South African Journal of Education
Copyright © 2005 EASA
Vol 25(1)50–55

Comparison of the learning effectiveness of computer-based and conventional experiments in science education

N.P.J. Molefe, M. Lemmer* and **J.J.A. Smit**
North-West University, Potchefstroom Campus,Potchefstroom, 2520 South Africa

An empirical study was conducted to compare the learning effectiveness of two interactive lecture demonstration methods that can be used in the teaching of kinematics concepts and graphs to Grade 11 learners in Physical Science in a South African school. The first method is the conventional ticker-timer experiment, whilst the second utilises high-technology computer-based equipment. Based on the outcome of the study, recommendations for the use of computers in South African schools are made. The results also have implications for the training of science educators. The results showed that the computer has the potential to develop into an effective teaching aid in South African schools. Three factors that can have an impeding effect on the use of computers as teaching aid are discussed, namely, the educator's acquaintance with computers and the associated methodology, the learners' experience with computers, and their alternative conceptions regarding the material taught. A spin-off is that the use of computers in the science laboratory can contribute to computer literacy of both educators and learners. Educators' training programmes should give particular attention to this aspect, especially as computers become more available in South African schools.

Introduction

In South Africa the number of schools with computers is increasing, and computer literacy has become part of the training of many teachers. In the year 2000 approximately 40% of the secondary schools in South Africa (2 060 out of 5 350) had at least one computer in the school (South African Department of Education, 2000). In February 2004 the Minister of National Education, Kader Asmal, announced that a White Paper on e-learning in all South African schools was under preparation (Rademeyer, 2004). The proposed target date for implementation of e-learning in all South African schools is 2013. Before that date all schools must be equipped with computers.

In this information age South African school learners have a disadvantage with regard to the use of modern technological equipment, especially computers, as compared to other countries such as the United States of America. In 1999 the National Center for Education Statistics of the Department of Education in the US launched a survey to investigate the extent and type of teacher usage of computers and the internet in elementary and secondary schools (Rowand, 2000; Smerdon *et al*., 2000). The survey found that 99% of full-time regular public school teachers reported that they had access to computers or the internet in their schools. Most public school teachers (84%) reported having at least one computer in their classrooms in 1999. They assigned learners to use it for internet research, practising drills and solving problems. South Africa is far behind in these figures. Furthermore, the Third International Mathematics and Science Study (TIMSS, 1995) and the repeated study (TIMSS-R, 1999) reflected that the quality of science and mathematics teaching in South Africa and the annual pass rates in the Grade 12 examination were low compared to other countries who contributed to the study (Howie, 1997; Howie, 2001). Less than 0.5% of pupils in South Africa formed part of the top 10% of achievers in both 1995 and 1999. South Africa was the only country that participated in the study where this low percentage was obtained in both years (Howie, 2001). Consequently, efforts should be made to improve the results. The use of computers in the science classroom may enhance the quality of science teaching and learning in South Africa. The purpose of this study is to shed light on this issue. In their research Hake (1998a) and Thornton and Sokoloff (1998) proved that interactive engagement strategies are significantly more effective than traditional teacher-centred lessons. Computer-based equipment is used successfully to create an interactive learning environment (Sokoloff & Thornton, 1997). Redish *et al*. (1997) compared the effectiveness of one-hour active-engagement tutorials using microcomputer-based laboratory (MBL) equipment with one hour of traditional problem-solving recitations in introductory physics. A comparison of the results of eleven lecture classes taught by six different teachers with and without tutorials showed that the MBL tutorials resulted in a significant improvement compared to the traditional recitations, when measured by carefully designed multiple-choice items. In an earlier study, Thornton and Sokoloff (1990) found that the computer-based laboratory activities in physics that they had designed were effective for the following five reasons:

- Learners can focus on exploration, since they are freed from time-consuming data collection and display.
- Data are plotted in graphic form in real-time so that students get immediate feedback and see the data in an understandable form.
- The consequences of a large number of changes in experimental conditions can be examined in a single laboratory period.
- Students can focus on the investigation of many different phenomena without spending a large amount of time learning to use complicated tools.
- A wide range of students from elementary school to university level are able to use the same set of tools to investigate the physical world.

