The effectiveness of science videos as a supplementary aid for students rewriting the Senior Certificate *Physical Science* examination

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For the Degree of Masters of Science by coursework and research report.

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DECLARATION

I declare that this research report is my own, unaided work, apart from the assistance acknowledged. It is being submitted in partial fulfilment for the degree of Master of Science in the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination at any other University.

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19 January 2009.

ABSTRACT

This study investigated how successful videos were as a supplementary aid when watched in the same way as a television broadcast, for students rewriting the Senior Certificate *Physical Science* examination. It also aimed to identify strengths and weaknesses of these videos from both an educational perspective and from the perspective of the students.

A pragmatic design was used, and data was collected in two stages. The bulk of the data was collected during the first stage when a quasi-experiment that used a “pre- and post-test” design was performed. Three topics were investigated, namely *electrochemistry*, *acids and bases* and *titrations*. The relative improvement in the post-tests by the treatment group (who watched the videos) compared to the control group (who did not watch the videos) was evaluated. Additional data about students’ reactions to the videos was collected using questionnaires and by observation. The data gathered was triangulated during the second stage of the study when the videos were reviewed.

The results obtained from the quasi-experiment showed there was no significant difference in the mean scores obtained for the tests by either group. Differences were detected, however, in the way individual questions were answered by the treatment group. Large gains were made in the post-tests for a fifth of the test questions (6 of the 30); however, about one eighth of the questions (4 of the 30) were answered incorrectly.

The use of analogies was one aspect that was considered to have helped students answer questions successfully, and they were used to explain the theory for half these questions (3 of the 6). Two of these analogies made links to simplified versions of the science. In one instance, the science had been simplified by using vocabulary from the analogue in place of scientific vocabulary, and in the other, the scientific concepts themselves had been simplified. For the majority of the questions (5 of the 6) the use of anthropomorphic and teleological explanations to describe chemical characteristics was considered to have aided students’ recall of these analogies and of the theory. The exposure to tutorial questions in the videos could also have helped students answer these questions successfully.

Of the questions that were incorrectly answered, half (2 of the 4) of the wrong choices could have resulted from oversimplified explanations coupled with inappropriate or inadequate use of scientific terminology in the videos. The incorrect answers to the remaining questions probably resulted from students’ misinterpretations of the visual footage and accompanying verbal text.

From the students’ perspective, a large percentage (over 80%) reported that the language used by the video presenter was acceptable, and the majority (70%) stated that the explanations used were “very good”. Just over one third (36%) cited the quality of the explanations as being their reason for choosing these videos in preference to other videos. However, some students (28%) commented that they were confused about specific aspects of the information presented. Anecdotal evidence collected during the study supported their comments, and showed that aspects of the footage in the videos were not understood.

DEDICATION

This research report is dedicated to my father who was at once my hero, my mentor, and my champion; and to my mother whose dogged determination to triumph over adversity still continues to inspire me.

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CHAPTER 1
BACKGROUND TO THE PROBLEM AND CONTEXT OF THE STUDY

This study focused on how successful a locally produced and commercially available series of science videos was at improving the performance of Grade 12 *Physical Science* students who watched them in the same way as a television broadcast. The motivation for doing this was to establish some of the strengths and weaknesses of this medium as a possible method of improving students' academic performance in the Senior Certificate *Physical Science* examination. The topics concerned were *"electrochemistry"*, *"acids and bases"* and *"titrations"*.

The study had three thrusts. Firstly, it investigated whether the videos helped a group of Grade 12 students improve their performance on tests. Secondly, it examined the strengths and weaknesses of the videos, and finally it investigated students' responses to the videos.

This chapter deals with the background to the study, including the problems which motivated the research, and the context of the study. A brief description of the videos under investigation along with a résumé of their use in South Africa is given. The aims of the study are made explicit at the end of the chapter.

1.1 BACKGROUND TO THE PROBLEM AND MOTIVATION FOR THE STUDY

Since independence in 1994 science has assumed a pivotal role in the South African government's strategy to improve economic growth, global competitiveness and social upliftment. The cornerstone of this strategy involves developing a national skills base in science from school level upwards. The government's commitment to this can be seen in the interlocking and sequential policies set out in the White Paper on Education and Training, the White Paper on Science and Technology and in the policy documents about the National System of Innovation (The Department of Arts, Culture, Science and Technology, 1996).

According to several reports (for example, see Walberg, 1991; Fedderke, 2001; Fukuda-Parr, 2001), science is important because typically scientifically skilled individuals manage technology, initiate technological advancements, and encourage innovation. The correlation between technological change and economic growth is so strong that in 1990 the Organisation of Economic Cooperation and Development issued a declaration stating that "*technological change was a fundamental source of economic growth"* (The Department of Arts, Culture, Science and Technology, 1996:12). Subsequently several member countries, including South Africa, placed science at the forefront of their development strategies. For example, the White Paper on Science and Technology states that *"(s)cience and technology (S&T) are considered to be central to creating wealth and improving the quality of life in contemporary society"* (Department of Arts, Culture, Science and Technology, 1996:11).

1.1.1 The importance of *Physical Science* to economic growth, individual development and social upliftment

Improving the national scientific skills base is likely to have numerous benefits for South Africa. The economy is expected to benefit in three ways: Firstly, increased scientific literacy ensures meaningful public participation in scientific, ecological and environmental debate, and this ensures that sustainable growth strategies are adopted (The Department of Arts, Culture, Science and Technology, 1996; Fukuda-Parr, 2001). Secondly, an educated and skilled workforce is more likely to attract foreign investment, according to the World Competitiveness Yearbook (Sergeant, 2007). Thirdly, technological adjustments and advances introduced by scientifically skilled individuals are likely to optimise production or spawn new products that will generate wealth not only for the associated business but also for the country.

Individuals are also likely to benefit from increased scientific skills. Firstly, individuals who join the workforce with a Senior Certificate pass in *Physical Science* are expected to have more opportunities for personal advancement as studies have shown that better educated workers tend to acquire skills more quickly (Fukuda-Parr, 2001). Secondly, individuals who pass Senior Certificate *Physical Science* on Higher Grade are more likely to go on to study at a tertiary institution according to Cosser (2006). He traced 1,610 Grade 12 students and found that 88% of the sample who had passed the Senior Certificate *Physical Science* on Higher Grade in 2002 had gone on to study at a tertiary institution the following year compared with just 65% of those who had Higher Grade passes in *Geography*. Thirdly, individuals who graduate from tertiary institutions with qualifications in science, engineering and technology tend to find jobs more easily and at higher salaries than their unqualified counterparts (The Department of Arts, Culture, Science and Technology, 1996). They also tend to be more adaptable and are thought to be able to apply their skills to new forms of employment, and are thus less likely to be unemployed (The Department of Arts, Culture, Science and Technology, 1996).

The family unit of scientifically skilled workers benefit because of the increased income and also because there are positive knock-on effects in terms of upgrading the skills of these workers' family members. In the short term, according to Cosser and du Toit, (2002), who conducted a survey of Grade 12 students across South Africa to probe their career aspirations, students were more likely to want to attend a tertiary institution if an older sibling had already done so. In the long term Louw, van der Berg and Yu, (2006), who used the information in the national censuses carried out between 1970 and 2001 to track the social mobility of South Africans, found that individuals with higher salaries tended to provide additional educational opportunities for their children.

Finally, all members of society benefit, not only because increased production means increased wealth that ultimately filters down to all members of society but also because the technological advances introduced may have the effect of reducing poverty, eliminating disease, *"improving health and nutrition, expanding knowledge, stimulating economic growth"* which allows people to *"enjoy a better standard of living, participate more in their communities and lead more creative lives"* (Fukuda-Parr, 2001:27).

1.1.2 The contribution of technology to economic growth in South Africa

Technology has played an increasingly important role in economic growth in South Africa over the last three decades, according to Fedderke (2001), who disaggregated economic growth into three components, namely capital investment, labour and technology. Fedderke reported that technology made a negligible contribution to growth in the 1970's, a weak contribution in the 1980's and finally a strong contribution in the 1990's, when it was the single biggest contributor. Fedderke explains that these findings indicate that technological changes implemented in the 1990's enabled the South African economy to use its existing capital and labour inputs more efficiently. He states that this fact alone is expected to increase capital investment in the country and so create more employment opportunities. Fedderke's findings also lend support to the government's strategies for increasing economic growth through the process of investing in science. He recommends:

- increasing the number of science and engineering graduates, as these graduates contribute significantly to economic growth.
- expanding and developing technology in niche areas indigenous to South Africa such as mining, crop development, and coal-based fuels, as these technologies are fundamental to maintaining global competitiveness.

1.2 STATEMENT OF THE PROBLEM

South Africa's ambitions to develop a vigorous and expansive science base have yet to come to fruition. The problems involved in achieving this goal are multifaceted and to a large extent interdependent, and they give rise to a number of symptoms, the most damaging of which is that the government's targets for economic growth and hence social upliftment will not be met (National Treasury, 2003). Four facets of this problem are discussed in this section.

1.2.1 South Africa's science base is weakening

In 2001 South Africa was ranked as a "dynamic adopter", along with countries like India and Brazil, in the Human Development Report of 2001 issued by the United Nations Development Program (Fukuda-Parr, 2001). "Dynamic adopters" are countries that have a workforce that is competent enough technically to adopt and adapt existing technology, without necessarily having the capacity to generate indigenous technology. In the Human Development Report of 2001, 167 countries were ranked using a "technological achievement index" that was calculated using national statistics about factors such as science achievements, power consumption and telephone coverage. Analysis of the scientific data used to rank South Africa as a "dynamic adopter" in this report reveals that much of it was collected in the mid-1990's. According to Fedderke (2001), towards the end of the 1990's many of these statistics had weakened resulting in slower than expected growth in South Africa over this period compared to other countries with similar resources and listed as "dynamic adopters" in the Human Development Report of 2001. Fedderke attributes this slower growth to South Africa's inability to exploit technological opportunities. According to Kraak (2004:62), who investigated human development in South Africa, this inability to exploit opportunities stems from the fact that South Africa does not have a *"dynamic and fast-growing science base to support innovation"*. While retirement and emigration contribute to the weakening science base, there are also insufficient numbers of new recruits (Kraak, 2004). For the country to operate ideally Kraak (2004) recommends that the science base be increased to levels in excess of the immediate requirements as this will ensure that the economy can draw on a pool of skilled personnel and so exploit any rapid growth opportunities that may arise in the future. To generate this science base South Africa needs to improve the number of students who pass Senior Certificate *Physical Science* on Higher Grade. This subject is a gateway subject that enables students to follow careers in scientific fields such as physics, chemistry, biology, and geology, and also in applied science fields such as engineering, medicine, agriculture and technology.

1.2.2 Performance on the Senior Certificate *Physical Science* examination remains unsatisfactory

Registrations for Senior Certificate *Physical Science* more than doubled during the seven-year period from 1991 to 1998, and although the numbers of students passing on Higher Grade increased, the growth rate was not maintained. In 1991, 27% of students who wrote Senior Certificate *Physical Science* passed on Higher Grade compared to just 17% in 1998. Since 1998 the Higher Grade pass rate, when expressed as a percentage of those writing, has never matched the percentage attained in 1991. Data for 1991 and 1998 are given in Table 1, along with information about the following seven years.

Table 1: Higher Grade passes for Senior Certificate *Physical Science* examinations, by year

Year	Total Writing	Students passing on Higher Grade	Higher Grade passes expressed as a percentage of those writing
1991	70,000	18,800	27
1998	157,000	26,700	17
1999	161,000	24,200	15
2000	164,000	23,300	14
2001	154,000	24,300	16
2002	154,000	24,900	16
2003	152,000	26,100	17
2004	161,000	26,700	17
2005	182,000	30,000	16

Sources: Department of Education (2005, 2006), Van der Berg (2004) and Kahn (2005)

Perusal of the final column in Table 1 reveals the underlying problem: an initial drop, and then a persistent lack of improvement in the Higher Grade pass rate. Since 1998 the number of Higher Grade passes has remained almost constant with less than 20% of all those attempting Senior Certificate *Physical Science* passing on Higher Grade. Reddy (2005) suggests that one reason for this lack of improvement may be that fewer physical science students register on Higher Grade thereby restricting the number of possible passes at this level. In 1997, 51% of all students writing Senior Certificate *Physical Science* were registered on Higher Grade compared to only 34% in 2001. Reddy suggests that many students who write on Standard Grade may have been able to pass on Higher Grade, but no statistical data to support or refute this claim could be located.

The lack of improvement in the percentage of students passing Senior Certificate *Physical Science* on Higher Grade is a source of concern, and when the results are disaggregated into various subsets such as provinces, individual school performances, and race, alarming disparities are observed. In short, the Higher Grade *Physical Science* pass rates of the various subsets support the contention that education in South Africa is not equal (Van der Berg, 2004; Kahn, 2005; Reddy, 2005).

- Firstly, ***predominantly urban provinces outperform predominantly rural provinces*** by a large margin. Consider the 2005 Senior Certificate *Physical Science* examination results listed in Table 2. Western Cape and Gauteng, which are predominantly urban provinces, performed significantly better than the rest (32% and 25% of the students writing Senior Certificate *Physical Science* in these provinces passed on Higher Grade, respectively). Students writing Senior Certificate *Physical Science* in the predominantly rural provinces of Eastern Cape, Mpumalunga, North West, Limpopo and KwaZulu-Natal were much less successful at achieving Higher Grade passes. In these provinces pass rates on Higher Grade ranged from 13% to 16% of the total number of students writing Senior Certificate *Physical Science*. Of all the provinces, the Eastern Cape's performance on Higher Grade was the worst with only 6% of the students writing Senior Certificate *Physical Science* in that province managing to secure a Higher Grade pass. The percentage of students who did not manage to pass *Physical Science* on either Higher Grade or Standard Grade in rural provinces is also deplorable, and nearly half of all the candidates that wrote in the Eastern Cape, Mpumalanga and Limpopo fell into this category. North West and KwaZulu-Natal provinces fared little better, with 44% and 46% falling into this category respectively. The problem with poor pass rates is compounded by the fact that these five provinces accounted for nearly 70% of all students writing Senior Certificate *Physical Science* in 2005. In total 78,196 students failed to get either a Higher Grade or Standard Grade pass for Senior Certificate *Physical Science* and of these 60,482 (or 77%) were schooled in predominantly rural provinces. The remaining two provinces, namely Northern Cape and Free State, are very sparsely populated and so are difficult to classify as either urban or rural provinces. The slightly higher than average pass rates in these two provinces are usually attributed to the increased funding available per student, as student numbers are low (National Treasury, 2005).

Table 2: Pass and failure rates for Senior Certificate *Physical Science* examinations in 2005, by province

Province	Total Wrote	Higher Grade passes	Percentage students passing on		Percentage students passing on LG or failing
			HG	SG	
Eastern Cape	26,684	1,641	6,1	44,2	49,7
Mpumalanga	14,575	1,846	12,7	37,5	49,9
North West	13,639	1,803	13,2	42,5	44,3
Limpopo	27,335	4,246	15,5	34,9	49,6
KwaZulu-Natal	44,021	6,341	14,4	39,3	46,3
Free Sate	8,687	1,800	20,7	47,7	31,6
Northern Cape	2,048	379	18,5	50,8	30,7
Gauteng	32,242	7,941	24,6	40,4	34,9
Western Cape	12,597	3,968	31,5	44,1	24,4
Totals	181,828	29,965			

Sources: Department of Education (2006); National Treasury, (2006)
HG = Higher Grade
SG = Standard Grade
LG = Lower Grade

- Secondly, ***a small minority of schools outperform the rest***. Although specific information about different schools' performance on Senior Certificate *Physical Science* is not available, it is possible to get an indication of schools' performance in this subject by analysing the Senior Certificate *Mathematics* results. According to Reddy (2005), over half the students who take Senior Certificate *Mathematics* also take Senior Certificate *Physical Science* and there is good correlation between performances in both subjects. Taylor (2006) disaggregated the 2004 Higher Grade passes for Senior Certificate *Mathematics* and found that in that year 10% of the schools generated 75% of the Higher Grade *Mathematics* passes. Of the remaining schools, the majority (80%) produced just 11% of the Higher Grade *Mathematics* passes.

- Thirdly, ***black students are underrepresented at Higher Grade*** in the Senior Certificate *Physical Science* examination. Perry and Fleisch (2006) disaggregated the Higher Grade results for the 2001 examination and found that black students accounted for only 29% of Higher Grade passes. Four years later, in 2005, this figure had only marginally improved, to 30% (Walwyn, 2006). Since over 75 % of South Africa's population is black, by accounting for only 30% of the Higher Grade passes, this percentage is considerably less than their demographic proportion.

While Higher Grade passes in Senior Certificate *Physical Science* are often cited by educators, policy makers and politicians to indicate attainment in science, or the health of the education system, students who do not have Higher Grade passes are not necessarily excluded from studying science, engineering and technology courses at tertiary institutions. Tertiary institutions' entrance requirements are sometimes listed on both Higher Grade and Standard Grade. Table 3 lists the entry requirements regarding Senior Certificate *Physical Science* for selected courses at four tertiary institutions in South Africa. The minimum entrance requirement in Table 3 is either an E on Higher Grade or a D on Standard Grade. It must be noted that students meeting Higher Grade requirements are usually given preference at tertiary level so a Standard Grade pass may well be career limiting.

Table 3: Entrance requirements for Senior Certificate *Physical Science* to gain admission into science, engineering and technology courses at four South African tertiary institutions in 2007

	Qualification	University of the Witwatersrand	University of Johannesburg	University of Cape Town	Tshwane University of Technology
National Diplomas	Chemistry		HG (D) or SG (B)		HG (E) or SG (D)
	Biotechnology		HG (D) or SG (C)		HG (E) or SG (D)
	Engineering		HG (D) or SG (B)		HG (D) or SG (C)
Degrees	BSc Science	Not specified	HG (C)	HG (C)	
	BSc Engineering	HG (C)	HG (C)	HG (C)	
	MB BCh Medicine	HG (A)			

Source: Yearbooks associated with each institution
HG = Higher Grade
SG = Standard Grade

1.2.3 South African science teachers are often under-qualified or inexperienced

Many of the disparities that arise between schools are due to differences in the qualifications and experience of teachers. Arnott and Kubeka (1997), who analysed information obtained for mathematics and science teachers from the 1995 national teacher audit, found that only 42% of science teachers at the time were qualified. Just over half of these met the minimum qualification requirement, namely matriculation plus a three-year education diploma specialising in science, and less than 25% had passed science subjects (chemistry or physics) at second year or higher at university. They also found disparities between the provinces, with Kwazulu-Natal having the smallest percentage of qualified science teachers (19%) and Gauteng having the largest percentage (62%). Science teachers in Gauteng were also more highly qualified, with 40% of them having at least two years of training at university in science. The average number of years of teaching experience was found to be low in the 1995 survey, with about 40% of the science teachers having less than two years teaching experience and only 35% having more than five years.

Current information about the qualifications of science teachers specifically is not available, but Crouch and Perry (2003), who compiled a report on teachers for the 2003 Human Development Report, quoted statistics that claimed the number of unqualified teachers had declined, from 36% in 1994 to 22% in 2000. The National Treasury (2004) used the Department of Education's Personnel Salary System (PERSAL) records to establish whether teachers were under-qualified and reported that in 2002 only 16% of all teachers were under-qualified. Crouch and Perry (2003) also reported that more teachers in urban areas had upgraded their qualifications than rural ones and surmised that this was probably due to the fact that urban teachers had easier access to learning centres.

Updated information about the experience of science teachers is also not available, but indications are that the situation has not improved. According to the National Treasury (2006:20) *"there is still a problem with the retention of existing mathematics and science teachers and the training of new mathematics and science teachers"*. Rural and township schools were singled out in this report as being the most vulnerable to science teacher attrition. Couch and Perry (2003) speculate that highly qualified teachers living in urban areas leave the profession to take up more lucrative positions in the industrial or commercial sector.

There are many parallels between teachers with limited content knowledge and those with limited teaching experience and neither group is expected to teach effectively. Insufficient content knowledge poses a *"significant barrier to effective teaching",* according to Tobin and Garnett (1988:207), who reported on case studies of 26 science teachers in Australia. They found that four teachers in their study had insufficient content knowledge and this resulted in these teachers being *"unable to focus student thinking, unable to provide appropriate feedback to students, and unable to discuss effectively the content dealt with in different classroom environments"* (Tobin and Garnett,1988:207). Harlen (1997), who investigated the teaching strategies used by primary school teachers with limited content knowledge, found that they coped by avoiding difficult content, focusing instead on those areas of the course in which they had more confidence, (for example, teaching more physics than chemistry) and by using a transmissive teaching style, by avoiding discussions, and by using only simple activities. Similar findings have been reported in South Africa. For example, Hewlett (1996), who interviewed 15 English second-language university students about their prior learning experiences at school, found that the main vehicle of content delivery was via transmissive teaching, copying notes from the blackboard, and reading the textbook.

Limited teaching experience also hampers the effectiveness of teachers, as the specific teaching skills required to transform content knowledge into an effective teaching strategy (known as pedagogical content knowledge) are complex and improve with experience. They are only successfully internalised with the practice of teaching, often requiring two to four years teaching experience (Moran, 1990; Veal, 2004; Grant, 2006; Liston, Whitcom, and Borko, 2006). Hogan, Rabinowitz, and Craven, (2003) re-examined several studies published in the 1980's and 1990's on the differences between novice and experienced teachers. For their analysis they used the domains described by Shulman (1986) – namely content knowledge, pedagogical content knowledge and pedagogical knowledge – and found the following general features of novice teachers: They taught in a regulated way using detailed scripts from which they tried to deviate as little as possible; they used fewer alternative teaching strategies; they were less likely to link lessons to previous or future lessons; and they tended not to recognise or integrate students' prior knowledge. Other researchers (Elbaz, 1983; Meyer, 2004) found that novice teachers' content knowledge was often poorly organised and this was reflected in their lessons, which tended to be poorly structured.

Hogan *et al.* (2003) point out that the main disadvantage of teachers with limited experience is that their focus in lessons tends to be centred on themselves (and not on what they are doing or on the students). Tobin and Garnett (1988) reported similar findings, noting that teachers with limited content knowledge avoid focusing on students' experiences in the classroom. As a result, opportunities to interrogate the students' understanding of the concepts are lost and consequently learning is expected to be of a poorer quality.

1.2.4 Teacher absenteeism is commonplace in South African schools

According to Taylor (2006), who investigated school reform in South Africa, 85% of schools have problems with teacher absenteeism, and every year several teaching days are lost. Although teacher absenteeism is often due to non-work related health issues, according to Hall, Altman, Nkomo, Peltzer, and Zuma, (2005), who investigated wellness issues associated with South African teachers, teachers increasingly cite stress relating to working conditions, particularly discipline problems in schools, as their reason for absenteeism. In a recent case study of three rural schools, Arenstein and Mhungwana (2004) reported that discipline problems arose because of students' poor attitude to school which resulted from students' perceptions that even a matric exemption will do little to improve their future prospects. The knock-on effect of these discipline problems, according to Arenstein and Mhungwana, is teacher demotivation and apathy. While these absences most commonly result from issues regarding teacher wellness, they can also arise because of industrial action. In 2007, industrial action on the part of teachers resulted in over three weeks of missed schooling. One consequence of teacher absenteeism is that students are unable to complete the syllabus and this limits students' chances of success in the final examination.

Science videos offer an alternative way for students to catch up missed material and they have the added advantage of not involving the teacher in working additional hours. This option may be particularly attractive to teachers' unions who argue that their members should not be required to work additional hours to catch up work missed during valid periods of teacher absence. For example, in 2007 teachers were asked to work additional hours on weekends to catch up work missed as a result of their industrial action. Although the teachers' union successfully managed to negotiate payment for this extra work, the recovery plan was not successfully implemented at all schools (South African Democratic Teachers Union, 2007).

1.2.5 Summary

One of the pivotal factors hindering South Africa's ambitions to develop a vigorous and expansive science base is the quality of instruction that students receive in *Physical Science*. Since many teachers are inexperienced or inadequately qualified, they are less likely to be effective, which impacts on both teachers and students. Teachers are less likely to enjoy their lessons and this causes their motivation and confidence to wane and this may lead to absenteeism or resignations (Arenstein and Mhungwana, 2004; Hall *et al.* 2005). Students are similarly affected: they get poor marks because the instruction is inadequate, which demoralises and demotivates them, so a destructive cycle of failure results.

1.3 THE SCIENCE VIDEOS UNDER INVESTIGATION

One possible method of improving access to quality science instruction in the short term would be to supplement teachers' input with science videos produced specifically for the South African market by an experienced science teacher.

