Broadband cellular radio telecommunication technologies in distance learning: a human factors laboratory experiment as a base for a field study

Filomena Papa, Sandra Spedaletti
Fondazione Ugo Bordoni, via B. Castiglione 59, 00142 Rome, Italy
Telephone: ++39654803521, Fax: ++39654804406, email: fpapa@fub.it

Abstract
This paper presents a virtual classroom laboratory experiment involving real users. The main aim was to test the effects of two multimedia system configurations with a different degree of interactivity on usability aspect and learning performance. Results confirm the effectiveness of the multimedia system both in terms of technical and psychological features. Some operational results are presented as well in terms of the basic features of multimedia systems used in virtual classroom and of the correct procedures for training teacher and learners in the equipment use. The usefulness of such operational results in setting up successful field trials is discussed.

Introduction
Cellular radio access for broadband interactive services in comparison to a cable access gives some advantages as lower realisation cost and the possibility to provide interactive services access for geographical areas (e.g. rural) in which cable, infrastructures are limited. However, the quality of transmission provided by the radio channel is not constant due to climate, terrain and interference constraints. In developing such kind of systems it is very important to develop trials involving users of different application fields of interactive services, order to improve service acceptance by users.

Tele-education is one of the most promising application fields of interactive services obtained from the integration of informatics and telecommunications. Broadband communication technologies give the opportunity to realise technologically advanced and interactive virtual classroom situations in which spatially distributed people (users) are involved in a learning/teaching real time process using multimedia systems. These systems, obtained by the integration of video communication with personal computer facilities, allow:

- the real time communication among a number of remote locations using different media to present information: speech, music, text, drawings, still images, full motion images, etc. This permits multimedia communication between the teacher and the learners and as well as among learners;
- The utilisation by the teacher of the multimedia chair providing the facilities to handle educational aids, e.g. slides, transparencies, video recorded materials, computer based training tools, etc.

1 This experiment has been developed in the framework of the CRABS (Cellular Radio Access for Broadband Services) Project of the ACTS Program funded by the European Union, in which Fondazione Ugo Bordoni is subcontractor of RAI
At the moment there is evidence that the availability of multimedia systems does not ensure automatically their actual use in distance learning. Some investigations (Hiltz, 1994) have demonstrated that the main barriers to the diffusion of tele-education are related to difficulties of interaction between users and technologies and to teachers and learners resistance in changing traditional educational methods. In dealing with these problems a very useful contribution is provided by the human factors discipline. The key concept of the human factors discipline is the usability. Usability is a very broad concept, which is related to the ease of use of the equipment by the users, to the effective use and to the users satisfaction in relation to the system. One of the tools available to human factors discipline is the so-called emulation approach. It allows taking into account users’ needs by the first stages of design process of a new system with the main aim to maximise system usability and service diffusion. In such a way it is possible to test different system configurations in order to select the best system functions and features, saving a lot of time and money in building prototypes and in setting up pilot experiments on the field. In order to investigate human factors aspects in virtual classroom situations realised using cellular broadband systems an investigation is in progress in Cupertino between RAI (Italian Public TV) and Fondazione Ugo Bordoni (FUB) in the CRABS Project. The general objective of the investigation is to experiment virtual classroom situations realised by cellular broadband systems considering in particular usability aspects of the multimedia tele-education system in terms of ease of use, learning climate, telepresence, users satisfaction. The investigation is developing in two main phases: Phase 1. Laboratory experiments are realised, in order to prepare the phase 2 field trial, emulating a broadband system in the human factors laboratory and involving a sample of potential users. Phase 2. A field trial is set up using cellular broadband systems made available by RAI. The main aim of the trials is to evaluate system usability by learners and teachers, and to evaluate learners’ performance taking into account the constraints due to the telecommunication system.

In the present paper the results of the laboratory experiment realised in the phase 1 are presented. In particular the operational results providing useful input for the field trial are shown. The main objective of the experiment was to compare the usability of two multimedia system’s configurations differing by rate of the interactivity allowed for learners. In fact, the two configurations of the system were different with regard to the equipment used by the learners. Moreover, the effectiveness of the tele-education was tested comparing the learning performance for the two configurations. It was hypothesised that the multimedia system was usable and allowed to learn in both configurations. Moreover, we expected that the most simple multimedia system configuration was more usable than the complex one, because in this last configuration the cognitive load to use sophisticated equipment was higher. However, we assumed also that the most complex configuration allowed the best
learning, because it provided the highest interactivity.

**Method**
The experiment was carried out in the human factors laboratory of Fondazione Ugo Bordoni (FUB). A virtual classroom environment using the broadband network was emulated in the laboratory (Papa, Perugini & Spedaletti, 1998).