Most of the researchers (Hake, 1998a; Thornton & Sokoloff, 1998) who worked on the implementation of the computer-based laboratory (MBL) agree that the computer has become an effective tool in the Physics laboratory. However, it has limitations (Lawson & Tabor, 1997; McKinney, 1997; Wellington, 1999), for instance:

- Computers could give misleading impressions of the nature of science.
- Science is portrayed as clean and nice, not as problematic and messy.
- The important labour, hands-on experimentation and investigation are displaced.
- Concepts such as electric current could be misrepresented.
- Manipulative skills such as screwing a clamp to a stand will not be developed in learners.
- Learners can play with the programme and not learn.
- Learners are tempted to do things on the computer that should have been done in the laboratory.

Computers are costly, and have to be upgraded regularly. The feasibility of introducing computers into science classrooms in South Africa has to be investigated. The aim of the study reported here was to compare the learning effectiveness of computer-based demonstrations with conventional demonstrations when teaching kinematics concepts in a South African secondary school. Kinematics is the study of motion without regard to the agents of motion. This topic was chosen because various research studies showed that learners experience difficulties with it (Halloun & Hestenes, 1985; McDermott *et al*., 1987). Furthermore, computer-based experiments on kinematics concepts and graphs have been used abroad in investigations by researchers such as Hake (1998a), Thornton and Sokoloff (1998) and Redish *et al*. (1997). This provides a means of comparison for the South African situation.

Research design

A group of 48 Grade 11 learners at Thuto-Boswa Secondary School, Ventersdorp in the North-West Province, South Africa, participated in the study. The mother tongue of most of these learners is Setswana. English, the medium of instruction, is the second or even third language of all of them. The learners all live in a rural area. The socio-economic status of most of their families is very low. Some do not even have a television set at home. A computer is unaffordable for them.

In the empirical study the learning effectiveness of two laboratory experiments that can be used to teach kinematics concepts and graphs were compared by means of pre- and post-tests. The first experiment was the conventional ticker-timer and tape experiment, whilst the second experiment utilized a motion detector connected to a computer. The learners were divided into two groups of comparable size and abilities (similar spreading in science marks), called Group A and Group B. Group A used the conventional apparatus and Group B the computer-based apparatus. Two afternoons (approximately 8 hours) were used for each of the two experiments.

Methodology

In both experiments the motion of a trolley on a runway was represented graphically. Constant velocity and constant accelerated motion were studied. Displacement versus time and velocity versus time graphs were plotted. The experimental methods differed mainly in the way the results were obtained and processed. In the conventional method the ticker-timer made dots on a tape attached to the trolley. The learners processed the tape manually by measuring displacements and calculating time durations and velocities. Graphs were then plotted by hand. In the computer-based method a motion detector determined the changing position of the trolley at small time intervals. The data were processed by the computer connected to the motion detector. The software package Vernier was used. Graphs were displayed on the screen in real-time.

In a 6 000-student survey, Hake (1998a) showed that the use of interactive engagement methods can increase learning effectiveness of introductory physics well beyond that obtained in traditional educator-centred practice. He defined interactive engagement as those methods designed

> at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors (Hake, 1998a:65).

Various interactive engagement methods can be used (Hake, 1998b). In this study, both experiments were presented in the form of demonstrations where learners were interactively engaged in ways appropriate for the particular experiment, namely,

- The inquiry approach (Trowbridge *et al*., 2004) was used with the conventional ticker-timer experiment. Small groups of five learners each made their own ticker-tapes. They were guided by the educator in their analyses of the tapes and plotting of the graphs. Inquiry questions were asked throughout the process.
- The prediction-observe-explain method (White & Gunstone, 1992) was found by Sokoloff and Thornton (1997) to be particularly efficient with microcomputer-based experiments, and was consequently used with the computer-based method. For each motion, the learners had to predict the form of the graphs, which were then displayed on the computer. Differences between the predicted and observed graphs were discussed.

There is no fundamental difference between these two methods, since both are learner-centered and have as foundation interactive questioning and answering by active learners.

The learning effectiveness of the two experiments was determined in terms of the outcomes reached and learning gains achieved in a questionnaire that served as pre- and post-test. The average normalised gain was calculated by means of the formula (Hake, 2002:3):

$$\text{Average normalised gain} = \frac{\text{Actual average gain}}{\text{Maximum possible gain}}$$

The actual learning gain obtained for an item was calculated by subtracting the pre-test percentage from the post-test percentage. The maximum possible gain is 100% minus the pre-test percentage. The average percentage actual learning gain for the questionnaire is the percentage value of the difference between the averages obtained by the two groups in the pre- and post-tests.