1.3.1 Development and use of these science videos

The science videos under investigation evolved from a series of lectures designed to help Grade 12 students cram for their Senior Certificate *Physical Science* examinations. The lectures were inaugurated in the 1970's and took place on Saturdays using lecture theatres on the University of the Witwatersrand campus. As the popularity of the lectures increased, larger venues were used, and by the 1980's the University of the Witwatersrand's Great Hall was being used as the lecture venue. Towards the end of the 1980's the possibility of taping these lectures and broadcasting them on television was mooted. By October 1990, videos on selected aspects of the *Mathematics* and *Physical Science* matric syllabi were being broadcast by the national broadcaster, the South African Broadcasting Corporation (SABC), under the "Exam Aid '90" banner with the aim of helping Grade 12 students cram for their final examinations (Makobane, 1990). Since the videos were first broadcast they have been refined and expanded to include the core aspects of the Senior Certificate *Physical Science* syllabus. Although the videos were broadcast on television for a number of years, they were later replaced with live, interactive broadcasts where tutorial and examination questions were solved. The videos are still available commercially and continue to be marketed to schools throughout South Africa. They have recently been converted to DVD format. The videos have also been broadcast by the national broadcasters of both Botswana and Zimbabwe, and also on TV Africa, a satellite television station that broadcasts in seven other African countries. According to promotional material associated with the videos, they have been viewed by an estimated 20 million viewers (Nkambule, 2001).

1.3.2 A brief overview of the videos

The complete set of *Physical Science* videos takes approximately 65 hours to view, and covers the core Senior Certificate *Physical Science* syllabus. A "taped-lecture" format is used in the videos. Bork (1995), who investigated the effectiveness of various types of educational media used in distance education, recommends that this label should be used to describe any video where the contents resemble a lecture. They often have "talking-head" footage and may include footage of lecture notes, practical work, demonstrations and other teaching-related activities such as educational excursions. According to the promotional literature for the videos, the essential theory for each topic is covered, along with hints for the examinations as well as common examination questions.

1.4 AIM OF THE RESEARCH

The aim of the research was to evaluate the impact the videos had on learning when viewed in the same way as a television broadcast and to determine some of the strengths and weaknesses of the videos.

1.5 RESEARCH QUESTIONS

The research sought to establish the answers to the following questions:

1. To what extent did the students' performance change after watching supplementary videos on the selected topics?
2. What were the strengths of the videos in terms of helping students to improve their performance? This question was answered by addressing the following sub-questions:
   (a) To what extent did students answer questions more successfully after watching the videos?
   (b) What were some of the possible reasons that these questions were answered more successfully?
3. What were the weaknesses of the videos? This question was answered by addressing the following sub-questions:
   (a) To what extent did students answer questions less successfully after watching the videos?
   (b) What were some of the factors that may have led to this poor performance?
4. How did students who were representative of the target audience react to the videos?

1.6 CONCLUDING REMARKS

In this chapter the important role that science is expected to play in South Africa's future economic growth and social development was discussed. Reasons for the current weakening of the national science base were outlined and problems associated with the persistent lack of improvement in the percentage of students passing Senior Certificate *Physical Science* on Higher Grade were identified. Of these, the problems of inexperienced and inadequately-qualified science teachers, as well as teacher absenteeism could be tackled in the short term by supplementing teachers' input with videos containing taped-lectures presented by a successful and experienced teacher. The next chapter outlines the advantages of using taped-lectures and gives the framework used to evaluate educational videos.

CHAPTER 2
ANALYSIS OF TAPED-LECTURES: A CONCEPTUAL FRAMEWORK

2.1 WHAT IS A "CONCEPTUAL FRAMEWORK" AND WHY IT IS REQUIRED?

A "conceptual framework"[1] is a collection of concepts, theories or constructs that defines the parameters of the study. Such frameworks are derived from both research and theories (Lederman, 2006). Such frameworks serve two broad purposes: firstly, they enable researchers' perspectives and values to be made explicit and secondly, they dictate how a study will be conducted. According to Mishra and Koelher (2006:1039), conceptual frameworks play

> *"an important role by guiding the kinds of questions that we can ask, the nature of evidence that is to be collected, the methodologies that are appropriate for collecting this evidence, the strategies available for analysing the data, and finally, interpretations that we make from this analysis."*

According to Mishra and Koelher (2006), a conceptual framework achieves this in three ways. Firstly, by providing the historical background against which the current study is situated, this narrows the focus of the research and enables researchers to identify and interrogate the pertinent issues only, ignoring the rest. Secondly, by identifying the relevant concepts and theories[2] associated with the phenomena being researched. This allows researchers to make predictions about the phenomena that they are researching, and to link their findings to each other and to existing classification schemes. Finally, by identifying different variables and relating them to the phenomena being investigated and by providing additional vocabulary where necessary. So a conceptual framework *"not only helps us identify phenomena in the world, but it also gives us a language to talk about it"* (Mishra and Koelher, 2006:1044). From the readers' perspective, a conceptual framework should persuade readers that the study has been carried out in an appropriate manner.

This chapter is divided into two sections, the first gives the historical background to educational videos and discusses some of their advantages, and the second discusses the pertinent aspects of videos, teaching and science and introduces a number of concepts, theories, and vocabulary.

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1 A "conceptual framework" is also commonly called a "theoretical framework" (for example, Lederman, 2006, uses these two terms synonymously). Since the term "theoretical framework" can be confused with the term "theoretical perspective" (see Footnote 5 for an explanation of this term), and because some people think theoretical frameworks can deal only with theories, only the term "conceptual framework" will be used in this research report.

2 According to Perla and Carifio (2009), in educational research these concepts and theories may be little more than expectations or hunches as social science research often involves theory-forming rather than theory-testing.

2.2 EDUCATIONAL VIDEOS

2.2.1 Historic perspectives and current trends in educational videos

Educational videos have a long and chequered history: their origins lie in the instructional films of the early part of the twentieth century and taped-lectures that were broadcast in the 1950's in the United States of America shortly after the advent of television. According to Becker (1987), who investigated the history of educational television in the United States of America, instructional films tended to follow documentary formats and often had dramatic storylines similar to those found on radio, the educational medium that preceded instructional film. The films were commercial ventures undertaken by large educational publishing houses such as Encyclopaedia Britannica, McGraw-Hill, and Oxford, and to be economically viable they needed customer appeal.

In contrast to this, the taped-lectures on mathematics and science that were broadcast in the United States of America in late 1950's were hastily prepared and, since they were government funded, did not need to be economically viable. They were conceived in a knee-jerk reaction to the launch of the Russian spacecraft Sputnik and their aim was to *"quickly educate masses of students"* (Becker, 1987:39). The hope was that these taped-lectures, together with other curriculum reforms at the time, would help the United States regain its footing as a world leader in science and technology. The taped-lecture format was selected instead of the documentary format used in instructional films not only because it was time- and cost-effective but also because the programmes were produced and presented by a panel of university professors. Becker (1987) suggests that taped-lectures must have seemed the natural choice to these professors as they had excellent content knowledge and considerable lecturing experience but had limited pedagogical knowledge with respect to high school students and almost no knowledge of media design, or theatrical expertise. The resulting programmes were considered boring and ineffective, a criticism that is still associated with taped-lectures today (Kent and McNergney, 1999).

Since the 1950's many other genres of educational videos have emerged, such as game shows, historic re-enactments, discussions and demonstrations (Groundwater-Smith, 1990) and many special filming techniques have developed such as close-ups, time-lapse photography, slow motion, animation, and simulations, and a number of technical developments have also taken place. According to Bates (1988) the introduction of the video cassette recorder in the 1970's meant that programmes no longer had to be viewed at fixed broadcast times; they could be taped, stored and viewed at a convenient time and place. Production costs also decreased significantly so educational videos could be produced privately and marketed directly to customers (Bourdeau and Bates, 1996). The "digital video disk" (now known as "digital versatile disk" or DVD), which was introduced in the 1990's (Oxford English Dictionary online, 2008), eliminated one of the fundamental problems associated with videos, namely the user's inability to locate specific portions of the video quickly. This could only be done by fast-forwarding, rewinding and watching the video which is very time-consuming. DVDs, which can be divided into several "tracks", "scenes" or "chapters", enable instant access to specific portions of the footage via the player or remote control.

2.2.2 Comparison of teaching styles in taped-lectures and in live classes

Bork (1995), who investigated the effectiveness of various types of educational media used in distance education, states that the main method of information delivery in the taped-lecture genre is by means of a monologue by an expert, and it is the reliance on this mechanism of information transfer (known as transmissive teaching) that is the main criticism of taped-lectures. However, Bork (1995) also states that the label "taped-lecture" may be misleading because it implies that the video is merely a reproduction of a "live" lecture involving predominantly "talking-head" footage. He claims that some examples of taped-lectures contain rehearsed, scripted "talking-head" footage that has been checked for errors and inconsistencies and this gives them an advantage over a typical lecture. Nonetheless, a number of criticisms have been levelled at this genre. According to Arnove (1976:10), who investigated the success of various educational television initiatives in developing countries in the 1970's, taped-lectures *"reinforce hierarchically arranged learning patterns and student passivity – one-way communication, and authoritative teachers as role models",* perpetuating the myth *"that learning results from the transmission of knowledge and information in a direct line from television set to pupil".* Other criticisms of transmissive teaching are that it places too much emphasis on memorisation of facts (known as rote-learning), that it requires low cognitive involvement, and that it can result in poor understanding and a fragmented knowledge base (Fenstermacher and Richardson, 2005).

The *"cognitive revolution"* of the 1970's shifted the emphasis in education from the teacher-centred approaches of the 1950's and 1960's to the learner-centred approaches that are prevalent today, according to Fenstermacher and Richardson (2005:200). In South Africa, as in other parts of the world, these educational reforms have meant that learners are intended to be actively involved in constructing their own knowledge rather than being passive receptors. According to Fenstermacher and Richardson (2005:203) students should be encouraged to *"develop meaning as their prior knowledge interacts with new or different knowledge they encounter in the classroom from such sources as the teacher, textbooks, and peers."*

2.2.3 Taped-lectures as a learning resource

Taped-lectures, like textbooks, can be thought of as a resource that is available to teachers and students to enhance the process of understanding science in their classes. Criticisms that taped-lectures do not cater for different learning styles, are not interactive, and that students *"cannot interrupt, interrogate or ask for clarification"* (Bates, 1983:62), can also be levelled at textbooks. While textbooks have a number advantages over taped-lectures [for example, they are highly portable and they do not require projection equipment (Kent and McNergney, 1999)], the content in textbooks is usually presented in a precise, unambiguous, impersonal way that is often difficult to decipher, particularly for English second language students, according to Parkinson, Jackson, Kirkwood, and Padayachee, (2007), who investigated how language skills impact on academic writing in South Africa. If presented by skilled teachers, taped-lectures are expected to have been transformed into a student-friendly and accessible form. According to Treagust and Harrison (2000), good teachers use metaphors, analogies, anthropomorphisms and other types of explanations and students are thought to be more receptive to receiving information via these types of explanations that use a narrative or storyline, according to several researchers (for example see Bulman, 1986; Lemke, 1990; Thagard, 1992; Treagust and Harrison, 2000; Hashweh, 2005). It is the narrative or storyline of explanations that is thought to first engage students, providing them with a sketch of the content landscape that can be expanded into rigorous theoretical knowledge later (Thagard, 1992; Treagust and Harrison, 2000; Hashweh, 2005).

Arguments that science teachers themselves should be able to process content so that it is easy for students to understand are valid, but within the South African schooling system a number of factors work against this. Firstly, a sound content knowledge is required to develop these strategies, according to Tobin and Garnett (1988), which under-qualified teachers lack. Secondly, Liston *et al.* (2006), citing international studies, report that developing a repertoire of successful strategies can take up to four years, and many South African science teachers have less experience than this. Other researchers (Van Driel, Verloop, and DeVos, 1998; Loughran, Mulhall, and Berry, 2006) claim that successful strategies can be accumulated through discussions with other teachers but the isolation of many rural schools in South Africa is expected to hinder the exposure of rural teachers to professional discussions of this type. A further complication expected in the South African situation is that many teachers have not had exposure to quality teaching themselves, as transmissive teaching styles were prevalent in South African schools until recently (Hewlett, 1996). So teachers may have had limited exposure to student-centred teaching strategies. Finally, discipline and other classroom management problems can overwhelm teachers and short-circuit any attempts to pilot new strategies (Sanford, 1988) and this hinders the process through which a repertoire of successful strategies is developed. Discipline problems in South African schools have been reported by several authors (for example see Arenstein and Mhungwana, 2004; Zulu, Urbani, van der Merwe, van der Walt, 2004; Hall *et al.* 2005).

2.2.4 Advantages of taped-lectures

Good quality taped-lectures, in addition to having their scientific content processed in a student-friendly and accessible form, have a number of other advantages. Firstly, they are cost effective, according to Bourdeau and Bates (1996), who investigated instructional design in educational media. They reported that the production costs of preparing one hour of teaching material for taped-lectures, at that time, was about 2 to 5 units compared to 2 to 10 units for texts, and 50 to 100 units for interactive multimedia computer programmes. Added to this, they state that if the taped-lectures are broadcast using the national broadcaster then the distribution costs are also low. Secondly, there is evidence that some students prefer direct instruction when learning science, according to Osborne (1996) who reported on different learning styles used by students. Bourdeau and Bates (1996) reported similar findings; they found that students with lower academic ability who studied using videos at the Open University preferred didactic videos as they found them easier to interpret than more sophisticated video genres. Thirdly, according to Bork (1995), pre-recorded taped-lectures are usually scripted, well structured, and more clearly presented than “live” lectures and so cover more material in the same amount of time. Fourthly, Bork (1995) points out that videos may be used to standardise the teaching process and, even though teachers are not the target audience, according to many researchers (Groundwater-Smith, 1990; Bork, 1995; Bourdeau and Bates, 1996; Kent and McNergney, 1999) teachers can benefit from viewing the videos and this can aid their professional development. Fifthly, according to Kozma (1991), the visual footage tends to be easier to recall particularly if the audio track has facilitated its interpretation. Meyer (1997) suggests that verbal and visual material may be stored and processed differently in the brain, and states that visual images may be easier to recall. Finally, like overhead projectors, videos require a low level of technical skill to operate compared to newer technologies like computers, and this is thought to make them accessible to more teachers (Kent and McNergney, 1999). Several researchers in the United States of America (Kent and McNergney, 1999; Rosenthal and Poftak, 1999; Neiss, 2005) have reported that teachers in that country do not have the confidence to use new technologies in their classrooms. For example, Kent and McNergney (1999) state that one reason why teachers avoid using computer-based learning packages is that they feel unable to assist students when difficulties are encountered with running the programmes. Rosenthal and Poftak (1999), quoting data collected in the late 1990's, state that the majority of teachers (80%) do not feel confident about using technology in their classrooms. Niess (2005), who investigated the difficulties student teachers encountered when using new technologies, found that although most were anxious to pilot these technologies in their classrooms, if their first attempts were unsuccessful, they avoided using the technologies again.

2.3 A FRAMEWORK FOR THE ANALYSIS OF SCIENCE VIDEOS

The purpose of this section is to describe the framework used to analyse the videos in this study. Since the videos were taped-lectures, the framework deals with features associated with these types of videos and pertinent features associated with "good" teachers and "good" teaching.

2.3.1 Features associated with educational videos

Bourdeau and Bates (1996) use the term "high-quality" to describe videos that make full use of the special filming techniques available to videos, and taped-lectures tend not to do this. Nonetheless, according to Bork (1995), the quality of taped-lectures can range from poorer examples, the contents of which imitate "live" lectures with little scripting or other production inputs, to better crafted examples that are well scripted and professionally produced. According to Bork (1995), taped-lectures generally tend to make excessive use of talking-head footage (i.e. head and shoulder footage of a person talking) so in his opinion the visual aspects tend to be poor. The knock-on effect of excessive talking-head footage is that time allocated to voice-over footage[3] is curtailed, and this impacts the amount of information that can be relayed visually. Bork (1995) also states that even when information is relayed using voice-over footage, the primary means of information delivery is via the audio track and not through the visual footage. Despite this, according to Koumi (1991), the visual footage is important as it can increase the "legibility" of the video. Table 4 overleaf lists recommendations for better crafted examples of educational videos but excludes any recommendations about the theatrical aspects of taped-lectures.

According to Koumi (1991), it is important to introduce theatrical elements to educational videos as these maintain interest in the video, and can encourage further involvement in the subject matter by viewers. A range of theatrical elements can be included in taped-lectures from the use of body language and facial expression to more sophisticated elements introduced via the scripting process, and through voice-over footage (Koumi, 1991). In Romiszowski's (1988) opinion the most important aspect of any educational video is that the target audience finds it interesting.

[3] The term "voice-over" describes any footage where the presenter can be heard but not seen (Taylor, 1988).

Table 4: Recommended features for educational videos

Aspect	Recommendations from the literature
Audio	• Maintain audio continuity (Romiszowski,1988). • Script the narrative (Koumi, 1991). • Pace the narrative appropriately* (Koumi, 1991). • Pronounce scientific and technical words correctly (Taylor, 1988). • Use vocabulary appropriate for the intended audience (Taylor, 1988, Koumi, 1991). • Use spoken cues ("signposts") to orientate viewers about their location on video (Koumi, 1991). • Use aural cues (sounds, also known as "signposts") to mark sections or activities (Koumi, 1991). • Limit the use of idiom (Koumi, 1988). • Refrain from introducing objectionable bias (Heinich, Molenda, and Russell, 1989).
Visual	• Maintain visual continuity (Romiszowski, 1988). • Limit distracting movements (Taylor, 1988). • Use appropriate, legible diagrams and text (Taylor, 1988). • Use visual cues (signposts) to orientate viewers (Bates, 1988). • Link apparatus to diagrams (Taylor, 1988). • Show spellings of scientific and technical terms (Taylor, 1988). • Demonstrate procedures used for specific skills (Taylor, 1988). • Write no more than 4 to 6 words a line and no more than 6 lines of text per screen (Taylor, 1988).
Structural	• Use segments of equal length, optimum 20 minutes (Kent and McNergney, 1999). • Use self contained segments with clear stopping points (Bates, 1988). • Use "signposts" to increase legibility (Koumi, 1991). • Use repetition (Koumi, 1991). • Structure each sample in a series of videos in the same way (Koumi, 1991).
Educational	• Highlight prior knowledge (Koumi, 1991). • Sequence content appropriately (Romiszowski, 1988). • Use repetition to reinforce ideas (Koumi, 1991). • Make generalizations (Koumi, 1991). • Highlight misconceptions (Romiszowski, 1988). • Teach error recognition (Romiszowski, 1988; Koumi, 1991). • Reinforce concepts using a range of examples (Koumi, 1991). • Introduce new concepts at an appropriate pace (Kozma, 1991). • Highlight non-examplars (Koumi, 1991).
Supporting documentation	• Provide information on the format, content and teaching approach (Forsslund, 1991). • Provide advance organizers for teachers (Forsslund, 1991). • Provide supplementary notes and worksheets for students (Bates, 1988).

* Romiszowski (1988) states that 71-102 words per minute is slow, 111-141 is optimal and 155-185 fast for films that teach technical skills in the United States of America.

2.3.2 Lay and professional qualities associated with teachers

According to Bork (1995:242), educational videos must be carefully designed and presented to be effective as he cautions that *"poor material from a pedagogical point of view cannot be made viable with marvellous media"*. Since the videos used in this study were taped-lectures, it is possible to appraise them using the parameters associated with "good" teachers. However the criteria used to judge teachers depends on one's perspective.

Students and parents (and possibly school principals) often use examination success, particularly at "high-stakes"[4] examinations like the Senior Certificate examinations, as their main criterion for judging the worth of teachers. However, according to Mehrens and Kaminski (1989), in some instances teachers may have used unethical practices to improve their students' scores: For example, they may have narrowed the syllabus and focused only on those aspects that are likely to result in examination success.

[4] According to Haladyna (2006) "high-stakes" examinations are those where the outcome has consequence for the advancement of the student, and the school.

Students, on the other hand, often expect more than just examination success from “good” teachers, according to Faranda and Clark (2004). These authors used interviews to establish the qualities 28 undergraduate students in the United States of America associated with “good” lecturers. Faranda and Clark found in these students’ assessment, “good” lecturers were friendly and outgoing, and delivered their lectures confidently and with humour, enthusiasm and passion. According to Wilson (1988), whose text examines ways of appraising teacher quality, for much of last century it was felt that some teachers, known as “born” teachers, were just naturally better than others. However, Happs (1987:79), who conducted case studies on two such teachers, claimed that one problem with the *“dynamic, forceful and convincing manner”* used by the teachers in his study was that they were *“teaching invalid information in the most convincing way”* (Happs, 1987:79).

From an academic perspective, the quality of teachers is often judged by their ability to demonstrate skills in the three broad knowledge domains set out by Shulman (1986), namely pedagogical knowledge, content knowledge and pedagogical content knowledge.

Pedagogical knowledge describes the generic teaching skills that can be applied within any content domain, and only a selection of these skills is likely to be demonstrated in a taped-lecture. According to Cole and Chan (1994), whose textbook examines teaching skills, examples of general pedagogical skills include the use of humour and facial expressions to engage students, and the use of thematic schemes to add interest and anticipation to lessons and to increase student involvement. Other teaching skills include the use of appropriate vocabulary (Johnstone, 1997), and the use of reassurance (Wildy and Wallace, 1995). One of the benefits of using reassurance, according to Wildy and Wallace (1995) who carried out a case study of a high school physics teacher in Australia, is that it builds students’ confidence in themselves and in the techniques that have been introduced to interpret theory and solve problems.

Content knowledge describes the knowledge of the subject, and it is of pivotal importance in the teaching process, according to Tobin and Garnett (1988). These authors reported on case studies of 26 science teachers in Australia, four of whom had incomplete content knowledge. Observations of their classroom interactions led Tobin and Garnett (1988:207) to conclude that *“(W)ithout this essential content base teachers are unable to focus student thinking, unable to provide appropriate feedback to students, and unable to discuss effectively the content dealt with in different classroom environments”.*

Content knowledge can be divided into substantive and syntactic knowledge. Abd-El-Khalick (2006:2-3) describes substantive knowledge as the knowledge of the *“facts, concepts and principles”* of the content, and syntactic knowledge as the *“principles of inquiry and values inherent to the field”.*

The study described in this research report only focuses on the substantive knowledge in the selected topics. An exhaustive review of the topics is not discussed in this section for two reasons: Firstly, the main thrust of the study was not to review the scientific content of the videos *per se* but rather to evaluate the strategies used to communicate those portions of the content that exemplified the strengths and weakness of the videos. This strategy meant that only small portions of the scientific content were evaluated. Secondly, the decision was taken to include brief explanations of these portions of the theory in Chapter 4. This was done in an attempt to provide readers who may be unfamiliar with the scientific content with a means of adjudicating the strengths and weaknesses of the videos.

The content knowledge required to teach *electrochemistry* at school has been rigorously tackled in the literature and is exemplified by the seminal articles of Garnett and Treagust (1992a & b) that provide lists of "conceptual and propositional" knowledge statements. Four additional knowledge statements have been added to these lists for the purposes of this study, using information from Moran and Gileadi (1989), Birss and Truax (1990), Ogude (1992), and Shriver, Atkins, Overton, Rourke, Weller, and Armstrong, (2006). The expanded list of "conceptual and propositional" knowledge statements can be found in Appendix A. Also included in Appendix A is a list of misconceptions associated with electrochemical cells. This list was first formulated by Garnett and Treagust (1992b), but a modified version by Sanger and Greenbowe (1999) is used in this research report.

Comprehensive lists of "conceptual and propositional" knowledge statements required to teach *acids and bases* and *titrations* at school could not be found in the literature. As a result a number of statements that cover the content divulged in the videos were drawn up by the researcher with reference to literature (Vogel, 1969; Masterton and Slowinski, 1977; Brock, 1992; International Union of Pure and Applied Chemistry, 1997; Silberberg, 2000). These statements are also included in Appendix A.

Pedagogical content knowledge describes any topic-specific strategies that are used to make the content comprehensible to students and is essentially derived from a process of blending content knowledge with pedagogical knowledge. According to Magnusson, Krajcik, and Borko, (1999), who analysed the processes involved in developing pedagogical content knowledge, an array of interrelated competencies are required to develop this skill. Its foundation rests not only on knowing the correct facts about the topic but includes knowledge of alternative conceptions or misconceptions that students may possess, the common difficulties students encounter with the topic, the assessment criteria, and how the topic fits into the curriculum both within the school year and throughout the schooling system. Teachers also need to be sensitive to the *"diverse interests and abilities"* of students when developing these topic-specific teaching strategies, according to Magnusson *et al.* (1999:96). Wallace and Louden (2003:560) state that teachers need to filter the content so that it is presented in an appropriate way for the students' *"age and stage"*.

