Alternatives in evaluating multimedia in secondary school science teaching

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Abstract

While different approaches to evaluation will yield different results, depending on the purpose of the evaluation this article describes an evaluation approach that was aimed at investigation the mental models of users of the programme. The study was driven by questions about the differences in mental models of the instructional designers and the learners, the time learners spent working through the program and the observable changes in their mental models. In this design experiment, a program was developed to teach basic principles of electricity. Three boys and three girls one each of high, medium and low achievement in science were selected from an advantaged urban school, and a similar sample was taken from a disadvantaged rural school. They were asked to draw their impressions of various concepts of electricity and then allowed free access to the program, where they could visit any section even if they had not completed a previous one. Afterwards they were asked to draw sketches again. Other instruments included an opinion questionnaire and observation of the learners working with a ‘‘think aloud’’ protocol. It was found that there were considerable differences in the mental models of the learners and designers about what to expect from computer-based learning. While navigational freedom allowed fast learners to move through work that they knew already, weaker learners tended to get lost. The sketches that learners made before and after exposure to the program provided valuable insights into the growth of their understanding of the concepts.

Keywords: Mental models; Computer-mediated learning; Evaluation; Media in education; Navigation

1. Introduction

This article reflects upon the formative evaluation of a multimedia science program teaching basic principles of electricity. We focus on the extent to which the learners’ view of the program corresponded with that of the designers, we consider the time spent, and the navigation through the program; and finally learners’ acquisition of certain learning concepts. This was a small, qualitative study with a purposive sample of strong, average and weak learners from affluent and disadvantaged schools. We do not aim at transferable results, but present our findings here in the hope that they may resonate with the experiences of others. In a sense our research augments an earlier article in this journal that concentrates on the support that teachers can give learners in a multimedia-rich environment (Hennessy et al., 2007).

The principal motivation for this study comes from Greca and Moreira (2000, p. 8) who call for better understanding of mental models both for teachers and researchers, because “We, so far, know neither how to identify what kinds of mental models the learners have in a given domain, nor what specific mental models they construct. For researchers, the main difficulty here seems to be a methodological one: how to seize these incomplete, unstable, and personal representations?”n this article, we describe a design experiment in which we developed a multimedia program and investigated how users responded to it. We present our findings as they answer our three research questions, and offer a number of conclusions and recommendations.

2. The problem

The problem underlying this research was to find a simple, multi-faceted way to understand how learners make sense of multimedia learning programs, because “(W)hen interactive multimedia programs are designed intentionally to support learning, some level of pedagogy is required” (Reeves, 1993, p. 81). We were specifically interested in an evaluation from a learner-perspective, since evaluation of educational software is strongly dependent on the perspective of the evaluator. A teacher would look for different qualities than would a leaner, or a school administrator. Even ratings from software review services are not valid indicators of the educational value of software. Since software is judged subjectively, as is the case with many software evaluation services, one cannot assume learners will or will not learn from it ([Borton and Rossett, 1989], [Burger, 1991], [Jolicoeur and Berger, 1988], [Owston and Dudley-Marling, 1988], [Preece and Jones, 1985] and [Zahner et al., 1992]).

There is still a strong emphasis on large-scale comparative research studies investigating the effectiveness of computer based approaches to other approaches to teaching ([Janniro, 1993] and [Lanza and Roselli, 1991]). Many of these findings have revealed no significant differences ([Clark, 1991], [Clark, 1994] and [Russell, 1999]). Reeves (1992) describes numerous theoretical and methodological flaws in existing media replication studies, and suggests implementing a multi-faceted approach to research that includes the conduct of intensive case studies and the application of mental modelling. Investigations of interactive multimedia should include both observational and regression methods. Our approach, therefore, was to use a variety of simple methods, using a small sample. We wanted to see what our learners were conceptualising, rather than to see if the program was successful.

Mental model research is based on the assumption that knowledge of how users represent systems and how users should represent systems will lead to a better understanding of usable systems (Ackermann & Tauber, 1990). Jih and Reeves (1992) state that: “Since our understanding of human perception does play a crucial role in the design of interfaces, research on mental models is a promising approach to analysing human–computer interaction and improving interface designs” (Jih & Reeves, 1992, p. 44). Johnson et al. (2006, p. 177) argue that “researchers can only learn of conceptual systems if individuals communicate their systems”. They suggest mental model research as a useful way for “the comparison of a group or an individual with themselves over time”. Coll and Treagust (2001) found that learners prefer simple mental models, while Duit and Treagust (2003) argue that learners’ understanding of concepts can affect the teaching of science.

3. Aim and objectives

The aim of the research was to consider how diverse individual learners respond to an interactive multimedia program developed to teach basic principles of electricity to adolescents. A characteristic peculiar to this multimedia program was that users were free to browse through any part of the program regardless of their previous knowledge. We were interested in the extent to which a linear progression through learning material was essential, and we also wanted to know what would happen if fast, average and slow learners were allowed to work entirely at their own pace. We also wanted to know the extent to which learners’ previous experience with computers influenced their learning from it. The focus of this article, therefore, lies not on the success or otherwise of the program we developed, but rather on what we learnt through a multi-faceted formative evaluation. Three main questions drove this study:

1. How did learners’ mental models of educational multimedia programs differ from those of the designers?

2. What could we learn from learners’ navigation through the program?

3. What visible growth could we see in terms of learners’ mental models of the subject matter?

4. Literature survey

This literature survey will begin with a discussion of an integrative approach to science teaching. Then we shall briefly discuss mental models, their role in the design of interactive learning systems, their relationship to prior knowledge, and conditions for their use in research.

4.1. Two approaches to teaching science

Science is traditionally taught in the classroom and in the laboratory. Over time what happens in the classroom has become known as instructivist, objectivist or supplantive direct instruction, while what happens in the laboratory has become known as constructivist, problem-based or generative learning (Smith & Ragan, 1999). Over time these two approaches have come to be regarded as opposing *paradigms* of teaching and learning. We feel, however, that these two approaches are not on opposite ends of a spectrum and that both styles should be accommodated. In this respect, Cronjé (2006) has proposed that objectivism and constructivism should be placed at right angles, resulting in a four-quadrant matrix, as shown in Fig. 1 (at end of article).

What happens in the classroom can be placed in the *injection* quadrant. It is the domain of the carefully planned lesson where the aim is to impart as much "clean" knowledge as efficiently as possible. What happens in the laboratory can be placed in the *construction* quadrant, where learners perform experiments, solve problems, and thus construct their own understanding. The *immersion* quadrant describes serendipitous learning – knowledge that is acquired without deliberate teaching or by carefully constructed laboratory problems. Finally the *integration* quadrant is where an instructional designer, or teacher, would select which aspects to teach via direct instruction, and which aspects the learner will discover.

The computer, of course, can function in all these quadrants. Tutorial programs, as well as drill and practice routines fall in the *injection* quadrant. Simulations and construction programmes such as virtual laboratories (*Interactive physics*, *Geometer's sketchpad*, *Chemlab*) fall in the *construction* quadrant, and open Internet searches belong to the *immersion* quadrant. The program that was developed and tested in our research contained tutorial sections and self-tests (*injection*) and simulated experiments and demonstrations (*construction*), while it allowed learners to work through any section at any time, without prescribing a sequence (*immersion*). It is hoped that the results of the research will indicate aspects to consider when one designs a deliberate path, or set of paths, through the program (*integration*).

4.2. What are mental models?

The term "mental model" was first coined by Craik (1943) who argued that the mind creates "small scale models" of reality in order to understand it. Johnson-Laird (1983) points out that mental models are generated through perception, imagination or comprehension. He warns that, although mental models represent explicitly what is true, they do not represent what is false – thus incorrect mental models can easily be formed. According to de Kleer and Brown (1985) the existence of many theories of mental models suggest the potential effectiveness of qualitative models in teaching learners about scientific systems.

Mental models can be either verbal and propositional or visual and spatial (Rouse & Morris, 1985). Mental models are frequently pictorial or image-like rather than symbolic and representational. Malamed (1991) suggests that animations, for instance, could make abstract contents tangible, resulting in the formation of a mental model. Mental models affect such factors as the effort we devote to tasks, our persistence, our expectation and prediction of results, and our levels of satisfaction after task execution (Jih & Reeves, 1992). Mental models are the source of users' expectations about the effects of their actions. Therefore, it can guide navigation or planning of actions, and contribute to the interpretation of feedback (Van der Veer, 1989).

