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Experimental Comparison of Virtual Reality with Traditional Teaching Methods for Teaching Radioactivity

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Research at the University of Nottingham has been carried out to investigate the potential of Virtual Reality (VR) for teaching secondary school science. This paper describes the evaluation of VR to teach radioactivity at secondary school level. Evaluation was carried out in a local school and compared directly to the traditional teaching methods currently used in the school to teach radioactivity. Computer experience, computer attitudes, general attitudes and knowledge gained were measured to allow comparisons to be drawn. Individual differences of gender, ability and home computer use were also looked at in relation to the above measures. Results indicated that both ability level and the order in which the conditions were completed significantly affected the attitude scores. High ability students reported higher attitude scores, both overall and for the VR class in particular. As a result of the evaluation study, the Virtual Laboratory has been heavily modified and further evaluation studies were then carried out.

Keywords: virtual reality; comparative studies; science education; evaluation; individual differences.

Introduction

The possibility that Virtual Reality (VR) may be a useful technology to apply in education has generated interest in the design and development of VR applications for schools. VR provides several unique attributes that set it apart from other computer technologies currently used in schools. Among these are: the ability to visualise and manipulate objects that cannot ordinarily be seen in the real world; the capability of taking on different perspectives; the facility for exploring dangerous situations and providing a medium for presenting complex three-dimensional concepts (Crosier and Wilson, 1998). In addition, there is the potential for motivational advantages of new technology and the opportunity for self-directed 'learning by doing' which has been described as a promising learning style (Bricken, 1991; Papert, 1993).

Previous studies have highlighted the potential benefits for VR in education (Byrne and Furness, 1994; Dede, 1995; Pantelidis, 1993; Winn, 1997b). Several studies have aimed to evaluate aspects of educational VR, for example its usability, or the effect of immersion and interaction, however there have been very few studies which have tried to compare the effectiveness of VR against non-VR teaching practices (Mikropoulos et al., 1998; Youngblut, 1998). Of those comparative studies that exist, most have tended to draw comparisons with multimedia-type learning environments (Byrne, 1996; Salzman et al, 1997). One study which did compare immersive VR with traditional lectures covering a similar content for teaching Physics (Brelsford, 1993), found that for both Junior High and University level education, post-test results were significantly higher following VR use than following the lectures. Most studies evaluating VR for education have concentrated on immersive VR. One study which compared desktop VR to immersive VR and video for teaching cell biology (Gay, 1994) found advantages for VR over video, but found no benefits of immersive VR over desktop VR. Other studies have also been unable to show that *immersion* is the beneficial quality of VR (Byrne, 1996). Additionally there have been worrying reports suggesting that use of head mounted displays (HMDs) with immersive VR can contribute to negative health and safety effects. Studies have shown users to experience negative effects, including nausea, dizziness and headaches, both for adult populations (Cobb et al., 1999; Nichols et al., 2000) and school age participants (Bricken and Byrne, 1992; Dede et al., 1996; Osberg et al., 1997). In addition, immersive systems and the equipment that they require are often beyond the capacity of many school budgets (Auld and Pantelidis, 1994). For these reasons, the current study examined desktop VR, which is an affordable alternative which could be used in schools at the current time.

There have been a few studies looking at individual student differences in the use of VR. Winn (1997a) compared low and high ability students in building their own immersive VR applications. They found that low ability students who did world-building significantly outperformed those studying in the traditional way. For high ability students there was no difference in performance. Salzman et al. (1999) proposed a model suggesting that individual learner characteristics, including gender and computer experience, may moderate the relationship between VR's features and learning, however specific relationships have yet to be investigated. Other studies report on gender differences for non-VR computer interaction. Selwyn (1998) examined home computer use by students and found, in accordance with previous studies, that male students were significantly more likely to have access to a home computer than females. He also found that having access to a home computer significantly affected students' attitudes to computers for both males and females, although the effect is stronger for males. Martin (1991) found that secondary school children's attitudes towards computers becomes progressively more favourable as a function of being male, doing a computer course and having a home computer.

This paper describes an experiment conducted to compare a VR application to teach radioactivity in UK schools at year 11 (age 15–16) to the traditional teaching methods (TTM) currently used in the classroom. The study also examined the effect of gender and ability on students' attitudes both to computers in general and to the teaching methods used. The evaluation was carried out in the field in order to gain as realistic results as possible, and to highlight issues involving the logistics of implementing VR into a classroom.

