Learner centred design for a hybrid interaction application

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ABSTRACT

Learner centred design methods highlight the importance of involving the stakeholders of the learning process (learners, teachers, educational researchers) at all stages of the design of educational applications and of refining the design through an iterative prototyping process. These methods have been used successfully when designing systems employing innovative concepts or technologies. In this paper we describe the design process of Move Grapher, a GPS-enabled, mobile learning application to support the teaching and learning of kinematic graphs in in schools and colleges to children aged 15 – 17. Move Grapher implements a hybrid mode of interaction; besides implementing a graphical user interface, it enables learners to employ an embodied type of interaction as a way of supporting them in generating learning insights. Involving stakeholders and iterative prototyping were important methods in the design process, however, the innovative nature of the technologies employed and the embodied element of the interface had a decisive influence in determining the roles the stakeholders played as well as the nature of the deployed prototypes.

Keywords

Learner centred design, mobile learning, location awareness, embodied interaction, kinematic graphs

Introduction

Students of mathematics and physics need to understand how to construct and interpret kinematic graphs which plot distance or speed against time (see figure 1). They need to do this with fluency and accuracy, recognising the meaning and significance of the variable, slope, area under the graph and intersections with the axes. However, students are susceptible to a number of misconceptions such as viewing the graph as a picture or confusing the gradient and height (McDermott, Rosenquist & van Zee, 1987; Beichner 1990, 1994; Beichner & Robert, 1994; Janvier, 2004). These are related with associating the symbols and representations in these graphs with the concrete movement of an object. For example, in the graph-as-picture error, students might think the graph is an illustration of the travelled terrain mistaking an increase in velocity with travelling up a hill.

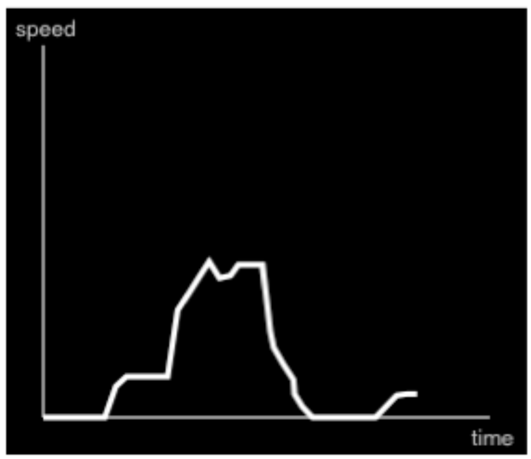

Figure 1. A Speed Time Graph

Two successful ways of learning about kinematic graphs are hands-on approaches and using tools and instruments. The idea behind hands-on approaches is that a powerful paradigm in learning is activity followed by reflection (Harel and Papert, 1991; Ackermann, 2001; Simpson & Noss, 2006) while using tools and instruments allows students to view in real time the effect of the movement of concrete objects on a graph (Mokros & Tinker, 1987; Thornton & Sokoloff, 1990). In the study reported here, we went beyond just combining these two approaches, we enabled students themselves to be the moving objects so that in this way we could exploit their kinesthetic functions to support effective mappings between movement and its graph representation. In order to implement such an approach, we employed innovative technologies such as location awareness and large screen capabilities of modern mobile phones. Developing learning applications using innovative technologies can however add an element of uncertainty and complexity to the design. In order to meet these potential challenges we employed a learner centred design (LCD) methodology, an approach that has been proven successful in these cases (Good & Robertson, 2006; Goolnik, Robertson & Good 2006).

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This paper describes the learner centred approach that was employed to design activities and representations that would effectively exploit the learner's kinesthetic functions when learning about kinematic graphs. The next section talks about the teaching and learning of kinematic graphs and about approaches that have employed similar technologies. The following section talks about the use of LCD for innovative systems. The section "The design process of Move Grapher" summarises the work done in terms of the LCD process followed. The section "Establishing the requirements" describes two initial studies aimed at clarifying the requirements of the design. The following section, "Paper prototyping", describes two studies intended to refine early versions of the prototype. The section "High fidelity prototyping" describes the iterative refinement of the computerised prototypes that implement the approach. The paper finishes with a discussion of lessons learned and relevant conclusions.

Innovative approaches for the learning of kinematic graphs.