4.3. Mental models and the design of interactive learning systems

In the field of computers and usability Donald Norman (1983) points out that the awareness and management of our mental models can provide us with some control over our experience and proficiency in specific tasks. The model can be analogical, incomplete, and sometimes very fragmentary with respect to its representation of how an integrated system functions. Users change their mental models while constructing them through the interaction with the system. Norman stresses the importance of ensuring correspondence between the mental models of designers and users of the same system.

A threat to the development of corresponding mental models lie in the way in which we form those models. Ball, Phillips, Wade, and Quayle (2006) show how mental models are often formed based on the believability of the model, rather than upon scientific processes such as a search for falsification. Thus, mental models suffer from the fact that they are often based on unfounded assumptions. These findings resonate with Hannafin & Oliver's findings that students tended to develop only partial mental models. They suggest that student understanding could be improved by the explication of student hypotheses, as well as "the continual testing of belief via analogical reasoning, research, communication and tool use" (2001, p.5).

4.4. Mental models and prior knowledge

Waern (1990) suggests that there are two approaches to constructing mental models depending upon whether or not learners have prior knowledge about the system. The *bottom-up* approach is used by learners who react to incoming fragments of information, interact with the system and gradually build a more consistent and complete mental model from the ground upward.

In the *top-down* approach, learners fall back on existing knowledge, modify it and reconstruct it into a new mental model according to the information they receive while interacting with the system. Most users use the *top-down* approach to construct their mental models, but new learners tend to use the *bottom-up* approach. (Mayer, 1989) and (Mayer and Moreno, 2003) argue that users systematically develop a mental model for any task in which they engage. In our research, we were interested to see the extent to which the prior knowledge of learners (and therefore the high correlation of their existing mental models with those of the learning program) would influence their movement through the program.

Moving on to the field of computers and education, mental models form a point of departure for Merrill, Li, and Jones (1990) Second-Generation Instructional Design Theory (ID2). They assume that learning results in the organising of memory into structures, termed mental models. Mental models are constructed by experiences and modified as a result of every new experience. Therefore, a student needs a variety of experiences to construct an adequate mental model (Merrill et al., 1990). Merrill (2005) continues by arguing that a complex mental model enables the learner to engage in complex human enterprise or integrated activity. Mental modelling can be used to assess the amount of learning that takes place using a multimedia tutorial (Sasse, 1991).

Norman (1983) makes a clear distinction between a system, the conceptual model of the system, and the mental model of the system:

1. Target system – the actual thing, in this case, the computer system.

2. Conceptual model – a correct description of the target system, as far as the human-machine interface is concerned, developed by the teacher and/or designer.

3. Mental model – the knowledge structure the user applies in his interaction with the computer.

The existence and value of mental models lie in the fact that the quality of interaction within integrated learning systems depends upon the functionality of the learners' mental models of the systems. When learners possess an adequate mental model of the structure and functions of hypertext or other complex integrated learning systems, they are less likely to become disoriented and they are more likely to learn (Jih & Reeves, 1992).

Gentner and Stevens (1983) argue that because a mental model evolves in the mind of a user as he or she learns and interacts with a computer system, the mental model will represent the structure and internal relationships of that system.

An ideal working mental model is one that is consistent with the conceptual model of the system developed by designers. Strong or accurate mental models show a functional or spatial similarity to the system or to the image the system presents to the users (Norman, 1983). Weak, inaccurate mental models lack key components or features of the actual system. Fisher (1991) did a qualitative study on users' usage patterns of a complex system and revealed that their mental models contained concepts that did not exist in the system, and further, that there were subsets of the system of which users were unaware.

4.5. Conditions to be met for mental modelling as a research strategy

Although Lucas and Ball (2005) suggest that heuristic-analytical models may in some cases better explain users' actions than mental models, Bucciarelli (2007) argues that introducing and constructing mental models is useful in the learning process.

Carley and Palmquist (1992) present a useful approach towards extracting, representing and analyzing mental models. Mind mapping is generally advocated as a way to uncover the mental models of learners (Mavers, Somekh, & Restorick, 2002). Nevertheless, mind-mapping is a highly complex skill and various complex techniques of analysis may be required (Johnson et al., 2006). Bauer and Johnson-Laird (1993) present a useful solution when they advocate the use of diagrams in support of mental modelling. Similarly Carney and Levin (2002) argue strongly in favour of the use of pictures to augment text in learning, while Ferguson and Forbus (2002) advocate sketching as a useful device for communicating knowledge about science.

In following a multi-faceted approach it would then make sense to use diagrams rather than mind maps to elicit mental models, and to use these in conjunction with a number of other methods. In a computer-based environment user tracking is a very useful and easy way of finding out about the interaction of learners with software (Alexander & Hedberg, 1994). However, the tracks reveal little other than time spent on a particular section of a program. Other techniques such as observation, questionnaires and interviews still remain useful.

The following conditions should be met when determining users' mental models. Learners should be involved in purposeful learning, driven by either intrinsic or extrinsic motivation. The learners should spend ample time interacting with the software, and the population of the learners should be diverse. Individual differences among learners with respect to aptitude, knowledge, skill, attitudes, personality, characteristics, previous experience, motivation, etc. should be accounted for ([Alessi and Trollip, 2001] and [Reeves, 1993]).

5. The research

Application of the conditions mentioned in the previous section implied that we had to select a target group out of a diverse population with respect to previous experience, skill, academic achievement, and social conditions. The target group consisted of learners who had a need for training in electrical principles. The learners were allowed to interact with the program for a maximum of 90 min.

Following suggestions from the literature we decided not to settle for one particular method to measure mental models, but used several methods in gathering the required data on systems models and content models ([Jih, 1991], [Kyllonen and Shute, 1989] and [Sasse, 1991]).

In our research diagrams, observations, questionnaires and electronic tracking programs were used to harvest and describe the mental models formed by users while working through an interactive multimedia program. Once these models had been identified, they were used to determine the users' response to the developed program.

5.1. Methods and procedures

The following procedures were followed in this study:

1. A theoretical model of learning via interactive multimedia, including input, context, process and outcome dimensions was developed and adopted.

2. An interactive multimedia program, *Introduction to Basic Electricity*, designed to teach electrical principles to adolescents, was developed using Authorware Professional as an authoring tool. The program was a blend of tutorial materials, supported by simulations of various experiments regarding static electricity, electric cells, and circuits. Fig. 2 (at end of article) presents an outline of the hypermedia program structure.

3. The learners were allowed to interact with the developed interactive multimedia program for a maximum of 90 min. Previous formative evaluation had shown that 60 min was more than sufficient for most participants. The approach followed was that of "analyse, explore, plan, implement, verify" as suggested by Pol, Harskamp, and Suhre (2005, p. 452). For each problem learners were first required to read and analyse problems related to basic principles of electricity. Then they had to activate that knowledge (explore), before making a plan, implementing the plan and verifying if their answers were correct. An electronic tracking program was built into the developed interactive multimedia program to trace the learners' paths through the program as well as their responses to queries. Fig. 3, Fig. 4, Fig. 5, Fig. 6 and Fig. 7 (at end of article) show screens where users analyse, explore, plan, implement and verify.

4. While the users worked with the interactive multimedia program, the development of their mental models were assessed through careful observation of their reactions.

5. On-line tests and interviews were used to assess that learning did take place.

6. Questionnaires were used to assess the demographic variables sex, age, education and previous experience with computers;

7. A questionnaire was used to address the affective domain of the user.

8. The mental models of the users were analysed in order to establish the dynamic between the user needs, and the program attributes.

9. Possible research questions on the design and use of interactive multimedia for future research were identified.

5.2. Identification of target group

We selected a target group that consisted of individuals from different socio-economic backgrounds. A leading resource and technology-advantaged secondary school in Pretoria, South Africa, and a rural disadvantaged secondary school about 2 h North of Pretoria were approached to take part in the study. Each school was asked to identify three female and three male learners in grade 10. They had to range in scholastic achievement in physical science from academically strong, academically medium and academically low achievement groups. The six learners per school were selected using the following procedure. Female and male learners in grade 10 were separately ranked according to their academic achievement. Both ranking lists were then divided into three groups of the same size (bottom third, middle third, and high third); and the male and female learner closest to the middle of each subgroup was selected as the experimental group. The sampling is tabulated later.

