DESIGN GUIDELINES FOR E-LEARNING SYSTEMS

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Keywords: E-learning, usability, eye movements.

Abstract: The effectiveness of an e-learning system of actually transferring knowledge to the users is strictly related to its level of functionality and usability. Evaluation is usually performed through methods that are mainly subjective and qualitative. A new evaluation methodology has been developed within the European IST Project E-TRACKING which is based on the analysis of exploration eye movements made by the subjects during interaction with e-learning systems. Thus the methodology has the main characteristics to be objective and quantitative. This methodology has been applied to the evaluation of three e-learning systems by examining a wide population of subjects. Quantitative results derived from eye movement analysis have been further processed by statistical methods and the results have been used to identify a number of guidelines related to browsing and page layout aspects. These guidelines are aimed at the development of e-learning systems optimized in terms of usability and functionality. Guidelines have been implemented within the same e-learning material used for the experimentation and further validated through eye movement analysis.

1 INTRODUCTION

In the framework of the European Project E-TRACKING (IST 2001-32323), guidelines were derived to foster the better design of e-learning systems. The use of guidelines is indeed very common in many different fields that spread from diagnostic and therapy in medical care to check-list control in airplanes before taking off, just to mention a couple of examples. Also IT has seen a proliferation of guidelines, but they have mainly focused either on usability in general (Nielsen, 1983; Carrol, 2000; Clark and Mayer 2003; Koyani et al., 2003) or on accessibility (W3C's Web Accessibility Initiative). Only in a limited part, the guidelines developed so far have been dealing with e-learning and, within this more specialized field, with the issue of fostering e-learning system design.

Our starting assumption was that e-learning systems need to be usable, acceptable and functional if they have to help users appropriately acquire knowledge. A number of techniques and methodologies already exist to measure the system degree of acceptability, functionality and usability (Rubin, 1994). Most of them, such as questionnaires, user tests, (cognitive) walkthroughs and usability inspection are qualitative, in the sense that they rely on the user's or the experiment's subjective evaluation. They focus on the *how* rather than on the *what*.

The E-TRACKING project has instead been focusing on the *what*-aspect of the problem. Therefore, it has developed a methodology based on the analysis of the user's eye movement during interaction with an e-learning system. Thus this methodology is objective and quantitative.

Eye movements are indeed needed to shift the gaze from one part to another of the visual scene the subject is exploring. They can therefore provide cues on where the subject is looking at and for how long

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Zambarbieri D., Robino C., Crespi S., Calvi L. and Marco Luccini A. (2006).
DESIGN GUIDELINES FOR E-LEARNING SYSTEMS.
In *Proceedings of WEBIST 2006 - Second International Conference on Web Information Systems and Technologies - Society, e-Business and e-Government / e-Learning*, pages 392-397
DOI: 10.5220/0001244203920397

his/her gaze remains on a specific part of the scene (in our case, the user interface). The subject's exploration behaviour consequently has a direct and significant influence on the level of learning attained by the subject: since visual information can only be acquired when the image of the object of interest falls onto the fovea, the information included in the part of the screen that is not explored can not be acquired by the subject at all. In this sense, eye movements are extremely informative in emphasising what would be the best location on the interface to put important information.

2 EYE TRACKING TECHNIQUE

Eye movements are recorded by the EyeGaze system (LC Technologies), a video-oculographic device that consists of a CCD camera mounted below the computer display. A small, low power, infrared light emitting diode (LED) located at the centre of the camera lens illuminates the eye. The LED generates the corneal reflection and causes the bright pupil effect which enhances the camera's image of the pupil. Specialized image-processing software identifies and locates the centres of both the pupil and the corneal reflection and projects gaze position within the video image.

3 METHODOLOGY

The methodology that has been developed to derive e-learning guidelines is based on the analysis of eye movements during subjects' interaction with e-learning systems.

Three test-bed scenarios were developed both to define and to validate this methodology, and they will be referred to as Case Studies in what follows. The Case Studies cover different knowledge domains such as foreign language learning, a collection of Kipling's poems as an example of the cultural heritage domain, and a descriptive statistic course for the technical issues domain. Their structures include a linear, a hierarchical, and a network architecture.

A population of 160 subjects have been examined during the experimental phase of the E-TRACKING project. During data acquisition also other interactions of the subject with the computer are recorded, such as mouse clicks and keyboard strokes, and the capture of the pages that the user is exploring to maintain a correspondence between the eye movement data and the object that has produced these movements, thus taking into account page scrolling. The subject navigates within the Case Study completely free or following a specific task. A pre-learning questionnaire is used to control the level of expertise of the subject within the specific topic of the Case Study, and a post-learning questionnaire is used to verify the level of learning reached after the navigation within the Case Study.