In order to determine the effect size of the experiments, *d* values were calculated. The *d* values are defined by (Statistical Consultation Service, 1991):

$$d \text{ value} = \frac{|\text{mean of conventional group} - \text{mean of experimental group}|}{\text{largest standard deviation}}$$

The results were compared with corresponding studies (Hake, 1998a; Redish *et al*., 1997 and Thornton & Sokoloff, 1998). Differences in the gains were explained in terms of factors that could affect the learning effectiveness in this study, namely:

- the educator's experience with the apparatus and methodology.
- the learners' acquaintance with the computer.
- alternative conceptions of kinematic concepts held by learners.

The educator's experience and the learners' alternative conceptions were determined in interviews while a questionnaire was used to probe the learners' acquaintance with the computer. The information obtained was used in the interpretation of the results of the pre- and post-tests.

Outcomes of the experiments

The questionnaire used as pre- and post-test probed the achievement of the outcomes of the experiments. Learners were expected to be able to represent a physical motion in graphic form. For a learner to understand such graphs of motion, the following outcomes (objectives) have to be accomplished (Molefe, 2004):

The learners should be able to:

1. conceptualise the displacement and velocity of a moving object;
2. conceptualise zero and negative displacements and velocities;
3. abstract the change in position and change in velocity of a moving object from its actual movement;
4. connect a one-dimensional motion to a two-dimensional graphic representation;
5. derive abstract kinematics concepts and their changes from different kinematics graphs;
6. apply the knowledge obtained to different motions of an object.

Outcomes 1 to 3 are prerequisites for the higher-level outcomes 4 to 6. The pre- and post-tests probed into the attainment of these outcomes. Examples of items used in the questionnaire of these tests are given in Table 1.

Results and discussion

On average, the two groups performed similarly in both the pre- and post-test. In the pre-test Group A obtained an average of 31.5% and Group B 30.8%. In the post-test the average percentage of Group A increased to 45.3% and Group B to 43.8%. Both groups had a gain of approximately 0.2.

Since the same average gain was obtained, the two methods seem to be equally effective. However, individual items yielded differences in gains between the groups. To determine the effect sizes of different performances, the *d* values were calculated. For 8 out of the 14 items (57% of the questionnaire) the *d* values were negligible or small, with $d < 0.3$. This implied that the experimental method used (whether conventional or computer-based) had no effect on the results (Statistical Consultation Service, 1991). Table 1 summarizes the items for which the effect sizes were small to medium ($d \geq 0.3$). In only one item (13.1) a large effect size ($d \geq 0.8$) was obtained.

It is interesting to note that Group A (who used the conventional apparatus) performed best in items 1 and 3.1 (see Table 1) that tested the lower-level outcomes 1 and 3. It indicates that the conventional ticker-timer experiment was more successful in establishing basic concepts and skills. This result makes sense, because basic concepts and skills were learned in the observations and measurements of the distances between dots on the ticker-tape, and implemented in the calculations and manual plotting of the graphs.

Table 1 Pre- and post-test questions for which medium to large (d ≥3) effect sizes were obtained by the two groups