Grade 10 learners from the two schools were invited to attend extra classes in physical science. During these extra classes, learners worked through the developed interactive multimedia program.

5.3. Demographic variables

Most of the demographic information, such as gender and cultural background, was established through the selection procedure of the test group, while other demographic variables were obtained via the pre-program questionnaire.

5.3.1. Differences in academic ability

Following the suggestions of Alessi and Trollip (2001), we selected a test group of learners who were much like those for whom the program was designed. Although they recommend that three participants take part in a pilot test we decided to use a pilot group of 12 learners to allow for maximum symmetric diversity.

Of the six learners selected per school, two learners (one male and one female) represented the best of the potential learners; two learners (one male and one female learner) represented the average learners, while two learners (one male and one female) represented the slowest of the learners that would use the lesson.

Table 1 (at end of article) shows the composition of the group in terms of academic ability.

5.3.2. Socio-economic background

Six learners came from a technology-enabled school. This school is situated in an affluent community, where academics and professionals reside. The other six learners came from a rural, disadvantaged school. This school caters for the needs of resource-deprived learners who are from a poor community where many residents are unemployed.

Table 2 (at end of article) shows the computer experience of the test group.

The learners from the disadvantaged school had previously been exposed to five sessions on a stand-alone computer-based instruction system installed on very old computers at their school. They had no prior mouse experience. The researcher therefore had to teach them how to use a mouse. Each learner was allowed to practice for 10 min, in which time they had to arrange 20 icons alphabetically by clicking and dragging.

All the learners from the technology-advantaged school had extensive computer experience. Three of the learners had previously used a computer to play games, while three learners were taking computer studies as an additional subject at school. They were familiar with the use of a mouse.

5.4. Description of research instruments

A variety of methods were used to obtain insight into learners' mental models, and their reaction to the program.

5.4.1. Observation of users using the system

Observation was selected as one of the methods for data acquisition because it gave us the opportunity to obtain firsthand information concerning the problems experienced with the execution and learning from the program.

Observation allows the researcher to collect a variety of information that provides depth to the analysis. The observer can view a situation firsthand as it develops. Recording of the observation takes place immediately, thus reducing the possibility of biased recall. According to Mouton and Marais (1990), observation should be considered when investigating the activities or behaviour of people; and when needing to corroborate opinions about a particular intervention.

Observed events could be subject to the subjectivity and bias of the observer. The observations were recorded on video because events happened so quickly that it became impossible to record every detail. Users of the system were observed while a video camera captured their reactions. Photographs were taken of users working on the system. Users were asked to explain the system using a teach-back “show me how to” procedure. They were also asked to provide reasons for specific program responses. The observations and responses from the users were duly recorded.

5.4.2. Sketches

Users were asked to sketch the concept “electricity” and the concept “atom” before they started to work with the program. After working with the program for 90 min, they were asked to sketch both concepts again.

5.4.3. Performance tests

A performance test was integrated into the program. Because the amount of user control was one of the questions the researcher tried to answer, maximum user control was allowed. Learners had the option either to do the test or to skip it.

5.4.4. Navigational pathways

A navigational pathway tracker was built into the program. This tracker sequentially recorded the path taken by the user, and the time spent at an interaction.

5.4.5. Questionnaires

Learners were briefed about the aim of the study. Then pre-program questionnaires were distributed for them to complete before they started working with the program. After completion of the program, then they were asked to complete the post-program questionnaire (See Appendix A and Appendix B). The main aim of the questionnaires was to obtain the learners’ opinions about certain design features of the program, as well as to assess a possible change in the mental models they may have formed.

Both the pre-program and the post-program questionnaires can be grouped into the following 5 sections: *Interaction, Interface, Involvement, Motivation*, and *Rate*.

A nine point checklist format was used to assess sections 1 to 5. The reason for using a nine point checklist was that the researcher wanted to allow for a neutral or a “not sure” response to highlight users’ uncertainties. In reporting the data, a response of 1, 2 or 3 was taken as “disagree”, a response of 4, 5 or 6 was taken as “not sure”, while a response of 7, 8 or 9 was reported as “agree”.

5.4.6. Exclusion of other methods to obtain mental models

We could also have asked the learners to draw mind maps or concept diagrams of the system, and we could have used heuristic if/then/else statements, as well as a number of other methods of harvesting mental models. Practical considerations, and data saturation, led to the exclusion of these alternatives.

6. Discussion of results

The ultimate aim of this research was to use the mental models developed by the users to refine and improve the program *Introduction to Basic Electricity*. The precise goal of the research reported here was to determine what we could learn from obtaining some insight into the mental models of the learners so that we can better decide upon the integration of generative and supplantive elements of a multimedia program. We chose to consider the research questions from various qualitative perspectives rather than to obtain and quantify the data. This was an exploratory study with a very small sample, and we make no claim to the transferability of our results.

The study set out to determine learner views on the program, compared with those of the designers; learner use of the system – time spent, and navigation through the program; and learners' acquisition of certain learning concepts. The questions driving this study will be used as headings in discussing the findings.

6.1. How did learners' mental models of educational multimedia programs differ from those of the designers?

6.1.1. Interaction

In the pre-program questionnaire learner mth indicated that he thought that computer based programs were boring. In the post-program questionnaire, learners mtl and mtm joined the views of learner mth and indicated that the feedback was boring. During interviews, they indicated that they would like to see more of a "bells and whistles" type of feedback. Learner mth also wanted audio/video feedback.

The wording: *I felt as if someone was engaged in conversation with me* on the post-program questionnaire was not understood by everyone. All the learners from the disadvantaged school indicated that they disagreed with the statement. When they were asked why they disagreed with the statement, they responded that they "heard nothing".

Two of the three male learners from the technology-advantaged school also indicated that they disagreed with the statement: *I was encouraged by the responses given to my answers of questions*, while one of them was unsure. Learners mtl, ftl, mdl and fdm indicated that they did not understand all the questions, although they were given answers.

If only the specific opinions of the test group outlined above are taken into account, without considering the rest of the data, one might be inclined to deduce that this program could be too easy for the high achiever, and at the same time too difficult to be of any use to the low achiever. As will be pointed out in later paragraphs, other data might indicate differently.

6.1.2. Interface

Except for learner mth, who expected video, sound and animation, all the learners responded positively on the interface and interface design.

In the pre-programme questionnaire, learners mdl and fdh indicated that computers usually frustrated them. In the post-programme questionnaire, these learners indicated that the program as such did not frustrate them.

Although 50% of the learners indicated that they were organised learners, they liked the freedom provided by the program to jump from one topic directly to another topic. These learners' mental models on learner control and navigation could be that maximum learner control will ensure maximum learning.

In the post-program questionnaire all, except learner mth, indicated that they loved the colours used in the program. Six learners indicated in the pre-program questionnaire that a red and orange screen would look nice. During the interview, learner mth indicated that he preferred brighter colours to the autumn colours used in the program. Although he did not like the animations in the program, he acknowledged that the animations in the program had simplified the content.

Two learners (fdl and mdl) indicated that, at times, they felt completely lost. In the pre-program questionnaire, these learners also indicated that they gave up easily if they did not succeed with something.

Table 3 (at end of article) shows that seven of the twelve learners had problems using the mouse in a drag-and-drop interaction. Two of the seven learners who had problems indicated that they had had ample computer experience.

The two learners from the technology-advantaged school who experienced mouse problems indicated that they had previously used the mouse to play games. When the researcher asked them about this, they said that they were used to pointing-and-clicking, but that they had seldom used the mouse for clicking-and-dragging. They had never used the computer as an electronic tool to simplify daily tasks, such as using the computer as a word-processor or calculation aid.

It is obvious that the mental models that they had about the computer system were limited to that of a machine allowing them to play games. Although they were aware that a computer is much more than a gaming machine, this knowledge had not been transferred to that of a working model allowing them to use the computer as a tool.

Five of the twelve learners had problems remembering the passwords they had selected. When the program asked them for a password, they just typed a keyboard sequence and when it asked them to retype the password, they were unable to retype it.

It is clear from the observations illustrated in Table 4 that most of the learners who had limited computer experience, experienced password problems. The reason for this could be that these users lacked the necessary keyboard experience to enable them to type faultlessly. The mental model that the researcher had of the user of the system was that all users will be able to type without any typing error. The password log on procedure could thus present a problem to users and should be redesigned.