The Virtual Radioactivity Laboratory

Through research and collaboration with 21 teachers from 16 schools in Nottinghamshire, UK, the area of radioactivity within the Physics curriculum was selected as a potentially beneficial area within which to develop a VR application (Crosier and Wilson, 1998). A user-centred methodology was used to design and develop the Virtual Laboratory. Iterative design and review meetings between programmers and teachers ensured that the content of the Virtual Laboratory matched the curriculum content for teaching radioactivity. The Virtual Laboratory was developed using Superscape VRT on a Pentium 133 computer and installed on standard PCs used in schools.

The Virtual Laboratory consists of a large, square room. Posters on the walls give information such as: the symbols for alpha, beta and gamma; different types of shielding; and health and safety information about radiation. The main area of the room contains two large benches that hold the experimental equipment (Figure 1).

The equipment includes:

- *A Geiger counter* – which can be switched on and off. When switched on it clicks and a needle indicates the strength of the radiation.
- *Stands* – for the radioactive sources and the shielding materials.
- *Radioactive materials* – Americium (alpha source), Cobalt (beta source) and Strontium (gamma source). These are contained in lead boxes.
- *Shielding materials* – paper, aluminium foil, aluminium (3 mm), lead.

The students are able to explore the Virtual Laboratory in their own time. They can perform a number of experiments using the experimental set-up together with the radioactive and shielding materials to find out which shielding materials stop which radioactive particles. The students turn on the Geiger counter, which gives a reading indicating background radiation if there is no radioactive material in the stand. The student then selects a radioactive material and a shielding material and places them in the appropriate stands. Once they have set-up an experiment they gain feedback from the Geiger counter to determine whether or not the radiation is being absorbed by the material (Figure 2). Additionally they may zoom in to observe what is happening at an atomic level. At this level atoms can be seen emitting the particular particle (labelled at the top of the screen), which is either absorbed by, or passes through, the shielding material.

Figure 1. Overview of Virtual Radiation Laboratory.

Figure 2. A Virtual experiment.

Method

Design

As the evaluation study was carried out in the field, it was necessary to design the experiment to cause as little disruption as possible. The experiment reported in this paper was conducted at one of the secondary schools participating in the overall project. The physics teacher at the school was the main point of contact for the study. Through collaboration with her, it was established that radioactivity was taught at year 11 (age 15–16) at this particular school and that the students are divided into ability groups for their science classes. It was decided that four intact classes would be used for the evaluation, two high ability and two low ability. The experiment was in the form of a two group, post-test only quasi-experimental design with repeated measures, such that in each ability grouping, one class would use the Virtual Laboratory first and the other had traditional teaching methods and then the groups would be swapped over. Unfortunately, prior to experimental running, timetabling alterations prevented VR/TTM presentation order split for the high ability group. This group all had TTM first. Therefore three groups took part in the experiment: Low ability A, Low ability B and High ability.

Participants

A total of 51 students took part in the study, 24 females and 27 males. The details are summarised in Table 1.

Table 1. Subject demographics

Ability	Group	Male	Female	Age
Low	A	6	7	15.7
	B	7	9	15.4
High		14	8	15.6

Materials

Computer use questionnaire A short questionnaire was produced to gather information such as age, gender and access to a home computer. The questionnaire also asked students to estimate the number of hours spent per week using a computer for different tasks, both in class and outside class hours.

Computer attitude scale A validated computer attitude scale (Selwyn, 1997b) was selected. The scale consists of 21 statements that are rated using a five point Likert scale.

Topic test A series of six questions related to the curriculum content of the radioactivity lesson were devised. These were presented to the students at the end of each class.

Post-session attitude questionnaire A questionnaire was devised to assess the students' attitudes. The questionnaire consists of 12 statements rated using a 5 point Likert scale, followed by some open-ended questions asking about the class. The questionnaire was given to the students after performance of each condition and asked specifically about that condition.

Worksheet A worksheet was produced to give some guidance as to what the students should do in the VE. It included information about the objects which were contained in the virtual laboratory and activities which should be undertaken.