One way that teachers demonstrate their pedagogical content knowledge is through the explanations that they use. Many attempts have been made in the literature to a classify teachers' explanations (for example see Dagher and Cossman, 1992; Dagher, 1995; Gilbert, Boulter, and Rutherford, 1998a & b) however no definitive classification exists, due in part to the different perspectives that researchers adopt when evaluating explanations. For example, Dagher and Cossman's perspective was to identify the types of verbal explanations used by 20 Grade 7/8 science teachers in the United States of America by analysing transcripts of their lessons (Dagher and Cossman, 1992). No attempt was made in Dagher and Cossman's study to evaluate how successful these explanations had been at communicating valid scientific content to students. The perspective of Gilbert *et al.* (1998a:87) was to evaluate explanations in terms of their *"plausibility"*, *"parsimony"*, *"generalisability"* and "*fruitfulness"*. Gilbert *et al.* (1998b:191) considered some of the explanations identified by Dagher and Cossman to be *"non-explanations"* or *"counterfeit explanations"* because they failed to meet one or more of their specified criteria.

The article of Dagher and Cossman (1992), however, demonstrates that teachers do not always use successful explanations in live teaching situations. Four possible reasons are: Firstly, according to

Gilbert *et al.* (1998b), teachers may lack content knowledge or pedagogical content knowledge and so are unable to construct appropriate explanations. Secondly, according to Magnusson *et al.* (1999:112), some teachers have difficulty *"sustaining momentum in a lesson, sometimes confusing themselves and their students"* as they endeavour to answer students' questions and give alternative or more detailed explanations. Thirdly, according to Treagust and Harrison (2000), science teaching explanations are different to science explanations as they depend on students' *"age and stage"*. Explanations that are considered appropriate for younger students may not be considered appropriate for older students. Finally, according to Gardner (1999), teachers adjust their explanations as their involvement with the topic increases. So teachers may use strategies that engage students and stimulate their interest in the topic when it is first introduced. Gardner (1999:81) calls these *"entry point"* strategies. Gardner (1999:82) states that teachers do not necessarily intend to *"incalculate specific forms or modes of understanding"* when using them, but aim instead to secure the students' *"cognitive commitment for further exploration"*. Teachers then proceed to an explanatory stage, which Gardner (1999:82) calls *"telling analogies"*. During this stage the parameters of the new topic are communicated to students in ways that incorporate and expand their existing knowledge. Finally teachers use strategies to communicate the *"central understandings"* or *"core notions"* of the topic by using more rigorous explanations (Gardner, 1999:83). Gardner (1999:83) calls this stage *"approaching the core"*.

Based on Gardner's ideas (listed above) it is expected that a range of explanations will be used in taped-lectures, from explanations that may be considered to be *"non-explanations"* to more rigorous scientific explanations, and including analogical explanations. Table 5 lists the types of explanations that are expected to be encountered and gives definitions for each.

Table 5: Types of explanations used by science teachers

Type of explanation	Definition: *An explanation that:*
Non sequitur	follows the structure of a causal explanation but the concluding statement does not follow logically from the preceding premises.
Rephrasing	uses simpler, more accessible language to re-explain complex vocabulary or new terms.
Simile	describes how one thing resembles another, usually introduced using "as" or "like".
Metaphor	uses a word from one context and applies it directly to another object, thus implying a resemblance.
Anthropomorphism	imbues non-human objects with human characteristics e.g. the ability to think, feel and have desires.
Teleology	attributes pre-determined purpose or design to non-human objects.
Analogy	describes an unfamiliar topic or concept in terms of a familiar topic or concept.
Causal	describes phenomena in terms of a causal law. There are three steps in a causal explanation. Firstly, a statement is made of the causal law; secondly a statement is made about the phenomenon; and finally, the deduced casual explanation is given (Gilbert *et al.* 1998b).
Comprehensive scientific	uses rigorous scientific parameters to describe scientific phenomena and may include mathematical equations or scientific models.

According to Ogborn, Kress, Martins, and McGillicuddy, (1997), the merits of classifying explanations into different types (such as those listed in Table 6 above) is limited, as knowledge is shared in many ways in live classroom situations. Inflections, intonations and body language used during verbal explanations convey meaning to students, and this information is usually accompanied by diagrams and models. Ogborn *et al.* (1997:17) point out that explanations *"hardly ever appear as isolated single events. They nest inside and fit alongside one another, to form larger patterns which are themselves explanations"*.

One way teachers explain the abstract and unfamiliar ideas associated with science is to use analogies (which can be composite explanations that include anthropomorphic, teleological and other types of explanations). Since analogies are commonly used by science teachers and have been widely reported in the literature (for example, see Duit, 1991; Thagard, 1992), vocabulary has been introduced to describe specific aspects of analogical explanations. Thagard (1992:537) calls the familiar domain (that should be accessible to the student) the *"source"* or analogue, and he calls the abstract or unfamiliar domain the *"target"*. Thagard (1992) states that when teachers use an analogy they must ensure that students have the same understanding of the source domain, and that they have make appropriate links (or correspondences) between the source and target domains. Finally, students need to know the limitations between the source and the target, because students can be misled by irrelevant features of the analogue (Thagard, 1992).

Thagard (1992) reports that teachers construct analogies based on three different types of similarities: *Semantic similarities*, where terms with common meanings are found in both domains; *structural similarities*, where the source and target have similar configurations; and *pragmatic similarities*, where the source and target work in the same way. According to Thagard (1992), chemistry teachers tend to rely on analogies based on semantic similarities. Thagard cautions that although students may be familiar with the source domain, there may be few structural or pragmatic similarities between it and the target.

According to Ogborn *et al.* (1997:74) the main advantage of using analogies when teaching science is that they provide students with *"a framework within which productive questions can be asked and answers can be sought without needing to know everything"*. Ogborn *et al.* (1997) state that the explanations available to science teachers are often hampered by their students' limited knowledge, and as a result science teachers' explanations tend to form *"the tip of an iceberg. Unseen, underneath and keeping it afloat is a large hidden mass of scientific explanation"* that may only be made explicit to students later (Ogborn *et al.*1997:13). Taber and Watts (1996) state that teachers often use anthropomorphic language to introduce new knowledge, and students are therefore likely to express their initial understandings using these devices. Taber and Watts (1996) anticipate that the use of anthropomorphic language by students will fall away as students' knowledge of the underlying scientific principles expand and mature. Gilbert *et al.* (1998b) warn, however, that students may see explanations as being definitive, and corresponding precisely with reality. This may act either as an impediment to further learning, or it may lead to frustration as earlier explanations have to be unlearned and replaced with more rigorous explanations. As a result, according to Birss and Truax (1990:403) students who may initially be fascinated or intrigued by science, may *"become disenchanted by* … (its) *apparent lack of consistency and logic"*.

2.4 CONCLUDING REMARKS

This chapter reviews some of the advantages of taped-lectures when used as a supplementary aid in the school environment. It provided a framework for evaluating taped-lectures by identifying a number of technical characteristics associated "better-quality" taped-lectures, and by listing many of the salient aspects associated with "good" teachers and "good" teaching. Although a wide range of technical and educational characteristics were listed or described in this chapter, the framework was not intended to be used prescriptively. Instead it served as a guide against which the videos in the study were compared and contrasted, and through which the occurrence of specific phenomena noticed in the videos was identified and explained.

CHAPTER 3
RESEARCH DESIGN

This chapter deals with the methods and data-gathering and data-analysis techniques that were used in this study, and justifies the choice of the selected methods. The techniques chosen were selected because they were thought to be the most pertinent for investigating the research aims, which were outlined in Chapter One and are rewritten here for convenience: The aims of the research were to investigate the impact the videos had on learning when viewed in the same way as a television broadcast, and to evaluate some of the strengths and weaknesses of the videos. The following questions were used to investigate the aims, and provided the parameters within which the study took place.

1. To what extent did the students' performance change after watching supplementary videos on the selected topics?
2. What were the strengths of the videos in terms of helping students to improve their performance? This question was answered by addressing the following sub-questions:
   (a) To what extent did students answer questions more successfully after watching the videos?
   (b) What were some of the possible reasons that these questions were answered more successfully?
3. What were the weaknesses of the videos? This question was answered by addressing the following sub-questions:
   (a) To what extent did students answer questions less successfully after watching the videos?
   (b) What were some of the factors that may have led to this poor performance?
4. How did students who were representative of the target audience react to the videos?

3.1 THE RESEARCH DESIGN

Before describing the research design used in this study it is important to address the term "research" as its meaning with respect to educational investigations differs from everyday parlance. Mertens (2005:2) describes it as *"a process of systematic inquiry that is designed to collect, analyse, interpret, and use data to understand, describe, predict, or control an educational … phenomenon".* While this definition lists a broad range of aims, in this study the aims were to understand and describe only.

In educational research the "systematic inquiry" devised to investigate an educational phenomenon is known as a research design. It is a detailed plan drawn up prior to beginning the field work, and provides the *"overall framework for collecting data"* (Leedy, 1989:92). Ideally, according to Leedy (1989:92), a well thought out research design will provide *"the complete strategy of attack upon the central research problem"*. In practice, the initial plan may be subject to adjustments and changes as the research proceeds (Mouly, 1970). In such cases the initial design serves as a prototype from which the actual research design is crafted. The initial research design serves a useful function, it describes the focus of the research and the strategies to be used; it enables the researcher to monitor the study; and it ensures that the aims are being met (Mouly, 1970). According to Mouly (1970:487), *"by reporting on the more important blind alleys that were abandoned",* readers of the research report are informed about the difficulties involved with certain approaches and this knowledge may be useful for future studies. The actual research design used, which is reported in the research report, gives readers a clear idea of the strategies used to *"collect, analyse, interpret and use data"* and allows them to make informed decisions about the value of the findings obtained (Mouly, 1970). According to Mouly (1970), the research design serves as a template that future researchers could use should they wish to replicate the study, although not all studies are considered to be replicable (see section 3.2 for a further discussion on this).

A visual representation of the procedures used in this study is given in Figure 1 on page 23. The study was performed in two sequential stages. The first involved showing the videos to a sample of students over a ten-week period (shown on the left-hand side of Figure 1, and shaded yellow, green and blue and titled "data-gathering stage involving students"). The purpose of this stage of the study was to collect as much information as possible about the students and their interactions with the videos. This enabled students' reactions to specific aspects of the videos to be made explicit and so provides additional evidence regarding the strengths and weakness of the videos. The study was planned so that all students attended lecture sessions, and these took place on Wednesdays and are shown in yellow on the bottom left-hand portion of Figure 1. The lecture topics covered during the study are indicated in the rectangular blocks, and if students wrote a test during the session, it is indicated in the boxes immediately above each lecture. The lecture sessions were not under direct investigation but they were observed using field notes and this is indicated in Figure 1 by the grey background behind the lecture sessions.

The video sessions, which were attended by only some students, took place on Fridays and are shown in Figure 1 in the top left-hand portion, and are shaded green. The topics screened at each video session are indicated in the bubbles and if students wrote a questionnaire during the session then this is indicated in the boxes immediately above the video session. The control group's video session took place on the final Saturday of the study and is shaded blue in Figure 1. Observation schedules and field notes were used to observe the students' reactions to the videos and the use of these techniques is indicated by the grey background behind the video sessions.

The second stage involved investigating the videos to provide evidence for the findings obtained from the first stage of the study (shown on the right-hand side of Figure 1, shaded mauve and titled "critical review of the videos"). Details of the techniques mentioned are described more fully later in this chapter. This stage had three purposes: first to review the videos to identify factors that may have influenced students to improve their performance (and so answer research question 2). Second to identify factors that may have impacted negatively on students' performance (and so address research question 3). Finally, to describe incidences that had influenced students' reactions (and so answer research question 4). The strategy used to review the videos started with summarising the content of each video, transcribing pertinent portions of the audio track, and investigating aspects of the visual footage. Analysis of the data obtained from all sources was then carried out and this process is shaded blue and is indicated in a central block towards the right-hand side of Figure 1.

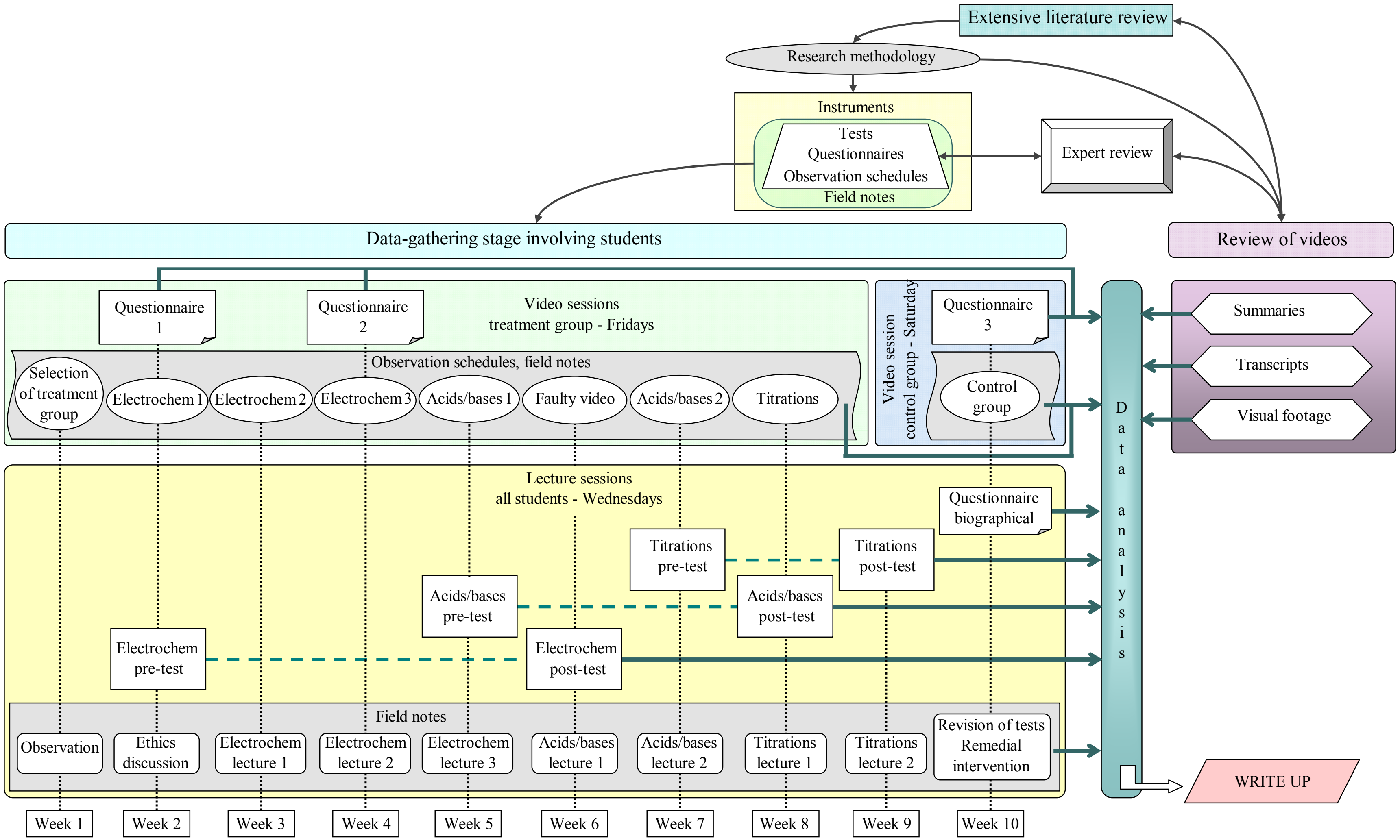

Figure 1 Schematic representation of the research design

3.2 RESEARCH PARADIGM[5]

According to Mertens (2003:139) in educational research *"a paradigm is a conceptual model of a person's worldview, complete with the assumptions that are associated with that view"*. Paradigms enable researchers' belief systems to be made explicit so predictions can be made about how they will interface with and interpret signals from the social world (Sandelowski, 2003). The researcher's paradigm therefore influences how the study will be implemented, the emphases placed on the findings, and the way in which the research report is written up – information that impacts readers of the research report (Sandelowski, 2003).

Before discussing the researcher's paradigm it is necessary to give an overview of the two major research paradigms and how they have influenced educational research, as this study draws on data-gathering strategies traditionally associated with both paradigms. The two major paradigms are based on diametrically opposed belief systems. They differ with respect to proponents' views about reality (ontology), and about how or if knowledge of reality can be acquired (epistemology), viewpoints that give rise to two different value systems (axiology) and subsequently two different data-gathering systems. This arises because data-gathering strategies often provide evidence that supports either one or the other of the two views of reality (Tashakkori and Teddlie, 1998).

The one paradigm, called the *"Analytic – Empirical – Positivist – Quantitative Paradigm[6]"* by Reeves and Hedburg (2003:30), is based on the belief that a *"separate, material reality ... exists apart from the beliefs of individuals, groups and societies"* (Reeves and Hedburg, 2003:30). Proponents of this paradigm, often called positivists (or postpositivists), use data-gathering strategies such as experiments that investigate and confirm this *"separate, material reality"*. These data-gathering strategies are commonly referred to as "quantitative techniques". Positivists place importance on the objectivity of their findings and try to isolate them from other extraneous influences, so attempt to make value-free observations and measurements. Positivists often use statistics to support their findings and, as a result of their pursuit for objectivity, they tend to use a passive or detached writing style in their reports (Sandelowski, 2003).

The opposing paradigm, called the *"Constructivist – Hermeneutic – Interpretivist – Qualitative Paradigm"* by Reeves and Hedburg (2003:31), is based on the belief that *"humans individually and collectively construct reality"* (Reeves and Hedburg, 2003:32). Proponents of this paradigm, often called constructivists, use data-gathering techniques that provide evidence of individuals' "constructed reality", such as interviews (Sandelowski, 2003). These data-gathering strategies are commonly known as qualitative techniques. Constructivists operate from the premise that all inquiry is value-

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[5] Some researchers use the term "theoretical perspective" synonymously with "research paradigm". For example, Greckhamer and Koro-Ljungberg (2005:736) state that a theoretical perspective *"refers to the philosophical stance informing the methodology and methods combining interrelated assumptions, concepts and propositions that form a particular view of the world"*. Also see Crotty (1998) and Creswell, Plano Clark, Gutmann, and Hanson (2003).

[6] Reeves and Hedburg use non-breaking hyphens, namely "Analytic-Empirical-Positivist-Quantitative" instead of the 'en dashes' used above. While the non-breaking dashes are easy to read in this instance, they make the label Reeves and Hedburg use for the pragmatic paradigm, namely "Eclectic-Mixed Methods-Pragmatic", more difficult to read in the researcher's opinion. For uniformity, the 'en dashes' have been used throughout.

laden and their findings tend to reflect this and are often subjective. Rather than reporting in a detached way, they use a descriptive style of writing that aims to provide contextualised information about the study (Sandelowski, 2003). According to Shapin (1984:491 cited by Sandelowski, 2003:332) writers of qualitative reports aim to give readers a vicarious experience of the study that *"obviates the necessity for either its direct witness or direct replication"*.

Of all the assumptions that underpin these two major paradigms, the assumption that *"abstract paradigms should determine research methods in a one-way fashion"* has been strongly debated (Howe, 1988:10). In recent years there has been a trend for researchers to base their selection of data-gathering strategies on practical rather than philosophical considerations, their aim being to use those strategies that work best to answer the research questions (Howe, 1988). Researchers who choose this approach are known as "pragmatists", and their studies are sometimes referred to a "pragmatic designs" or more commonly "mixed method studies" (Johnson and Onwuegbuzie, 2004). According to Tashakkori and Teddlie (1998:21) pragmatists *"consider the research question to be more important than either the method they use or the worldview that is supposed to underlie the method"*. Reeves and Hedburg (2003:34) state that pragmatists identify with the *"Eclectic – Mixed Methods – Pragmatic Paradigm*" and that they *"rarely concern themselves with ultimate conceptions of reality, preferring to deal with the practical problems that confront them as educators"* (Reeves and Hedburg, 2003:35).

Two aspects of the above framework, described by Reeves and Hedburg, are disputed in some academic circles. Firstly, the term "paradigm" may imply that all pragmatists have the same belief system, when in fact they only agree that paradigms are not intrinsically linked to data-gathering techniques so are not important when making research design decisions (Greene and Caracelli, 2003). Secondly, the assumption that pragmatists *"rarely concern themselves with ultimate conceptions of reality"* is also challenged. Greene and Caracelli (2003:95) believe that *"all inquirers approach their work with some set of assumptions about the social world, social knowledge and the purpose of social research"*. While Greene and Caracelli (2003:95) claim that these assumptions may be either *"a formal philosophical paradigm or more of a 'crude mental model'"*, they posit that they influence what a researcher will interpret as knowledge when conducting a study. Sandelowski (2003:324) concurs, stating that researchers' belief systems dictate their "*attitude toward and interpretive treatment of the data collected"*. Sandelowski (2003:326) offers the following practical example: *"researchers may view interviewees as potentially biased informants or forgetful reporters of events or as narrators"*. So *"paradigms can matter in mixed method* (pragmatic) *inquiry"* (Greene and Caracelli, 2003:107). The influences of a researcher's paradigm may be discerned by readers of the research report when investigating the treatments given to data, but are most likely to be apparent in the way in which a study is reported (Sandelowski, 2003).

Despite these philosophical concerns, there are several advantages to using a pragmatic approach or stance (see Greene and Caracelli, 2003) when designing a study. According to Johnson and Onwuegbuzie (2004), one of the strengths of a pragmatic design is that complementary information can be generated, and often findings generated via one method can be confirmed by another. Also, according to Creswell, Plano Clark, Gutmann, and Hanson, (2003:211), *"because all methods of data collection have limitations, the use of multiple methods can neutralise or cancel out some of the disadvantages of certain methods"*. But the main motivation for using a pragmatic design, according to Greene and Caracelli (1997:7), is that they are most likely *"to generate deeper and broader* *insights,* [and] *to develop important knowledge claims that respect a wider range of interests and perspectives".*

In this study the researcher used a pragmatic approach or stance to select data-gathering strategies and this resulted in a pragmatic design that used techniques traditionally associated with both the quantitative and qualitative paradigms. The decision to use these different techniques was driven by the researcher's desire to give a balanced interpretation of the findings.

3.3 RESEARCH METHODS AND DATA-GATHERING STRATEGIES

According to Creswell (2002), data refers to any information that researchers collect which enables the research questions to be answered. Data was collected in two stages in this study, with the bulk of the data collected during the first stage, when a group of students volunteered to supplement their regular lectures with videos. The second stage involved collecting data from the videos themselves, through a reviewing process. Various methods were used to collect data in this study and the characteristics, advantages and disadvantages of each are discussed in this section along with the procedures used to select the samples.

3.3.1 The quasi-experiment[7]

Experiments are used in educational research to investigate causal relationships, namely how altering one variable (the independent variable) brings about changes in another (the dependent variable) (Mouly, 1970; Creswell, 2002). There are various types of experiments, and in this study a specific type of "between-group" experiment (Creswell, 2002) was used to investigate whether watching the videos in the same way as a television broadcast would help students improve their performance in *Physical Science* tests. The decision to use a "between-group" experiment in this study was based on the fact that that instructional products tend to be evaluated in this way so several examples of such studies can be found in the literature (for example, Mevaresh, Shir, and Movshovitz-Hader, 1992). Reeves and Hedburg (2003), whose text examines evaluation systems used for instructional products, state that researchers are motivated to use this approach because often the first question asked about a new instructional product is how it compares to existing products or traditional teaching.

"Between-group" experiments involve comparing the performance of two groups where one group (known as the experimental or treatment group) is exposed to the independent variable (known as the treatment or intervention) and the other group (known as the comparison[8] or control group) is not. Using two groups allows for a certain number of extraneous factors – factors that may *"affect the outcome and provide an alternative explanation"* for the results (Creswell, 2002:318) – to be

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[7] Traditionally, a "quasi-experiment" would be referred to as a "quasi-experimental design" however, in this study the term "design" is applied to the overall design, see Figure 1, instead of being applied to the individual strategies used to gather data.