6.1.3. Involvement

After working with the program, more learners favoured the computer based instruction. Learner mth was the only learner whose neutral views on computer-based instruction remained unchanged.

Learner mth indicated in the pre-program questionnaire that he agreed that the lessons in class were mostly dull. In the post-program questionnaire, he indicated that the multimedia lessons were difficult to follow and that they were dull. During the interview, he admitted that the lessons were not difficult to follow, but they were dull in that he had expected more of an action-type of feedback.

6.1.4. Motivation

All the learners acknowledged that working through the program was a stimulating and motivating experience, although learners mth and fth indicated that the program did not challenge them to do their best. In the pre-questionnaire, both learners indicated that even the teachers did not always challenge them to do their best. Learner mth also indicated that the program did not really keep him involved.

In the pre-program questionnaire, six learners had indicated that they would not really like to learn more about atoms and electricity. After working with the program, these two learners showed more interest in this topic.

In the pre-program questionnaire, learner mth indicated that he thought that a computer program will not make the normal classwork easier. After working through the program, his views on the usefulness of the computer in a classroom changed completely.

In the pre-program questionnaire, four learners indicated that to them, extra classes were a waste of time. None of these learners thought that working through the program was a waste of time, although learner mth was relatively neutral on this aspect.

If one compares the pre-program and post-program responses, one can see that most of the learners were positively motivated through the use of the program.

6.1.5. Rate

All the learners of the technology-advantaged school indicated that they were pressed for time while working with the program. This is true, because they had a limited time available to work with the program. All the learners indicated that despite the limited time available, they felt that they could work at their own pace.

For learners mth, fth and mdl the course material was presented too slowly, although learner mdl also indicated that the program ran too quickly.

6.1.6. Summary of mental models of designers and users

The various instruments allowed us to derive an understanding of how the users viewed the program. Comparing their view to the initial design specifications we were able to determine the differences and similarities between the mental models of the researcher/designer and the users as shown in Table 5 (at end of article)

Table 5 shows that there was a reasonably high level of correlation between the mental models of the designers and the users in terms of the didactic usefulness of graphics and animation, a preference for this program over classroom instruction about the same topic, and the possibilities of learners working at their own pace. In one instance, the effect of maximum learner control, the learners were sure that learner control would ensure maximum learning, while the designers thought that it might. Of course it turns out that maximum learner control was not useful for all learners. The strongest disagreement between the mental models of designers and users came with the use of the help facility. Here it was clear that users did not even expect there to be a help facility, while the designers expected all learners to use it. It is our opinion that here we, the designers, were probably naïve in our expectations.

6.2. What could we learn from learners' navigation through the program?

The following observations were made while the learners were working on the system:

6.2.1. Using help

Although a full on-line hypertext help facility was available, it was only accessed by one learner. This specific learner accessed help at the end of the session, after she had already worked through the whole program. When asked why she chose the help-facility, she answered “I am just curious what the program can do”.

The results illustrated in Table 6 (at end of article) might indicate that the users' mental models of the system did not include the tools available to assist them when working with the system. The focus of the users could have been so task-oriented that they did not see the help-facility as being part of the system.

6.2.2. Time spent with the program

No indication of maximum time allowed or any other indication concerning time was given to the learners, although the researcher has decided beforehand to allow a maximum of 90 min per learner. The learners were not briefed on how long the program would take, in order to allow them to proceed at their own pace.

Unfortunately, the group from the technology-advantaged school indicated that they had limited time to help evaluate the program. Therefore, they spent less time working on the program than the group from the disadvantaged school, although more content was covered by the first group than the second group.

Fig. 8 (at end of article) graphically represents the time taken by the learners working with the program.

6.2.3. Navigation

6.2.3.1. Navigation through the program

The built-in user tracking option of *Authorware* was used to determine which sections (or levels) of the program were accessed and when. Some learners followed a linear progression through the program, visiting each section, and doing so in numerical order. Others accessed sections seemingly at random. Although they accessed almost all the sections they missed important information, while other learners worked slowly and systematically, but sequentially completing only about 50 per cent of the program.

Fig. 9 (at end of article) represents the number of sections visited by the learners while using the program. "Deepness" refers simply to the number of sections visited, and how far into the section the learner went.

6.2.3.2. Navigational pathways

Although all the candidates were allowed to interact with the program for a maximum of 90 min, many candidates indicated that they had worked through the program using less time.

Examples of the navigational pathways through the program for some learners are presented visually and discussed in Fig. 10, Fig. 11 and Fig. 12 (at end of article). The vertical axis denotes the level reached inside the program and is calibrated in terms of interactions. The horizontal axis shows time. The dotted

diagonal line represents the hypothetical track of a learner taking a linear path through the program and completing it exactly on time in one hour.
The navigational record of learner mth seems to confirm Waern (1990) view in that experienced users first try a *top-down* approach. Fig. 10 (at end of article) shows that he started the *Introduction to Static Electricity* module, but two interactions before the end of the module, he jumped to *Electric Fields* and completed all the sections. He then jumped back to *Coulomb's Law* and completed the first section. He jumped to *Electrical Fields* and completed all the sections of this module. In the interview, he mentioned that he jumped to this section because they had not yet done this topic in class. This was also the reason why he skipped *Atoms*, because he thought that he knew enough of the topic.

Fig. 11 (ate end of article) shows that learner mtl spent 12 min working on the first module *Introduction*. He jumped back to the menu and once again worked through the first module. He jumped to module *Atoms* and did the test. Although the program advised him to revise the first section again, he ignored the advice, skipped the next section of the module *Atoms* and completed the last section of this module. After starting off linearly, the learner used the *top-down* approach (Waern, 1990) for the rest of the program. It would seem that allowing free access to low achievers is not a good idea. This is confirmed by the tracks of the other low achievers, such as learner fdl. From some of their graphs one could deduce that they got lost completely in the program and spent most of their time returning to the menu and then trying another section.

Fig. 12 (at end of article) shows that learner fdl jumped to the second module, *Atoms*, after working through the first 2 interactions of the first module. She decided not to take the on-line test, and jumped to the second section where she spent about 30 min working on it. After completing section 3, she returned to section 2 of the same module, and, after working through the first 3 interactions, started to jump randomly to different sections in the program.

After completing the module on atoms, learner fdl jumped back to the menu, and then she started to jump, apparently randomly, to different sections in the program. The facilitator offered some help, and she told him that she was once again trying to find the Atoms and electricity module. It appears as if she got "lost in hyperspace" for a short time. These unintentional jumps might possibly be ascribed to limited computer experience.

In considering the navigational paths of the high and low achievers it would seem that low achievers do not benefit from free access – they get lost. High achievers, on the other hand, benefit from free access as it allows them to save time by skipping sections that they already know. It might be useful to develop an intelligent tracking system that would grant linear access to low achievers and random access to high achievers – based on their results as they work through the program.

6.3. What visible growth could we see in terms of learners' mental models of the subject matter?

In an attempt to measure learners' growth in understanding of various concepts we asked them to draw sketches of such concepts as "electricity" and "atom". We discuss here the growth we saw in the learners' understanding of the concept "atom". Similar results were found with the concept "electricity" and it would be repetitive to relate these here.

To be able to categorise the mental model of the concept "atom", we considered the historical development of the model of an atom and the mental models that scientists have formed of the atom over the years (Table 7 at end of article).

In our research participants were asked to sketch the concept "atom" both before and after using the program. The results are summarised in Table 8 (at end of article).

Table 9 (at end of article) shows a classification of the results from table 8 using the categories of table 7 as a basis, while Table 10 (at end of article) graphically illustrates the changes in the concepts that took place.

It is clear from the data illustrated in table 9, and table 10 that, except for learners fdl and ftm, the pre-program mental model that users had of the atom had changed for all the learners after working with the program.

If one assumes that the mental models which scientists held of the atom had cognitively reached higher levels through history, it can also be assumed that the mental models that the learners had of the atom had cognitively reached higher levels through the interaction with the program. The program, of course, presented the learning material in a linear fashion, moving from Dalton's model to that of Schrödinger. Learners who did not spend enough time going through the last section, did not shift their mental models far enough.