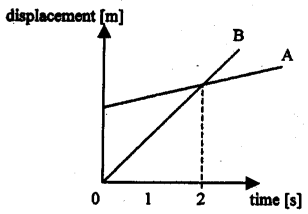
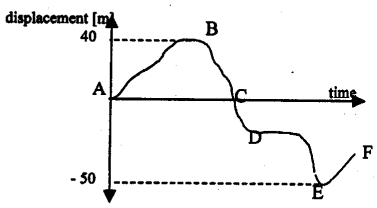
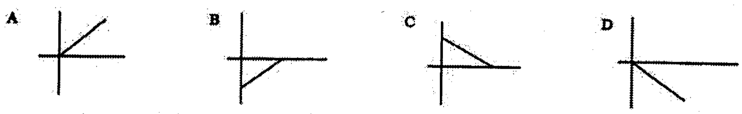
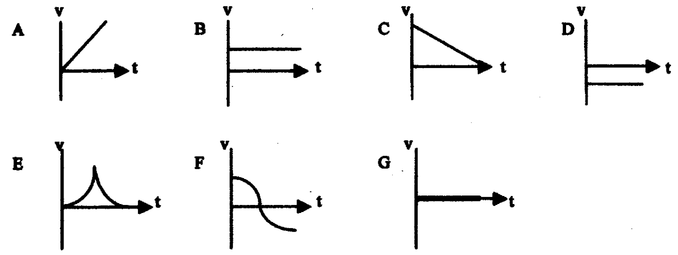
Outcome	Item	Largest gain in	d value
1	1. Define the following concepts. Illustrate each concept by means of a sketch or example.		
	c) speed	Group A	0.50
	d) velocity	Group A	0.35
3	3.1 Two cars A and B travel from Ventersdorp to Potchefstroom. Car A leaves before car B. Both cars reach Potchefstroom at the same time. How do the distances travelled by the two cars compare?	Group A	0.55
5	9. Two cars A and B move on a straight road. Use the displacement–time graph below to choose the correct answer to the question. At the instant t = 2 s, the speed of car A is a) greater than the speed of car B b) less than the speed of car B c) equal to the speed of car B	Group A	0.42
			
5	11. Answer the following question using the displacement–time graph of the motion of an object.		
			
	a) Where is the object furthest from its original position?	Group B	0.31
	b) Describe its position relative to the origin (place where it started) at point C.	Group B	0.50
	c) Where is it standing still?	Group B	0.61
5	12. Consider the following graphs and write down the letter or letters (A, B, etc.) of those with a negative gradient.	Group B	0.35
			
4	13. An object can move in either direction along the + distance axis. Choose the correct velocity–time graph for each of the following questions. Which graph shows the object		
	13.1 moving away from the origin at a steady (constant) velocity	Group A	0.84
	13.2 standing still	Group B	0.50
	13.3 moving towards the origin with a constant velocity	Group A	0.51
	13.4 reversing direction	Group B	0.23
	13.5 increasing its speed at a constant rate	Group A	0.32

Table 1 (continued)



The performance in the three items on outcomes 5 (Table 1) was dominated by Group B with an average gain of 0.17 versus the average gain of 0.05 by group A. The computer-based experiment (performed by Group B) therefore yielded the better performance in the higher outcome 5. This result can be explained by the repeated experience that learners obtained with real-time graphical presentation of a larger variety of motions. This is in accordance with modern learning theories, namely, when concepts are taught in multiple contexts, learners are more likely to abstract the relevant features of the concepts and develop a more flexible representation of knowledge (Bransford *et al.*, 2000:62; 78).

In item 13, which tested for outcome 4, some sub-questions were better answered by Group A learners and others by Group B learners. Group A outperformed group B in graphing the motions of a trolley moving away from the origin at a constant velocity (item 13.1), moving towards the origin at a constant velocity (item 13.3) and increasing its speed at a constant rate (item 13.5). These were the only types of motions that Group A dealt with in the conventional experiment. The conclusion was that these graphs were consequently better understood by Group A learners. The motions described in the remaining two items, namely a stationary trolley (item 13.2) and a reverse of direction (item 13.4), could only be demonstrated with the computer-based experiment. As can be expected, group B performed better in these two items. Item 13 also served in the pre- and post-tests of Thornton and Sokoloff (1990:864). They reported large positive gains (gains ≥ 0.4) with the computer-based experiments in all types of motions addressed in this item.

In the empirical study reported here, the average gains of 0.2 that were obtained for both experiments, is lower than gains obtained in comparitive studies abroad which also utilized interactive engagement learner centered teaching strategies (Hake, 1998b). Gains of approximately 0.2 were reported for traditional educator-centered courses, whilst interactive engagement yielded gains between 0.2 and 0.7. Computer-based tuition seemed to be more effective than other methods (Redish *et al.*, 1997) with gains of 0.6 or even larger (Hake, 1998a). Possible reasons for the lower gains obtained in this study were investigated. The results are discussed in the following paragraph.