[8] According to Creswell (2002), a "comparison group" is exposed to an alternative treatment in place of the treatment while a "control group" is not exposed to an additional intervention during the data-gathering stage of the experiment. So, in this study the two groups used are correctly described as a "treatment" and a "control" group.

controlled or minimised. The rigour of an experiment can be improved by testing both groups before and after the intervention, known as a *"pre- and post-test design"* (Creswell, 2002:330). Any improvement by the treatment group relative to the control group at the end of the study is attributed to the treatment and can be verified using appropriate statistics (Mouly, 1970).

In the most rigorous experiments (known as true experiments) participants are randomly assigned to groups as this allows better control of extraneous factors that might influence the impact of the treatment (Mouly, 1970). In practice, because educational research involves human participants, it is impossible to control for all factors, and at best the use of randomisation is expected to *"distribute bias randomly"* (Creswell, 2002:318). Pragmatic constraints often mean that random assignment cannot be used and an *"adequate, but less-than-rigorous"* assignment strategy must suffice (Creswell, 2002:318), resulting in what is known as a quasi-experiment, where "quasi" means similar to but not the same (Oxford English Dictionary Online, 2008).

A common strategy used to assign participants in quasi-experiments is to use pre-existing, intact groups such as existing classes, and to make one intact group the treatment group and the other the control group (Creswell, 2002). This strategy was not used in this study even though two classes of students were available; instead participants were drawn on a volunteer basis from the two classes. Still known as a quasi-experiment, the decision to do this was based on a number of factors unique to the non-traditional school that was used in the study. These are discussed in section 3.4.

The advantages of using an experiment are that the research can take place over a relatively short time-frame, which limits the amount of disruption to classes (Gay and Airasian, 2003), and that it provides numerical data that can show relationships *"between and among carefully defined sets of variables"* (Picciano, 2004:51).

Experiments suffer from a number of disadvantages. Firstly, they often take place in situations where the natural setting has been manipulated, which impacts on the validity and generalisability of the findings. These and other related problems are discussed in section 3.6 (ensuring quality and rigour in the study). Secondly, according to Gay and Airasian (2003) the results obtained are only as reliable and valid as the instrument used for gathering the data, in this case the pre- and post-tests. The tests are discussed more fully in section 3.3.2. Thirdly, the selection of the sample that participates in the study may be a potential source of bias so sample selection needs to be described fully, see section 3.4. Finally, there are ethical implications of exposing only one group of participants to an intervention (Wellington, 2000), although the researcher attempted to minimise participant reactivity and ethical problems by allowing the control group to view the videos at the end of the study. Problems that arose as a result of the selection criteria are discussed in sections 3.4.2 and in Chapter 5, section 5.1.2.

A schematic representation of the structure of this part of the study is given in Figure 2 on the following page. Three topic-based tests, labelled T_1, T_2 and T_3, were constructed. Each test was written twice, once as a pre-test and once as a post-test, and they were written by all the students who attended the specific lecture sessions when the tests were scheduled (see Figure 1 on page 23). More information about the tests can be found in section 3.3.2. The dashed line in Figure 2 indicates that the treatment and comparison groups were not randomly selected. Figure 2 also shows that the control group had the opportunity to watch the videos after they had written the last post-test but before they wrote the Senior Certificate *Physical Science* examination. The sequence in which the lectures were attended, the tests written, and videos attended can be seen in Figure 1, on page 23.

Group		**Pre-tests**	**Intervention**		**Post-tests**	**Intervention**	
		T_1			T_1		
Treatment	O_1	T_2	lectures + videos	O_2	T_2		Senior Certificate *Physical Science* examination
		T_3			T_3		
		T_1			T_1		
Control	O_3	T_2	lectures	O_4	T_2	videos	
		T_3			T_3		

Where: O_1 = Measurement of dependent variable before (treatment group)
O_2 = Measurement of dependent variable after (treatment group)
O_3 = Measurement of dependent variable before (control group)
O_4 = Measurement of dependent variable after (control group)
T_1 = Pre- and post-test 1, electrochemistry
T_2 = Pre- and post-test 2, acids and bases
T_3 = Pre- and post-test 3, titrations
Dashed line = Non-randomised sample

Figure 2: Schematic representation of the pre- and post-test quasi-experiment

Implementation of the research

When the study started only ten weeks of the teaching term remained and the Senior Certificate *Physical Science* examination was scheduled to take place ten days later, so no extensions to the study could be accommodated.

The original plan for the study was to hold six two-hour video sessions for the treatment group and then three longer video sessions on the last three Saturdays of the study for the control group. However, the control group's video sessions had to be altered for two reasons. Firstly, a faulty video extended the treatment group's video sessions by one week (the video developed sound problems and stopped playing), and, secondly, there was a scheduling clash with the school (impromptu revision classes in various subjects, but not physical science, were scheduled on the penultimate Saturday of the study). As a result the control group's video sessions were reduced to a single, full-day video session.

Since the videos were marketed as a supplementary aid to help students pass the Senior Certificate *Physical Science* examination, the same topic was dealt with at both the video and lecture sessions. This meant that the treatment group received a double exposure to the topics. However, according to research carried out by Mevarech *et al.* (1992), this does not necessarily translate into improved learning. Mevarech *et al.* (1992) investigated the combined and separate effects of computers and videos on learning using a sample of 268 Israeli school children, and found that there was no improvement in learning when students used both computers and videos. These authors suggested two reasons for this, either the students were not given sufficient time to master each learning method or using two methods increased the likelihood of *"cognitive confusion"* (Mevarech *et al.,* 1992:113).

The lecture sessions: Students attended a one-hour lecture session each week in a large lecture theatre capable of accommodating about 250 students. The lectures were given by a lecturer employed by the school. For more information on this see section 3.4.1. Tests were written during the lecture sessions and, because students recorded their student numbers on the test papers, the tests were also used to monitor students' attendance at lectures.

The video sessions: The videos were screened from 16:00 to 18:00 on Friday afternoons in a smaller lecture theatre capable of accommodating about 120 students. The videos were projected onto a large screen using a multimedia projector so the image the students saw was about 2m x 2m. Students were given photocopies of the "student worksheets" that accompanied the videos. The sound level for the videos was fixed at the start of each session and could not be adjusted thereafter as access to the room where the volume control was kept was locked by the University's media personnel shortly after sessions started. This meant that sound fluctuations on the videos were more significant than they may have been otherwise, and it also meant the overhead fans could not always be turned on as the added noise sometimes made it too difficult to hear the audio-track. Students also requested that the lights in the room be dimmed so they could see the screen more clearly. Although dimmed, there was still sufficient light for students to take notes and for the researcher to record observations.

The attendance-monitoring procedure used at the video-screening sessions mimicked the procedure used to monitor attendance at the school. Students who elected to view the videos were given a video access card that was stapled onto their student cards, provided by the school. Access to the videos was only granted to students with these cards. The cards were clipped in specific places at the start of each session by the researcher using conductor's clippers. Attendance was read off the cards later by examining where the cards had been clipped. At the last session students wrote their student numbers on the back of these cards and handed them in. Outstanding cards were collected during subsequent lecture sessions, and an independent record of all students who attended the first *electrochemistry* video session was made by the researcher by getting the attendees to sign an attendance register.

3.3.2 Tests

Pencil-and-paper tests containing multiple-choice questions (sometimes known as "knowledge questionnaires") were used in this study to assess student achievement by the treatment and control groups. According to Gall, Gall, and Borg, (2003:189), a test is a *"structured performance situation that can be analysed to yield numerical scores, from which inferences can be made about how individuals differ in the performance construct measured in the test"*. In educational research, analysis of the "numerical scores" is often considered to be less important than analysis of answers to individual questions (sometimes called test items). This is particularly true for those questions specifically designed to investigate areas of learning difficulty, known as diagnostic (or sometimes qualitative) questions. These questions contain distractors that list commonly held misconceptions about specific content. According to Haladyna (2004), whose text examines various aspects of the construction and use of multiple-choice questions, diagnostic questions should either be constructed from students' responses given during interviews or from answers given to open-ended questions. By analysing the options selected by students (known as item analysis) valuable information about their understanding of, or deficiencies in, these areas is gained. According to Gay (1991), diagnostic questions can also provide an indirect means of identifying problems with tuition.

Diagnostic questions are usually not included in Senior Certificate *Physical Science* examinations, according to Ogude (1992), who investigated difficulties South African high school and first-year university students had with *electrochemistry*. Ogude states that examinations tend to focus on basic knowledge (such as the recall of facts and recognition of procedures) and algorithmic skills (using a particular sequence of operations to solve a problem). Ogude's study found that students sometimes had fundamental misunderstandings of the underlying chemical principles involved in *electrochemistry* despite having passed the Senior Certificate *Physical Science* examination. For this reason both diagnostic and typical Senior Certificate *Physical Science* multiple-choice questions were included in the tests. The tests consequently yielded a variety of information: the numerical scores indicated overall knowledge gains, and item analysis provided specific information about the how these gains were achieved. The typical Senior Certificate *Physical Science* questions provided information about the effectiveness of strategies that were taught to answer these questions and the diagnostic questions provided information about how students' understanding of the microscopic processes in chemistry altered during the study.

Developing and piloting multiple-choice questions was considered to be beyond the scope of the study. Instead, typical multiple-choice questions were selected from previous Senior Certificate *Physical Science* examinations and diagnostic questions were taken from Ogude (1992) and from the Chemistry Department's question-bank for first-year students at the University of the Witwatersrand. Ogude (1992) reported that her diagnostic questions had been constructed from student interviews, but it was not known how the distractors in the University's diagnostic questions had been constructed. The use of diagnostic questions taken from the University of the Witwatersrand's question-bank was justified because Ogude's study had shown that high-school and first-year university students share many of the same misconceptions (Ogude, 1992).

Many advantages of using multiple-choice tests are outlined in the literature. Haladyna (2004) states that they are quick and easy to administer and to mark, and according to Gay (1991), they are marked in the same way by all markers. Haladyna (2004) also states that they provide an uncomplicated method of investigating content knowledge and misconceptions, particularly in large populations. Haladyna (2004) claims that well constructed diagnostic questions can give reliable results so are a viable alternative to more time-consuming methods of inquiry such as interviews. According to Gay (1991), the advantage of using questions taken from public examinations such as the Senior Certificate *Physical Science* examinations, is that they can be assumed to be well written. According to Haladyna (2004), using a familiar format when testing has the advantage of reducing test anxiety for those writing the tests since anxiety is heightened when tests use novel formats. Also, the use of typical examination questions in this study was expected by the researcher to be a likely predictor of the students' future Senior Certificate *Physical Science* examination success. According to Clerk and Rutherford (2000), using diagnostic questions developed in a local study has the advantage of ensuring that the language is appropriate, whilst Sanger and Greenbowe (2000) point out that they also can be used to highlight the extent of locally held misconceptions, information that can contribute to the development of strategies for their elimination.

One disadvantage of using tests to monitor achievement is that a number of extraneous factors can negatively impact on students' performance. For example, according to Haladyna (2004), students' can suffer from test anxiety, and according to Gall *et al.* (2003) random influences such as the ambient weather conditions can also affect students' scores. Tests containing multiple-choice questions have specific disadvantages. Firstly, students may interact with the questions in unexpected ways. For example, students may improve their performance through the use of test-wiseness strategies such as the elimination of implausible distractors to narrow down the options (Towns and Robinson, 1993), or by cheating or copying (Haladyna, 2004). Some students may also confound the process by deciding not to participate, for whatever reason. This may manifest itself as sections in the test that are left out or through the use of *"aberrant response patterns"* such as answering questions in a sequence like ABCDE (Haladyna, 2004:234). Secondly, the wording of the questions may unintentionally increase the difficulty of questions, for example, by using incomplete or negatively worded stems (Haladyna, 2004), or because the question does not test what it intends to test. Clerk and Rutherford (2000), who conducted a South African study involving nine English first-language speakers, used interviews to establish that the majority (84%) who had selected the main distractor in various items did not have the target misconceptions diagnosed by the test. Instead, their selection was the result of linguistic inadequacy or *"unconscious editing"*, essentially unconsciously adding or removing words that renders the alternative correct in the mind of the student (Clerk and Rutherford, 2000:707). Finally, using the same test as both a pre-test and a post-test, as was done in this study, has disadvantages: students may give the same answers in the pre- and post-tests, or they may have worked out the correct answer in the post-test because they have spent time mulling over the questions.

The test-setting procedure used in this study is outlined below:

- To eliminate bias each test was set before the videos were viewed by the researcher. They were based on the title written on the spine of the videos.
- 15 to 20 multiple-choice questions from the sources described above were selected for each topic.
- The questions were standardised so that each contained five alternatives. This required the generation of an extra alternative for questions taken from previous Senior Certificate *Physical Science* examinations, which have only four alternatives.
- For questions involving algorithmic tasks, the arithmetic complexity of the questions was reduced as it was not known whether the students would have calculators. By doing this, it was hoped that students without calculators would be able to do the calculations using mental arithmetic.
- The researcher attempted to maintain an approximately equal mix of typical Senior Certificate *Physical Science* questions to diagnostic questions, as it was hoped that this would make comparisons between the numerical scores obtained for each test more meaningful.
- The questions were then given to a science education expert whose speciality was chemistry, to face validate. According to Hastings and Stewart (1983:701 cited by Sanders and Mokuku, 1994:482), face validation involves confirming that *"on first impression it* (the test) *appears to measure the intended construct or trait"*. The expert used in this study was familiar with the Senior Certificate *Physical Science* syllabus and common testing procedures and also had extensive knowledge of the common misconceptions experienced by high school *Physical Science* students. The expert reviewed the tests on two occasions.

  On the first occasion he was asked to peruse the selected questions and to choose the ten best questions, and make suggestions about how they should be altered if necessary. In the *electrochemistry* test the expert recommended that students should not be asked to calculate the cell potential of an electrochemical cell made from zinc and copper half-cells as teachers commonly use this example to explain the theory. If used, students might be able to recall the value of the cell potential from class (or in this case the video) instead of using the skills the question aimed to test. The expert also recommended the use of terms commonly used in South African classrooms instead of the accurate scientific terminology as it was not known whether students would be familiar with the more accurate terms. For example, the term "half-reaction" was used instead of "half-equation" in the *electrochemistry* test. By definition the term "reaction" describes the physical reaction that takes place while the term "equation" describes the symbolic representation of that reaction (Silberberg, 2000).

On the second occasion the expert was asked to moderate the test and to confirm that it covered an acceptable range of content and to evaluate whether the questions were of the appropriate standard.

Test administration: As mentioned previously the tests were not piloted before being administered because all of the questions had been used before, either in previous Senior Certificate *Physical Science* examinations or in a prior study (Ogude, 1992) or at first-year university level. Copies of the tests can be found in Appendix B.

The tests were written by all the students who attended the lecture sessions and they were written in the last ten minutes of the lecture period. A further ten minutes was given to allow slower students time to finish. Each test was written twice, once as a pre-test and once as a post-test. The pre-test was written before the topic was introduced and the post-test in the lecture session immediately after the last video session on the topic. The time period between the pre-test and post-test varied for each topic. There was a four week interval for the *electrochemistry* test, a three week interval for the *acids and bases* test, and a two week interval for the *titrations* test.

The tests were administered by the researcher. Before being handed out students were informed of the following:

- Firstly, that the tests would be revised at the end of the study and that they would receive their marks at that stage. This was done in an attempt to limit the amount of discussion about the tests.
- Secondly, that the tests contained some questions that were not similar to the type of questions usually found in the Senior Certificate *Physical Science* examination. This was done to limit possible disappointment with poor test performance.
- Finally, that answers must be written directly on to their question papers following the instructions given on the test. These instructions had been taken from a previous Senior Certificate *Physical Science* examination and were included on the front page on both the *electrochemistry* and *acids and bases* tests. Students answered the questions directly on their question papers, which were handed in so that no copies of the tests could be accessed by students before the post-tests were written. Students were identified using the student numbers which had been assigned by the school.

Test marking and data capture: The tests were marked by the researcher and this data, as well as the individual choices per question, were captured on a spreedsheet. Both the marking and data capturing processes were checked for accuracy by a colleague of the researcher.

3.3.3 Questionnaires

According to Galfo (1975:27), questionnaires are data-gathering instruments that are used to obtain *"factual data, opinions, and attitudes in a structural framework from respondents"* without the respondents and data-gatherer needing to come into contact with each other. They can be used collect a wide range of information about respondents, from their demographic and biographical details to their opinions, attitudes and interests (Galfo, 1975). In this research report the discussion is limited to questionnaires that investigate this sort of information, although Fraenkel and Wallen (1996) broadly classify questionnaires to include achievement and aptitude tests. This is due to the fact that questionnaires, like achievement and aptitude tests, can contain lists of closed questions presented in a set order (Groves, Fowler, Couper, Lepkowski, Singer, and Tourangeau, 2004).

Questionnaires were used in this study because of the following advantages. Firstly, they are a good method for getting information quickly from large populations (Gay and Airasian 2003), particularly when the information is straightforward and uncomplicated (Denscombe, 2003). Secondly, the use of closed-ended questions makes questionnaires mentally undemanding, so they are easy to complete (Denscombe, 2003), and closed-ended responses also means that they are easy to mark. Finally, because participants answer in private and anonymously, their answers are expected to be more candid than answers given in face-to-face interviews (Groves *et al.,* 2004).

There are several disadvantage associated with questionnaires. Firstly, the absence of the researcher when the questionnaire is being completed means that the questions must be as unambiguous as possible (Galfo, 1975), and the options must cover an adequate range of responses (Creswell, 2002). If questions are poorly worded then respondents may be unable to answer them, or they may interpret them incorrectly and supply invalid answers. If the options limited, then respondents may not be able to adequately express their opinions, either ignoring the question or selecting the next best choice: Strategies that lead to the collection of biased data (Denscombe, 2003). Secondly, the responses to open-ended questions can be difficult to code, and according to Denscombe (2003), respondents often avoid answering open-ended questions. Thirdly, Creswell (2002) states that the fixed format of a questionnaire means that once administered it is not possible to alter the sequence of the questions or to add to them; nor is it possible to probe any interesting answers supplied by respondents. Fourthly, questionnaires typically have a low response rates but the *"captive"* sample in this study meant that a good response rate was obtained (Gillham, 2000:9). Finally, respondents can be a confounding influence, even in the case of a well designed questionnaire. For example, some respondents may not take the questionnaire seriously, and so they may give frivolous answers (Gillham, 2000). If they are not confident about their anonymity, they may not give candid answers; and in some instances respondents may supply the answers that they think the researcher is expecting (Gillham, 2000). It is important to remember that even well designed questionnaires are able only to give an indication of what respondents say their *"factual data, attitudes and opinions"* are, and not what they actually may be (Creswell, 2002).

Questionnaire design: Four questionnaires were completed by the students during the study. Each was designed in collaboration with two experts in the field of science education, one whose speciality was the impact of language on learning and the other whose speciality was chemistry education. Both experts had experience in constructing questionnaires and they made recommendations about the wording of the questions. For example, one recommended the use of commonly used terms, such as "sex" instead of "gender", in the biographical questionnaire as it was not known whether the students would be familiar with the latter term. They also recommended the use of open-ended questions as a way of eliciting students' opinions and concerns about the videos. Both experts reviewed the questionnaire before administration as a final step in face-validating the instruments. Three of the questionnaires were designed to gauge the students' reactions to the *electrochemistry* video (attitudinal questionnaires). They aimed to provide supplementary information about the strengths and weaknesses of this video, and so enable research questions 2 and 3 to be answered more fully. The fourth questionnaire was designed to establish the biographical details of the students who participated in the study (a biographical questionnaire).

The attitudinal questionnaires were designed to be completed in less than ten minutes as the researcher wanted to limit the amount of disruption to the video sessions. This was done by limiting the number of questions. The closed-ended questions used a three-point Likert scale to probe students' opinions of the videos and each questionnaire contained one open-ended question. Each questionnaire had a different emphasis; the first focused on the pacing and verbal difficulty of the videos and used an open-ended question to investigate whether any information in the *electrochemistry* videos had been previously taught in a different way to the students. (The students were all rewriting the Senior Certificate *Physical Science* examination, see section 3.4.1.) The second questionnaire focused on how well certain activities in the videos (the tutorial questions and the practical demonstration of an electrochemical cell) were received. It also used an open-ended question to investigate whether the students were confused about any sections of the *electrochemistry* video. The third questionnaire was given to the control group and it used an open-ended question to establish the perceived strengths of the video presenter from the students' perspective.

The biographical questionnaire was designed to determine the age, gender, past and current schooling experiences of the students, and their exposure to educational television. Students' career aspirations were also probed and this question served as a proxy to establish the importance these students attached to passing the Senior Certificate *Physical Science* examination. Copies of the questionnaires can be found in Appendix C.

Questionnaire administration: The questionnaires were not piloted before being administered but the fact that they were reviewed by experts before being administered affords them a measure of face validity. The three attitudinal questionnaires were completed during the screening of the *electrochemistry* videos only. Questionnaires 1 and 2 were administered to the treatment group about three quarters of the way through the first and third video sessions respectively. Questionnaire 3 (the control group questionnaire) was administered after the first four segments of the *electrochemistry* video had been viewed, about two hours into the full-day video session. The questionnaires were given out at these times and not at the end of the sessions to ensure that all the students completed them, as students tended to leave the venues promptly at the end of sessions. The biographical questionnaire was administered during the last lecture session. The stages at which the attitudinal questionnaires were administered during the study are indicated in Figure 3 on the following page.

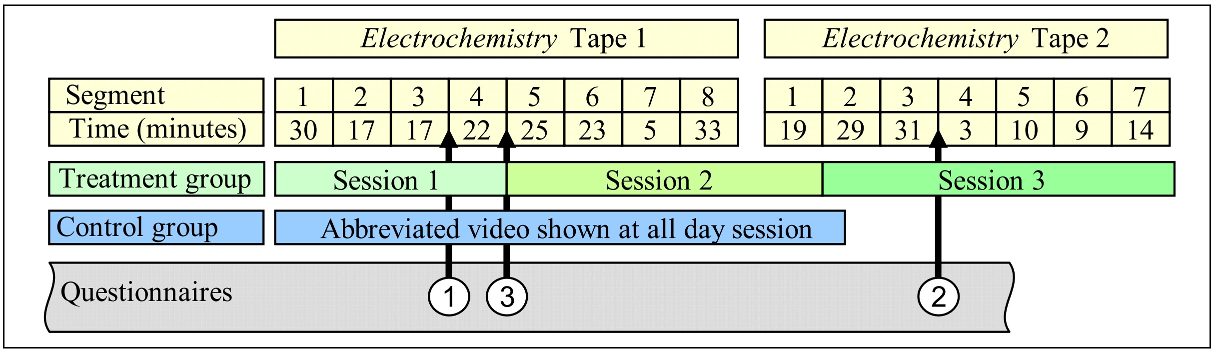

Figure 3: Schematic representation showing when attitudinal questionnaires were completed

3.3.4 Observational techniques

According to Gronlund (1976:429), observational techniques are used in educational research to provide *"factual descriptions of the meaningful incidents and events"* that arise during live situations. They have the advantage of being recorded as the situation unfolds and they provide contextualised information that is often not elucidated through other avenues of enquiry (Gronlund, 1976).

Under normal circumstances all aspects of a live situation are transitory and would be lost if not captured immediately, but in this study the videos provided a permanent record of the "teaching" input the students received. This made observation of the live situation somewhat easier, as it was only necessary for the students' reactions to incidents on the videos to be recorded, and not details of the incidents on the videos. It was important to flag incidents on the video during the live observation process and this was done by either describing the incident or transcribing a salient portion of the audio track. If necessary the incident on the video could be described in detail later by viewing the video.

Students' reactions to the videos were recorded using two different observational techniques. The first technique (field notes) was used to describe incidents that took place before and after the video sessions and on any occasion during the sessions when videos were not being screened. The second technique (observation schedules) was used to describe how students reacted when the videos were being screened.

Field notes: According to Creswell (2002:201), field notes are *"text recorded by the researcher during an observation"*. These notes are used to describe any pertinent events that are seen or heard by researcher during the observed situation (known as descriptive field notes), and they can include the researcher's personal reactions, thoughts, ideas and feelings (known as reflective field notes).

The advantage of field notes is that they give a first-hand account of how the research situation unfolded and include information about the context as it happens – information that can be used to jog the researcher's memory when recalling events later (Denscombe, 2003).