During the experiment the teacher was placed in the principal room which contains the multimedia chair that provides the facilities to handle the educational supports: slides, transparencies, video recorded materials, computer based training tools, objects presentation. The learners were placed in three smaller rooms, two learners for each room.

Two experimental conditions were compared. They differ with respect to the degree of interactivity of the involved multimedia system configuration.

**Condition A**: The multimedia system allows:
- video and audio real-time communication between teacher and learners and among learners;
- the use of a multimedia chair by the teacher.

**Condition B**: In this condition, the main features of the system configuration were the same of condition A. Moreover, the system allowed further facilities:
- the learners to use a camera for documents and objects;
- everybody (teacher and learners) to use shared whiteboard on the computer.

A sample of RAI employees (N=36, 15 males and 21 females) took part in the experiment. Subjects’ age ranged from 25 to 51 (mean age = 36). All subjects were graduated (32 high school and 4 university). In total 36 subjects were involved in the experiment. Of the 36 subjects, 18 were assigned to A condition and 18 to B condition.

Two different kind of experimental designs were performed to test the hypotheses. An independent groups experimental design (Cook & Campbell, 1974) was adopted to asses the effect of A and B conditions (independent variable) on the measures of usability (dependent variables). A repeated measure experimental design was adopted to compare pre-test and post-test learners performance in each condition with the lesson regarded as treatment. The within-subject factor consists of the number of correct answers to a 12 closed-ended test administered before and after the lesson.

The teacher and the learners who participated in the experiment were previously trained to use the multimedia system. This training was performed adopting adequate procedures.

During each experimental session the teacher delivered a first, introductive lesson on PC use in the framework of a "Windows Workstation Course". The lesson was focused on five main topics and was thus temporally framed as a sequence of five 'explanation-exercise' units. At the end of each topic explanation by the teacher, the dyads in each room were asked to co-operatively perform a practical exercise about that topic. The learners in the other rooms were free to ask questions and to ask for clarifications but they were not explicitly asked to discuss the topic of the lesson in group.

Six experimental sessions were realised. A small group of 6 learners was involved in each experimental session.
Data about the learners’ performance were collected by the same test administered before and after the lesson (pre- and post-test). Data about usability were collected by a questionnaire administered at the end of the session. Qualitative data were obtained from a teacher interview realised at the end of all the experimental sessions. Non-participant observation and video recording was used to collect data on user's behaviour.

All statistical analyses were performed with S.A.S and S.P.S.S.

**Main results**

*Usability aspects*

For the purposes of the present experiment, that is related to an interaction between real users mediated by the multimedia system, a broad concept of usability was adopted including ease of use, satisfaction, helpfulness of the system for participating in the lesson and for performing practical exercises, tele-presence and perception of image (see Gnisci, Papa & Spedaletti, in press).

ANOVA was performed to detect the effects of A and B conditions on each of these aspects of usability. The main results are summarised in Table 1. In the table are reported, for each aspect under investigation the Cronbach's $\alpha$ showing the reliability of each scale, average scores, standard deviations for the two experimental conditions, ANOVA’s test (F), and its associated statistical significance (p.).

<table>
<thead>
<tr>
<th>USABILITY ASPECTS</th>
<th>$\alpha$</th>
<th>MEAN VALUE (S.D.)</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Condition A</td>
<td>Condition B</td>
</tr>
<tr>
<td>User satisfaction</td>
<td>0.76</td>
<td>3.55 (.34)</td>
<td>3.43 (.46)</td>
</tr>
<tr>
<td>Ease of use</td>
<td>0.83</td>
<td>3.52 (.46)</td>
<td>3.31 (.62)</td>
</tr>
<tr>
<td>Helpfulness for participating in the lesson</td>
<td>_</td>
<td>3.56 (.78)</td>
<td>3.78 (.54)</td>
</tr>
<tr>
<td>Helpfulness for performing practical exercises</td>
<td>0.90</td>
<td>3.71 (.57)</td>
<td>3.76 (.52)</td>
</tr>
<tr>
<td>Tele-presence</td>
<td>_</td>
<td>3.39 (.78)</td>
<td>3.11 (.83)</td>
</tr>
<tr>
<td>Perception of image</td>
<td>0.79</td>
<td>3.07 (.48)</td>
<td>3.10 (.56)</td>
</tr>
</tbody>
</table>

All are 5-points scales (0-4)

Table 1 shows that all the usability aspects under investigation to be consistently measured by proper items ($\alpha$ ranging from .76 to .90). The mean values of each aspect fall in the last positive grade of each scale. ANOVA does not show any significant difference between A and B conditions.