Factors influencing learning effectiveness

Factors that can influence learning are the quality of the teaching, the learners' pre-knowledge and their abilities, attitudes, needs and perception of context (White, 1989:14-21). In order to explain the low gains obtained in the empirical study (especially with the computer-based experiment), the following three factors were identified as important differences with research that yielded higher gains. These factors are the educator's experience with the apparatus and the associated methodology, the learners' acquaintance with computers and their alternative conceptions of the kinematic concepts involved in the study.

Educator's experience with the apparatus and methodology

An interview was conducted with the educator who performed both the experiments to determine her experience with the apparatus and the methodology of interactive instruction (Molefe, 2004). The educator had learned to conduct conventional ticker-timer experiments during her training, and demonstrated them several times to groups of learners. She was used to guiding learners with the aid of relevant questions. However, it was the first time that she had utilised the computer as teaching tool. She had followed a computer literacy course as part of her training as teacher, but had never before used it in conducting experimental work in the classroom. The interactive methodology associated with it was also new to her. Her supervisor had instructed her prior to the lessons on the use of the computer, the software (Vernier) and the associated methodology. She was skilled with both experiments at the time the lessons started.

Hake (1998b) suggested that one of the factors that could contribute to low average gains was the apprenticeship education of instructors new to interactive-engagement methods. In this study, the educator's lack of experience with interactive-engagement methods could therefore have contributed to the low gains. Furthermore, she was not as acquainted with the use of the computer as with the ticker-timer apparatus. It can be expected that with more experience, the computer method would give better results than the ticker-timer method, as was found with the skilled lecturers in the study of Redish *et al.* (1997).

Learners' acquaintance with computers

The acquaintance of the learners of Group B with computers was determined by means of a questionnaire. The purpose of the questionnaire was to probe the learners' experience with and interest in computers.

The questionnaire revealed the following:

- The majority of learners (74%) reported that they had never worked on a computer before. For more than 50% it was the first time that they had even seen work done on a computer.
- Most of the learners were very interested (58%) and fascinated (71%) by the computer. One of the learners expressed his astonishment by asking "How is it possible that the boy's movement can get into the computer?"
- Only half of the learners (50%) said their focus was on the graphs displayed on the screen and the explanation by the educator during the lesson. Twenty-one percent of the learners admitted that the computer had distracted their attention from the explanation of the educator.

These results showed that some learners with little or no experience of computers are distracted by this new tool with a consequent lowering of learning effectiveness. It can be accepted that the subjects in the studies conducted in the USA by Hake (1998a) and Redish *et al.* (1997) were more acquainted with computers due to their availability and use in schools (Rowand, 2000; Smerdon *et al.*, 2000). Learners' non-acquaintance with computers could therefore contribute to the lower gain obtained in the empirical study reported here. It is expected that with computer-literate learners considerable higher gains may be expected.

Learners' alternative conceptions

Words that are commonly used in everyday life situations are often used in science with a different meaning (Duit, 1983). Such alternative conceptions are detrimental to the acquisition of the proper scientific meaning. Prior knowledge can be based on the learners' personal and idiosyncratic experiences, experiences attributable to developmental stages through which they may have passed, as well as the kind of knowledge that learners acquire because of their social roles, such as those connected with race, class, gender and their culture and ethnic affiliations (Bransford *et al*., 2000:71-72).

The proper understanding of the kinematics concepts (e.g. distance, displacement, speed and acceleration) is a prerequisite for the understanding of kinematic graphs. Researchers such as Trowbridge and McDermott (1980) identified alternative conceptions encountered by students in their study of kinematics. Alternative conceptions held by African children were found to be similar to those of Europeans, although conceptual change tended to occur at a later age (Rollnick & Rutherford, 1990; Thijs & Van den Berg, 1995). Nkopodi (1998) and Lemmer *et al*. (2003) related learners' alternative conceptions with language and cultural aspects. The learners who were involved in this research were mainly Setswana-speaking, an indigenous South African language. The kinematic conceptions used by these learners were interpreted in the context of their mother tongue.

Only two of the eight kinematic concepts investigated could be translated into Setswana with a single term, namely distance and speed (Molefe, 2004). The other concepts had to be described. Disadvantages are that the scientific meaning could be lost in a description (e.g. the words "rate of" are omitted in the description of acceleration), or the description may be incorrect (e.g. displacement is described as a short distance). The descriptions are qualitative and relative, and consequently differ from the operational definitions of physics.