The first step in data analysis is the reconstruction of the user's scanpath. For each page, regions of interest (RoIs) are defined (Figure 1). A region of interest is a part of the page that contains visual or content-related information particularly salient and interesting for the comprehension or that can attract the subject's attention. The analysis of eye movements computes quantitative parameters for the whole page and for each RoI (Goldberg, Schryver, 1995, Goldberg, Kotval, 1998). Permanence time, mean fixation duration and number of fixations are temporal measures that can indicate which are the centres of interest within the page and whether difficulties have been encountered by the subject during the identification and the integration of information. The length of the scanpath and the sequence of accesses to different zones within the page are spatial measures, linked primarily to geometrical and structural characteristics of the interface. Spatial measures can thus reflect visual difficulties or attention problems.

Statistical analysis has been conducted on the previously mentioned dependent variables in order to verify the following experimental hypotheses: the existence of a significant difference in terms of eye movements parameters between the two groups of experimental subjects characterised by different tasks (i.e., learning-to-do vs learning-to-recall), and among homogeneous pages in the e-learning course.

Within-page analysis considers the behaviour of subjects belonging to different groups for each page and for each RoI. Significant statistical differences should demonstrate the influence of the tasks given to the subjects on their learning behaviour.

Between-pages analysis takes into account the non-homogeneity of the different pages comparing pages and RoIs with similar structure among them.

Correlation analysis verifies how strictly two selected variables vary accordingly, thus expressing the degree of their linear relationship.

Finally, *linear regression analysis* expresses the linear relationship among the selected variables by the computation of the slope and the intercept of the best fit regression line.

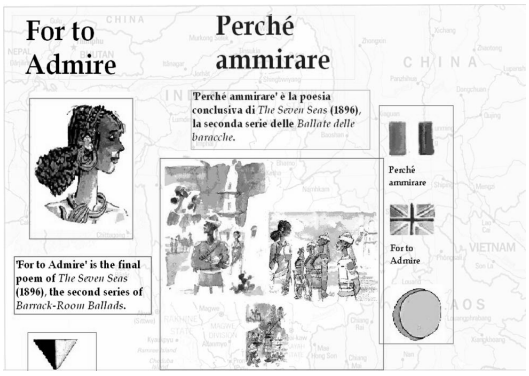

Figure 1: An example of page with identification of regions of interest (RoI).

The development and validation of this new methodology has two main outcomes. First, it provides a simple test for the evaluation of e-learning systems from the user's point of view; second, from the results of the experimental part of the project, guidelines are constructed for the development of "optimal" e-learning systems.

4 E-TRACKING GUIDELINES

Guidelines have been derived from the statistical analyses of the experimental results. They represent recommendations for the development of e-learning courses improved in terms of usability and functionality. Two typologies of guidelines have been identified. The first one concerns navigation or browsing through the material, the second one gives suggestions about the organization of the page layout.

In this Section guidelines are described by giving an issue definition to better explain what captured by the title, followed by the guideline text itself. The fully detailed description of the E-TRACKING guidelines with the experimental evidence supporting them is available on the project web site: http://e-tracking.unipv.it.

4.1 Navigation Guidelines

Information Architecture

This guideline is necessary to determine which course organization to adopt. Although this choice strictly depends on the nature of the content, this issue is fundamental because it influences users' navigation and their consequent learning.

1. Make sure that the course plan reflects the course material organization.
2. Nodes should represent real turning points in the learning development.

Course plan representation for hierarchical and graph-connected courses

Hierarchical and graph-connected courses represent a very special case of course organization since users can more easily get lost and may have a lower content comprehension because of this complex node-and-link structure. In these courses, therefore, the availability of a well-defined course plan can make the difference in users' learning.

1. The course plan should be always available.
2. Make sure that the course plan clearly reflects the course structure.
3. The course plan in the index page should be condensed in order to show the first levels of the structure only.
4. Wording of the course plan items should be accurate.
5. The course plan itself should be placed in a prominent position within the index page.
6. Whenever the course plan or part of it is replicated within the course, all instances should follow the same pattern set in the index page.
7. The index page should be placed in a prominent position within the course.
8. The Table of Contents (TOC) should clearly reflect course structure.
9. The TOC in the index page should be condensed in order to show the first levels of the structure only.
10. Wording of TOC should be accurate.
11. The TOC itself should be placed in a prominent position within the index page.
12. Whenever the TOC or part of it is replicated within the course, all instances should follow the same pattern set in the index page.
13. Hierarchical courses with a linear navigation path should have a direct link (visible and easily accessible) to course first topic.