These results indicate that the learners explicitly recognise that the multimedia system is easy to use, effective, helpful and provides good image perception. Therefore, in general the virtual classroom session and its peculiar technological and organisational features seem so satisfying for the user that they consider the experimented configurations very usable.

All the analyses on usability do not show any significant difference between A and B conditions. This indicates that a complex configuration of the system is just as usable as a simpler one. Then the initially formulated hypothesis, that the most simple multimedia system configuration was more usable than the complex one, was not
verified, at least for multimedia systems similar to the one presented in our experiment. However, in both the configurations the usability is guaranteed, no matter the technological sophistication of the particular configuration.

Learners performance
The data analyses related to the learners performance (see Gnisci et al., in press) showed that the lesson allows and improves learners performance both in A and B condition.
A further analysis was carried out to verify whether the performance of learners is improved significantly more in one than in the other condition. On this respect the result is that subjects learned more in the less interactive configuration.
As a general picture, the virtual classroom lesson studied in this experiment improves the correct answers by learners both in A and B conditions, and, thus, promotes and facilitates learning. Still, although both configurations enables the users to learn, our analyses show that the increase of learning performance of users in the less interactive condition is better than in the most interactive configuration. Then the initially formulated hypothesis, that the most complex configuration allowed the best learning, because it provided the highest interactivity, was not verified. This finding is related to the kind of learning task considered in this experiment (a lesson including explanations by the teacher and related practical exercises by the learners). More complex configurations should be needed when more complex tasks require additional functions (e.g., groupware to allow learners to share documents and applications) not permitted by the simplest configuration considered in the present experiment.

Training evaluation
The learners were submitted to a particular training procedure. To evaluate the effectiveness of this procedure two closed-ended questions were included in the questionnaire on how much the instructions provided by experimenters before the lesson were clear and exhaustive. A third item was presented only to subjects of the most interactive condition (B) because in this case the equipment provided to the subjects was more complex and the procedure of instructions was more complicated. The data analyses (see Gnisci et al., in press) suggested that the training procedure was effective and well established in both conditions.

Operational results
From the whole results of the experiment some suggestions related the training procedures for teachers and learners and to the multimedia system configuration have been obtained. These are tools to be used in the second phase of the project. They are summarised in the following.

Procedure for training teachers
As mentioned before, the use of multimedia systems implies some changes in the ways usually adopted by the teachers in designing and in delivering lessons. Moreover the virtual classroom situation implies new skills for the teacher; for instance the teacher should be able to deliver the lesson in front of a camera. In order to face these problems an adequate procedure for training the teacher was adopted. The procedure developed through the following steps:
1. Presentation to the teacher of opportunities of the multimedia system both in terms of multimedia communication and multimedia chair (by demonstration).
2. Analysis of delivery methods, educational aids, time use, etc. usually adopted by the teachers in the face-to-face classroom (interviewing teachers).
3. Identification of objectives of training, delivery methods, development of contents, educational supports, time use, multimedia system configuration etc. in the virtual classroom situation.
4. Setting up preliminary trials for training teachers in interacting with the multimedia system.
5. Helping the teachers in preparing adequately the educational aids.
6. Providing the teacher with adequate indications for promoting and managing the communication among learners in the virtual classroom.

The steps from 3 to 6 have to be performed in an iterative way, with the main aim to provide teachers with the necessary skills to deliver lessons in the virtual classroom.

In comparison to the procedures identified in previous experiments (see Abbolito et al., 1995) this procedure is specially oriented for training of teachers operating in interactive virtual classroom situations. In these situations, relationships among learners are of fundamental importance (co-operative learning situations).

**Procedure for training learners**

In interactive virtual classroom situations the functions made available to the learners may increase the complexity of the system. As a consequence an important aspect is the identification of adequate procedures for training learners in the equipment use. Moreover these procedures should provide the learners with indications about the behaviour and the protocols of communication to be followed in the virtual classroom.

The procedure adopted in this experiment for training the learners before the session developed through the following steps:

1. Providing learners with information about virtual classroom situation and its opportunities for learning.
2. Presentation to the learners of the multimedia system configuration (without details) including learners’ equipment, audio-video and computer communication features.
3. Providing the learners with indications about the behaviour to be adopted during the session including use of the camera, possible equipment failure, protocols of interaction.
4. Providing instruction about equipment use (by demonstration).
5. Setting up some simple practical exercises about the system utilisation, involving the learners.

The steps from 4 to 5 have to be performed in an iterative way, with the main aim to provide learners with the necessary skills to use correctly the multimedia system during the lesson.