Disadvantages associated with field notes are that they are time consuming to record, and to be useful they need to be recorded in detail as soon after the event as possible (Gronlund, 1976). Researchers also need to hone their skills in recording field notes and often the quality of these notes improves as the study proceeds, which can mean that important details at the start of the study may be missed

(Gall *et al.*, 2003). Field notes can also be subject to "observer bias" as the researcher's framework influences what is perceived to be important. This means that some incidents may be emphasised while other may be glossed over or not recorded at all (Gall *et al.*, 2003). Another disadvantage of observation is the fallibility of the human observer. Perceptions of observers are influenced by their past experiences, their mental and emotional state, and their ability to recall and describe incidents later (Denscombe, 2003).

Observation schedules: According to Creswell (2002:175), observation schedules are checklists used *"to collect data on specific behaviours"*. Their format allows researchers to systematically monitor selected behaviours at fixed time intervals during the observation situation. One advantage of observation schedules, according to Creswell (2002:175), is that only the actual behaviour is monitored and not the researcher's *"views or perceptions"* of the behaviour. According to Wragg (1987), whose text examines teacher appraisal, this has the advantage of allowing researchers to make consistent and objective observations and so observation schedules tend to be easier to use and less time-consuming than field notes. By altering the duration of the time intervals used, observation schedules can be used to indicate whether a selected behaviour occurs, how often it occurs and, in some instances, the time period over which it occurs (Wragg, 1987).

Limitations can arise from the design of the schedule. According to Lincoln and Guba (1985) using pre-selected behaviours may deflect attention away from other pertinent but unselected behaviours. Also, Wragg (1987) states that some pre-selected behaviours may not yield any pertinent information and so are of little value. The observer can also be a source of error, particularly if observations are not accurately recorded. Observational errors are most likely to occur when large classes are observed as the observer may not notice all behaviours or may be distracted and so not record all or any of the incidents (Wragg, 1987).

Wragg (1987) makes the following recommendations about constructing observation schedules:

- Pre-select a number of pertinent behaviours and limit the number if a large class is to be observed.
- Leave blank spaces in the schedule so that unanticipated but relevant behaviours that occur during observation can be incorporated.
- Select an appropriate time interval, usually between one to five minutes.

When using an observation schedule Wragg (1987) recommends that a single tick be placed in the schedule at the appropriate time slot if a selected behaviour occurs, even if the behaviour occurs more than once during that time interval. Wragg explains that this is because knowing that the behaviour has occurred yields more pertinent information than knowing the frequency with which the behaviour occurs in the set time interval. Wragg (1987) recommends that behaviours that occur all the time should be dropped from the observation schedule as they can be commented on in general terms.

The observation schedules used in this study were designed by the researcher using the above recommendations by Wragg (1987). A one-minute time interval was chosen and the pre-selected behaviours were chosen in consultation with the two science education experts mentioned earlier (see section 3.3.3). The pre-selected behaviours were: note-taking, watching the screen, laughing, and off-task behaviours such as talking, muttering, yawning, and dozing. While observing the first video session, one unanticipated behaviour occurred frequently, namely answering some of the questions the video presenter asked during the video (these and other reactions to the videos are discussed in more detail in section 4.4), and some pre-selected behaviours either happened all the time or were difficult to monitor so they were dropped. For example, the students were very attentive throughout the study and always watched the screen; they all took notes but quite sporadically, making it difficult to monitor; and only one student dozed, and he dozed at every session. The final observation schedules recorded the occurrence of five behaviours only: answering questions, laughing, talking, fidgeting, and sighing. A sketch of the observation schedule used is given in Figure 4 below. It illustrates examples of typical behaviours that occurred and shows how the comments section in the schedule was used to record supplementary notes about students' reactions as well as details about the incidents that triggered these reactions. This strategy helped to identify incidents in the video that could be investigated later if required. Observations made in the first minute of a video segment were recorded under the time "0", and in the second minute under the time 1 – this corresponded to the time given on the video machine's display panel. (A copy of the observation schedule can be found in Appendix D.)

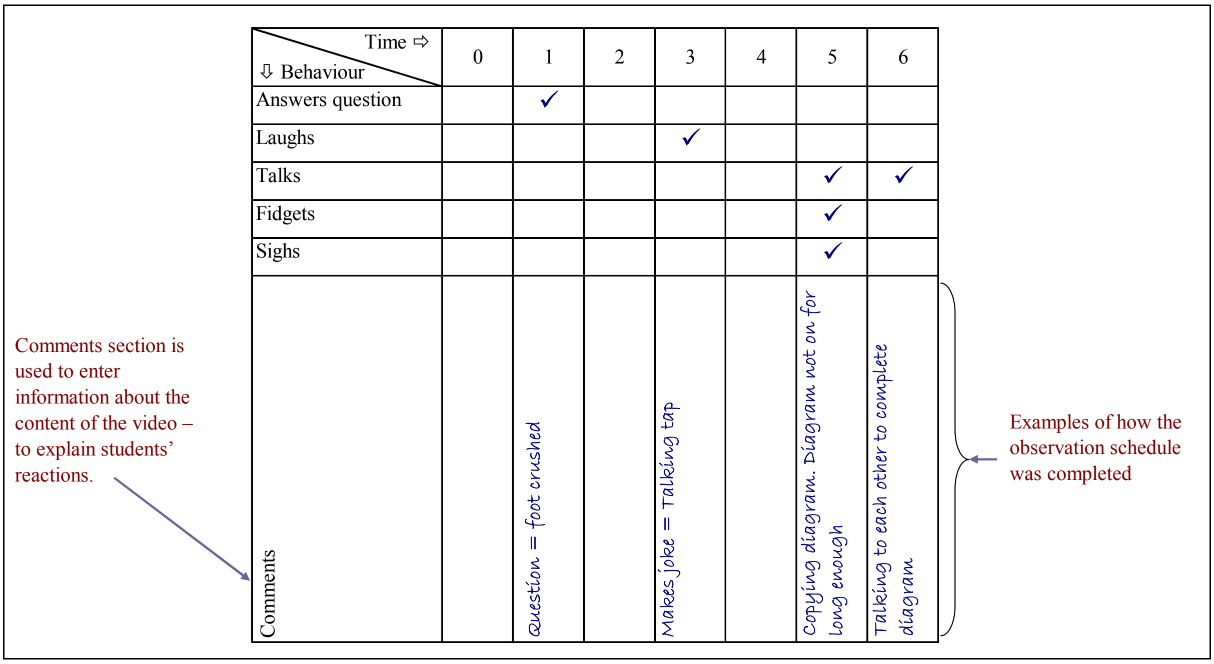

Figure 4: Sketch of the observation schedule used to record students' reactions to the videos

Administration of observational techniques: Despite using two different observational techniques during the video sessions the recording process was straightforward, as each technique was used separately. The observation schedules used to record students' reactions to the videos were easy to use as they only recorded five pre-selected behaviours, and since the students were engrossed with the viewing process other behaviours seldom occurred. This meant that there was sufficient time for unselected behaviours to be recorded and for the comments on the video that triggered specific responses to be flagged in the observation schedule. This was done by recording one or two words of the comment. For example, students responded to the question: "is your foot crushed?" so the words "foot crushed" were recorded at the appropriate time interval in the observation schedule thus flagging or identifying the comment (see minute 1 in Figure 4 above). A new observation schedule was used at the start of each segment and the time at which specific incidents occurred in the segment was used to locate pertinent portions of the videos later, when required. The timing was done using a stop watch in conjunction with the display panel on the video machine.

Field notes were used to describe any events that took place when the videos were not being viewed. They were used to capture the questions students asked during breaks, to record the difficulties that were experienced during the sessions, to comment on the ambient weather conditions, and so on. Initially, the researcher aimed to be a non-participant observer but this was not possible as the video sessions were run single-handedly by the researcher. Many interactions with the students involved practicalities about the sessions themselves, such as the audibility and visibility of the videos and the comfort of the lecture theatre. Sometimes discussions about the videos were initiated by the students and they often queried the content or made other comments about the videos. Queries about the content were resolved by first investigating the student's understanding using probing questions before providing an explanation. Some important anecdotal information was recorded as a result. As many of the comments and interactions as possible were recorded during the sessions. Field notes recorded during sessions were typed up by the researcher immediately after each session.

Field notes were also used to monitor the lecture sessions, even though these sessions were not under direct observation. This was done for two reasons: firstly, the researcher wanted to record whether watching the videos had any impact on the lectures, as the video presenter often advised students to "ask your teacher" if they experienced any difficulty with the videos. Secondly, the researcher wanted to monitor the input that the students received during lectures.

Both field notes and observation schedules were used to monitor the students' behaviour at the control group video session. They were used in the same way as described for the videos session but observations were only made during the first two hours of the *electrochemistry* video, which was screened at the start of the all-day video session. This decision was taken because it was thought that all participants, including the researcher, would suffer from fatigue as the day progressed and so meaningful observations would be less likely later on.

3.3.5 Reviewing the videos

Analysis of videos is a complex task since both the verbal and visual components have to be evaluated simultaneously. Two other factors complicate the analysis process further. Firstly, according to Koumi (1991:145), video producers and screenwriters use a *"complex mixture of craft, intuition, art and practical psychology"* to construct their products. Secondly, videos are a transient medium, according to Kozma (1991) as their output cannot be captured in a stable form. So, while the video itself is a tangible object, its contents are intangible and are only accessed during the viewing process. The transient images projected by the video can only be verified by re-watching the video or through a process of converting the output into series of photographs and transcripts.

According to Creswell (2002:259), thorough analysis of any audio material, or in this case audiovisual material, can only proceed once the audio track and visual footage have been converted into *"text data"*. One way of doing this would be to transcribe the audio track, but this is a time-consuming procedure and transcription of the audio track would not have yielded information about the visual footage and its interactions with the audio track, so it was not attempted. Instead data was collected from the videos by summarising the content, transcribing relevant portions of the videos and by commenting on visual footage, for example, comments were made about diagrams, experiments and factory visits shown on the videos. The advantage of writing summaries was that they provided a detailed account of the scientific content that could be scrutinised later and this restricted the number of times that the videos had to be re-watched.

Administration of the video review process: The videos were reviewed after the first stage of the study was completed. Portions of the audio track were transcribed by the researcher and were checked for accuracy by getting a third party to listen to the videos while reading the transcripts. When transcribing the videos no attempt was made to capture hesitations, drawn-out words, inflections, or emphases, as this was considered to be beyond the scope of the study. Brief notes were made about the activities the video presenter was engaged in when making the transcribed comments, for example, if he was giving a very animated talking-head discussion using hand gestures or if the comments were made while he was involved in writing on the screen blackboard (voice-over) and so on. The summary of the *electrochemistry* video was reviewed by the expert in chemistry education mentioned previously and he made various comments about the correctness of the scientific content and the types of explanations used.

3.4 SAMPLE DETAILS

This section reports on the samples used in this study. According to Creswell (2002:649) a *"sample is a subgroup of the target population that the researcher plans to study for the purpose of making generalisations about the target population"*. In this study the samples were drawn from two populations, namely the people involved in the study and the materials that were used in the study.

3.4.1 The school, lectures, lecturer and general student population

The students who took part in the study were attending a non-traditional, part-time school known as a "matric rewrite school" (the school). It is sponsored by a number of large corporations and for a nominal fee it offers students who have already attempted Senior Certificate examinations but who have failed, tuition in a number of subjects (including *Physical Science*) and the opportunity to rewrite the Senior Certificate matriculation examinations. Although the school has a head office in central Johannesburg where administrative functions are performed it has no campus, and lecture facilities at the University of the Witwatersrand are used.

Tuition at the school takes the form of a one-hour lecture per subject per week throughout the academic year, beginning in January and ending in October. During the study each lecture was delivered twice, in two consecutive sessions that took place in the late afternoon. The lectures were given in English and the lecturer ("the lecturer") who taught *Physical Science* at the school was a PhD chemistry student at the University of the Witwatersrand. He had been teaching at the school for four years.

According to the lecturer, approximately 450 students were registered for *Physical Science*. Lectures took place in a large lecture theatre capable of accommodating about 300 students, and the students were divided evenly between the two sessions. However the first session was more popular as it meant that students could get home earlier. Students who had registered for the second session often attended the first session and it was for this reason that the use of an intact class was avoided when designing the quasi-experiment. The lecturer stated that attendance at the lectures was somewhat erratic, with approximately 250 to 350 students attending lectures each week but fewer than 250 students attending regularly. This erratic attendance was confirmed using data obtained during the study, as 379 students submitted at least one test or questionnaire but only 126 wrote all the tests. It was the data from these 126 students that was analysed in this study. This introduces a possible source of bias to the study as these students were probably more committed than those excluded from the study by their erratic attendance, so the students involved might not be typical of the population studied.

From the biographical questionnaire, which was completed by 246 students, it was established that all the students were repeating the Senior Certificate *Physical Science* examination, and in the year prior to the study 91% had been attending traditional schools. More than 140 different schools were listed by the respondents and the maximum number of respondents registered at any one school was nine. Most of the schools were situated in the greater Johannesburg metropolitan area, although some respondents had attended schools elsewhere such as Durban, Cape Town and Port Elizabeth. Most were unemployed, but 12% were attending traditional schools during the earlier part of the day and 3% had some form of employment. The average age of the respondents was 20,1 years, and all of them were English second-language speakers. On average they were registered for four subjects at the school, with a range from one to seven subjects. According to the lecturer, the students were highly motivated and would exploit any opportunity to expand their knowledge.

3.4.2 Selection of the treatment group

The treatment group was selected on a volunteer basis and their only incentive was that they would be able to watch the videos. No claims were made about the video's effectiveness. The lecturer recommended that the treatment group be limited to no more than 120 students based on the attendance characteristics mentioned earlier. Students were informed that places would be assigned on a "first come, first served" basis and that an attendance register would be kept. They were also encouraged to attend all six video sessions. In an effort to reduce the number of students volunteering, video sessions were scheduled to run on Friday afternoons and assurances were given at the start of the study that all students would be able to watch the videos before the end of the study.

Despite these restrictions and assurances a number of problems were encountered. Over 300 students volunteered for the selection session and they were already present at the venue by the time the researcher arrived, which was more than one hour before the designated start. For this reason the "first come, first served" selection criterion could not be used and a different selection process had to be put in place. The impromptu procedure was devised and administered by the lecturer and it entailed forcing the students to stand in two queues and selecting 120 students from the most orderly queue. Regrettably this selection criterion did not meet with the approval of the students who were not selected; they demonstrated their dissatisfaction by forcing their way into the lecture theatre, breaking down the lecture theatre door in the process. Once inside they sat down and demanded the right to watch the videos. This led to the cancellation of the session and the following lecture session was used to resolve the dispute (also see section 3.7.3). The students only agreed to allow the study to continue once assurances that the control group would have the opportunity to watch the videos prior to the end of the study had been reiterated.

3.4.3 Students involved in the study

Only data obtained from students who had written all six tests were analysed. An extra criterion imposed on the treatment group was that these students had to have attended at least one video session per topic. Data from the tests were analysed for 126 students, 57 from the treatment group and 69 from the control group. Biographical information was only obtained for 108 of these students and this data is summarised in Table 6 below.

Table 6: Biographical information about the students used in the study

Group	Treatment	Control
Number of respondents for the biographical questionnaire (percent of total)	49 (86%)	59 (86%)
Average age (years)	20,2	19,7
Average number of subjects registered for per student, including *Physical Science*	4,1	4,0
Percent female / male	55%	54%
Percent male	44%	46%
Percent attending full-time school	10%	5%
Percent working	4%	0%
Percent wanting to pursue science-related careers if they pass	94%	86%
Percent wanting to repeat matric if they fail	67%	68%
Percent who had watched any educational television broadcasts	53%	54%

3.4.4 The videos

An eleven-hour sample of videos was selected from the full set (which covered the Senior Certificate *Physical Science* syllabus in 65 hours). This sample represented 3 topics from the full set of nine chemistry and ten physics topics. The choice of topics was made by the lecturer at the school where the study took place and was governed by the topics that were still to be taught during that academic year. Since no user's guide was available with the videos when the study commenced, the sequence in which the topics were shown was decided by the lecturer.

3.5 DATA ANALYSIS

This section reports on the data-analysis strategies that were used in this study. According to Marshall and Rossman (1989:112), the aim of data analysis is to *"bring order, structure, and meaning to the mass of collected data"*, and the procedures used to do this vary depending on the type of data collected, and the emphasis of the study. In this study a diverse range of data was collected that necessitated the use of both quantitative and qualitative data-analysis procedures. Reporting on quantitative data-analysis procedures is relatively straightforward as often a limited number of well-established (usually statistical) procedures are used, but reporting on qualitative data-analysis procedures is more difficult. There are two reasons for this: firstly, according to Taylor and Bogdan (1998:140), qualitative data-analysis is not a "*mechanical or technical process, it is a process of inductive reasoning, thinking and theorising"* and secondly, according to Creswell (2002:258), there is no definitive way to do this, "*it is an eclectic process in which you try to make sense of the information"*.

Data analysis in this study took place in three stages. The first involved converting raw data into a format that would allow further analysis. The tests were marked, the overall scores calculated and histograms were obtained for each question that showed how students' answers had altered between the pre-test and post-test per group. Averages were obtained for closed questions in the questionnaires and the open-ended questions were classified into common themes. Where possible comments and anecdotes from the observation schedules and field notes were incorporated into the summaries obtained during the video review process.

The second stage involved data reduction and this was achieved by using the research questions as a filtering device in conjunction with data obtained from the tests. The overall scores obtained in the tests were used to determine how students' performance had altered (research question one), and individual questions in the tests that highlighted the strengths or weaknesses of the videos were selected for analysis (research questions two and three respectively). The strengths of the videos were assessed by selecting those questions where there was a marked increase in the percentage of students from the treatment group choosing the correct answer in the post-test relative to the control group. The selection criteria used was that the relative improvement by the treatment group had to be at least 9% more than any improvement shown by the control group. Similarly, the weaknesses of the videos were assessed by selecting those questions where there was a marked increase in the percentage of students from the treatment group selecting the main distractor coupled with either no improvement or a decrease in the correct answer relative to the control group. An increase of more than 7% by the treatment group relative to control group was used as the selection criterion to choose these questions. Although both these percentages were arbitrarily set, it was hoped that the chosen questions would reflect influences arising from the videos rather than the lectures, which both groups had attended.

The final stage involved using different data-analysis strategies to answer the research questions. Research questions 1, 2(a) and 3(a) used statistical techniques but research questions 2(b) and 3(b), which aimed to establish why the selected questions had been answered in the specific way, used qualitative data-analysis strategies that collated pertinent data from as many sources as possible. Some qualitative researchers call this process triangulation, and according to Creswell and Miller (2000:126), it is a *"procedure where researchers search for convergence among multiple and different sources of information to form themes or categories in a study"*. A less formal and more inductive procedure was used in this study to establish themes and it involved repeatedly reading through the data and watching the videos. According to Taylor and Bogdan (1998), this inductive procedure works because on repeated exposure to the data researchers are able identify that specific vocabulary and activities recur. By keeping track of these recurring themes researchers are able to relate *"different pieces of data to each other"* and ultimately to make generalisations about the data (Taylor and Bogdan, 1998:145). Anfara, Brown, and Mangione, (2002:31) state that researchers are able to make these links because they have *"an acute awareness of the data"* along with knowledge of the research context and the literature (Strauss and Corbin, 1998).

The procedures used to evaluate the selected questions were to first evaluate how the content tested in the question was taught in the videos. This could be done by reviewing the summaries or, as was often the case, by purposively sampling the videos. According to Creswell (2002), purposive sampling involves focused intentional sampling to gather data that supports the trends that have emerged from analysis of other pertinent data. An additional strategy that was applied to those questions that had been answered successfully was to identify whether any error recognition strategies had been taught on the videos. Next the questionnaires, observation schedules and field notes were investigated to establish whether they contained any evidence that supported the findings obtained from the video review process, and often this process resulted in the videos being re-watched and re-sampled. The procedures were not necessarily applied linearly, and often data from all sources was reviewed repeatedly. One of the advantages of this analysis process was that it enabled unanticipated but relevant features of videos to be explored and reported.

3.6 ENSURING QUALITY AND RIGOUR IN THE STUDY

For research to be of practical use to educators, it is important for researchers to demonstrate the reliability and validity of their findings. Since this study used a pragmatic approach to collect and analyse data, it is important to note that concepts of reliability and validity are taken from the quantitative paradigm and have specific meanings within that paradigm. Although Lincoln and Guba (1985) suggested alternative terms that articulate the constraints encountered when assessing the quality and rigour of qualitative studies, many researchers (for example see Creswell and Millar, 2000; Anfara *et al*., 2002) still use the terms reliability and validity but broaden the definitions. In this research report the terms reliability and validity will be used. However, it is important that terms are explained.

Reliability refers to the degree to which observations or measurements can be replicated, and according to Wellington (2000:200) reliability is a judgement of *"the extent to which a test, a method or a tool gives consistent results across a range of settings, and if used by a range of researchers"*. Hammersley (1992:6) identifies the researcher as a possible source of inconsistency, stating that reliability *"refers to the degree of consistency with which instances are assigned to the same category by different observers or by the same observer on different occasions"*. Data which is unreliable will also lack validity.

According Creswell (2002), validity is used to describe whether the observations or measurements taken during a study give an authentic account of the phenomenon that was observed or measured. It is therefore concerned with the success or truthfulness of the observation or measurements taken during the study. Sanders and Mokuku (1994) raised four important points about validity of test scores in quantitative studies, points that are applicable in any paradigm.

- Validity does not refer to the instrument used to collect the data but rather to the results themselves.
- Validity is context dependent and related to how the results are used, so inferences made can be valid in one situation and not in another.
- Validity is an ideal that researchers should strive for but it is not a tangible, measurable entity.
- Validity is multifaceted: it is as important to evaluate the results obtained from the data-gathering instrument as it is to evaluate the inferences made from these instruments by the researcher.

The following steps were taken in this study to improve the validity of the study. Firstly, the instruments (tests, questionnaires and observation schedules) were face-validated by experts, as discussed earlier (see section 3.3). Secondly, triangulation of data obtained from the various methods and sources was used to confirm the findings obtained, and to answer the research questions, as discussed in section 3.5.

3.7 ETHICS

This section reports on the strategies that were used to ensure that the study was conducted ethically, although it was completed before the formal requirements for ethics clearance for educational research were imposed by the University of the Witwatersrand. As a result no written informed consent forms were obtained from any of the participants. Despite this a number of steps were taken to ensure that the study was carried out ethically.

3.7.1 The videos

The video presenter instigated this study by approaching the University of the Witwatersrand and asking for the videos to be investigated. His overriding concerns centred on how English second-language students would react to the videos. To investigate this, the video presenter suggested that English second-language students attending a school that he administered be used in the study. He also made numerous suggestions about how the study could be conducted. Before commencing the study, a verbal agreement between the researcher and the video presenter was reached regarding the parameters of the research. The video presenter agreed to allow the researcher to conduct independent research, and the researcher agreed to give feedback about how the students reacted to the videos. This information was relayed telephonically to the video presenter by the researcher on various occasions during the first stage of the study.

3.7.2 The design

The design of a study can also be a source of ethical constraints, especially in a situation where one group may be subjected to a supplementary input while the other is not. To limit these ethical problems, the study was designed in such a way that both groups would be able to view the supplementary material before the study was completed.

3.7.3 The students

The students volunteered to participate in the study after listening to a lecture where the aims and purpose of the study were presented. At this lecture, students were invited to supplement their routine lectures with six two-hour video sessions. The fact that only a limited number of volunteers would be selected was emphasised, as was the voluntary nature of the video sessions. Potential volunteers were strongly encouraged to make the commitment to attend all the video sessions. The implications of using a quasi-experimental design was explained at this lecture and the students agreed in principle to the necessity of having an experimental and control group. Students were given assurances that they would all have the opportunity to watch the videos before the end of the study. They were also assured that their anonymity and confidentiality would be respected throughout the study. The reality of being assigned to the control group however triggered a considerably amount of discontent that almost caused the termination of the study (see section 3.4.2) and resulted in a further discussion with students about the aims and structure of the study. Assurances that all the participants would have the opportunity to watch the videos before the end of the study were repeated and a verbal agreement was reached with the students to allow the study to continue.

3.7.4 The implementation

Permission to use lecture time to administer the tests and the biographical questionnaire was obtained from the lecturer before the study commenced. In an attempt to minimise the amount of disruption of the classes, the tests and the biographical questionnaire were administered during the last ten minutes of the lectures and the 15-minute break between lectures was used to complete the tests when required.

3.7.5 The final report

One of the problems with reporting findings using thick, rich description is that this descriptive process can expose the identities of participants. In this study, where nearly 400 students participated, it is unlikely that the identity of any individual student would be revealed, but it is likely that readers may be able to identify the video presenter. This leads to a dilemma because any attempt at obfuscation would invalidate the study and so it was not attempted. The onus therefore falls on readers (who may be able to identify the video presenter as a result of the descriptions given in this report) to be mindful of the fact that his anonymity should be respected.