Procedure

It was necessary to keep the interference to students and teachers to a minimum, so the experimental sessions were completed during normal timetabled science lessons. For each group the sessions took place during two science classes which for the low ability classes were on consecutive days and for the high ability class were a week apart. For the low ability classes, one class used the VE first and had their normal lesson second, and the other class had their normal lesson first and then used the VE. The high ability class had already had their normal radioactivity class. This class was not observed, but the participants completed the appropriate questionnaires following the session.

The VE session took place in the school's computer room. The radioactivity VE was loaded onto 12 networked PCs. Most of the participants worked in pairs on the VE, although some worked individually. The TTM session took place in the normal classroom. The class included a 15 minute video and written work from the blackboard.

Results

Descriptive Statistics

Observations Informal observations were made during the experimental sessions. There was a noticeable difference in the two ability groups' reactions to the VE. The low ability groups seemed restless and bored and the class was noisy, while the high ability group was much more engaged in the task. The low ability groups also demanded a lot more attention of their teacher. The written worksheet given to the participants was largely overlooked by the low ability groups.

Computer experience The computer use questionnaire provided some interesting results regarding access to and use of home computers by the participants. Only 34% (10/29) of the low ability students have access to home computers as opposed to 64% (14/22) of the high ability students. Additionally, of those 34% of low ability participants who had access to computers at home, only 70% (7/10) made use of them as opposed to 100% (14/14) of high ability participants. There appeared to be no gender difference in access to and use of home computers.

The participants were also asked to rate their weekly computer use for different categories. The categories were: word processing; spreadsheets; Internet; CD-ROMs and PC-Games. These were rated for both in-class and outside-class use. The low ability students appear to make more use of computers in-class, however this is likely to be largely under the teachers' control and would also depend on the subjects that they are taking. Out of class, the biggest use of computers for both low and high ability participants is PC-Games.

Attitude questionnaire The attitude questionnaire included a yes/no question and four open-ended questions that aimed to find out more about the participants' attitudes to the different classes. The yes/no question asked: 'Do you think that the [computer/class] helped you to learn about radioactivity?' Overall, a higher proportion of participants felt that the traditional class had helped them to learn about radioactivity than for the VE class. The ability level of the participants appears to have affected the responses, with the high ability group giving a greater proportion of positive answers for both classes. Interestingly, the order in which they had the classes appears to have affected their opinions of whether they think they learnt anything. Looking at the responses for the low ability groups, those who had the TTM class first (group B) responded more positively towards both classes than those who had the VE class first (group A).

VE attitudes Of the low ability participants who stated that the VE did not help them to learn, 57% (8/14) claimed that they did not understand what they had to do, many citing inadequate instructions as the reason for this. The high ability group were generally quite positive about the VE, most liking the facility for individual learning and the fact that it was 'different' and 'interesting'.

There was contrast in the two groups' opinions regarding what they liked about the VE (Table 2). While several of the low ability group said that there was nothing they liked about the VE, a few gave some positive feedback. One participant said: '*I liked it because you could explore anything you wanted to in your own time*' and another said: '*It was more interesting than working from a book*'. The majority of comments from the high ability group were positive, most stating that the VE was easy to use. One student commented: '*it was active learning, doing things and seeing them happen instead of being told that they happen*'.

Something that both ability groups disliked about the VE was that there was not enough to do, and for many participants this resulted in boredom. This problem is again highlighted in Table 3 where the biggest change both groups would like to see to the VE is the inclusion of more content.

TTM attitudes The attitudes for the normal teaching class differed between groups. Those groups who had completed the TTM class before the VE (low ability B and all high

Table 2. What students liked about the Virtual Laboratory

What did you like about the Virtual Laboratory?	Low ability	High ability
Nothing/not much	7	3
It was easy to use and/or understand	0	7
Exploring	4	1
It was VR	3	0
Learning by yourself	2	2

Table 3. What students would change about the Virtual Laboratory

What would you change about the Virtual Laboratory?	Low ability	High ability
Add more rooms/activities/experiments	10	12
Provide more instructions	3	0
Make it easier to understand	2	0
Make it more interesting	3	0
Other	6	4

ability), generally commented that they felt they had learnt about radioactivity from the class because they had started with no knowledge on the subject. Of the group which had completed the VE prior to their normal class (low ability A), only 3 of the 13 felt that the class had helped them learn about radioactivity. Many of the group answered ‘don’t know’ and did not comment on why. Only the low ability group were asked to comment on which aspects of the TTM class they liked and disliked. 79% (19/24) said that they liked the video, with 13% (3/24) saying there was nothing about the class that they liked and 8% (2/24) saying they liked ‘getting to know about radiation’. 86% (19/22) said they disliked copying information from the board. General comments regarding how the class could be improved included making it more interesting, fun and active.

