBN 1-58113-867-9, Gallipoli, Italy, 2004. ACM Press.

Bergman, L. D.; Banavar, G.; Soroker, D. & Sussman, J. B. (2002). Combining handcrafting and automatic generation of user-interfaces for pervasive devices. *Proceedings of the 4th international conference on computer-aided design of user interfaces (CADUI),* pp. 155-166, Valenciennes, France, May 2002.

[5] Compatible with CSS, DHTML and Javascript (*e.g.* Opera Mobile: www.opera.com/products/mobile).

Buyukkokten, O.; Garcia-Molina, H.; Paepcke, A. & Winograd, T. (2000) Power browser: efficient web browsing for pdas. *Proceedings of the SIGCHI conference on human factors in computing systems (CHI)*, pp. 430-437, ISBN 1-58113-216-6, The Hague, The Netherlands, April 2000. ACM Press.

Cochran, W. G. & Cox, G. M. (1992). *Experimental designs.* Wiley & Sons, ISBN 978-0-471-54567-5, Canada, 2nd edition, 1992.

Denis, C. & Karsenty, L. (2004). Inter-usability of multi-device systems - A conceptual framework, In : *Multiple user interfaces: Cross-platform applications and context-aware interfaces*, pp. 374-385, Wiley & Sons, West Sussex, UK, 2004.

Dömel, P. (1995). Webmap: A graphical hypertext navigation tool. *Computer Networks and ISDN Systems*, v. 28, pp. 85-97, ISSN 0169-7552, 1995.

Coninx, K.; Luyten, K.; Vandervelpen, C.; den Bergh, J. V. & Creemers, B. (2003). Dygimes: dynamically generating interfaces for mobile computing devices and embedded systems. *Proceedings of the 5th international conference on human-computer interaction with mobile devices and services (MobileHCI),* pp. 256-270, Udine, Italy, September 2003.

Eisenstein, J.; Vanderdonckt, J. & Puerta, A. R. (2000). Adapting to mobile contexts with user interface modeling. *Proceedings of the 3rd IEEE workshop on mobile computing systems and applications (WMCSA)*, pp. 83-92, ISBN 0-76950-816-2, Monterey, CA, USA, December 2000. IEEE Computer Society.

Florins, M.; Trevisan, D. G. & Vanderdonckt, J. (2004). The continuity property in mixed reality and multiplatform systems: a comparative study. *Proceedings of the 6th international conference on computer-aided design of user interfaces (CADUI),* pp. 323-334, Funchal, Isle of Madeira, Portugal, January 2004.

Gaeremynck, Y.; Bergman, L. D. & Lau, T. (2003). More for less: model recovery from visual interfaces for multi-device application design. *Proceedings of the 8th international conference on intelligent user interfaces (IUI)*, pp. 69-76, ISBN 1-58113-586-6, Miami, FL, USA, January 2003. ACM Press.

Gajos, K. & Weld, D. S. (2004). Supple: automatically generating user interfaces. *Proceedings of the 9th international conference on intelligent user interfaces (IUI)*, pp. 93-100, ISBN 1-58113-815-6, Funchal, Portugal, January 2004. ACM Press.

Grudin, J. (1989). The case against user interface consistency. *Commun. ACM*, v. 32, n. 10, pp. 1164-1173, ISSN 0001-0782, 1989.

Hajdukiewicz, J. (2006). Interaction momentum - industrial application design and consistency across platforms. *Proceedings of the CHI 2006 workshop on the many faces of consistency in cross-platform design*, 2006.

Hartley, J. (1998). *Learning and Studying. A research perspective,* Routledge, ISBN 0-41516-851-1, London, UK, 1998.

Hodes, T. D.; Katz, R. H.; Servan-Schreiber, E. & Rowe, L. (1997). Composable ad-hoc mobile services for universal interaction. *Proceedings of the 3rd annual ACM/IEEE international conference on mobile computing and networking (MobiCom),* pp. 1-12, ISBN 0-89791-988-2, Budapest, Hungary, 1997. ACM Press.