3.8 CONCLUDING REMARKS

This chapter dealt with the research design and methods that were used in this study. The design of the instruments was discussed along with the procedures used to collect and analyse the data. The steps taken to improve the quality of the research were also discussed along with the procedures that aimed to ensure that the study was carried out ethically.

CHAPTER 4
RESULTS AND DISCUSSION

The purpose of this chapter is to report the findings obtained during this study. The chapter is divided into four sections: the first uses the mean test scores to evaluate the effectiveness of the videos as a learning aid. The second section examines those questions where the treatment group showed a marked improvement compared to the control group, and so aims to make the strengths of the videos explicit. The third section reports on those questions where there was a marked increase in the selection of the main distractor by the treatment group compared to the control group, and aims to make some weaknesses of the videos explicit. The final section reports students' reactions to the videos.

4.1 COMPARISON OF THE OVERALL SCORES

This section aims to answer the first research question.

> RESEARCH QUESTION 1:
> To what extent did the students' performance change after watching supplementary videos on the selected topics?

The results of the tests are given in Table 7 below, and from this table it can be seen that the performance of the two groups before the study started were very similar, based on their pre-test averages (the control group scored slightly higher on both the *electrochemistry* and *titrations* pre-tests, while the treatment group scored slightly higher on the *acids and bases* pre-test). These differences, although small, were never the less statistically adjusted for using analysis of co-variance, as explained on p. 49.

The results show that there was an improvement in performance for both groups, from the pre-test to post-test results, which was to be expected since both groups had attended lectures on the topics during the study. Both groups improved to the same extent on the *acids and bases* test (namely by $^{1.2}/_{10}$) and the *titrations* test (namely by $^{0.3}/_{10}$). The treatment group performed slightly better than the control group in the *acids and bases* test but slightly worse than the control group in the *titrations* test. The test where the treatment group (who had watched supplementary videos on the topics before writing the post-tests) showed the largest improvement relative to the control group was the *electrochemistry* post-test. In this test the treatment group improved by an average score of $^{0.9}/_{10}$ while the control group improved by $^{0.5}/_{10}$.

Table 7 Descriptive statistics obtained for the tests

Topic	Control group (n = 57) Maximum score = 10			Treatment group (n = 69) Maximum score = 10			Levene's test Equality of variances p-value	ANCOVA p-value
	Pre-test	Post-test	Improvement	Pre-test	Post-test	Improvement		
Electrochemistry	3.6	4.1	0.5	3.4	4.3	0.9	0.66	0.41
Acids and bases	3.4	4.6	1.2	3.5	4.7	1.2	0.18	0.67
Titrations	1.9	2.2	0.3	1.7	2.0	0.3	0.82	0.61

This improvement can be seen more easily when the data is presented graphically (see Figure 5), as steeper slopes indicate greater improvement. For example, the graphs show that in the case of the *electrochemistry* results, the slope of the treatment group's graph is more pronounced that that of the control group, showing that the treatment group improved to a greater extent than the control group for this topic. In the case of both the *acids and bases* and *titrations* tests, the parallel graphs show both groups improved to the same extent.

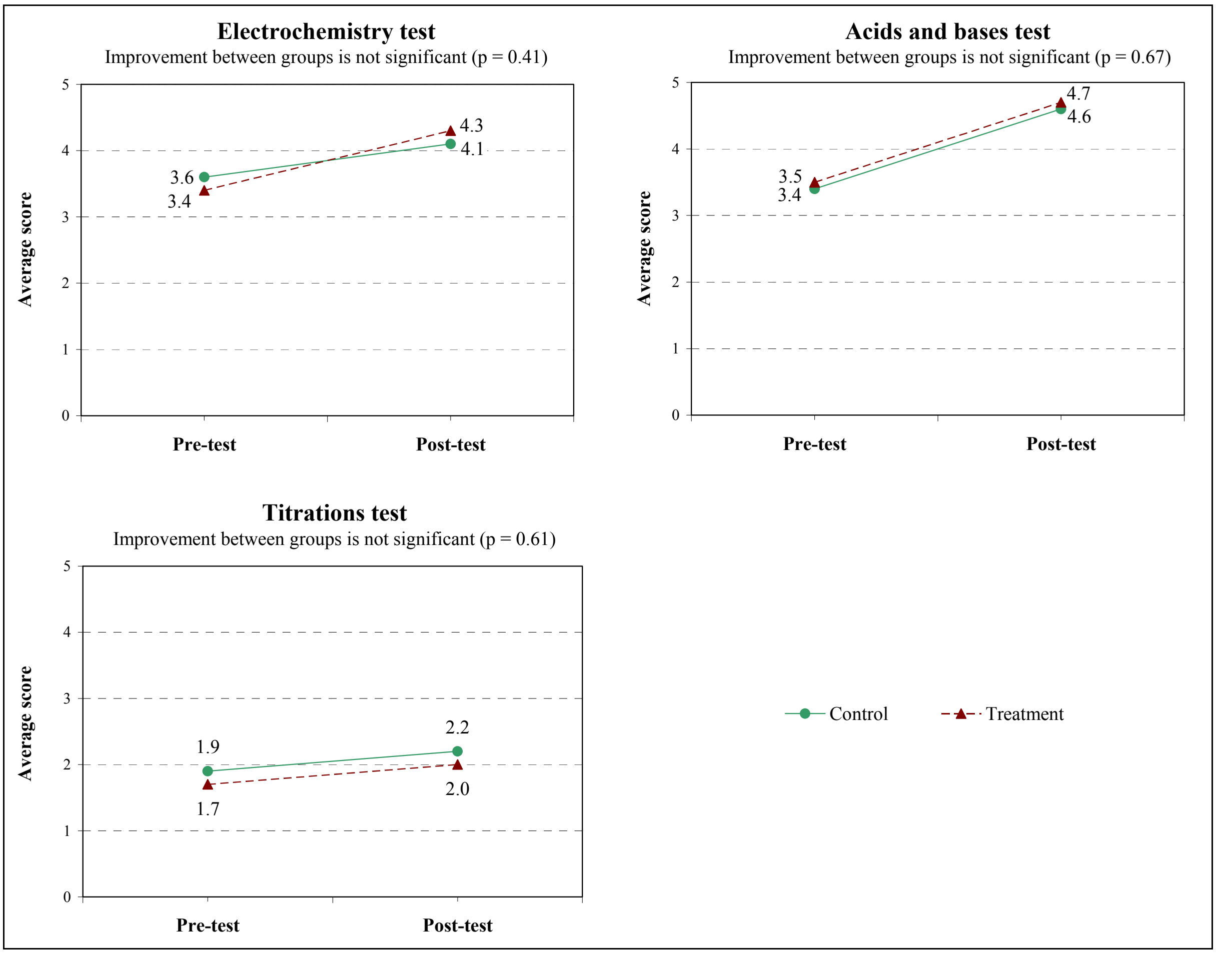

Figure 5: Graphs showing the improvement in scores for the treatment and control group

Since the improvements made by the treatment group relative to the control group were small, a statistical procedure that was sensitive enough to detect whether these improvements were significantly different was required. The procedure used was analysis of covariance (usually abbreviated ANCOVA). According to Steffens (1984), the advantage of this procedure is that it addresses a problem that can arise when performing experiments, namely that the groups may not be comparable at the start of an experiment. These initial differences may mask the groups' response to the treatment, making differences between groups difficult to detect from the data obtained at the end of the experiment. This problem was likely to occur in this study where the participants had not been randomly assigned to groups at the start.

According to Steffens (1984), ANCOVA uses a variable that is related to the response but is not affected by the treatment to adjust the dependent variable (in this case the post-test scores). This variable is known as the covariate and in this case the pre-test scores were used. ANCOVA then compares the treatment effects after these adjustments have been made. According to Steffens (1984), instead of comparing the means obtained at the end of the experiment, ANCOVA fits straight lines to the adjusted data using linear regression[9], and then compares the constant terms of these straight lines (namely the slopes and intercepts). So ANCOVA, by eliminating the differences with respect to the covariate at the start, increases the likelihood that any differences between the two groups will be identified.

One constraint associated with ANCOVA is that this statistical procedure should only be applied to data that is normally distributed. The Levene's test of equality of variances was performed on the data to check for this. Since the p-values calculated for the data using the Levene's Test (see Table 7) all exceed 0.05[10], it is possible to conclude that at the 95% confidence interval there is no evidence that the variances of the treatment and control groups differ from each other.

The results obtained for the ANCOVA are given in Table 7 and, since the p-values are greater than 0.05 (see footnote 10), it is possible to conclude that the difference in improvement between the treatment and control groups for each topic was not statistically significant at the 95% confidence interval. This implies that there is a high probability that the differences in the means were a matter of chance (and not statistically significant).

Although this statistical procedure reduces the effects arising from differences in the covariate (the pre-test scores) at the start, it must be remembered that the two groups may have differed in other ways that were not taken into account when performing this study.

4.2 ANALYSIS OF QUESTIONS WHERE IMPROVED PERFORMANCE WAS NOTED

This section aims to answer the second research question.

RESEARCH QUESTION 2:
What were the strengths of the videos in terms of helping students to improve their performance?

(a) To what extent did students answer questions more successfully after watching the videos?
(b) What were some of the possible reasons that these questions were answered more successfully?

Only those questions where the treatment group showed a marked improvement in getting the answer correct in the post-test compared to the control group were analysed. The selection criterion used to identify these questions was that the treatment group's mean score for the correct answer had to be at least 9% more than that of the control group, as larger improvements were more likely to be attributable to the videos. The extent to which the treatment group outperformed the control group by 9% or more on individual questions is discussed in section 4.2.1. Tactics identified on the video that

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9 A statistical procedure used to calculate the equation of a data set with a linear relationship (Steffens, 1984).

10 This number represents the "confidence interval" with which statistical results are reported. If a p-value of **less than 0.05** had been obtained then the probability is less than 5% that the observed difference happened by chance (Steffens, 1984).

were thought to have helped students get the correct answer are described for each question in the remainder of this section. Since both Romiszowski (1988) and Koumi (1991) recommend that educational videos should teach error recognition, any tactics that may have helped students in the treatment group avoid selecting incorrect choices in the post-test are discussed for these questions. Where relevant, student reactions to some of the tactics are included to give the reader an idea of how well they were received.

4.2.1 The extent to which questions were answered more successfully after watching the videos

Although the difference between the treatment and control group mean scores for each topic was not statistically significant, marked improvements were demonstrated by the treatment group for six of the thirty questions in the tests, about 20% of the questions. Of these questions, three came from the *electrochemistry* test, and three from the *acids and bases* test. No relative improvement of 9% or more was shown by the treatment group for any question in the *titrations* test. The relative improvements obtained for each question are given in Table B1 in Appendix B. Table 8, given below, shows what task is tested for in each question, all of which can be classified as typical Senior Certificate *Physical Science* questions (see Chapter 3, section 3.3.2 for an explanation of these types of questions). The percentage of students getting the answer correct in the pre-tests and post-tests along with the percentage improvement (or gain) achieved by each group is shown in table. The final column lists the relative improvement (or gain) attained by the treatment group.

Table 8: Table showing questions where the treatment group showed a marked improvement compared to the control group

Topic	Question		Control (%)			Treatment (%)			Relative gain by treatment group (%)
	No.	Task being tested	Pre-test	Post-test	Gain	Pre-test	Post-test	Gain	
Electrochemistry	5	Identify the reaction at an electrode	29	39	10	25	44	19	+9
	9	Identify a reduction half-equation	43	52	9	21	49	28	+19
	10	Calculate a cell potential	26	33	7	28	58	30	+23
Acids and bases	4	Identify a substance reacting as a Brønsted-Lowry base	35	48	13	33	58	25	+12
	7	Calculate pH from hydroxide ion concentration	9	12	3	7	23	16	+13
	10	Identify a basic salt	38	35	–3	21	32	9	+12

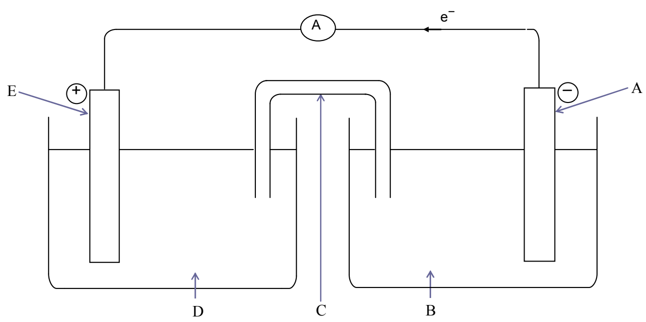
A statistical procedure that evaluated whether the improvements made by the treatment group on individual questions were significantly different to the improvements made by the control group could not be found. However, from Table 8 it can be seen that the treatment group demonstrated the most marked relative improvement for Question 10 in the *electrochemistry* test, and made more modest gains for Question 5 in the same test. The questions and possible tactics identified in the videos that may have aided the treatment group's performance are discussed in the following six sub-sections. To improve the readability of this section of the chapter all the histograms have the same format, and in each case the correct answer is indicated with an asterisk. Option N on the histograms represents the percentage of students who did not answer the question for each test.

4.2.2 Electrochemistry test, Question 5: Identifying the reaction at an electrode

This question, which is given in Figure 6, along with a histogram of the results, asked students to identify the reaction occurring at a specific electrode (labelled A) in a sketch of an electrochemical cell. (This question, which was taken from a previous study conducted in South Africa, had two entities “labelled A”: the electrode and the ammeter. This problem is discussed later in this section.)

Electrochemistry test - Question 5

Questions 4 and 5 refer to the electrochemical cell which is illustrated below:



When the electrochemical cell operates the reaction which takes place at the electrode A is:

A. oxidation
B. crystallisation
C. neutralisation
D. oxidation and reduction
E. reduction

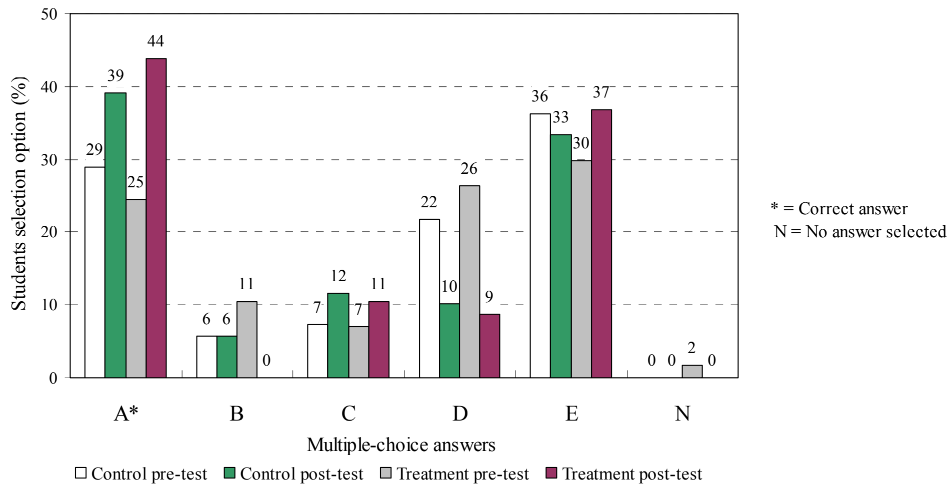


Figure 6: Electrochemistry test: Question 5, and a histogram of the results obtained

To answer this question students needed to determine whether the electrode is an anode or cathode and, having established this, to recall the naming conventions for these electrodes. By convention the electrode where oxidation takes place is called the anode, and the electrode where reduction takes place is called the cathode (Garnett and Treagust, 1992b). There are two ways to identify the electrode in the sketch: firstly, the direction in which electrons move between the electrodes can be used (they move from the anode to the cathode) or secondly, by the labels given to the electrode (in electrochemical cells anodes are labelled “-” and cathodes “+”).

The correct answer to this question is option A. The histogram shows that the percentage of students in the treatment group answering this question correctly improved from 25% to 44% in the post-test, an improvement of 19% compared to the control group's improvement of 10%.

***Possible reasons for improved performance**:* Two tactics may have been responsible for the improved performance on this question by the treatment group relative to the control group. The first was an analogy presented in the video that helped students identify the anode and to predict the direction in which electrons move in an electrochemical cell. The second was a mnemonic the video presenter gave that students could use to remember the type of reaction occurring at the specific electrodes.

The analogy compared a bakery (the analogue) to an anode (the target)[11] and was used to help students remember the processes that occurred at the electrodes, and how electrons move in the external circuit. In this analogy the video presenter compared a bakery, where "*bread is made*", to an anode, where "*electrons are made*". Since bread is "*used up at your house*", "*your house*" was likened to the cathode as this is where "*bread*" (or electrons) "*are used up*". The "*bread*" (or electrons) travel from the "*bakery*" (or anode) to "*your house*" (or cathode) via the "*road*" (or external circuit). Figure 7 shows the main links between the analogue and the target for this analogy although no such diagram was presented on the video. The analogy was only mentioned verbally.

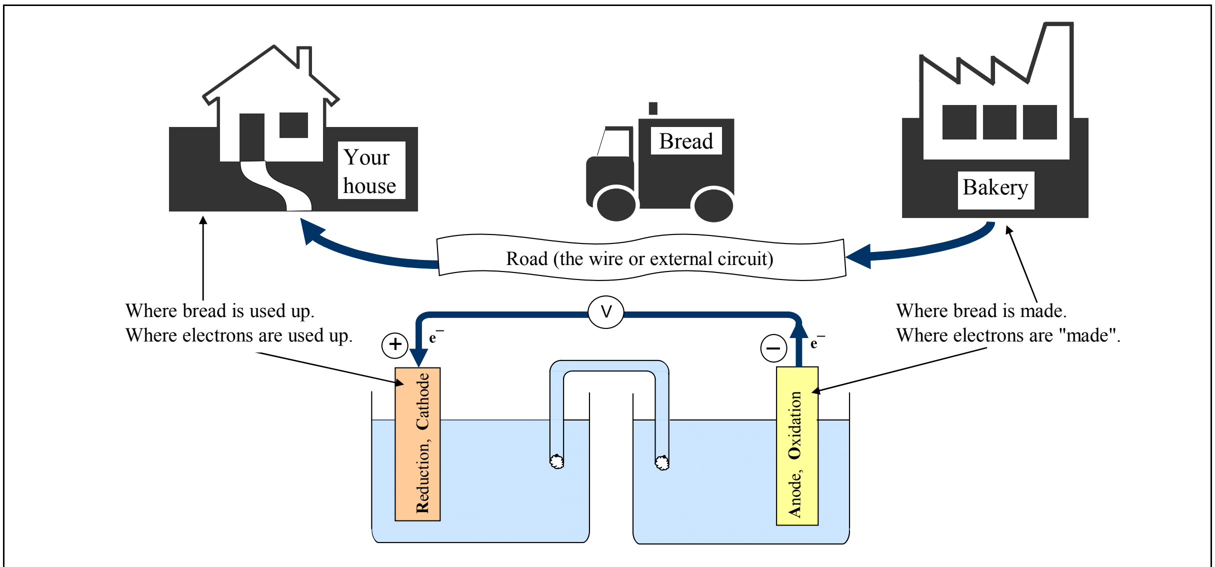


Figure 7: Diagram showing the links between a bakery and an anode

Although only a small amount of video time was devoted to this analogy (less than three minutes) the analogy was considered by the researcher to have been an effective way of communicating salient points about the reactions at the electrodes and the movement of electrons between the electrodes via the external circuit. There were two drawbacks surrounding the introduction of this analogy on the video. First, the differences between the analogue and target were not highlighted. For example, the video presenter repeatedly stressed that electrons were "*made*" at the anode when this is not the case. Electrons are extracted from the chemical species[12] that undergoes oxidation. Duit (1991) recommends that teachers highlight features that differ between the analogue and target as students

[11] See Chapter 2, section 2.3.2, for an explanation of these terms.

[12] "Species" is a generic term used to describe an atom, molecule or ion (Masterton and Slowinski, 1977).

can be misled and can extend the analogy in ways that were not intended by the teacher. The second drawback was that although the video presenter correctly states that the anode has a negative label in electrochemical cells because electrons are "*made*" there, he complicates this explanation shortly afterwards by saying that "*anodes are positive … in a thing like electrolysis – where the apparatus is taking in electricity*". By introducing this information and not explaining it adequately, students are likely to conclude that the anode is no longer "making" electrons (and so no longer undergoing oxidation) in electrolysis when this is not the case. According to Garnett and Treagust (1992b), many students incorrectly think that because the labels are reversed in electrolytic cells[13], the reaction at the electrode / electrolyte interface is also reversed, so they think that reduction occurs at the anode. This analogy is likely to reinforce this misconception. Nonetheless, since information about electrolytic cells was not examinable, students may have been able to disregard this information.

The following mnemonics were given by the video presenter to help students remember the reactions that take place at the electrodes: "*Anode – **O**xidation, the vowels go together*", "***R**oman **C**atholic, reduction – cathode … the consonants go together*". The mnemonic "*Anode – **O**xidation*" is often mentioned in textbooks (for example, see Silberberg, 2000). The effectiveness of these mnemonics could have been improved if the video presenter had mentioned that electrodes are named in this way by convention, and that they apply in both electrochemical and electrolytic cells. Without this information students have no other choice than to accept the explanation that oxidation happens at the anode because the "*vowels go together*" or because the video presenter claims that this is the case. According to Johnstone (1997), students find logical explanations easier to remember than explanations that rely on rote memorisation. Sutton (1992) recommends that teachers explain the etymology of scientific terms as they often have metaphorical origins that have been forgotten. Sutton states that reawakening these lost metaphoric meanings can enable students use the terms to interpret science rather using the terms as labels only. For example, consider the terms "anode" and "cathode". According to Sutton (1992) they were coined by Michael Faraday in collaboration with William Whewell, and are derived from Greek words "an-" and "cath-" meaning "up" and "down" respectively, along with the word "-ode" meaning way. So, anode means "way up", while cathode means "way down". Knowing this information about the terms "anode" and "cathode" may help students remember how electrons move between electrodes.

Analysis of the distractors (see Figure 6) shows that there was an increase of 7% in the percentage of students in the treatment group selecting the main distractor, E (reduction) compared to a decrease of 3% for the control group. One possible reason for this may have been because students merely guessed the answer. The almost even distribution between the correct answer and the main distractor (44% compared to 37%) may lend support to this supposition. Another reason may be that the anode was always placed on the left-hand side in all the sketches of electrochemical cells drawn in the video, and this may have led students to believe that electrode A was the cathode, and so to select this distractor. Sanger and Greenbowe (1997) found that students sometimes made this incorrect association as a result of the sketches given by teachers and textbooks. The anode is placed on the left-hand side in sketches because the "standard cell notation"[14] – a shorthand system used to indicate the components

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[13] Electrolytic cells are non-spontaneous cells; to function they need an external power source. Electrons are supplied to the cathode so it is given a negative label, and they are removed from the anode so it has a positive label (Silberberg, 2000).

[14] Somewhat confusingly, the standard cell notation can also be called the "cell diagram" (Levine, 1978).

of an electrochemical cell – has a fixed format. By convention the anode must be placed on the left-hand side in this format. In a later article, Sanger and Greenbowe (1999) state that textbooks and teachers often apply these conventions to sketches of electrochemical cells, even though there is no regulation regarding the format of sketches of electrochemical cells. To prevent students making this incorrect association, Sanger and Greenbowe (1999) recommend that teachers alternate the placement of the anode when drawing sketches of electrochemical cells. Figure 8 below, shows an annotated example of the standard cell notation for an electrochemical cell composed of tin (Sn) and iron (Fe).