Kinematic graphs are an important part of the language of physics and being able to construct and interpret them correctly is essential to understanding and communicating mechanical concepts effectively. However, in using kinematics graphs for mathematics and science, students are susceptible to a number of important misconceptions (Beichner 1990, 1994). These include: viewing the graph as a picture, confusing the gradient and height, confusing variables (mistaking acceleration for velocity, for example), assuming (for the purpose of calculation) that the line representing the movement passes through the graph's origin, and confusions involving areas (misunderstanding the area, or calculating area instead of the gradient and visa versa). The first two errors are the most common (Beichner 1994).

Because of the importance of kinematic graphs for the science curriculum, a wide variety of instructional approaches have been implemented to address the difficulties described above. From those, two have been particularly successful: hands-on approaches and using tools and instruments. In the latter, students are allowed to engage in learning activities that have the concrete output of building or modifying something, while in the former a variety of tools are used to produce real-time graphs of the movement of concrete objects. Zollman (1994), for example, uses a hands-on approach as he enables students to perform low-tech, manual editing of motion videos. Students place acetate transparencies on video screens to mark the changing positions of key objects. This enables them to answer their own inquiries at their own pace (Zollman, 1994). Beichner (1996) uses similar techniques to provide a more direct validation of the approach. He employs video motion analysis software in a variety of situations ranging from teacher-led demonstrations to allowing students to edit and analyse the videos by themselves. The greatest learning gains were associated with the hands-on approach. Hoyles and Noss (2006) enabled students to produce motion animations using a programming environment. Students engaged in a range of activities: exploring motion and plotting graphs, predicting graphs after observing motion, "guess my graph" (trying to reconstruct motion based on a graph) and matching descriptions of motion. Each of these activities reflects the importance of the students constructing their own graphs.

Probably the most well known programme of research associated with the use of tools and instruments to learn kinematic graphs has been the micro-computer based laboratory (MBL) tools (Mokros & Tinker, 1987; Thornton & Sokoloff, 1990). MBL tools link sensor equipment to computer software to allow the real-time generation of graphs from the movement of concrete objects. The idea behind this approach is that observing the changes in position, speed and acceleration of concrete objects can achieve a deeper appreciation of the relationships between movement and the corresponding graph. More recent studies (Nerimovsky, Tierney and Wright, 1998; Arzarello & Robutti, 2004) have adapted the sensor equipment to detect the student's movement, either producing real-time graphs on the desktop screen or storing the data for later display. They justify their approach in terms of an embodiment perspective (Johnson, 1987; Lakoff, 1987), the notion that thinking is an activity that involves the whole of the human body and not just the brain. Arzarello & Robutti (2004) in particular, argue that the interpretation of movement graphs can be supported by the direct experience of generating them and that that embodied interaction combined with collaboration can support the transition from perceptual facts to symbolic representations. Beichner (1990) argues that the ability to view results in real time is as important as the kinesthetic elements. The study reported here follows a similar approach, however instead of using bespoke sensor equipment and desktop computers, we have employed the location awareness and relatively large screen of Apple's iPhone for both detecting the student's movement and displaying the corresponding movement graphs. In order to design a learning application with this innovative technology we employed a learner centred methodology. Before describing the design process that we followed the following section talks briefly about learner centred design.

Learner centred design

Move Grapher is an application that employs innovative technologies and whose activities and representations will be unfamiliar to learners. Therefore, to minimise the risk of producing software that would be difficult to understand and use it was important to employ an approach that has proven successful for designing innovative learning applications. LCD advocates the involvement of stakeholders (teachers, learners, education policy makers, educational researchers, etc.) at all stages of the design process as well as the use of iterative prototyping to refine the design of learning applications (Good & Robertson, 2006; Goolnik, Robertson & Good 2006). Similarly to Participatory Design (Muller & Kuhn, 1993), LCD is in favour of stakeholders partnering with designers as a way of producing more useful technology. However there are differences between these two approaches stemming mainly from the fact that in LCD the main users are young people. This fact raises issues related with the responsibilities young people should have if they are part of the design team and in general with the role and involvement that learners should have in the design process.

According to Druin (2002), the four roles that children can play in the design of new technology, from least to most involvement, are: user, tester, informant, and design partner. A user role assumes that children's interactions with technology would be observed to assess the impact it has on their learning. Traditionally, this happens once there is a finished system and the feedback obtained could be used to improve future technologies. In the tester role, besides observing their interactions with technology, researchers could ask children for their comments and opinions regarding their experiences from those interactions. Also as testers, children interact with prototypes, versions of the system that have not yet been released, and their feedback can be used to refine those prototypes. As informants, children can participate in the design process at various stages, from giving their opinions about early paper sketches or storyboards of intended ways to use technology to interacting with prototypes or with the finished system. Finally being a design partner implies an equal opportunity of contribution throughout all stages of the design process.