The learners' understanding of these concepts was further probed in interviews. Alternative perceptions were identified, some of which are a consequence of the description of the concepts in Setswana (Molefe, 2004). An example of an altertive conception is that learners perceive the distance from home to school to be shorter when travelling by bicycle than by foot. These ideas can explain their problems with items such as item 3 (refer to Table 1) in the questionnaire.

Lemmer (1999) found that the effect of language and culture were more significant than gender or environment in alternative conceptions concerning space and time as well as related concepts such as the kinematic concepts. The alternative perceptions of the kinematic concepts held by the learners involved in the study can consequently explain the lower gains.

Conclusions and recommendations

In the educational environment of the empirical study, both the conventional and computer-based methods yielded similar learning effectiveness, but with lower average gains than comparative studies done abroad. Three factors that could account for the lower gains were identified, namely, the educator's experience with the apparatus and methodology of interactive engagement, the learners' acquaintance with the computer, and their alternative conceptions.

The teaching strategies of both experiments were based on interactive engagement. Since the data were collected and processed manually in the conventional ticker-timer experiment, only two types of motion (i.e. constant velocity and accelerated motion of a trolley moving away from the origin), could be analysed during the two afternoons available. Furthermore, certain kinematic graphs cannot be studied with the aid of the ticker-timer experiment, namely, graphs of reversing motion and stationary objects. The computer-based experiment had the disadvantage that measuring and data processing skills were not practiced, but the benefit that a large variety of motions could be demonstrated and discussed. These differences in the methods explain why the ticker-timer experiment was found to be more effective in teaching basic kinematics concepts, whilst the computer-based experiment improved understanding and accomplished higher-level outcomes. This is in accordance with the assertion of Redish *et al.* (1997) that microcomputer-based laboratories can be effective in helping students build conceptual understanding, but do not provide a complete solution to the problem of building a robust and functional knowledge for many students. In computer-aided methodology care should therefore be taken that the basic concepts are established before more advanced situations are dealt with. In the current situation it is recommended that the conventional ticker-timer experiment be used first to establish basic concepts. The same motions can then be repeated by means of the computer to ensure trust in the new method. Thereafter a variety of motions can be studied to enhance understanding and insight.

The study showed that computer-based demonstrations are not necessarily more effective than conventional demonstrations in the teaching of science. Learners who are not acquainted with computers can be distracted and inexperience of educators can decrease the learning gains. As acquaintance and experience with computers grow and learners' focus shifts towards the investigation, the effectiveness of computer-based activities should increase, as stated by Thornton and Sokolof (1990). As apprenticeship education of instructors is turned into experienced usage of computer technology, higher learning gains can be expected (Hake, 1998b). The use of a computer as a teaching aid requires knowledge, skills and experience in utilizing specific software packages and appropriate teaching strategies (Sokolof & Thornton, 1997). The outcomes and teaching strategy of computer-assisted education differ from other methods, because of features such as real-time feedback and "what if" inquiries (the possibility to explore a variety of ideas). Attention should be paid to it in teacher training programmes, as the role of computers in South African education is expected to increase dramatically in the next decade.

Computers, peripherals (such as the motion detector), and accompanying software are expensive and have to be maintained and upgraded regularly. Therefore, before any huge expenses are incurred, educators should be computer-literate and trained to use the apparatus effectively so that they are in a position to train the learners. Apart from improving learning, exposure to the usage of computers in their classrooms can be the first step towards computer literacy of the learners. In this way the computer can become an effective tool in the teaching and learning of science and other subjects.

References

Bransford,JD, Brown AL & Cocking RR (eds) 2000. *How people learn: Brain, mind, experience and school*. Washington: National academy press.

Duit R 1983. Some methods for evaluating the meaning of concept names. In: Helm & Novak (eds). *Proceedings of the international seminar on Misconceptions in Science and Mathematics*, June 20-22, Cornell University, Ithaca, USA.

Hake RR 1998a. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66:64-74.

Hake RR 1998b. *Interactive-engagement methods in introductory mechanics courses*. [Online] Available url: http://www.physics.indiana.edu/~sdi/IEM-2b.pdf

Hake RR 2002. Assessment of student learning in introductory science courses. *2002 PKAL Roundtable on the future: Assessment in the service of student learning*. Duke University. [Online] Available url: <http://www.pkal.org/events/roundtable2002/papers.html>.