**System configuration**

The results of the laboratory experiment realised in phase 1 suggest that the requirements of the multimedia system are as follows:
- self-view: each participant has to see his/her portrait;
- audio continuous presence: each participant (teacher and learner) has to be continuously audible during the lesson;
- a proper human communication protocol among participants: for instance, it concerns the turn taking, the writing on a whiteboard, the modalities of learners’ interaction defined by the teacher;
- continuous video-feedback for the teacher: all learners have to be continuously visible by the teacher;
- visual control for the teacher of the video signals to be transmitted to the learners: what the learners see has to be continuously visible by the teacher;
- a multimedia chair: the teacher has been provided with various teaching aids (e.g. slide projector, videoplayer, CD-ROM player, etc.);
- a teaching aid selection function: the teacher has to be able to select the teaching aids from the multimedia chair;
- a proper switching procedure to select images to be presented to learners: this procedure has to be controlled both by the teacher and by the learner.

The requirements of the image quality are strongly depending on the particular learning/teaching field in which the trials will be carried out (e.g. medical field, humanities, etc.) and have to be defined considering the application field. Of course, at each location the workplace of participants has to be ergonomically designed with regard to the environmental conditions (e.g. lighting) and to the user interface.

Discussion
One of the objectives of the experiment was to compare two configurations of the same multimedia system that provide different levels of interactivity. With this regard the results are unambiguous: no difference between conditions was found for all usability aspects. And, although both configurations enable the user to learn, the less interactive is the one that provides the best learning performance. So, the configurations are similar for all respects but education outcome. This suggests that in virtual classroom, when the users are provided with the same possibilities to accomplish the task-related goals and to realise the same interactional functions, improving the technological equipment available to the learner (i.e., interactivity) leaves almost unchanged the usability aspects but decrease the learning performance. Hence, usability factors being equal, the less interactive configuration is preferable, as it requires less technological and training resources.

As far as our results show, the benefits of the proposed multimedia system are strongly based on its multiple features of usability, as well as the on possibilities to get an educational outcome for learners. These experimental findings suggest that we have identified and validated an effective multimedia system for virtual classroom. The main features of this system, shared by both the experimented configurations, can be summarised as follows: a) audio continuous presence, i.e. all participants are continuously audible during a session; b) video continuous presence for the teacher, i.e. all learners are continuously visible by the teacher in order to have a visual feedback.; c) "self view ", i.e. each participant can see his/her own image; d) different multimedia educational supports utilised by the teacher (a camera for documents and objects, telepointing and teledrawing facilities, a “tilting” camera); e) an adequate
procedure to switch video signals to be presented to learners. The results of the experiment suggest that the multimedia system to be used in virtual classroom should satisfy the previous basic requirements. These requirements suggest useful guidelines for designers of multimedia systems to be utilised in a virtual classroom situation. Furthermore, the experimental findings along with the results of training evaluation provide indirect evidence that the identified procedures for training teacher and learners in using the system are effective, simple and straightforward. In particular, the main aim of procedure for training teachers was to provide them with the necessary skills to use correctly the multimedia system, to design and to deliver lessons in the virtual classroom. As well, the main objective of the procedure for training learners was to provide them with the necessary skills to use correctly the system. Indeed, the procedure has been built up to make the learners think to be able to master the multimedia system, that is, to increase their self-efficacy. In a previous study we have found some evidence that if the learners think that they are able to master the distance learning system their performance improves, on the contrary, if they think they are not able to do it their performance deteriorates. Thus, it is important to take into account this variable to obtain a higher learning performance (Papa, Perugini, Spedaletti, 1998).

As said before the main aim of this laboratory experiment was to prepare a field study to be realised using a real telecommunication system. On this respect some tools to be utilised in the field study have been identified: the multimedia system configuration and some procedures for training learners and teachers. Moreover, the laboratory experiment allowed setting up an adequate experimental procedure to be utilised in the field experiment. Such operational results are of fundamental importance in setting up successfully the field trials. They have provided a very useful tool in the realisation of the field experiment. In particular the multimedia system configuration identified during the laboratory experiment was reproduced in the field. To provide high interactivity between teacher and learners and among learners, a telecommunication system using a 40 GHz cell and a 2 Mbit/s return channel for each remote location was utilised. In particular four remote locations were connected: one teacher location and three learners’ locations. The first results of the field study indicate that the proposed multimedia system configuration and the training procedures have been validated in the field. This fact confirms the opportunity to utilise laboratory experiments involving a sample of real users and performing real tasks in setting up field investigations.

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