There have been different views as to what is a suitable level of involvement for children when designing innovative technology. Until recently, it was assumed that the most appropriate role was as user (see for example Conlon & Pain, 1996) but lately higher levels of involvement have been considered as desirable. Scaife & Rogers (1999), however, question the wisdom of involving children as design partners given that frequently they know little about the domain and the way it should be taught. They suggest that in some contexts it would be more appropriate for children to be considered as testers rather than as design partners. A design partner role is sometimes challenging even for teachers as they might know about difficulties children encounter when learning with traditional materials but not about what might be effective with innovative technology. Druin (2002) points out that this is not necessarily a problem as every stakeholder will have areas of expertise and areas they might not know much about. While children cannot do everything adults can do, they might have special experiences and view points that can enrich the design process.

Regarding the types of prototypes that could be employed, there is a continuum on the level of fidelity, how much resemblance with the final product there is, that the prototype can embody. At one end of the continuum there are low fidelity prototypes. These are prototypes produced in a medium different from the final product, for example paper sketches or storyboards illustrating intended uses of the technology. Next are mid-fidelity prototypes, possibly computerised versions but with very limited functionality. High fidelity prototypes are typically similar to the final product although they might only implement a subset of the functionality and might not be very robust (Rogers, Preece & Sharp, 2002).

Typically, low fidelity prototypes are employed early in the design process, to design the conceptual model (the high-level conceptualisation of the structure of the system), to explore alternative designs quickly and cheaply or to understand and model workflow, for example. High fidelity prototypes, on the other hand, tend to be used later in the process and mainly to evaluate interaction (Rudd, Stern & Isensee, 1996). Usually there is a smooth progression as prototypes evolve from low to mid and high fidelity. Low fidelity prototyping has been used successfully in supporting the design of the representations employed or in evaluating aspects related with the interface for learning applications, (Goolnik, Robertson & Good 2006), in mobile learning (Parsons, Ryu, Lal & Ford, 2005) as well as for systems implementing an embodied form of interaction (Fernaeus and Tholander, 2006).

The design process of Move Grapher

Move Grapher was designed as an application to allow users to generate and display, immediately, distance and speed time graphs of their own motion whilst walking and running. So that learners could focus on the concepts taught rather than the working of the interface, the application needed to be quickly learnable by students and teachers. The application was designed to help identify misconceptions and gaps in knowledge while reinforcing and consolidating understanding, two of the purposes of academic games identified by Gredler (1996). Teachers involved in establishing the requirements (as described in the next section) also emphasized the importance of competitive and collaborative elements.

The iPhone has many advantages as a platform for developing an application of this nature. With GPS it is capable of detecting movement, and its 85mm screen with a resolution of 480 x 320 pixels is ideal for displaying graphs generated, allowing individual students to view their own graphs immediately. The iPhone software development kit includes frameworks for capturing and retrieving location data. The nature and popularity of the device might also prove a motivating factor for students using it.

Using GPS entails a requirement to use the device outdoors which has both costs and benefits: logistical issues arise (supervision, constraints of poor weather) but learners are freed from the space constraints of the classroom allowing them to generate graphs with a wider range of movements over a longer time period. Although the iPhone also includes an accelerometer from which movement data could be captured for the purpose of generating kinematic graphs (Anastopoulou, 2004), unfortunately the accuracy appears to be insufficient to be useful in this context. Using the accelerometer to capture motion over these distances would also require the user to maintain consistent orientation of the device, but if future iPhone revisions improve the accuracy of accelerometer data, an option could be provided to use it in this way in place of GPS with very little impact on the user interface.

Move Grapher was designed in a Learner Centred fashion and the main stakeholders (teachers, educational researchers, learners with and without any knowledge of the subject matter) participated at different moments of the design process. This process comprised an initial stage devoted to establishing the requirements of the application, a subsequent phase of generating and refining a conceptual model and its associated interface and a final stage of refining and evaluating a computerised prototype of the application. The following sections describe each of these phases.