Putting together what was learnt from the navigational pathways and the sketches, it becomes clear that the program was good for the faster learners, but had limited value for the slow ones. Once again this would indicate that a more traditional approach would be better for low achievers.

7. Conclusions and recommendations

Three questions were asked in this study: How did learners' mental models of educational multimedia programs differ from those of the designers? What could we learn from learners' time spent with the program and their navigation through it? What visible growth could we see in terms of learners' mental models of the subject matter? We now present the conclusions and recommendations in the same sequence.

7.1. Alignment of mental models of designers and users

As has been shown, the user's ideal working mental model of a program is one that is consistent with the conceptual model of the program developed by the designer. A user's accurate mental model shows a model functional to the program. Weak or inaccurate mental models lack key components or features of the actual program.

In order to evaluate the program, using the mental models users had of it, one should determine if users had certain mental models that contained concepts that did not exist in the program, and further, if there were subsets of the program of which users were unaware. Once these mental models were determined and described, suggestions for program improvement could be made.

One of the aims of this research was to use the mental models developed by the users to refine and improve the program. Although some of the recommendations below were initially peculiar to our program, we believe that they may be generalised to open-ended learning environments generally.

Mental models need to be adjusted from both sides. Our analysis of the difference of mental models of learners and designers showed, for instance, that learners do not believe that the help function exists as an integral part of the programme, while designers take it for granted that learners would use the help. In this case, designers need to take note that there are two types of help, system help and learning material help, while they also need to realise that learners may have to be taught and even prompted to access the help function. Many users do not view the help-facility as being a part of the program. Although the help pull-down menu was always available, users did not focus on the pull down menus, because they were busy with an interaction that took place somewhere else on the screen. A solution could be to show a perpetual push-button, icon or hot spot on every screen, allowing the user free access to the help system, or to allow a help prompt to appear when it becomes evident to the program that the user needs help.

Games are a powerful instructional tool that can provide an environment that facilitates learning or the acquisition of skills (Alessi & Trollip, 2001). Because many users do associate a computer to a gaming machine, extensive use of this mode could be made in future versions of the program. In teaching school subjects to adolescents using a game metaphor may well enhance their motivation.

The existing log-on interface presented problems for users. Learners also had problems with fill-in answers. Spelling checkers may go some way towards helping here.

In keeping with Johnson-Laird (1983), we found many instances of incomplete or even false mental models. Continuous formative evaluation is necessary to ensure that the language can be understood by the target population. Here again the mental model of the designers need to be adjusted to ensure a higher level of user-centred design. Some questions, both in the program and in future questionnaires, should be reworded to ask for information precisely and directly. Many more questions could be built into the program. Automatic remediation paths could be incorporated into the program to ensure that learning did take place.

The pre- and post-program questionnaires show that the program could be a motivational factor in the learning of users. Owing to the small test group, further research is necessary to confirm this deduction. However, many learners had previously used a wide range of multimedia programs and expected extensive audio and video features to be integrated into the program. Although extensive use has been made of graphics and animation in the present version of the program, this aspect should not be neglected in future versions of the program.

Where possible, the user could be allowed to change the colour palette of certain screens to allow for individual preferences. Further research to investigate the relationship between colour and successful learning should be conducted.

7.2. Navigation and time

The navigational path records of the users revealed that maximum learner control was not advisable in a multimedia tutorial. Navigational freedom should be allowed in relation to the computer skills and the existing knowledge of the user. Therefore, jumps to specific modules should not be allowed if the user does not possess the knowledge base necessary to successfully complete the module.

Although the program successfully allowed users to work at their own pace, this prevented some users from completing all the modules. We found three clear tendencies. At least one fast learner found the program too easy, dipped in and out, and then, having realised that he knew all the work, terminated his use. The fast female learner, however, worked systematically and methodically through the program although she knew all the work – thus effectively wasting her time. More than one slow learner got lost in the program and learnt noting – also a waste of time. A tracking program could be incorporated within the program that records the progress of the users. This data should be made accessible to the teacher. This implies that an administrative module should be added to the program to monitor and manage the progress of every learner.

7.3. Acquisition of learning concepts such as “atom”

Table 10 highlights the changes that occurred in the mental models that users held of the concept “atom”. Significant and fundamental changes did occur in the mental models users had of the atom before working with the program, and the models users had of this concept after working with the program. Of particular interest here was the value of using pre-and post-program sketches of the concept and comparing those.

7.4. Recommendations for further research

Over all our results presented and discussed here concur with those of Hennessy et al. (2007) who report “a shift away from the educational legacy of ‘exemplary scientific practice’ within the school curriculum as characterised by real experiments” (p. 149). We support their argument for the teacher’s role “in selecting appropriate resources, sequencing and structuring learning activities, adapting to particular learners’ needs” (2007, p. 149). We believe that this “selection, sequencing and structuring” is the pre-requisite for learning in the *integration* quadrant (Cronjé, 2006) and we suggest that qualitative research into the mental models of learners would be a useful way for teachers to determine those needs.

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Vitae

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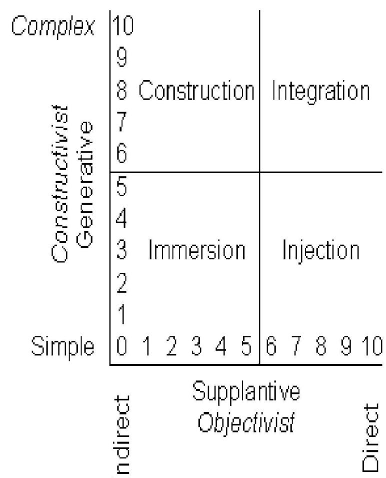


Fig. 1. Integrating objectivist and constructivist teaching (Cronjé, 2006, p. 412).

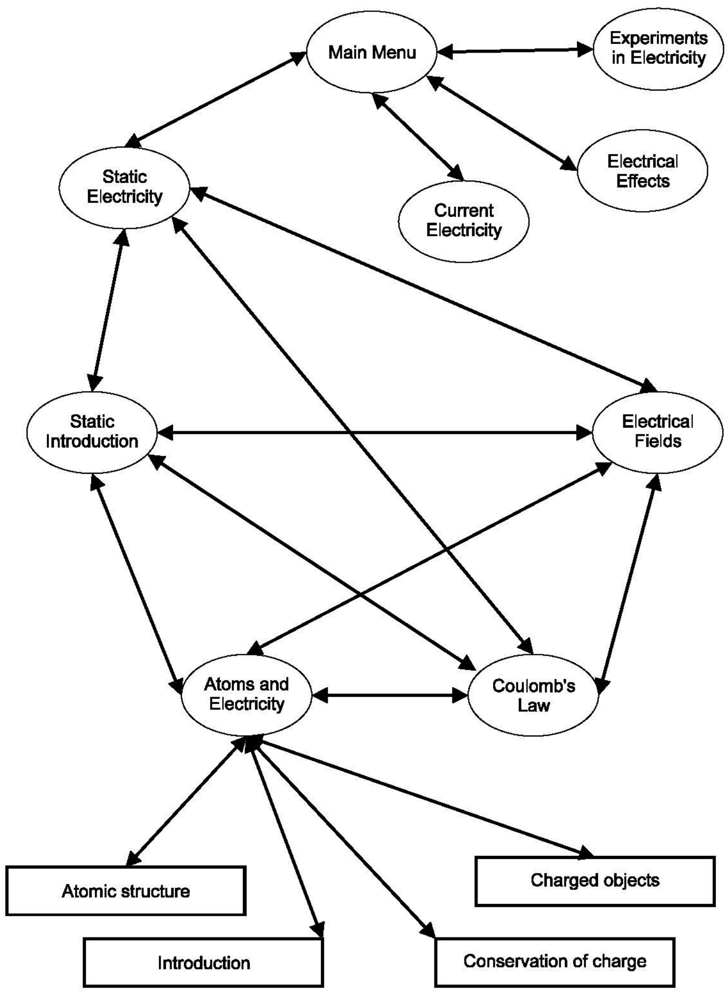


Fig. 2. Structure of the program.