Statistical Analysis

Topic Test Scores The topic test that was given to the participants was informal and not written. It was also very short, a maximum total of 6 marks were awarded. In addition, only the low ability students took the topic test, as it would not have been possible to compare for the high ability students as only one class was used. For these reasons there was a large ceiling effect associated with the test results which meant that the data could not satisfy the conditions for a parametric test.

A Mann Whitney U Test was carried out on the data which was significant ($U = 43$; $n = 12,13$; $p < 0.05$) indicating that the students performed better following their normal class (TTM) than after using the virtual environment (VE).

Attitude Scores

Effect of teaching method on attitude score A three way ANOVA was performed on the attitude scores with independent variables of teaching method (VE, TTM), ability (high, low) and gender. There was a significant main effect of ability level on attitude scores ($F = 11.252$; $df = 1,39$; $p < 0.01$) with the high ability participants having a more positive attitude towards both classes than the low ability participants. Additionally, there was a significant interaction of method and ability ($F = 5.902$; $df = 1,39$; $p < 0.05$). A post hoc *t*-test showed that the ability level significantly affected the attitude scores for the VE condition ($t = -3.672$; $df = 41$; $p < 0.001$) but not the ITM condition.

Table 4. Attitude scores post-VR and post-TTM

	High ability		Low ability	
	Male	Female	Male	Female
VR *N*	13	7	11	12
Mean (SD)	29.00 (6.39)	31.86 (6.12)	23.27 (7.24)	20.92 (8.26)
TTM *N*	13	7	11	12
Mean (SD)	29.46 (5.87)	25.43 (5.83)	25.73 (4.27)	23.92 (6.16)

Effect of order on attitude score Due to the fact that all of the high ability students had their normal class first, followed by the VE, an order effect could only be examined for the low ability students. A two way ANOVA was performed on the attitude scores of the low ability students with the independent variables of teaching method (VE, TTM) and order (VE 1st, TTM 1st) Significant main effects were found for both teaching method ($F = 8.627$; $df = 1,21$; $p < 0.01$) and order ($F = 23.677$; $df = 1,21$; $p < 0.001$). There was also a significant interaction between teaching method and order ($F = 7.945$; $df = 1,21$; $p < 0.01$). A post hoc *t*-test confirmed that the order significantly affected attitudes to the VE condition ($t = -5.448$; $df = 21$; $p < 0.001$), but not the attitudes to the TTM condition. Figure 3 illustrates that if the participants had the VE condition first their TTM attitudes were a lot higher than their VE attitudes, while if they had the VE condition second there was not much difference in their attitudes to the two conditions.

Table 5. Attitude scores post-VR and post-TTM

	VR 1st	TTM 1st
VR*N*	11	12
mean (SD)	14.64 (6.56)	26.42 (3.48)
TTM *N*	11	12
mean (SD)	22.73 (5.61)	26.58 (4.48)

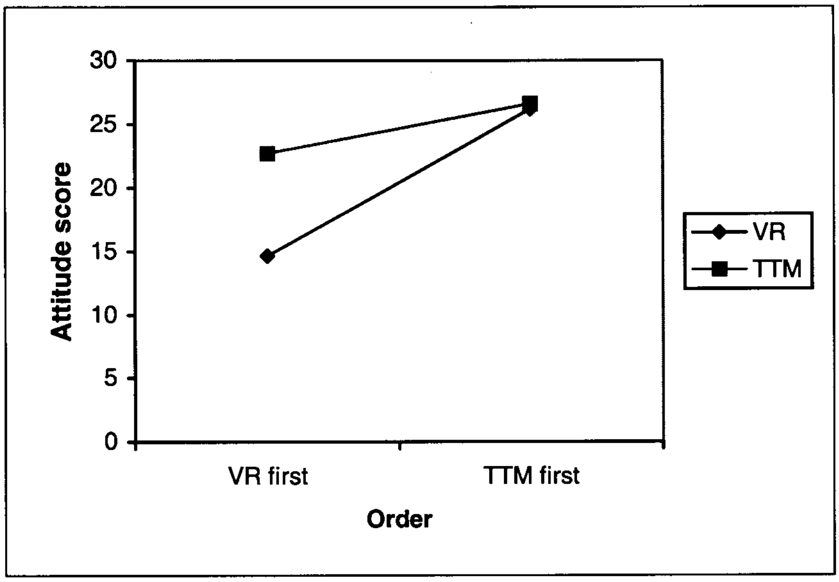

Figure 3. Interaction of teaching method and order on attitude scores.