Establishing the requirements

In determining how the application would support the teaching and learning of the concepts underlying distance and speed time graphs, nine mathematics teachers were involved in a series of interviews to establish how the application should address concepts and misperceptions, how it might be used, and what they saw as its essential requirements. Each of the teachers participating in the study was involved in delivering to students of 16-17 years of age topics in mechanics in which the understanding and application of the knowledge of distance and speed time graphs constituted a key component. The participant teachers had experience in the delivery of these topics ranging from three to over thirty years teaching.

The teachers were interviewed individually. Interviews combined closed and open questions. Each interview comprised discussions of three key aspects that would inform the development of the prototype. These were: the conceptual difficulties that their students had encountered and particularly struggled with, how the application might be used and integrated into learning activities, and the requirements it would be essential that the application should fulfill. In establishing and prioritising these requirements, a mixture of proposed requirements and those generated by the teachers was selected by them and ranked in order of importance.

From the responses given by the teachers, it was established that the application should allow both teachers and students to create and send a graph to other users (promoting collaborative learning), that students should be able to try to match a graph displayed on screen by recreating the movement described, that students should have a high level of control in starting and stopping the recording and graphing of their movements and that an element of competition should be incorporated into the activities that application supported. Additionally, some of the teachers considered it important to distinguish between graphing distance and speed (ignoring direction) and graphing their vector counterparts (accounting for direction in how the graph is constructed); but on the means necessary to do this, perhaps by requiring users to walk in a straight line or by resolving components of the motion, there was no consensus. The action of sending graphs between users was identified in three contexts: teachers sending graphs to students; students sending graphs to their peers; and students sending graphs to teachers. The first context would allow teachers to provide students with graphs appropriate to particular (possibly differentiated) learning outcomes, the second would promote independent and group learning and the third would allow teachers to assess and provide feedback on the product of the students' work.

Paper prototyping

The paper prototyping studies can be divided into two, the first to support the generation and refinement of the conceptual model with educational technology researchers as participants and the second to refine the graphical interface with students as participants.

Generating the conceptual model
The concrete aim of this part of the study was to choose a model to ask student participants to evaluate, identify potential issues that students might have with the initial interface designs presented, and to generate ideas as to how the affordances of the iPhone might support the aims of the application.

Two storyboards were prepared based on alternate conceptual models. The first was closely based on a constructionist approach (Papert and Harel, 1991) in which the graphs themselves are learning objects to be generated, shared and discussed by students (Simpson, Hoyles and Noss, 2006). The other placed greater emphasis on creating graphs as part of an academic game (Gredler, 2006), in which key concepts required for creating and interpreting kinematic graphs were implicit rather than explicit, but in which knowledge gaps are identified and understanding is consolidated and reinforced. In each case collaboration was central to the design. Each cell in the storyboards showed a screen in a particular state, marked with indications as to what would appear when any given control was touched.

The educational technology researchers comprised six members of the University of Sussex Interactive Digital Educational Applications, some of whom also had recent involvement in the teaching and learning of kinematics. They were asked to conduct a cognitive walkthrough using two tasks for each prototype, taking on roles as students and considering whether the user would understand the action required, see what was needed to complete it and interpret the response at each stage. The object-based prototype was evaluated by walking through the process of creating a distance time graph (by moving around) over a specific period to send to a fellow student, then as that student receiving the graph and creating (again through movement) a graph to match it as closely as possible, and reading of the accuracy score representing how close they came. For the purpose of evaluating the level based prototype, the researchers considered two tasks: beginning and playing the game by moving around; and viewing and helping another user by calling directions.

The findings showed that the object-based prototype was easier to understand than the level-based prototype, although it was felt that the latter might make a better game. An advantage offered by the object-based prototype was the depth of understanding that explicitly connecting with and reinforcing graphing concepts would offer. Based on this feedback, the object-based prototype was developed for evaluating with students, incorporating a number of minor changes to the graphical user interface to improve navigation within the application.

Refining the graphical interface
Learners were involved in evaluating the paper prototype that was developed from the storyboards incorporating refinements from the educational technology researchers. The purpose of this study was to inform refinements to the graphical interface by eliciting feedback from students drawn from the target user group, and to identify any other barriers or obstacles in the completion of tasks typical of those that might form part of a lesson on kinematics. The paper prototypes constituted pen and paper sketches of the application screens, with controls and other dynamic elements of the graphical interface represented by sticky notes as illustrated in Figure 2. The tester manipulated these elements, and drew graphs where appropriate, in response to the learners' actions. This allowed users to dynamically interact with the graphical interface, seeing the effect of their interactions represented immediately. Because of the nature of the prototype, learners remained static whilst using the application and where user movement formed an inherent part of the task they described in their own words how they would move.