Navigation menu tree

The navigation menu tree is the best way of representing a course plan and of guaranteeing a quick and easy access to it as a way to improve users' confidence in their own learning path awareness and progress.

1. The Navigation menu tree should be placed in a fixed and well defined position in the page structure.
2. The navigation menu tree should be clearly visible and easy to be accessed.

3. Users' current position in the course structure should be clearly visible.
4. The navigation menu should be always available.

Navigation Links

Links, whether textual or symbolic, are essential in navigating an e-learning course as well as any hypertextual and / or interactive product. Their effectiveness can therefore affect course comprehension.

1. Links should be visible, identifiable and easily accessible.
2. Links should be readable.
3. Links should be effective.
4. Links must not be confusing.

The introductory page and the summary page for hierarchical courses

Introductory and summary pages are always useful, especially for hierarchically highly structured courses with several nested levels of in-depths, as they help users get a first general idea (in the case of introductory pages) of the overall course or draw the necessary connections among material and review own learning progress (in the case of summary pages).

1. The exact positioning of the introductory page in the courseware should be justified by actual learning needs.
2. The title of the page should clearly reflect the summarized course content.
3. The introductory and summary pages should have the same layout and content format.
4. The introductory page textual content should clearly summarise the part of the course depending on it.
5. The summary page textual content should clearly and concisely recap the part of the course it is stemming from.

Help

The presence of a menu or of a page explaining the meaning of the elements used to navigate within the e-learning course may be useful to help users to understand the functionalities of the navigational tools before starting to use the system.

1. Design carefully the help tool.
2. The help tool should be always visible and easy to access.
3. Symbols associated to the help tool should be clear and self-explanatory.
4. It could be useful to make the help menu accessible before the course is started.

4.2 Layout Guidelines

Page layout

Page layout and elements position in a page have an influence on subjects' explorative behaviour.

1. Decide what the most relevant element in the page (the 'eye catcher') is.
2. The 'eye catcher' should be visible and easily accessible.
3. The page layout should be maintained through homogeneous content pages.

Building the lesson page for hierarchical courses

In hierarchically structured e-learning courses, page layout and format play a key role for users' comprehension due to their more complex structure.

1. Pages containing informational content should be easy to identify and access.
2. Page structure has to be clearly defined and set-up.
3. Page title should be clearly visible and identified.
4. Overall course plan should be available and easily accessible.
5. In courses that can be navigated linearly the lesson page should have direct links (visible and easily accessible) to course following, previous and parent topics.
6. Content should be easy to identify and access.

Building the example page

Example pages are very useful for a better course comprehension. They support the user and provide some useful in-depths.

1. The example should be effective.
2. The example should be visible and easily accessible.
3. The page title should clearly reflect the example page content.
4. The example page content format and layout should be coherent to the lesson page content ones.
5. In courses that can be navigated linearly the example page should have direct links (visible and easily accessible) to course following, previous and parent topics (backward, upward and towards closely-related examples).

Images structure

Images are very important elements in an e-learning course, and greatly support users' comprehension and learning. The structure of an image influences subjects' behaviour, and helps to capture subjects' attention.

1. Choose the image carefully.
2. The image should be visible and easily accessible.

Image captions

Image captions can be a useful support for providing users more informative content or to explain / detail image content.

1. Captions should be appropriate.
2. Captions should be informative and salient.
3. Captions should be readable and easily comprehensible.

Page size and delivery media

Content segmentation is a key issue in building e-learning courses. The most important factors to be taken into account are the page size available and the delivery media to be used. Both have a strong influence on each other.

1. Scrolling should be preferably avoided.
2. Big content chunks should be split into smaller 'units' whenever possible.
3. The content 'units' size should fit the displaying requirements of the delivery device.

Symbols

Symbols are used for several purposes. Usually they represent navigation elements (such as links) or shortcuts to supporting tools (for triggering tasks like printing or starting a collaborative work session). Their comprehensibility is a key issue that can greatly affect users learning performance.

1. Symbols should be visible, identifiable and easily accessible.
2. Links should be effective and meaningful.

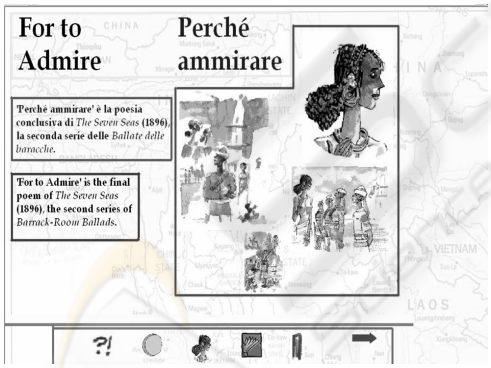

Figure 2: The page shown in Figure 1 after the implementation of the Guidelines.