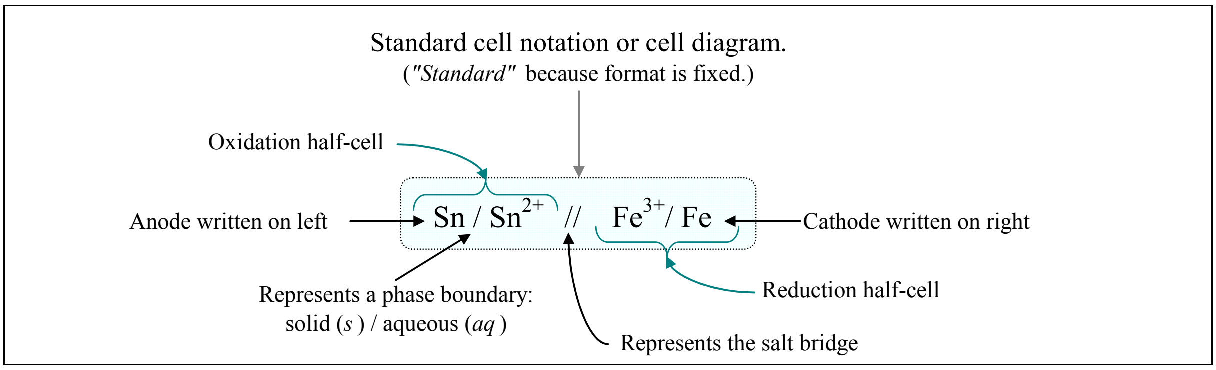


Figure 8: Annotated diagram showing the information given by standard cell notation

The histogram of the results (see Figure 6 on page 50) suggests that the video may have been effective at eliminating distractor B (that crystallisation occurs in an electrochemical cell). It is not known why some students chose distractor D (oxidation and reduction) in the post-test but one possible explanation may be that these students mistook the ammeter drawn in the sketch (and also labelled A) for an electrode. Since similar percentages of students from both groups selected this distractor in the post-test, it was felt that video was not responsible for persuading students to select this option. The increase in distractor C (neutralisation) by both groups was thought to have arisen as a result of careless use of the term "neutralisation" by both the video presenter and the lecturer. Although analysis of the lectures was considered to be beyond the scope of this research report, both the video presenter and the lecturer had used the term "neutralisation" to describe the processes occurring in the salt bridge. See section 4.3.3 for a discussion on the use of this term.

4.2.3 Electrochemistry test, Question 9: Identifying a reduction half-equation

Question 9, which is given in Figure 9 on the following page along with a histogram of the results obtained, asked students to identify a reduction half-equation[15]. To answer this question, students would have to recall that reduction is defined as the gain of electrons, and that in a reduction half-equation the electrons are written on the reagent's side of the equation, namely: $M^{2+} + 2e^{-} \rightarrow M$.

The correct answer to this question is option E. The histogram shows that the percentage of students in the treatment group answering this question correctly improved from 21% to 49% in the post-test, an improvement of 28% compared to the control group's improvement of 9%.

[15] The term half-reaction was used in the test because it was not known whether the students would be familiar with the more accurate term, namely half-equation. The video presenter used the term "half-reaction" to describe these equations in the video.

Which of the following reactions is a reduction half-reaction?

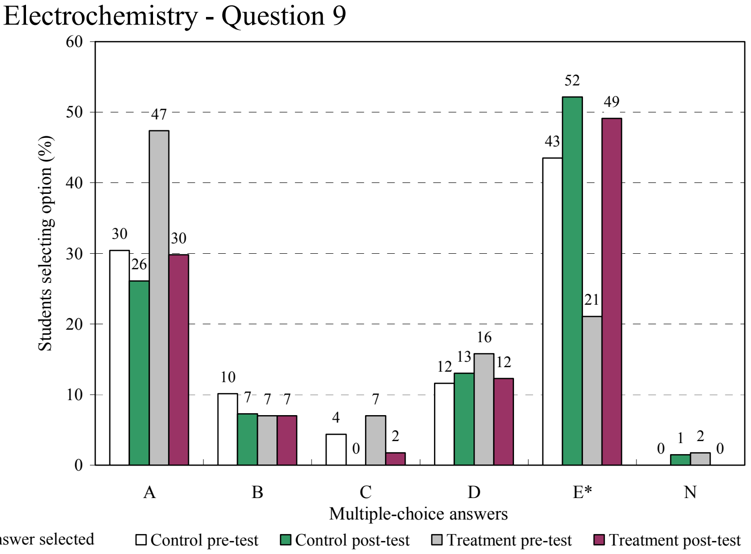
A. $Zn \rightarrow Zn^{2+} + 2e^{-}$

B. $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

C. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

D. $Cu + 2e^{-} \rightarrow Cu^{2+}$

E. $Cu^{2+} + 2e^{-} \rightarrow Cu$



* = correct answer N = no answer selected

Figure 9: Electrochemistry test: Question 9, and a histogram of the results obtained

***Possible reasons for improved performance*:** One possible reason for the treatment group's improved performance may have been that zinc and copper were used as the primary means for communicating ideas about oxidation and reduction. A total of 40 minutes of video time was used to explain that zinc would undergo oxidation and that copper would undergo reduction. During these explanations the video presenter made extensive use of anthropomorphic and teleological explanations. Transcript 1 gives an indication of the explanations used for each element. This question, which was taken from a previous Senior Certificate *Physical Science* examination paper, also listed zinc and copper undergoing oxidation and reduction respectively[16]. As a result it is possible that students may have selected the correct half-equation because they recognised it from the video, and this may have skewed the results. No special tactics were introduced to help students recognise oxidation and reduction half-equations, the video presenter merely stated that the electrons are "*on the right*" in an oxidation half-equation and "*on the left*" in a reduction half-equation. The amount of time devoted to these explanations and their anthropomorphic content may have enabled students to recall how these elements react.

Transcript 1

"*The zinc atoms says: 'In this set up I can go from being less stable to being more stable'. And the first atom ionises, it runs downhill, and in doing so it produces two electrons*".

"*Do you know what's happened? The copper said to the zinc: 'Zinc, I love you, because your needs are my needs. I'm working with you. I want to go in this direction. I want to take your electrons. This is the way I'm designed to go.'*"

16 A more accurate picture of students' understanding of symbolic representation of oxidation and reduction would have been obtained if different elements had been used in place of zinc and copper. See Chapter 5 for a further discussion on the test questions.

Analysis of the distractors shows that the video was fairly successful at reducing the main distractor, A (an oxidation half-equation). The percentage of treatment group students selecting this option decreased by 17% in the post-test compared to 4% for the control group. According to Sanger and Greenbowe (1997) students often mix up the definitions for oxidation and reduction, blaming their incorrect choices on a memory lapse, and this may have been the case in this question or alternatively it may be due to careless reading. Clerk and Rutherford (2000) found in their South African study that some students select the first answer that looks correct and so do not consider all the alternatives when answering multiple-choice questions.

Although the percentage of students in the treatment group choosing D ($Cu + 2e^{-} \rightarrow Cu^{2+}$) decreased by 4% compared to an increase of 1% for the control group, students were not exposed to half-equations of this type in the video. Option D is an unbalanced half-equation (the reagents have an overall charge of – 2 while the product has + 2 charge). Students were only exposed to correctly balanced half-equations in this video and no strategies were shown to teach students how to balance half-equations for charge. As a result students never had the opportunity to troubleshoot incorrectly balanced half-equations. Haladyna, Nolen, and Haas, (1991) recommend that appropriate error recognition strategies be taught as they enable students to develop a range of troubleshooting skills that build confidence in the correctness of their own knowledge. One possible reason why the video presenter did not include a discussion on balancing equations for charge may have been because they were dealt with in another video (the full set of videos contained a one-hour video entitled "redox reactions").

4.2.4 Electrochemistry test, Question 10: Calculating a cell potential

This question, which is given in Figure 10 on page 56, along with a histogram of the results, asked students to calculate the cell potential of an electrochemical cell. Three steps are required to solve this problem. First, students would need to identify the relevant half-equations from the standard cell notation ($Sn/Sn^{2+}//Fe^{3+}/Fe$), which by convention lists the anode on the left and the cathode on the right. Next, they would need to find the standard reduction potentials for the anode and cathode from a list known as the standard reduction potential table[17]. The standard reduction potentials are listed adjacent to relevant reduction half-equations and under the symbol E^{Θ}. Finally, students would calculate the cell potential by substituting into the formula $E^{\ominus}_{cell} = E^{\ominus}_{cathode} - E^{\ominus}_{anode}$.

If students were unable to identify the anode and cathode from the standard cell notation, they could use the information given in the standard reduction potential table to work this out because two conventions govern its format.

- Half-equations are always listed as reduction half-equations. According to Birss and Truax (1990) this convention has been in place since 1953.
- Half-equations are listed in order of decreasing standard reduction potentials[18] so cathodes (which are more likely to undergo reduction) are listed above anodes (which are less likely to undergo reduction).

[17] Birss and Truax (1990), recommend the use of this name as it most accurately describes the data given in the table. "Standard" is used because the potentials are measured at standard conditions, "reduction" because the half-equations are listed as reduction half-equations, and "potentials" because the table lists potentials.

[18] Although some authors (Birss and Truax, 1990; Garnett and Treagust, 1992b) state that this is a convention, no evidence to support this claim could be found.

Electrochemistry test - Question 10

What is the cell potential for the following standard cell?

$Sn \ / \ Sn^{2+} \ // \ Fe^{3+} \ / \ Fe$

		$E^{\ominus}$
given:	$Fe^{3+} + e^{-} \rightleftharpoons Fe^{2+}$	$+0,77$ V
	$Fe^{3+} + 3e^{-} \rightleftharpoons Fe$	$-0,04$ V
	$Sn^{2+} + 2e^{-} \rightleftharpoons Sn$	$-0,14$ V
	$Fe^{2+} + 2e^{-} \rightleftharpoons Fe$	$-0,44$ V

A. – 0,14V
B. – 0,18V
C. + 0,10V
D. + 0,34V
E. – 0,10V

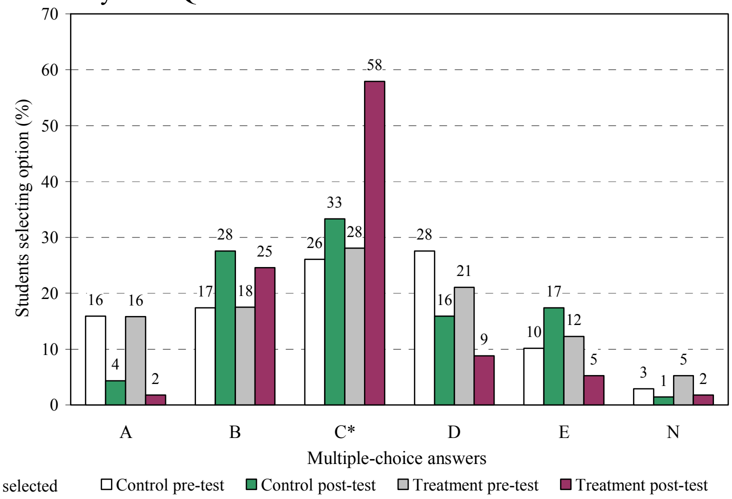


Figure 10: Electrochemistry test: Question 10, and a histogram of the results obtained

The correct answer in this question is option C, and the histogram (see Figure 10) shows that the percentage of students in the treatment group answering this question correctly improved from 28% to 58% in the post-test, an improvement of 30% compared to the control group's improvement of 7%.

***Possible reasons for improved performance*:** The introduction of an analogy in the video that enabled students to remember how to apply an algorithm was thought to be responsible for the treatment group's improved performance. The analogy was fairly complex as it linked two features about water in a tank (the analogue) to features associated with reduction half-equations listed in the standard reduction potential table (the target). Since these half-equations represent the half-cells used to make up electrochemical cells, the analogy also linked water in a tank to half-cells. Figure 11 on the following page uses similar illustrations to those presented in the video to show the links between the analogue and the targets that were made during the course of the video. The analogy was presented in three stages but no illustration that showed the links between the water tank and the scientific domain as given in Figure 11, was presented in the video. (The links between the analogue and scientific domain are indicated in Figure 11 using double headed red arrows and by restating the questions.)

The first stage of the analogy used the diagram showing the water tank to introduce the concepts embodied in the questions: "*Which way is downhill?*" and "*How much downhill?*". The second stage introduced sketches showing "*half-cells*"[19] and introduced the concept that there was a difference in energy between the electrode and the surrounding solution[20]. Only one "*half-cell*" is drawn in Figure 11. A similar sketch was used to illustrate the processes that occurred in a copper "*half-cell*". (Although the copper electrode had a positive charge and the solution had a negative charge. See section 4.4.7 for more information about students' reactions to this "*half-cell*".) The third stage used

[19] The *"half-cells"* drawn in the video (which are illustrated in Figure 11) are not half-cells because they are not connected in an electrochemical circuit. As illustrated they represent an electrode in an aqueous solution only. Under these conditions no potential difference would develop (Birss and Truax, 1990). Italics are used to indicate that the video presenter used the term "half-cells" to describe this situation.

[20] Electrodes in electrochemical cells do not have a charge, the "-" and "+" labels merely indicate the chemical processes occurring at the electrode / electrolyte interface (Garnett and Treagust, 1998b).

the questions developed during the first stage to link the information disclosed in the second stage to the information given in the standard reduction potential table.

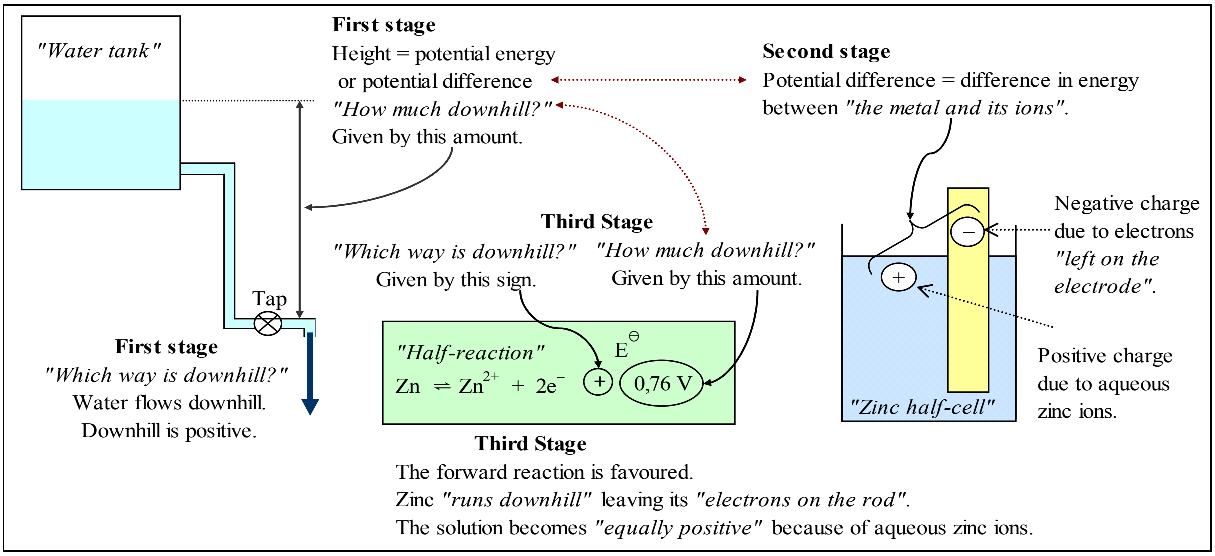


Figure 11: Diagram showing the links between water in a tank to a half-cell and the standard reduction potential listed in the standard reduction potential table

Aspects of this analogy were used by the video presenter to introduce a narrative or storyline that helped students remember how to apply a four step algorithm that reliably calculated the cell potentials. The steps are listed below along with some aspects of the storyline.

- Step 1: Compare the absolute "$E^{\ominus}$" (pronounced E standard) values of the two half-equations and use this information to answer the question: "*How much downhill?*". The half-equation with the largest absolute "$E^{\ominus}$" value is "*the winner*", and the other equation is called "*the loser*".
- Step 2: Inspect the sign of "$E^{\ominus}$" associated with "*the winner*" and decide "*which way is downhill*". "*The winner*" must "*win*", so its "$E^{\ominus}$" must have a positive sign. If it does not have a positive sign, then "*the winner*" must be written in the opposite direction (i.e. as an oxidation half-equation), as the sign of "$E^{\ominus}$" changes when half-equations are turned around. The video presenter often described steps 1 and 2 as logical: "*So the logic ... pick the winner ... write him left to right downhill*".
- Step 3: Write the second half-equation ("*the loser*") so that its electrons are on the other side of the equation to "*the winner's*". This may result in "*the loser*" going "*uphill*" but this "*doesn't matter*" because "*the winner*" is able to "*force the loser*" to go "*uphill*". The video presenter reinforces this notion occasionally by saying "*Nobody runs uphill unless you chase her. Right chaps? And then she doesn't run, she waddles*"[21].
- Step 4: Add the two "$E^{\ominus}$*s*" together to get the cell potential.

Figure 12 uses the information given in Question 10 to show how this approach works. Step 1: the tin (Sn) half-equation is "*the winner*" because its absolute $E^{\ominus}$ value is the largest, and the iron (Fe) half-equation is "*the loser*". Step 2: "*the winner*" is written so it "*runs downhill*". The equation is written in the reverse direction and the sign of $E^{\ominus}$ becomes positive. Step 3: "*the loser*" is written so its electrons

[21] The video presenter made this comment in a jocular fashion and students laughed whenever it was made.

are on the other side of the equation to "*the winner's*". Step 4: the "$E^{\ominus}$" values are added together to get the cell potential. The oxidation and reduction half-equations are also obtained using this approach, and provided that students can remember the convention that oxidation occurs at the anode, the anode and cathode are also identified. (The overall cell equation could be found if an extra step – Step 5 – were to be performed.)

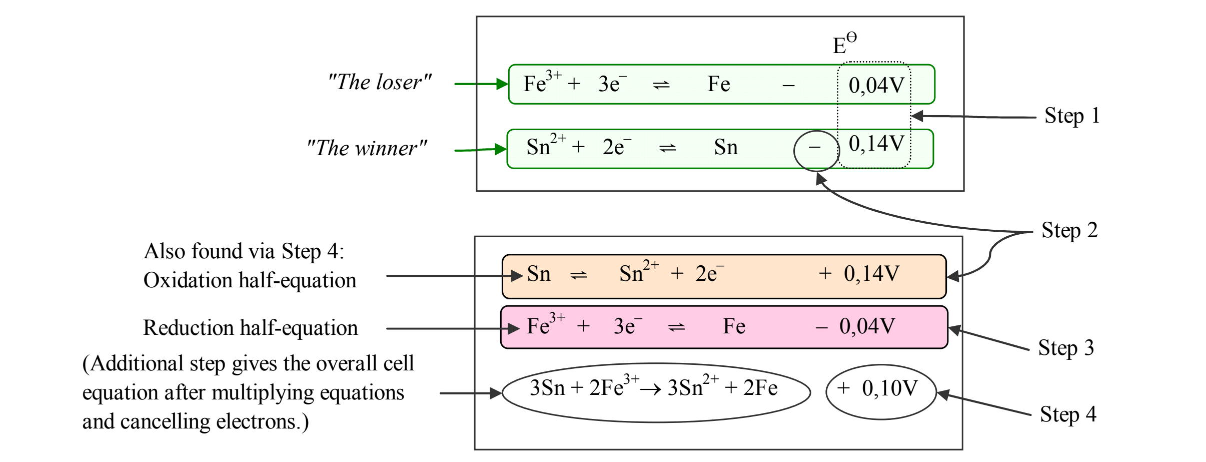


Figure 12: Applying the algorithm to calculate the cell potential

The initial drawback of this analogy was that the video presenter never adequately explained why the first segment of this video (which was 30 minutes long) was spent discussing how water flowed out of a tank. Although he mentioned that electrochemistry was related to chemistry and electricity, his main focus in this segment was to relate water in a tank to electricity, see Transcript 2. As a result when this video session was over four students complained to the researcher that they had come to the videos "*to learn more about chemistry not water*".

Transcript 2

"*In electricity, electric pressure is called the potential difference, which is measured in volts. Volts is electric pressure. And please notice you do not need flow to get water pressure. With the tap closed, you've got pressure, you've got no flow.*"

He relates these concepts to electrochemistry in the following way:

"*This is what cells is all about; we don't really work in chemistry with the flows from cells .... The big thing in electrochemistry is to calculate the pressure of electricity when chemicals are producing it.*"

Then he returns to electricity:

"*So folks, what we are going to study now – very carefully – is the concept that electricity has got volts, and ... volts is electric pressure.*"

One advantage of the video presenter's approach (which students initially called "*the tap method*" then later called "*the downhill concept*") was that it was independent of the format of the standard reduction potential table (called "*the table*" in the videos). It could be applied to any half-equation irrespective of whether it was written as a reduction half-equation (gain of electrons) or an oxidation half-equation (loss of electrons). It was also independent of the half-equation's position in "*the table*". Students were unlikely to encounter any of these alternative formats of "*the table*" because of the conventions mentioned earlier (see page 55).

Another advantage of the video presenter's approach was that by using generic terms like "*E standard*" ($E^{\ominus}$) to represent potentials, and the fictitious concepts of equations and going "*up-*" and "*downhill*" and "*winning*" and "*losing*", the video presenter decreased the cognitive load of the information presented to students. According to Tobin and McRobbie (1999), the topic of electrochemistry is dense with scientific vocabulary, some of which has alternative meanings in everyday parlance. When these authors investigated the classroom practices of a teacher giving an introductory lecture on electrochemistry they noted that 19 scientific terms associated with electrochemistry were introduced, and that most were used without explanation. According to Kozma (1991:193), the likely effect of bombarding students with too much new information at once is that "*comprehension failure*" can result. By limiting the number of new terms the video presenter may have avoided this. The first mention of the terms "oxidation" and "reduction" came one hour into the video, and the terms "anode" and "cathode" were only introduced after that. The video presenter never connected "$E^{\ominus}$" with the concepts of reduction or oxidation potentials; he used statements like "*the E standard* ($E^{\ominus}$) *of the winner*" instead. One student commented on the lack of scientific terminology in Questionnaire 1 (which asked students if any of the information they had received that day had been taught to them differently before): "*He left out anode and cathode and the reactivity series*".

While the video presenter's approach may have been helpful in allowing students access to electrochemistry (the target domain), Tobin and McRobbie (1999) warn that careful coaching is required to transform fictitious concepts of this type into meaningful scientific knowledge. Without this coaching students may regard these fictitious concepts as valid interpretations of the science, particularly in those cases where they can be used fruitfully to generate correct answers. Sanger and Greenbowe (1997:394) state that under these circumstances the absence of conceptual understanding "*may not even be noticed*" by students.

The video presenter made no attempt to transform these fictitious concepts into meaningful scientific knowledge. He also stated that some of his fictitious concepts were derived as the result of an "*international agreement*", see Transcript 3. This deceptiveness was regrettable because it was likely that students would have a great deal of difficulty unlearning this "logical" and apparently internationally agreed upon version of electrochemistry.

Transcript 3

"*By international agreement if the equilibrium – as you have written it – is downhill left to right … the sign of E standard* ($E^{\ominus}$) *is positive, and if left to right is uphill … the sign of E standard* ($E^{\ominus}$) *is negative. Now if you're saying why? This has been an international agreement, that's all it is.*"

Although the video presenter often attested to the veracity of his "science" by including statements like: "*if I'm telling you the truth, and I am telling you the truth, …*" when explaining, it was thought that some students did not believe his version of the science. One student made the following comment in Questionnaire 1 (in answer to the question about whether any of the information they had received that day had been taught to them differently before): "*The presenter's introduction about the tap method was superb not just to bubble in* [babble on] *the topic like our school teachers, but I think after this you must go back to your textbook.*"

Two comments from Questionnaire 3, which asked students why they would select the video presenter's videos instead of another teacher's, show that they were influenced to some extent by the video presenter's reassurances about the "truthfulness" of his version of the science.

"*He talk slow and talking the truth and I can understand him.*"

"*If the video presenter is telling us the truth, why is the other teacher not doing it?*"

The primary reason that the video presenter used this approach seems to have been his perception that the standard reduction potential table has no fixed format and consequently is the source of a number of errors when performing these calculations. His attempts to reassure the audience that his novel approach works irrespective of the format of "*the table*" only served to introduce confusion about the scientific conventions governing this table (see Transcript 4). It is possible that had the video presenter known about these conventions, he might have devised a more appropriate approach to teach students how to calculate cell potentials.

Transcript 4

Surely, you say, the anode is the one at the top and the cathode will be the one at the bottom ... until they turn the table around. And when they turn the table round, which by the way has already been done, you've got big problems. And, if I was your examiner and scrambled the table, that would make it even worse. OK, so this is why I don't like the formula."

Analysis of the distractors (see Figure 10 on page 56), suggests that the video may have been instrumental in reducing the percentage of students who selected option E (a negative cell potential). The percentage of students selecting this option in the treatment group decreased by 7% compared to the control group where there was a 7% increase. The decrease in the percentage of students in the treatment group choosing this option in the post-test may have been due to the video presenter's repeated statements that the overall cell reaction "*must flow downhill*", and so must be positive. The remaining distractors were answered in similar ways for both the control and treatment groups in the post-test so it was felt that the video had introduced no specific strategy that successfully reduced these sorts of errors.