Students taking part in the evaluation had already studied kinematics, some at advanced level, and were therefore capable of critically reflecting on the application and its relation to their previously acquired knowledge of the relevant concepts. The decision to involve students with a previous knowledge of kinematics was taken given that, according to Scaiffe & Rogers (1999), children cannot discuss knowledge they have not yet acquired. These students were all advanced level mathematics students of between sixteen and seventeen years of age. They could be considered proxy users because of their prior learning: the effect of the study on their own learning was not a part of the evaluation (although the application is also designed as a tool for revision and consolidation for which this would be a target user group).

The paper prototype was developed through two iterations, each being evaluated with four or five learners. Different students were used in each case so all participants were equally unfamiliar with the application. Each learner individually completed a set of tasks by touching the paper prototype and, where appropriate, describing how they would move with the device. Although learners carried out these tasks individually, they included sending, receiving and interacting with graphs as if collaborating with classmates. Feedback was gathered through a short sequence of questions both before and after the tasks were completed, and from during the task using the "think aloud" protocol. Video of the paper prototype was recorded along with the learner's commentary so that their progress through the application could be reviewed along with their words.

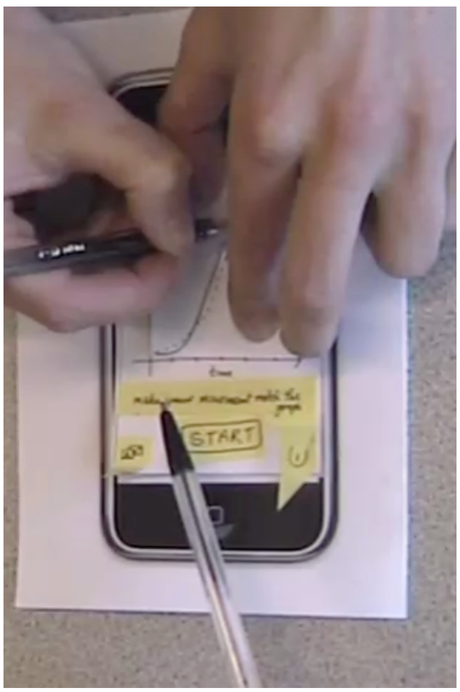

Figure 2. First paper prototype

Figure 3. New graph screen, first high fidelity prototype

Several of the learners commented on the overall ease of use and simplicity of the interface. However the most important finding from the study arose when it became clear that users could complete an entire task without realising that they were creating a distance time graph rather than a speed time graph. The interface was redesigned to force users to make an explicit choice. In several cases, the learners also did not see how to start and stop the application from recording and graphing their movement, one of the requirements highlighted as a priority by the teachers. Improvements to the interface rationalised how these settings were presented. Besides these critical changes, the results of the evaluation also highlighted aspects of the interface where the symbols or terminology used was not fully understood by the learners allowing these to be made more appropriate to the target audience.

High fidelity prototyping

The aim of the previous evaluations had been to use information from the learners to improve the graphical user interface. With a hybrid mode of interaction inherent in the design, however, it was important to evaluate the interactivity, particularly its embodied element. Progressing to the development of a high fidelity prototype at this stage made it possible to conduct further studies, both to assess the usability of both forms of interaction and to conduct a preliminary evaluation of the effectiveness of the application for supporting the learning of movement graphs. To determine how the response of the application compared to user expectations, both from usability and educational perspectives, it was essential to implement a prototype that actually employed GPS to allow user interaction in the physical domain. This interaction could have been simulated to build a medium fidelity prototype by having the iPhone view a web-based version of the interface, and having the users movements entered by a researcher, however the complexity involved in implementing such a prototype would be similar to that of the high fidelity prototype. Therefore to benefit from having users interact with GPS a high fidelity prototype was implemented next.