Johnson-Laird, P. N. (1983). *Mental Models,* Cambridge University Press, ISBN 0-67456-882-6, Cambridge, 1983.

Jones, M.; Marsden, G.; Mohd-Nasir, N. & Buchanan, G. (1999). A site-based outliner for small screen web access. *Proceedings of W8 conference,* Toronto, USA, May 1999.

Lam, H. & Baudisch, P. (2005). Summary thumbnails: readable overviews for small screen web browsers, *Proceedings of the SIGCHI conference on human factors in computing systems (CHI)*, pp. 681-690, ISBN 1-58113-998-5, Portland, OR, USA, April 2005, ACM Press.

Lin, J. (2005). *Using design patterns and layers to support the early-stage design and prototyping of cross-device user interfaces.* PhD thesis, University of California, Berkeley, 2005.

MacKay, B.; Watters, C. R. & Duffy J. (2004). Web page transformation when switching devices, *Proceedings of the 6th international conference on human-computer interaction with mobile devices and services (MobileHCI)*, pp. 228-239, ISBN 3-540-23086-6, Glasgow, Scotland, September 2004, Springer.

Manktelow, K. & Jones J. (1987). Principles from the Psychology of Thinking and Mental Models, In : *Applying cognitive psychology to user-interface design,* pp. 83-117, John Wiley & Sons, ISBN 0-471-91184-4, New York, NY, USA, 1987.

Milic-Frayling, N. & Sommerer, R. (2002). Smartview: Enhanced document viewer for mobile devices. Technical Report MSR-TR-2002-114, Microsoft Research, November 2002.

Mori, G.; Patèrno, F. & Santoro, C. (2003). Tool support for designing nomadic applications. *Proceedings of the the 8th international conference on intelligent user interfaces (IUI),* pp. 141-148, ISBN 1-58113-586-6, Miami, FL, USA, January 2003. ACM Press.

Nation, D. A.; Plaisant, C.; Marchionini, G. & Komlodi, A. (1997). Visualizing web sites using a hierarchical table of contents browser: Webtoc. *Proceedings of the 3rd conference on human factors and the web*, Denver, Colorado, USA, June 1997.

Nichols, J.; Myers, B. A.; Higgins, M.; Hughes, J.; Harris, T. K.; Rosenfeld, R. & Pignol, M. (2002). Generating remote control interfaces for complex appliances. *Proceedings of the 15th annual ACM symposium on user interface software and technology (UIST)*, pp. 161-170, ISBN 1-58113-488-6, Paris, France, October 2002. ACM Press.

Nichols, J. (2006). *Automatically generating high-quality user interfaces for appliances,* PhD thesis, Carnegie Mellon University, Pittsburgh, Pennsylvania, December 2006.

Nichols, J.; Chau, D. H. & Myers, B. A. (2007). Demonstrating the viability of automatically generated user interfaces. *Proceedings of the SIGCHI conference on human factors in computing systems (CHI),* pp. 1283-1292, ISBN 978-1-59593-593-9, San Jose, CA, USA, April 2007. ACM Press.

Norman, D. A. (1988). *The psychology of everyday things.* Basic Books, ISBN 0-46506-709-3, New York, NY, USA, 1988.

Norman, D. A. (1993). *Things that make us smart: defending human attributes in the age of the machine.* Addison Wesley Publishing Company, ISBN 0201626950, 1993.

Paternò, F.; Mancini, C.; Meniconi, S. (1997). ConcurTaskTrees: a diagrammatic notation for specifying task models. *Proceedings of the IFIP TC13 international conference on human-computer interaction (INTERACT'97)*, pp. 362-369, ISBN 0-412-80950-8, Sydney, Australia, July 2007. Chapman & Hall.