Halloun IA & Hestenes D 1985. Common sense concepts about motion. *American Journal of Physics*, 53:1056-1065.

Howie SJ 1997. Mathematics and Science Performance in the Middle School Years in South Africa. A Summary Report on the Performance of South African Students in the *Third International Mathematics and Science Study* (*TIMSS*). Pretoria: Human Sciences Research Council.

Howie SJ 2001. Mathematics and Science Performance in Grade 8 in South Africa 1998/1999. An executive summary on the performance of South African students in the *Third International Mathematics and Science Study Repeat (TIMSS-R)*. Pretoria: Human Sciences Research Council.

Lawson DA & Tabor JH 1997. Computer-based experiments in mechanics. In: Houston SK, Blum W, Huntley ID & Neill NT. *Teaching and learning mathematical modelling: innovation, investigation and applications*. Chichester: Albion.

Lemmer M 1999. First-year university students' conceptions of time and space in Physics. PhD thesis, Potchefstroom: North-West University.

Lemmer M, Lemmer TN & Smit JJA 2003. South African students' views of the universe. *International journal of science education*, 25:563-582.

McDermott LC, Rosenquist ML & Van Zee EH 1987. Student difficulties in connecting graphs and physics: Example from kinematics. *American Journal of Physics*, 55:503-513.

McKinney WJ 1997. The educational use of computer based science simulations: some lessons from the philosophy of science. *Science and education*, 6:591-603.

Molefe NPJ 2004. A comparison of the effectiveness of the conventional and computer-based methods in kinematics. MEd dissertation. Potchefstroom: North-West University.

Nkopodi N 1998. Language and conceptual change strategies in Physics teaching. PhD thesis. Johannesburg:Witwatersrand University.

Rademeyer A 2004. In 2013 moet alle skole kan 'e'-leer. *Beeld*, February 9.

Redish EF, Saul JM & Steinberg RN 1997. The effectiveness of active-engagement computer-based laboratories. *American Journal of Physics*, 65:45-54.

Rollnick M & Rutherford M 1990. African primary school teachers - what ideas do they hold on air and air pressure? *International journal of science education,* 12:101-113.

Rowand C 2000. Teacher use of computers and internet in public schools. *Education statistics quarterly: elementary and secondary education*, United States Department of Education. [Online] Available url: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2000090.

Smerdon B, Cronen S, Lanahan L, Anderson J, Iannotti N, Angeles J & Greene B 2000. *Teachers' tools for the 21st century: a report on teachers' use of technology*. Washington: United States Department of Education, National Center for Education Statistics.

Sokoloff DR & Thornton RK 1997. Using interactive lecture demonstrations to create an active learning environment In: Redish EF & Rigden JS.The changing role of physics departments in modern universities. *Proceedings of ICUPE*, 1996, 1061-1074.

South African Department of Education 2000. 2000 School register of needs database. Pers. comm.

Statistical consultation service 1991. *Praktiese statistiek vir die geesteswetenskappe*. (Practical statistics for the humanities). Potchefstroom: North-West University.

Thornton RK & Sokoloff DR 1990. Learning motion concepts using real time computer-based laboratory tools. *American Journal of Physics*, 58:858-867.

Thornton RK & Sokoloff DR 1998. Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, 66:338-35.

Thijs GD & Van den Berg E 1995. Cultural factors in the origin and remediation of alternative conceptions in physics. *Science and education*, 4:317-347.

TIMSS 1995. *Third International Mathematics and Science Study*. [Online] Available url: http://timss.bc.edu.

TIMSS-R 1999. *Third International Mathematics and Science Study — Repeat.* [Online] Available url: http://timss.bc.edu.

Trowbridge DE & McDermott LC 1980. Investigation of student understanding of the concept of velocity in one dimension. *American Journal of Physics*, 48:1020-1028.

Trowbridge LW, Bybee RW & Powell JC 2004. *Teaching secondary school science: Strategies for developing scientific literacy*. 8th edn. New Jerey: Pearson Education.

Wellington J 1999. Multimedia in science teaching: friend or foe? *Physics Education*, 34:351-359.

White RT 1989. *Learning science*. Oxford: Basil Blackwell.

White RT & Gunstone R 1992. *Probing understanding*. London: The Palmer Press.