The high-fidelity prototype was developed on the iPhone based on the final paper prototype (see Figure 3). It was implemented in Objective-C using the following tools and libraries from the iPhone Development Kit: X-Code 3, Interface Builder and the Cocoa Touch application-programming interface. In particular, GPS locations were accessed using the Core Location framework, and graphs displayed using functions from Core Graphics. The prototype version also used the Bonjour Service Discovery Protocol for discovering and connecting with other

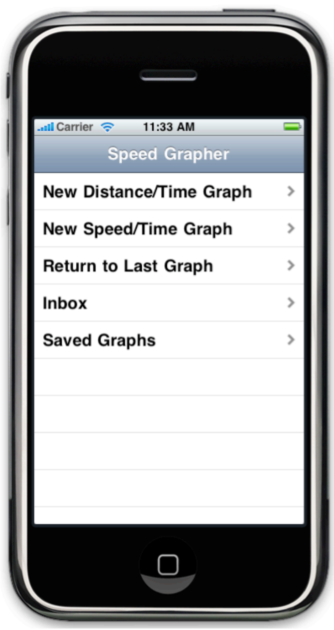

Figure 4. The start menu

Figure 5. The graph received alert

devices running the application for the purpose of sending graphs; the next revision will use the Bluetooth peer to peer networking in the Game Kit framework to offer this functionality without any Wi-Fi network being necessary. The current version of the prototype comprises approximately 3,700 lines of code in twenty custom classes.

The prototype offers the functionality to create distance and speed time graphs from movement; save, send and receive these graphs; to browse through an illustrated table of saved and received graphs stored on the device; and match a received graph or guess (by tracing on the screen) the shape of a hidden graph. For matched or guessed graphs, the application also calculates a measure of closeness between the learner's version and the original. Figures 4 and 5 illustrate the application's options to activate some of these functions.

Evaluating the usability of the interaction

The prototype was refined iteratively through evaluations with users. This study shared with the previous one the focus on the usability of the interface, and again proxy learners with a well-developed understanding of the mathematical concepts were employed in the studies. Once again an evaluation was conducted with five learners, the results of which informed refinements to the prototype, and a further evaluation involving five learners provided feedback both on these refinements and any other aspects the changes brought to light. Similarly to the paper prototype evaluations, different students were used in each case so all participants were equally unfamiliar with the application.

Whilst the structure of the process for each learner followed a similar pattern, the high fidelity prototype was tested out of doors where a good GPS signal could be obtained. Testing the application in this context made it possible to evaluate its performance in a range of conditions, for example with bright sun on the screen which proved not to cause any problems. Similarly to the paper prototype evaluations, feedback was gathered through a short sequence of questions both before and after the tasks were completed, during the task using the "think aloud" protocol and from the recorded video. However difficulties were encountered with capturing usable video, and better results might be obtained by building a mechanism for screen and audio capture into the application itself. As before, the tasks included simulated collaborative interaction: sending, receiving and interacting with graphs as if working with classmates.

The results of the evaluation included highlighting the usability of the application, specifically the simplicity and intuitiveness of the user interface, which as with the low fidelity prototype several users explicitly mentioned. Users described the application as fun as well as useful. Over the two iterations, a number of improvements were suggested and implemented to address issues where users failed to find settings or cleared their graph unintentionally: From the first test it became clear that a lag (of approximately 5 seconds with a good GPS signal) was confusing users. The lag may be due to the hardware (the GPS chip, antennae or processor speed) or Apple's implementation of the Core Location framework. Future firmware or hardware versions of the iPhone should see this delay reduced, but an indicator showing where the graph would be drawn was found to be useful by users in the second round of testing. It also became apparent that learners with prior experience using an iPhone or iPod touch recognised where to look for controls positioned consistently with the iPhone human interface guidelines, whilst other learners took one or two attempts to locate these.

Preliminary educational evaluation

To test the effectiveness of the application, we intend to test the application as a learning resource with several groups of learners collaborating on activities in the context of a pre-university course. This evaluation has yet to take place, however in a preliminary small-scale study to investigate the effect on learning of the application prototype, three learners at the lower end of the target age range were asked to use the final prototype in a number of activities reflecting the way the teachers had originally suggested the application might be used. The users were selected to include one learner who had yet to be taught kinematics, one user who had begun to learn the topic, and one user who had studied the topic over two years (aged 13, 14 and 15 respectively).

To assist in clarifying how the students' knowledge developed, the students were asked to complete a set of multiple-choice questions before using the application, and a similar (but different) set afterwards. These questions were based on those developed by Beichner (1994) and Simpson, Hoyles and Noss (2006).