Payne, S. J.; Squibb, H. R. & Howes, A. (1990). The nature of device models: the yoked state space hypothesis and some experiments with text editors. *Human-Computer Interaction*, v. 5, n. 4, pp. 415-444, 1990.

Ponnekanti, S.; Lee, B.; Fox, A.; Hanrahan, P. & Winograd, T. (2001). ICrafter: A service framework for ubiquitous computing environments. *Proceedings of the 3rd* *international conference on ubiquitous computing (Ubicomp)*, pp. 56-75, Atlanta, Georgia, USA, September 2001. Springer.

Pyla, P. S.; Tungare, M. & Pérez-Quiñones, M. (2006). Multiple user interfaces: Why consistency is not everything, and seamless task migration is key. *Proceedings of the CHI 2006 workshop on the many faces of consistency in cross-platform design.*

Rasmussen, J. (1987). Mental models and the control of action in complex environments. *Proceedings of the informatics and psychology workshop*, pp. 41-69, 1987.

Roto, V.; Popescu, A.; Koivisto, A. & Vartiainen, E. (2006). Minimap: a web page visualization method for mobile phones. *Proceedings of the SIGCHI conference on human factors in computing systems (CHI),* pp. 35-44, ISBN 1-59593-372-7, Montreal, Canada, April 2006, ACM Press.

Santo, G. D. & Zimeo, E. (2007). Reversing guis to ximl descriptions for the adaptation to heterogeneous devices. *Proceedings of the 22nd ACM symposium on Applied computing (SAC),* pp. 1456-1460, ISBN 1-59593-480-4, Seoul, Korea, March 2007. ACM Press.

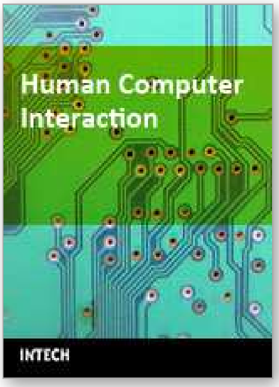
Sharp, H.; Rogers, Y.; Preece, J. (2007). *Interaction Design: Beyond Human Computer Interaction.* 2nd. ed. Wiley & Sons, ISBN 0-470-01866-6, New York, USA, 2007.

Sohlberg, M. M. & Mateer, C. A. (1989). *Introduction to cognitive rehabilitation: theory and practice.* Guilford Press, ISBN 0-89862-738-9, New York, NY, USA, 1989.

Thorndike, E. L. (1898). *Animal intelligence: an experimental study of the associative processes in animals.* Psychological Review Monograph Supplement, v. 2, n. 4, pp. 1-109, 1898.

Wozny, L. A. (1989). The application of metaphor, analogy and conceptual models in computer systems. *Interacting with Computers,* v. 1, pp. 273-283, 1989.

Young, R. M. (1983). Surrogates and mappings: two kinds of conceptual models for interactive devices, In: *Mental models,* Gentner D. & Stevens A. (Ed.), pp. 35-42, Lawrence Erlbaum Associates, ISBN 0-89859-242-9, Hillsdale, NJ, USA, 1983.



Human Computer Interaction
Edited by Ioannis Pavlidis

ISBN 978-953-7619-19-0
Hard cover, 522 pages
Publisher InTech
Published online 01, October, 2008
Published in print edition October, 2008

This book includes 23 chapters introducing basic research, advanced developments and applications. The book covers topics such us modeling and practical realization of robotic control for different applications, researching of the problems of stability and robustness, automation in algorithm and program developments with application in speech signal processing and linguistic research, system's applied control, computations, and control theory application in mechanics and electronics.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Rodrigo de Oliveira and Heloisa Vieira da Rocha (2008). Multi-Device Design in Contexts of Interchange and Task Migration, Human Computer Interaction, Ioannis Pavlidis (Ed.), ISBN: 978-953-7619-19-0, InTech, Available from: http://www.intechopen.com/books/human_computer_interaction/multi-device_design_in_contexts_of_interchange_and_task_migration

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821