Computer Attitude Score

Effect of use of VE on computer attitude score A three way ANOVA was performed on the computer attitude scores with the independent variables of time of completing the questionnaire (pre VE, post VE), gender and ability. No difference was found between pre- and post-VE computer attitude scores. An overall effect of ability was found ($F = 11.575$; $df = 1,37$; $p < 0.01$) on the scores, with high ability students having higher computer attitude scores.

Table 6. Computer attitude scores pre-and post-VR

	High ability		Low ability	
	Male	Female	Male	Female
Pre *N*	12	6	11	12
Mean (SD)	65.58 (6.30)	57.00 (8.74)	52.73 (6.96)	55.25 (6.27)
Post *N*	12	6	11	12
Mean (SD)	64.67 (6.12)	56.50 (7.04)	54.00 (7.85)	53.58 (5.28)

Effect of home computer use on computer attitude score A two way ANOVA was performed on the pre-VE computer attitude scores with use of home computer and gender as the independent variables. Significant main effects were found for use of a home computer ($F = 9.104$; $df = 1,39$; $p < 0.01$) and gender ($F = 5.898$; $df = 1.39$; $p < 0.05$). As

Figure 4 illustrates, those participants who did use a computer had more positive attitudes to computers, and males had more positive computer attitudes than females. There were no interaction effects between the variables.

Table 7. Computer attitude scores pre-VR

	Use home computer		Don't use home computer	
	Male	Female	Male	Female
Pre *N*	8	8	15	12
Mean (SD)	65.75 (7.85)	57.63 (7.52)	56.07 (8.23)	51.33 (9.33)

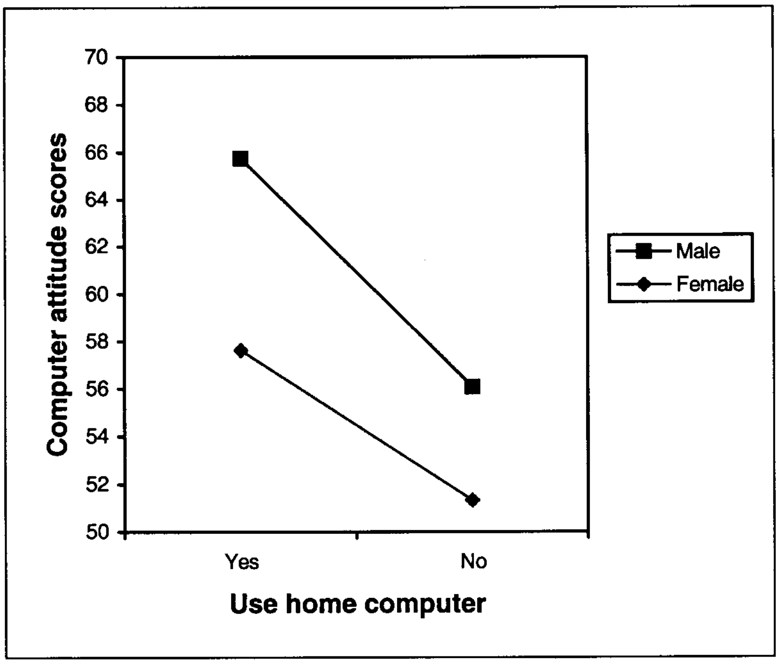

Figure 4. Effect of home computer use on computer attitude scores.

Discussion

This study has provided a first step into determining the feasibility of implementing desktop virtual environments into classrooms at the present time. Comparisons have been provided in terms of the effectiveness of virtual environments against the teaching methods that are currently used in schools.

On examination of the quantitative results, it may be observed that no obvious benefits were found for the use of VR over traditional teaching methods (TTM) both in terms of test scores and attitude ratings. There are, however, a number of factors that may have contributed to these results which should be addressed. These are discussed in turn.