After completing the first set of questions, the students were shown how to create distance/time and speed/time graphs using the application and asked to spend five minutes exploring these and to explain what they thought the differences were. They were asked to save a graph of each type and talk

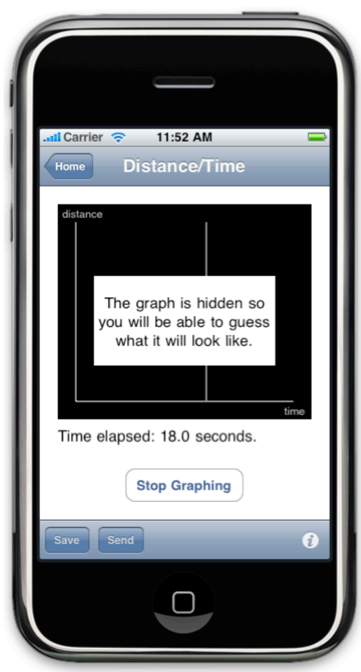

Figure 6. Graph Guessing mode

through what they considered the important points. The students were then given two exercises to complete. In the first they were then given a graph of each type (similar to the one shown in Figure 1) to try to match by moving, and asked to comment on which aspects they found easy and which they found difficult in accomplishing this. In the second, the students were asked to create a graph of each type with the guessing mode on, and to try and predict what it would look like (see Figure 6). Again, they were asked to say what they found more or less challenging.

The student who was unfamiliar with kinematics was unsure at first whether to wave the phone around to create a graph, or to move around herself; experimenting she discovered that walking produced a response on screen. However, her confusion at exactly how the graph related to movement continued; she persistently confused distance and speed time graphs during the activity and when she got counter-intuitive results she would switch both the type of graph on the phone and her mental model, recreating the mismatch. She was able to identify on the graphs where her motion changed (especially in terms of changes in speed) but was not always confident in predicting how this would affect the graph drawn on the iPhone if required to sketch it. She gave her most accurate answers when discussing matching a speed time graph, immediately identifying how to modify her motion to obtain a closer match on the screen. The next youngest learner was familiar with calculating speed but not acceleration. The learners with some familiarity with distance and speed time graphs also initially confused distance and speed, but were quicker to recognise the connection between these concepts and the graphs displayed on the iPhone. They both made similar mistakes initially, but the eldest learner became fluent in identifying the correct type of motion to employ most quickly, and responded accurately to questions as to where the greatest and least speeds were drawn on each type of graph.

Discussion

Overall, the LCD approach proved very useful in producing an application that can exploit students' kinesthetic functions to support effective mappings between movement and its graph representation. In particular, involving stakeholders in all phases of the design process and the use of iterative prototyping were of central importance to identify a suitable conceptual model and to validate and refine the design. However some characteristics of the application and the modes of interaction influenced the roles some stakeholders could play in evaluating the prototypes, and the complexity of simulating location awareness relative to implementing a GPS aware high-fidelity prototype affected the choice of prototype deployed.

Move Grapher enables students to create movement graphs while moving, and to observe these graphs outdoors, where they have been generated, using a combination of innovative technologies and concepts: mobile phones with location awareness and relatively large screens as well as an embodied type of interaction. All these innovations are central in supporting the learning activity. Without location awareness it would not be possible to create real time graphs and without embodied interaction graph generation usually requires students to make use of advanced computing or programming skills (Simpson, Hoyles & Noss, 2006). This could divert their attention from the main learning task.

Students were involved in low fidelity prototype evaluation, however these were students already with a basic knowledge of movement graphs who could discuss the application in the context of this knowledge and focus on any confusions arising from the interface (rather than from the concepts). Given that they already knew about the principles of movement graphs, they could be considered as proxy learners; although interaction with the application would be a way to consolidate their knowledge and highlight misconceptions in its application. In terms of Druin's (2002) classification, students in this case could be considered as falling into a type between testers and informants. They were involved relatively early in the design process and voiced their opinions about low fidelity prototypes, however their participation in those cases was limited to evaluating the user interface and they did not participate in generating or refining the conceptual model. Other stakeholders, teachers and educational technology researchers, were involved at early stages of the design to support the generation of a suitable conceptual model and the refinement and validation of the initial paper prototypes.

A related issue is the fact that the design went from paper prototypes to high fidelity prototypes implementing most of the functionality. Frequently this transition is smoother but in this case there was not much point in generating prototypes that would only simulate location awareness or would not run on a handheld device given that the complexity involved in implementing them would have been similar as that of generating the high fidelity prototype.