5 GUIDELINES VALIDATION

Where a mismatch between the Case Studies and the guidelines was found, or when the statistical analyses pointed out users' difficulty to understand and to learn the domain content, the Case Study has been modified by implementing the appropriate guidelines. As an example some results of validation are reported concerning the implementation of the following guidelines:

- Introduction of a navigation bar grouping all links available for the navigation through the material
- Suppression of scrolling
- Improvements in the comprehension of the navigation links
- Changes in pages' layout in order to maintain the homogeneity among pages with the same content.

In Figure 2 it can be observed that all links have been grouped at the bottom of the page and that figures and texts are organised in different sections of the page. This layout is maintained throughout all the hypertext.

Then, a further experimental phase has been executed to verify the improvements of the e-learning systems in terms of subjects' behaviour and learning level. A significant reduction in the permanence time within the page, and in the number of fixations has been found. Also mean fixation duration is reduced from 280 to 237 msec.

For the "optimized" Case Studies, statistical indexes show that a considerable amount of data meets the requirement of a normal distribution, differing from the previous version of the Case Studies. This result could be considered as a first suggestion that the modifications introduced by applying the guidelines have produced less biased data. The increased layout's homogeneity obtained by the insertion of the Navigation Bar and by the separation of text and images has influenced subjects' navigation behaviour. The rigorous material's organisation let subjects develop a similar way of interaction with the different pages and RoIs as indicated by the values of the mean fixation time. Finally, the correlation analysis results seem to highlight that the Case Study modifications have increased the homogeneity of the pages' organisation, and this in turn has positively influenced the learning strategy adopted by the subjects during the navigation. In fact, subjects have now developed a common exploration strategy that tends to be the same through all the material. This behaviour can be explained by the elaboration of a common mental model that can be always applied during navigation. This can produce a better performance in terms of time, accuracy and learning. The optimisation of the Case Study organisation supports the optimisation of the learning interaction allowing a faster and better information acquisition.

This enhanced information acquisition is demonstrated by the fact that the analysis of the

post-learning questionnaires indicates a slightly best performance in terms of learning if compared with the results obtained during the first round experimentation. This allows us to conclude that the interaction at interface level has been improved, since the interface layout and presentation have been modified as to take the user's eye movement into account. Moreover, this study has also demonstrated that there is a correlation between the user's explorative behaviour as revealed by his/her eye movements and learning, since a better interface interaction has resulted in a better learning performance.

6 CONCLUSION

The paper has presented a set of guidelines for the design of usable, acceptable and functional e-learning systems. These guidelines were derived by means of an evaluation methodology that is based on the analysis of exploration eye movements. The application of these guidelines to the Case Studies set up in the project brought to an optimized e-learning course organization. This result is confirmed by the outcomes of all the analyses carried out on the improved course. In fact, statistical analysis clearly demonstrated that the modified Case Study strongly benefited in terms of homogeneity and of a more rigorous and balanced structure.

The E-TRACKING guidelines are not in competition with existing guidelines produced within the Human-Computer Interaction field but rather represent a product that aims to complete and enrich the survey of e-learning systems supplying both a new evaluation methodology of these systems and a suggestion for the optimization of the systems themselves. Compared to classical methodologies, the data resulting from eye movements analysis can indeed not be affected by recollection errors and are not influenced by the personal opinions of both the subject and the experimenter.

In conclusion, it can be suggested that the methodology developed within the project and the corresponding results obtained so far in terms of quantitative data represent a powerful tool for further investigations not only of the usability of e-learning systems but also more in general of all situations of HCI. Therefore this methodology represents a first step for future applications of subjects' eye movement analysis in other fields of HCI. Moreover, a possible follow-up which could bring considerable benefit to the users could be represented by the institution of a certification of quality for Human Computer interfaces (e.g. in particular in relation with e-learning courses) based on the E-TRACKING Methodology.

ACKNOWLEDGMENTS

E-TRACKING project (IST-2001-32323) is partly funded by the European Commission under the Information Society Technologies 5th FP. Partners of the project: Università di Pavia, Université de Nice Sophia Antipolis, Giunti Interactive Labs., Fraunhofer Institute for Applied Information Technology, Telefónica I.D., ARDEMI.

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