In terms of test scores, students performed better following the TTM class than the VR class. However, there was a large ceiling effect for the TTM scores so accurate comparisons could not be expected. Unfortunately, it was only possible to compare for the low ability group, who, as the attitude scores and computer attitude scores indicated, had more negative general computer attitudes than the high ability group. It would be recommended in future studies to ensure an adequate number of experimental groups to allow for unforeseen dropouts and also to use a more comprehensive knowledge test.

The attitude scores of the two classes show a difference in ability groups, with high ability students having more positive attitudes than low ability participants, both overall and particularly for the VR class. Attitudes were generally better for the TTM class, however there was a noticeable effect of the order in which the classes were taken on the students' attitude. If the VR class was taken first attitude scores were fairly low for VR and a lot higher for the TTM. If the TTM class was taken first there was very little difference in attitude scores between the conditions. This would seem to support findings that background knowledge is an important factor in ensuring that a student can comprehend a subject (Bowman et al., 1999). Giving students an overview of the subject, its concepts and terminology, puts them in a stronger position to be able to understand and interpret meaning from the objects and concepts presented in VR. An alternative explanation for the results obtained in this study is that, as the order effect could only be examined for the low ability group, the differences could be accounted for by differences between the two classes.

Interesting results were obtained in terms of computer experience and computer attitudes. The use of VR did not affect the computer attitude scores. Ability level did affect the scores, with high ability participants having significantly higher computer attitudes than low ability participants. Also gender and home computer use had effects with males having better computer attitudes than females and home computer users having better computer attitudes than non-home computer users. This supports findings by Selwyn (1997a) and Martin (1991), however in contrast to these findings there was seen to be no gender difference in terms of access to home computers. Here there was only a difference between ability levels with high ability participants having greater access to computers than low ability participants. It could be suggested that there is a link between computer access and educational achievement. Nakhaie and Pike (1998) have shown that parents' education and social status influences provision of a home computer and they suggest that upper classes are able to reproduce themselves by adopting computer technology as part of their strategy of reproduction. This would indicate that those students with parents gaining high academic achievement would be more likely to be provided with a home computer than those with parents with low academic achievement.

The students' opinions of VR generally support the quantitative results. The high ability group enjoyed the freedom to explore and the fact that they could create their own learning, while in contrast the low ability group felt that they needed more guidance and instruction. Both groups felt that more content was needed in the virtual environment. The interesting point to note here is that the Virtual Laboratory had originally intended to replicate an experiment that would be carried out in the laboratory if it were not for the safety or cost implications. In this situation the experiment would only form a small part of the overall class with teacher explanations and support prior to, during and following the experiment. However, due to the current situation of technology in schools, the computers were situated in a dedicated computer room on the other side of the school from the science classroom. This meant that the teacher and pupils expected a VR application that would utilise the entire science lesson and have the corresponding amount of content. This discrepancy between what was expected and what was provided may account for some of the results obtained in this study.

Conclusions and further research

The most important finding of this study is the fact that real-world testing showed that *how* VR is to be used in the school needs to be considered early in the design process. Although the teachers had been heavily involved in the design and development of the Virtual Laboratory, it was not until the real-world testing that their real needs were realised. In this particular case teachers required a comprehensive piece of software that occupied an entire 40-minute lesson and taught the equivalent amount of information. Students' comments indicated that this is what they had expected as well.

In addition to providing more content, the results generally indicated that some teaching should take place prior to use of VR. This would ensure that the students are aware of the topic of study, its concepts and terminology that are represented in VR and enable them to extract the relevant information from it.

An interesting finding was the marked difference in VR use by the two ability groups. Comments by the low ability groups indicated that they needed more guidance and instruction when using the Virtual Laboratory. They did not seem to have the inclination to draw out their own learning and needed additional support to prompt them in the appropriate direction. In contrast, observations of and comments by the high ability group indicated that they liked directing their own learning and found the Virtual Laboratory easy to use and understand.

As a result of this study, the Virtual Laboratory has been heavily modified to take into consideration the current facilities for computer use in schools, together with student comments and suggestions for improvements. Further school-based studies have been carried out to evaluate the modified Virtual Laboratory and in particular the research has examined in more detail the difference between the ability levels in terms of the provision of direction and instructions.

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