Other important issues stemming from the study are the suitability of GPS technology to produce real time graphs, the appeal and motivation of the learning tasks, and the preliminary conclusions that can be drawn regarding the educational potential of the application.

The Move Grapher application graphs distance or speed against time with a good GPS signal, and accuracy is sufficient to display movement and walking pace meaningfully. However, the limitations due to the technology are significant: firstly the delay between a movement being made and the production of the graph is approximately of five seconds, so that the graph being viewed is not presented in real time. While this is still reasonably fast (compared to the 20 second delay discussed by Beichner, 1990), users found the delay in the first version of the high fidelity prototype confusing. It has been possible to find a suitable workaround to help users predict where the graph will be drawn, and users in the subsequent test responded positively to this. However true real-time graphing would eliminate this issue entirely. Secondly, the inaccuracies are still such that it has been necessary to use a moving average to "smooth" the results that are displayed, introducing a "softening" of sudden movements, so that graphs may not accurately reflect user expectation causing confusion for the learner who may attribute an unexpected result their own misconceptions when in fact the graph should have confirmed their understanding. The nature of the application makes it difficult to write an algorithm to filter or extrapolate from the results using intelligent guesswork and prediction, since if it is used as intended there should be no "typical" movement to base any such algorithm upon.

Collaboration and competition are key aspects of the application. Simply creating a graph from movements is a useful exercise but of limited appeal. The facilities to share graphs to other users, to try to match graphs or to predict how graphs will look are all essential to the learning process: the user is engaged in interpreting movement as a graph or visa versa. The scoring of closeness introduces a game element that can motivate an individual (trying to improve on previous scores) or groups (trying to get the highest score, trying to create a graph that will be difficult to match). Further ideas for introducing game elements, like those developed at the early stages of the design process, may increase the intrinsic appeal of the application. For example the notion of levels could stage progression to support the development of the learner's skills and designing them would be an opportunity for learners to exercise their own creativity. The process of constructing a level rather than a graph would stretch the user to develop their abstract conceptual understanding even further.

The evaluation of high fidelity prototypes included an element which could be considered as a preliminary educational evaluation. This evaluation has shown that the application can be effective in drawing users' attention to their misconceptions where an understanding of kinematics is already developed. However, it may be that for users trying to develop this understanding persisting confusion acted as a barrier to engagement. By providing a more accessible primary goal ("winning" a level) while reinforcing the underlying concepts as a secondary effect, a more game-like virtual environment might engage beginners for longer and so support conceptual development more effectively. However these conclusions have to be considered as preliminary given the small numbers of participants involved in that part of the evaluation, and as hypotheses they will be tested in the full scale educational evaluation that has yet to be carried out.

Conclusion

The paper has described the design of Move Grapher, an application that employs innovative functionality of modern mobile phones such as location awareness and relatively large screens and that aims to support the learning of movement graphs for pre-university students. The development of the application followed a Learner Centred Design process; stakeholders were involved at every stage of the process and the design was refined trough iterative prototyping. The final version produced met the initial requirements: it enables both teachers and students to create graphs by moving, to send those graphs to other users and allows students to match a graph displayed on screen by recreating the movement described. Users have a high degree of control in generating, sending and receiving graphs of their movements. The application has a good usability and a preliminary learning evaluation suggests that the tool has plenty of scope in reinforcing the learning of movement graphs and addressing students' misconceptions in this area. Learner Centred Design proved very useful when designing learning applications for which innovative concepts and technologies play a crucial role. In this design approach iterative prototyping is encouraged and frequently medium-fidelity prototypes that simulate some part of the functionality are created. However in this case it was found that the complexity of implementing this type of prototype would be similar to that of the high fidelity prototype and therefore a high fidelity version was directly implemented. Two important drawbacks from the particular location aware technology used are a five second delay between the movement being made and the graph being generated and an insufficient accuracy to produce a smooth graph. The application addresses these limitations by using a workaround (asking students to predict the shape of the graph) and by "softening" very sudden changes in the reported position.

Although the technologies employed and in particular the developed prototype have shown strong potential to support the learning of kinematic graphs, the reported study represents an initial step in our research agenda. Move Grapher needs to be evaluated to investigate its educational merits. The evaluation should take place within the context of kinematics pre-university courses that employ the tool as a learning resource, involving using the tool collaboratively in group work and ideally investigating its effectiveness for students with different levels of kinematics knowledge. Further work should also include the implementation of game-like elements in the application to increase its appeal.

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