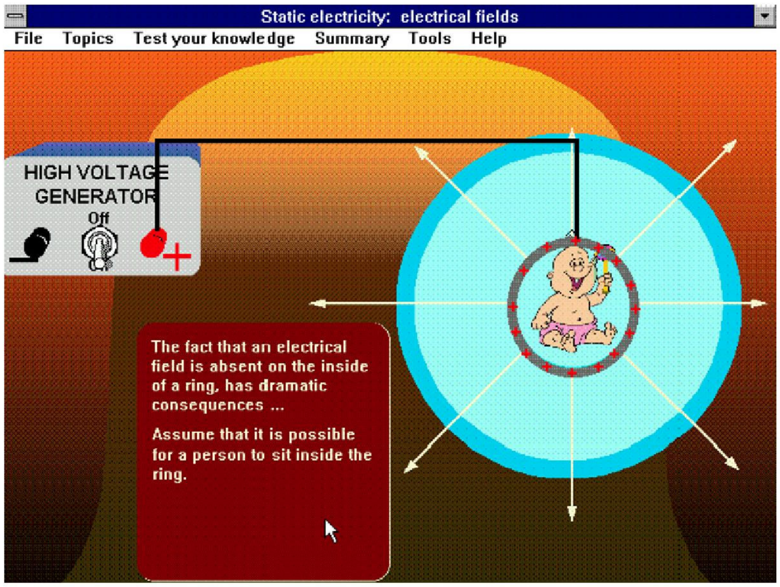


Fig. 3. Read and analyse.

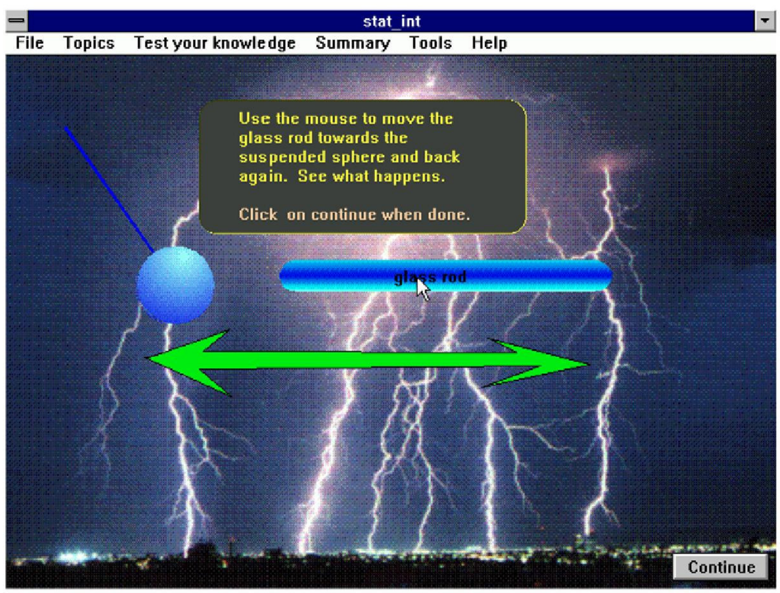


Fig. 4. Explore.

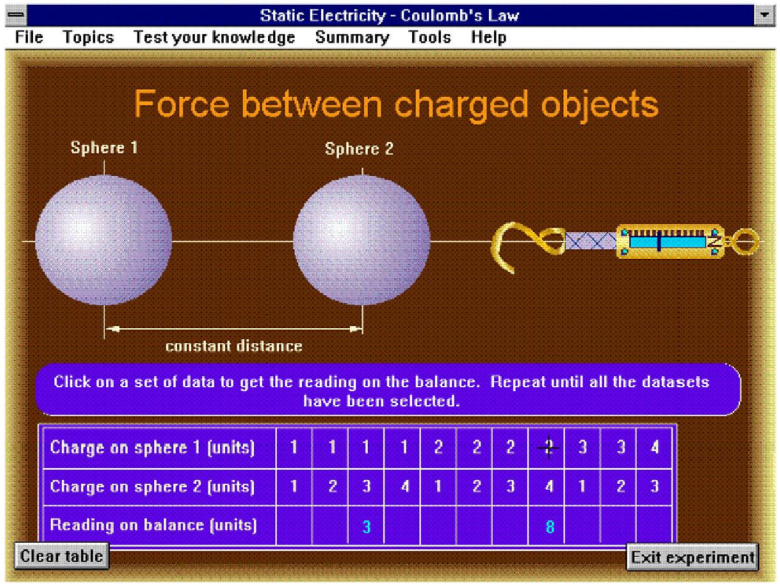


Fig. 5. Plan.

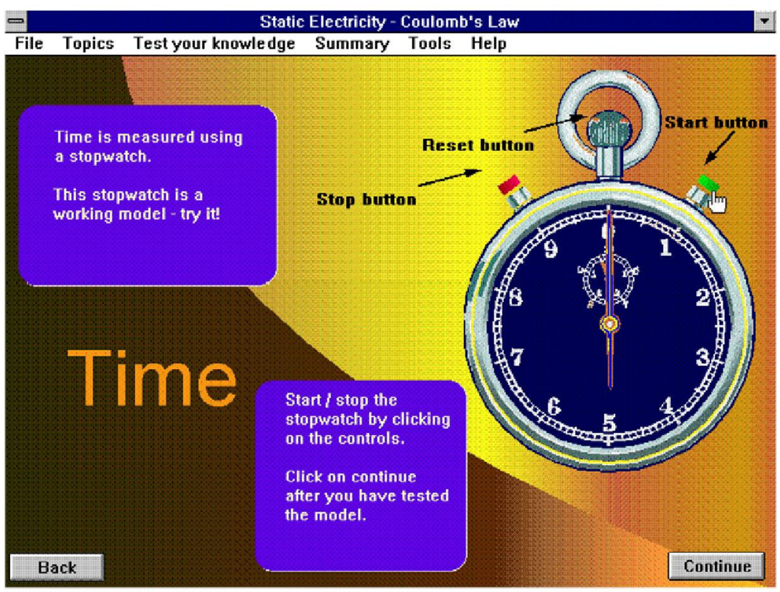


Fig. 6. Implement.

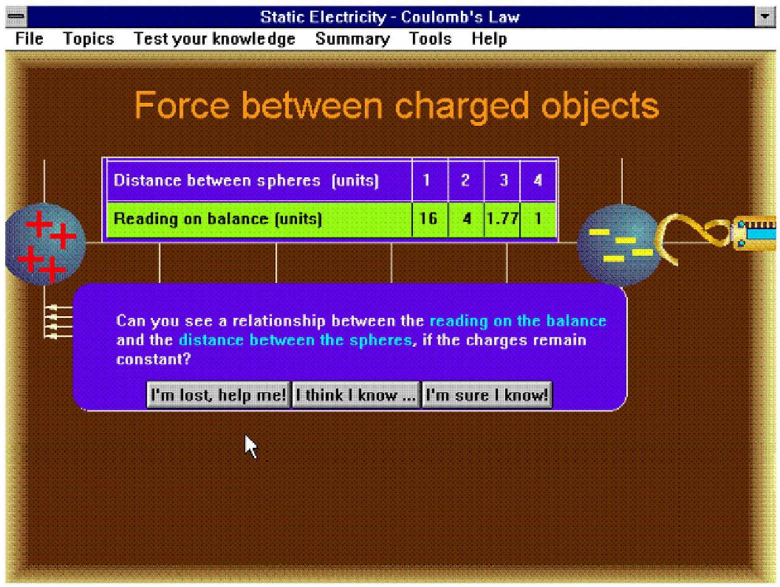


Fig. 7. Verify.

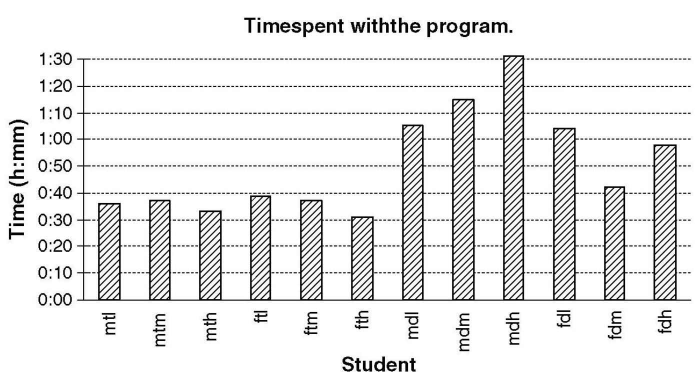


Fig. 8. Time spent with the program.

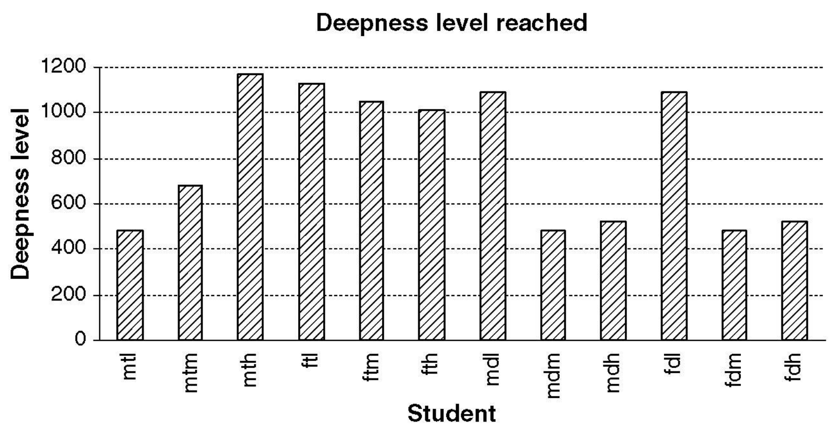


Fig. 9. Program deepness level reached by learners.

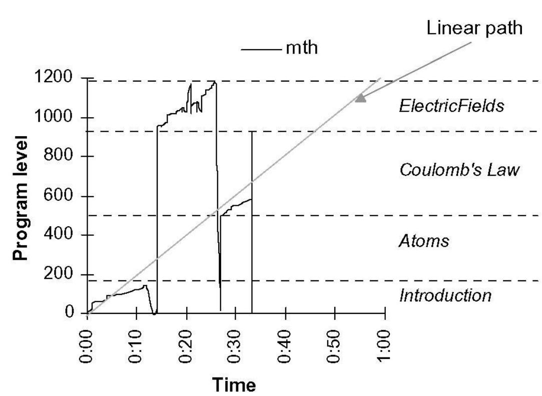


Fig. 10. Navigation tracking record of male, technology-advantaged, high achiever.

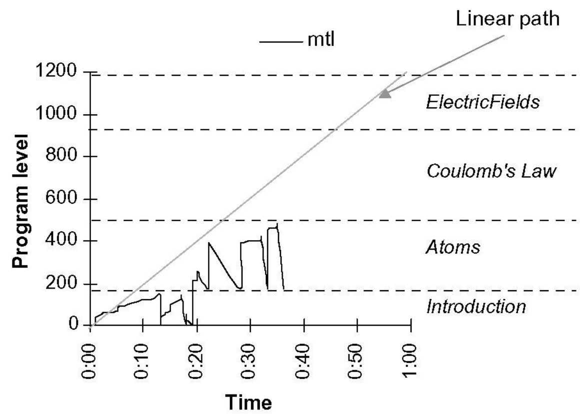


Fig. 11. Navigation tracking record of male, technology-advantaged, low achiever.

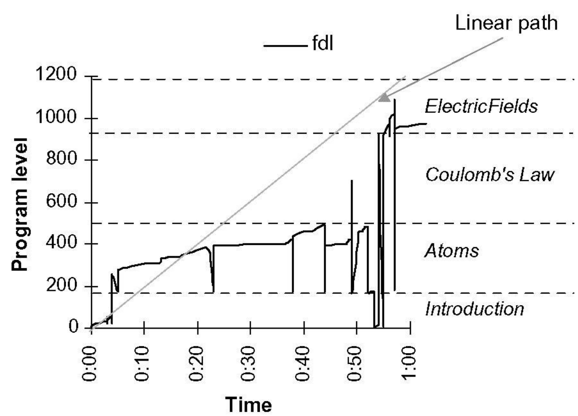


Fig. 12. Navigation tracking record of female, disadvantaged, low achiever.

Table 1
Target group identification matrix

	Academic ability		
	Low	Medium	High
Female, disadvantaged school	fdl	fdm	fdh
Male, disadvantaged school	mdl	mdm	mdh
Female, technology-enabled school	ftl	ftm	fth
Male, technology-enabled school	mtl	mtm	mth

Code. mtl = male, technology-enabled, low ability; fdh = female, disadvantaged, high ability, etc.

Table 2
Computer experience of the test group

	Academic ability		
	Low	Medium	High
Female, resource-disadvantaged school	5 sessions CAI	5 sessions CAI	5 sessions CAI
Male, resource-disadvantaged school	5 sessions CAI	5 sessions CAI	5 sessions CAI
Female, resource-advantaged school	Games	Games	Computer Studies
Male, resource-advantaged school	Games	Computer Studies	Computer Studies

Table 3
Learners having problems with drag-and-drop mouse actions

	Academic ability		
	Low	Medium	High
Female, resource-disadvantaged school	♦	♦	♦
Male, resource-disadvantaged school	♦	♦	*
Female, resource-advantaged school	•	•	*
Male, resource-advantaged school	*	*	*

• Previous computer experience; experienced mouse problems.
♦ Limited computer experience; experienced mouse problems.
* Did not experience any mouse problems.

Table 4
Learners who experienced password problems

	Academic ability		
	Low	Medium	High
Female, resource-disadvantaged school	♦	♦	*
Male, resource-disadvantaged school	♦	♦	*
Female, resource-advantaged school	•	*	*
Male, resource-advantaged school	*	*	*

• Previous computer experience; experienced password problems.
♦ Limited computer experience; experienced password problems.
* Did not experience any password problems.

Table 5
Description of the mental models of the researcher and program users

#.	Designer's model	Users' model	Users' model held by
1.	The computer is a didactic tool	The computer is a game machine	2 learners
2.	Everybody will type without any typing errors	The computer will automatically correct typing errors	5 learners
3.	All users will access the help pull-down menu when experiencing problems	The help-facility is not part of the program	11 users
4.	Everybody will understand figurative speech and expressions	Wordings of questions should be taken literally	5 users from the resource-disadvantaged school
5.	Too many audio and video effects could shift the focus from important concepts towards cosmetic extras	Multimedia programs should contain "bells and whistles", video and much more audio	3 male users from the resource-advantaged school
6.	All users will always understand all the questions if answers are given	A computer program should always explain everything in detail	6 users
7.	Graphics and animations simplify contents	Graphics and animations simplify contents	All users
8.	Maximum learner control might ensure maximum learning	Maximum learner control will ensure maximum learning	All users
9.	Constant, visually pleasing colours should be used in a presentation	Bright colours should be used in a presentation	One user
10.	A computer-based lesson might be preferable to normal class instruction	A computer-based lesson is preferable to normal class instruction	All users
11.	The program *Introduction to Basic Electricity* might motivate learners	The use of program *Introduction to Basic Electricity* was a motivating experience	All users
12.	A computer-based lesson will allow users to work at their own pace	A computer-based lesson will allow the user to work at his own pace	All users

Table 6
Learners accessing the help facility

	Academic ability		
	Low	Medium	High
Female, resource-disadvantaged school	*	*	*
Male, resource-disadvantaged school	*	*	*
Female, resource-advantaged school	*	*	◇
Male, resource-advantaged school	*	*	*

◇ Accessed the help facility.
* Did not access the help facility.

Table 7
Historical development of the atomic model

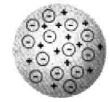
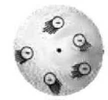
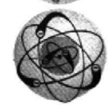
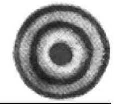
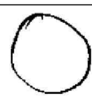
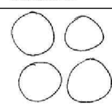
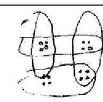
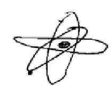
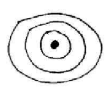
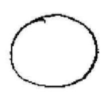
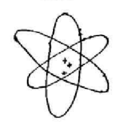
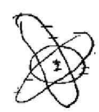
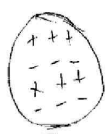
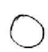
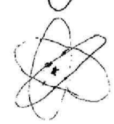
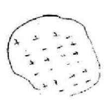
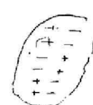
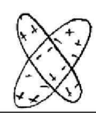
Year	Model developed by	Model also known as	
1803–1807	Dalton	Billiard ball model	
1898	Thomson	Plum pudding model	
1910	Rutherford		
1913	Bohr	Planetary model	
1925	Schrödinger	Wave mechanical model	

Table 8
Sketches of atoms

	Pre-program sketches			Post-program sketches		
	Academic ability			Academic ability		
	Low	Medium	High	Low	Medium	High
Mt						
Ft						
Md						
Fd						

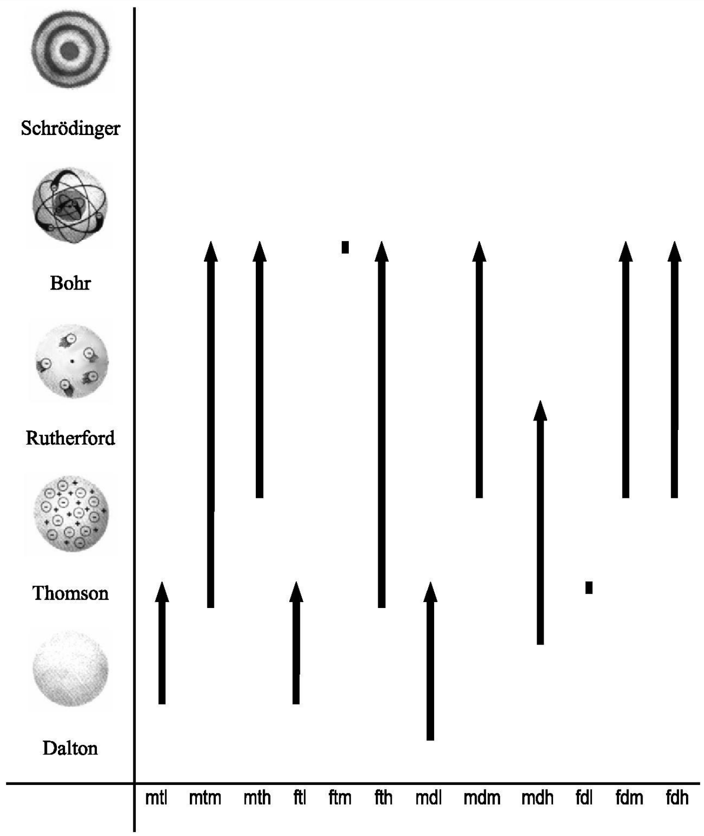
Code mt = male, ex-TED school; ft = female, ex-TED school; md = male, ex DET school; fd = female, ex-DET school.

Table 9
Categories of atom concepts

Category	Pre-program	Post-program
Other	Mdl	
Billiard ball model	mtl, mtm, ftl, fth, mdh	
Plum pudding model/Rutherford	mth, mdm, fdl, fdm, fdh	mtl, ftl, mdl, mdh, fdl
Planetary model	ftm	mtm, mth, ftm, fth, mdm, fdm, fdh

Code. mdl = male, Disadvantaged school, low academic ability; ftm = female, technology enabled school, medium academic ability.

Table 10
Changes in users' models of the concept "atom"



Appendix A. The pre-program questionnaire

Pre-program questionnaire

Name		Date of Birth								
Male/female		Previous computer experience?								

		Very strongly disagree								Very strongly agree
Interaction	I would love it if the computer could speak back to me.	1	2	3	4	5	6	7	8	9
Interaction	I always guess the answer for multiple choice questions.	1	2	3	4	5	6	7	8	9
Interaction	I hate it if a teacher marks my problems wrong and writes a long story about it.	1	2	3	4	5	6	7	8	9
Interaction	In class, the teacher provides me with answers, but I still do not understand.	1	2	3	4	5	6	7	8	9
Interaction	I think computer based education programs are boring.	1	2	3	4	5	6	7	8	9
Interface	I love animations!	1	2	3	4	5	6	7	8	9
Interface	I consider myself as being "artistically inclined".	1	2	3	4	5	6	7	8	9
Interface	I always organise my learning: e.g. I will complete my Mathematics first, before starting my Science.	1	2	3	4	5	6	7	8	9
Interface	A red and orange screen would look nice.	1	2	3	4	5	6	7	8	9
Interface	I always use sketches when I learn.	1	2	3	4	5	6	7	8	9
Interface	Computers normally frustrate me.	1	2	3	4	5	6	7	8	9
Interface	When trying something, I give up easily if I do not succeed.	1	2	3	4	5	6	7	8	9
Interface	It is normally easy to work with a computer.	1	2	3	4	5	6	7	8	9
Involvement	I prefer the computer based type of lesson to traditional instruction.	1	2	3	4	5	6	7	8	9
Involvement	When starting a new year at school, I am concerned that I may not be able to cope with the work.	1	2	3	4	5	6	7	8	9
Involvement	I hate science!	1	2	3	4	5	6	7	8	9
Involvement	The lessons in class are mostly dull.	1	2	3	4	5	6	7	8	9
Motivation	I really think I would like to learn more about atoms and electricity.	1	2	3	4	5	6	7	8	9
Motivation	I tense easily.	1	2	3	4	5	6	7	8	9
Motivation	I think a computer program will make the normal classwork much easier.	1	2	3	4	5	6	7	8	9
Motivation	I think extra classes are mostly a waste of time.	1	2	3	4	5	6	7	8	9
Motivation	I am always totally involved in class.	1	2	3	4	5	6	7	8	9
Motivation	My teachers always challenge me to do my best..	1	2	3	4	5	6	7	8	9
Rate	I learn best when I feel I am pressed for time.	1	2	3	4	5	6	7	8	9
Rate	I love to work at my own pace, without being pushed.	1	2	3	4	5	6	7	8	9
Rate	Sometimes the teacher goes too slow because he keeps on explaining things to the rest of the class.	1	2	3	4	5	6	7	8	9
Rate	I consider myself to be a patient person.	1	2	3	4	5	6	7	8	9

Appendix B. Post-program questionnaire

Post-program questionnaire

Name		Date of Birth								
Male/female		Previous computer experience?								
		Very strongly disagree						Very strongly agree		
Interaction	I felt as if someone was engaged in conversation with me.	1	2	3	4	5	6	7	8	9
Interaction	I guessed the answers to some questions.	1	2	3	4	5	6	7	8	9
Interaction	I was encouraged by the responses given to my answers of questions.	1	2	3	4	5	6	7	8	9
Interaction	I was given answers, but still do not understand the questions.	1	2	3	4	5	6	7	8	9
Interaction	The feedback was boring.	1	2	3	4	5	6	7	8	9
Interface	I did not like the animations in the program.	1	2	3	4	5	6	7	8	9
Interface	I did not like the screen layout at all.	1	2	3	4	5	6	7	8	9
Interface	I like the fact that I can jump from one topic directly to another topic.	1	2	3	4	5	6	7	8	9
Interface	I loved the colours.	1	2	3	4	5	6	7	8	9
Interface	The animations in the program made the contents easy to understand.	1	2	3	4	5	6	7	8	9
Interface	The program frustrated me.	1	2	3	4	5	6	7	8	9
Interface	Sometimes I felt completely lost	1	2	3	4	5	6	7	8	9
Interface	The program is very easy to work with.	1	2	3	4	5	6	7	8	9
Involvement	I prefer the computer based type of lesson to traditional instruction.	1	2	3	4	5	6	7	8	9
Involvement	I was concerned that I might not be able to understand the material.	1	2	3	4	5	6	7	8	9
Involvement	My feeling towards the course material after I had completed the program was favourable.	1	2	3	4	5	6	7	8	9
Involvement	The lessons in the program were dull and difficult to follow.	1	2	3	4	5	6	7	8	9
Motivation	As a result of having studied by this method, I am interested in learning more about the subject matter.	1	2	3	4	5	6	7	8	9
Motivation	I felt quite tense when I worked through the program	1	2	3	4	5	6	7	8	9
Motivation	I think that what I have learned from the program, should make the normal classroom and laboratory work easier to understand.	1	2	3	4	5	6	7	8	9
Motivation	I think working through the program was a waste of time.	1	2	3	4	5	6	7	8	9
Motivation	The lessons were interesting and really kept me involved.	1	2	3	4	5	6	7	8	9
Motivation	The program challenged me to try my best.	1	2	3	4	5	6	7	8	9
Rate	I could have learned more if I had not felt pushed.	1	2	3	4	5	6	7	8	9
Rate	I felt that I could work at my own pace.	1	2	3	4	5	6	7	8	9
Rate	The course material was presented too slowly.	1	2	3	4	5	6	7	8	9
Rate	The program ran much too fast.	1	2	3	4	5	6	7	8	9