4.2.5 Acids and bases test, Question 4: Identifying a substance acting as a Brønsted-Lowry base

This question, which is given in Figure 13 on the next page along with a histogram of the results obtained, asked students to identify the reaction where a substance acts as a base[22]. To answer this question students would need to remember that a base accepts a proton or hydrogen ion (H^+) so after reacting the $H_2PO_4^-$ will have an extra H and one less negative charge, so the product formed would be H_3PO_4.

The correct answer in this question is option D. The histogram shows that the percentage of students in the treatment group answering this question correctly improved from 33% to 58% in the post-test, an improvement of 25% compared to an improvement of only 13% by the control group.

[22] The chemical species $H_2PO_4^{2-}$ cannot act as an Arrhenius base so although this question does not specify acting as a "Brønsted-Lowry" base, it is implicit in the question. Nonetheless the question should have been more carefully worded. See Chapter 5 for a further discussion on the wording of the questions.

In which one of the following reactions does $H_2PO_4^-$ act as a base

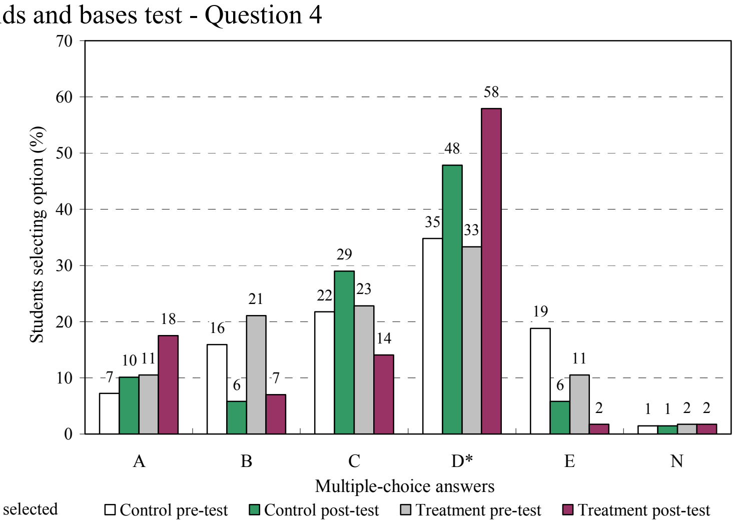
A. $H_2PO_4^- + 2OH^- \rightleftharpoons 2H_2O + PO_4^{3-}$

B. $H_2PO_4^- + HCO_3^- \rightleftharpoons H_2CO_3 + HPO_4^{2-}$

C. $H_2PO_4^- + H_2O \rightleftharpoons H_3O^+ + HPO_4^{2-}$

D. $H_2PO_4^- + H_3O^+ \rightleftharpoons H_2O + H_3PO_4$

E. $H_2PO_4^- + CO_3^{2-} \rightleftharpoons HCO_3^- + HPO_4^{2-}$



* = Correct answer N = No answer selected

Figure 13: Acids and bases test: Question 4, and a histogram of the results obtained

***Possible reasons for improved performance*:** Three possible reasons for the improved performance of the treatment group were identified in the video. Firstly, the video presenter reduced the cognitive load of information that students had to absorb about Brønsted-Lowry acid-base pairs by identifying only two acid-base pairs for each reaction when there are a total of four pairs (see Figure 14 below). The video presenter narrowed the terms down by only naming the acid and conjugate base in the forward direction, and the acid and conjugate base in the reverse direction. This procedure resulted in each species being described by only one term instead of the usual two terms and this may have helped students answer the question.

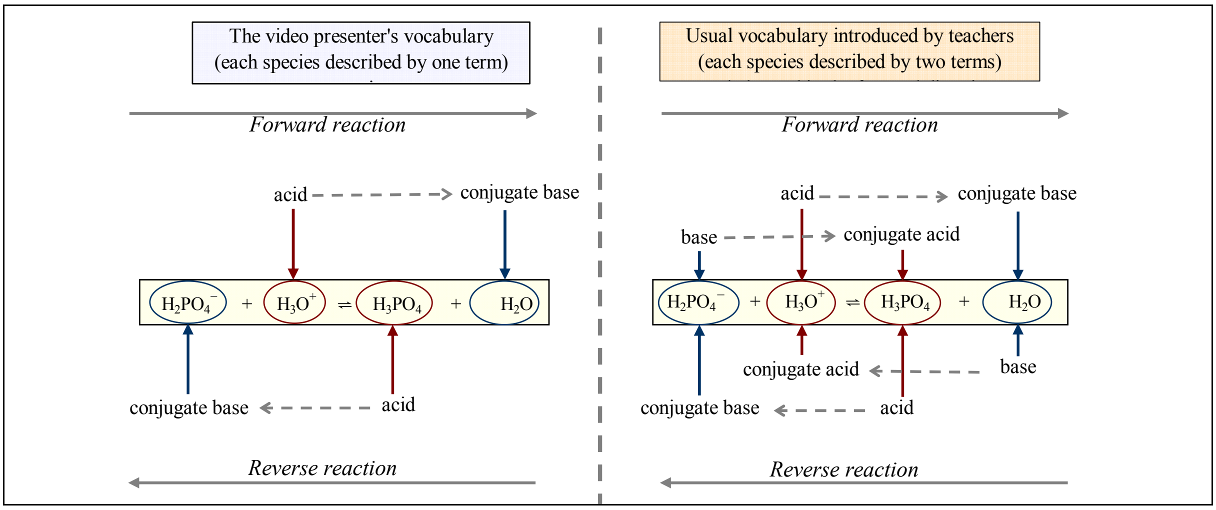


Figure 14: Terms used in the video compared to terms normally introduced for Brønsted-Lowry acid-base pairs

The second tactic introduced in the video was to inspect the conjugate acid for the presence of an additional hydrogen in the formula. Although the difference in charge between acid-base conjugate pairs was mentioned in the video, inspecting the charges of the species was not put forward as a potential strategy for solving problems of this type in the video.

The final tactic that may have helped the treatment group to improve their performance was that several examples of substances that can act either as a Brønsted-Lowry acid or base (known as amphiprotic substances[23]), including $H_2PO_4^-$, were performed so these students had repeated exposure to this type of problem.

Analysis of the distractors (see Figure 13 on page 61) shows that there was a considerable amount of confusion about these concepts in the pre-test for both groups at the start since each alternative attracted a similar response. The fact that these students could not eliminate options B, C and E in the pre-test (they all had the same product, namely HPO_4^{2-}, and since they could not all be correct, they could all be eliminated) suggests that these students were not skilled in the use of test-wiseness strategies, as discussed in section 3.3.2 (also see Towns and Robinson, 1993). The use of such test-wiseness strategies as a method for eliminating choices was not identified in the video.

The 9% decrease in the percentage of students from the treatment group choosing distractor C ($H_2PO_4^-$ acting as an acid with water) in the post-test compared to an increase of 7% for the control group suggests that the video helped some students identify this reaction as incorrect. The decrease in the percentage of students choosing distractors B and E ($H_2PO_4^-$ reacting with HCO_3^- and CO_3^{2-} respectively) was thought to have arisen because the discussions in the video about Brønsted-Lowry acids and bases were confined to reactions occurring in aqueous solutions only, and neither of these alternatives contain water or a derivative of water. It was not known why there was a slight increase in the percentage of students choosing distractor A ($H_2PO_4^-$ reacting with a hydroxide ion) but since it occurred with both groups it was not attributed to the video.

4.2.6 Acids and bases test, Question 7: Calculating pH from hydroxide ion concentration

This question, which is given in Figure 15 on the next page along with a histogram of the results obtained, asked students to calculate the pH from a hydroxide ion concentration. This problem could be solved in two ways: firstly students could use the equation $pOH = -\log[OH^-]$ to find the pOH and calculate the pH by substituting into the formula: $pH + pOH = 14$. Alternatively, students could calculate the $[H_3O^+]$ by substituting into the formula: $[H_3O^+]\,[OH^-] = 1{,}00 \times 10^{-14}$ and then find the pH by substituting in the formula: $pH = -\log[H_3O^+]$.

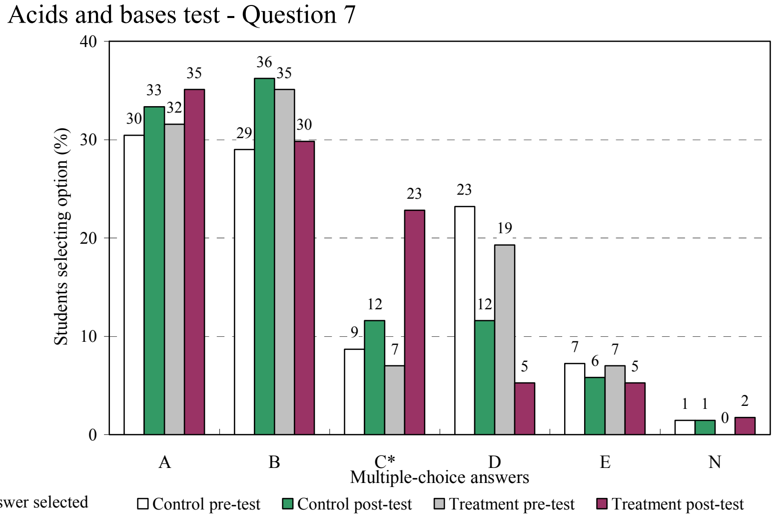
The correct answer in this question is option C. The histogram shows that the percentage of students in the treatment group answering this question correctly improved from 7% to 23% in the post-test, an improvement of 16% compared to an improvement of only 3% by the control group.

***Possible reasons for improved performance*:** No special tactics were used to teach students how to calculate the pH from a solution with a known hydroxide ion concentration although the video presenter did rearrange the formula for pH to $[H^+] = \log^{-pH}$. This format may have been new to some students and it may have helped them to solve this question. No special tasks were introduced to help students understand the concept of a logarithmic scale but the video presenter did convert the scientific notations for 1×10^{-4} and 1×10^{-12} into the following fractions, $^1/_{10,000}$ and $^1/_{1,000,000,000,000}$ respectively.

[23] Amphiprotic substances were sometimes called *amphoteric substances*, or *ampholytes* in the video.

What is the pH of a solution which has a hydroxide concentration of 0,001 (1×10^{-3}) mol dm^{-3}?

A. 3
B. 1
C. 11
D. 7
E. 13



* = Correct answer N = No answer selected

Figure 15: Acids and bases test: Question 7, and a histogram of the results obtained

Analysis of the distractors (see Figure 15) shows that the percentage of students choosing the main distractor A (the pOH of the given solution) increased marginally for both groups. Since similar increases happened for both groups, the increase shown by the treatment group cannot be attributed to the video. However, no procedure was put in place in the video to help students remember that substituting the value given in the question into the formula would yield the pOH and not the pH. In the researcher's experience[24] this is common mistake and probably results from careless reading of the stem of the question. Substituting the formula (OH^-) for the name (hydroxide) into the stem of the question may prompt students to continue with the calculation. Students' choice of distractor B (a pH of 1) [and to some extent the main distractor A (a pH of 3) and possibly distractor E (a pH of 13)] may have arisen because students could not be bothered to do the calculation. They may have based their choice on guesswork since the numbers 1 and 3 were present in the stem of the question. Students' choice of distractor D (a pH of 7) was somewhat surprising as this alternative was not expected to attract any response. This suggests that some students in both groups were having difficulty with the concept of pH.

4.2.7 Acids and bases test, Question 10: Identifying a basic salt

This question, which is given in Figure 16 on the next page along with a histogram of the results obtained, asked students to identify a basic salt. To do this, students would have to inspect the choices given in the question and use the identities of the cations and anions to decide which salt would be basic. The anions and cations are used to identify the acids and bases that were used to form the salts. Neutral salts are formed when strong acids react with strong bases, basic salts are formed when weak acids react with strong bases, and acidic salts are formed when strong acids reacts with weak bases.

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[24] The researcher has 18 years experience teaching foundation chemistry courses at tertiary institutions.

Which one of the following salts is basic in aqueous solution?

A. NH_4Cl
B. KI
C. $CaBr_2$
D. Na_2CO_3
E. K_2SO_4

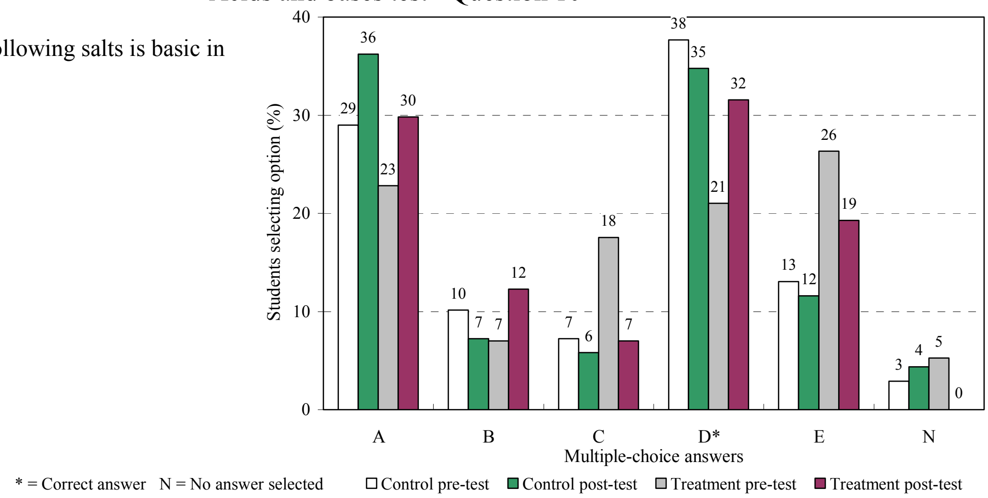

Figure 16: Acids and bases test: Question 10, and a histogram of the results obtained

It is possible to tell whether a salt will be acidic, basic or neutral by inspecting the formula of the salt. Figure 17 lists the anions and cations associated with strong and weak acids and bases, and classifies the salts given in Question 10 as acidic, basic or neutral. The reason salts are acidic or basic is because the ion (called the conjugate base or acid) associated with the weak acid or weak base reacts with water via a Brønsted-Lowry reaction to re-form the weak acid or weak base (through a process known as dissociation). For example, consider sodium carbonate (Na_2CO_3), the correct answer for this question. The sodium ions dissolve completely in water, and since they have no lone pair of electrons, they do not react with water and so they do not alter the pH of the solution. Carbonate ions, on the other hand, have a lone-pair of electrons and will accept a proton from water to re-form the acid via dissociation. This reaction generates OH^- ions which renders the solution basic. The equation for the reaction is: $CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$.

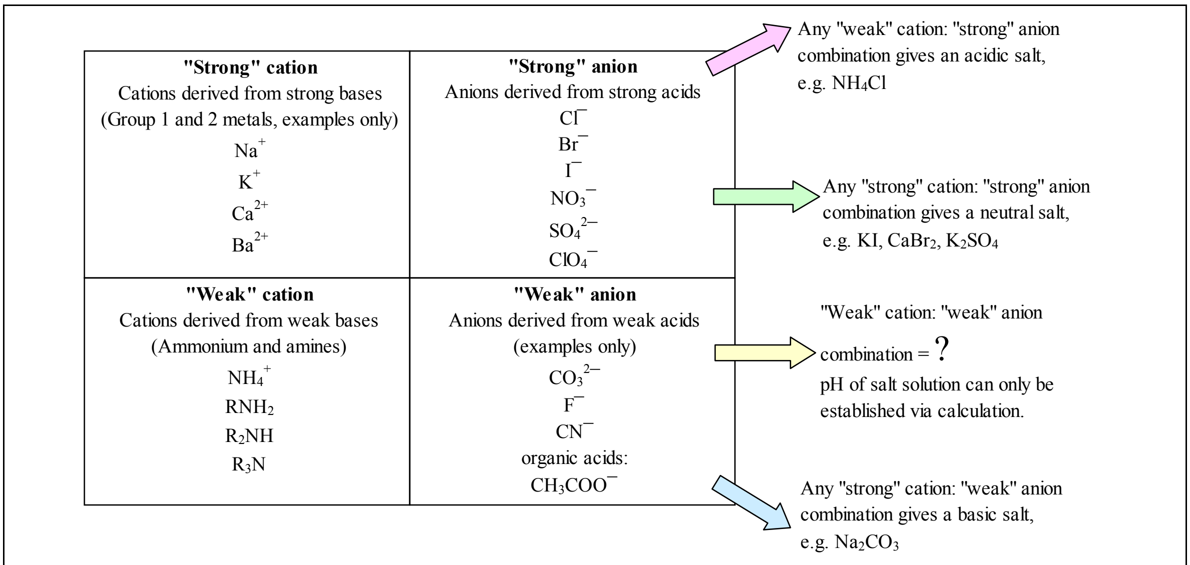

Figure 17: Chart showing how to predict whether a salt is acidic, basic or neutral based on the identity of cations and anions

The correct answer in this question is option D and the histogram (see Figure 16) shows that percentage of students in the treatment group answering this question correctly improved from 21% to 32% in the post-test, an improvement of 11% compared a decrease of 3% by the control group.

Possible reasons for improved performance**:** An analogy that compared strong acids to "*strong he-men*", weak acids to "*wish-washy men*"; bases to women, and salts to "*marriage*" was used in the video to account for the properties of salts. Although this analogy had a reasonable amount of *semantic* correspondence between the analogue and scientific (or target) domains, the video presenter made the incorrect link between the analogue and target to explain why salts can be acidic or basic. For example, he explained that a salt made from the reaction between a strong acid and a weak base would be acidic because "*the acid doesn't lose its habits, it's strong, the salt tends to be acidic, it tends to have a pH of lower than 7*". The video presenter's explanation implies that the conjugate acid of the weak base (represented by the cation in the formula of that salt) plays no part in the pH of the final solution when this is not the case. The correct link between the analogue and target to describe this situation would be to state that the conjugate acid of the "wish-washy" or weak base (called a weak cation in Figure 17) "behaves like" a strong acid. It "does the things that strong acids do", namely it "produces" hydronium ions. It does this by reacting with water via a Brønsted-Lowry reaction to re-form the weak base. The following equation uses the ammonium ion, derived from a weak base (ammonia), to illustrate this reaction: $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$.

It is speculated that the video presenter may have introduced the incorrect links in an attempt to simplify the theory. When the analogy is applied in this way, students would not need to remember how weak acids and bases dissociate in water. The roles weak acids and weak bases play in influencing the pH of the salts are never mentioned in the video and this may lend support to this speculation. Transcript 5 gives a portion of the video presenter's explanation.

> Transcript 5
>
> "*But what happens if a real he-man marries a wishy-washy woman. When they form a partnership, the he-man dominates and as a togetherness, as two people together, they tend to go and do things that men do rather than woman do, because in the partnership you've got a real he-man and a very weak woman. But it works the other way round. If you have a wish-washy man, not a very strong man, and he marries a strong she-woman. When they form a partnership and they work together, the woman is going to dominate and as a partnership they will tend to do things that woman do, not that men do, because of the two partners, the woman is the strong one and I don't mean physically strong, I mean as womanly things go. Alright, that is exactly what happens when an acid reacts with a base to form a partnership, a salt.*"

The advantage of this analogy was that it was relatively easy to apply as long as students could remember which acids and bases were strong. The video presenter only mentioned four of the six strong acids usually mentioned in textbooks (Silberberg, 2000), namely hydrochloric, sulphuric, nitric and hydrobromic, omitting perchloric and hydroiodic acids. He never articulated any reason why bases are considered to be strong, nor did he give a list of strong bases. He did however mention that sodium hydroxide was a strong base, but he often referred to it by its common name (caustic soda) in this video. Students may not have been familiar with this name and so may not have been able to process this information.

The main problem with this analogy was that students were likely to have drawn the wrong conclusions about how weak acids and bases react with water to influence the pH of salt solutions. This would possibly impact on their future learning in this topic. No information was collected during the study to confirm what conclusions students may have reached regarding their interpretation of the analogy. The video presenter's assurances that this analogy represented the scientific situation "*exactly*" (see the last sentence in Transcript 5 above) was likely to have persuaded them that whatever conclusion they had drawn was correct. The video presenter's use of reassurance was a common feature in every video and he used it on a number of occasions during this section. For example, he stated that this section was "*fascinating, because it's just like human nature, two people getting together*". He also used a pH meter to "*prove*" that acidic and basic salts form acidic and basic solutions respectively by measuring the pH of the solutions they formed.

The second problem was that the video presenter had emphasised that neutral salts are formed when weak acids react with weak bases, see Transcript 6. This is an oversimplification. According to Masterton and Slowinski (1977), the pH of such a salt can only be obtained via calculation using the dissociation constants for each reagent (or by measuring the pH of a solution containing the dissolved salt). This type of calculation is beyond the scope of the Senior Certificate *Physical Science* examination. This oversimplification could possibly impact on students' future learning in this topic.

Transcript 6

"*When you marry a weak acid to a weak base they form a partnership called a salt. The salt is also neutral, around 7, because neither partner is very strong, and they are both weak, and therefore they tend to do about average.*"

Analysis of the distractors (see Figure 16 on page 64) shows that the percentage of students in the treatment group selecting distractor C ($CaBr_2$) in the post-test decreased by 11% compared to the control group's decrease of only 1%. This was thought to be because the video presenter had used an analogy where he compared hydrobromic acid (which he calls H Br) to Tarzan, see Transcript 7.

Transcript 7

Look, we've agreed that water's neutral. So, when you come with a big, strong acid like H Br. H Br says: 'me Tarzan, you Jane' and water says, 'alright, I'll be Jane.' Remember water is either way. So when you come with a strong acid, water is able to say, 'alright, alright, I'll be your base'.

(The video presenter made extensive use of these types of anthropomorphic explanations, some of which could be up to ten minutes long. His use of body language and animated facial expressions made these explanations entertaining and added a theatrical element to the videos.)

The seven percent decrease in the percentage of students in the treatment group selecting distractor E (K_2SO_4) in the post-test compared to the control group's decrease of 1% was thought to be because the video presenter had mentioned on a number of occasions that sulphuric acid was a strong acid. On one occasion he jokes about why vinegar is used in salad dressing and not sulphuric acid (see Transcript 8 on the next page).

Transcript 8

"*Why do you use vinegar on your salad instead of sulphuric acid? Both will give your salad a nice, sour tang. The trouble is that sulphuric acid will eat your salad before you do. Why? Because it's a strong acid. No sir, we put vinegar on, because vinegar gives the tang without munching up your salad*[25]."

The increase of 7% in distractor B (KI) in the post-test for the treatment group compared to a decrease of 3% for the control group was thought to be because HI (hydroiodic acid) had not been included in the video presenter's list of strong acids. Students in the treatment group may have selected this option because they may have incorrectly concluded that HI was a weak acid. (This aspect of acids and bases had not been covered during the lectures and this may account for the similarity between the control group's pre-test and post-test selection for this option.) The remaining distractor A (an acidic salt) was selected to a similar extent for both groups. Its selection may reflect that students have grasped some of the underlying principles of this section but are unable to apply them correctly.

4.2.8 Summary of the factors thought to have improved students' performance

The use of analogies and the simplification of scientific vocabulary and ways of thinking about some scientific concepts were thought to have been some of the elements of the videos which had led to more successful learning. According to Kozma (1991), who investigated the advantages of learning with different media, these tactics reduce the cognitive load of the information received by learners, and this is particularly important when the information is relayed using a transient, ephemeral medium like video. Another tactic that was thought to have helped students answer the above questions was the use of drill-and-practice, as approximately half the video time for the *electrochemistry* and *acids and bases* videos was allocated to applying these newly taught approaches to solving problems. According to Thagard (1992), when students first start to apply new knowledge to solve problems their approach is to identify similarities between the new problem and a previously solved problem and then to link similarities from the earlier problem onto the new problem. So according to Thagard (1992), when students start solving new problems their approach is analogical, irrespective of whether the new information was taught using an analogy or not. Working through problems therefore affords students the opportunity to reinforce the semantic and structural links between old and new problems and to relate that information to the theory. According to Thagard (1992), this reinforcement is thought to play an important role in rendering new information accessible for future learning.

There were nine tutorial questions (called examples) on the *electrochemistry* video, and Questionnaire 2 used a three-point Likert scale to asked students' what they thought of this number of examples. The majority (86%) thought they were "*OK*", 7% thought there were "*too many*", and 6% thought there were "*too few*". One student commented in this questionnaire that "*The more examples, the more we understand*". The number of examples was also cited by a student in Questionnaire 3 as a reason for choosing the video presenter's videos: "*He has more examples to explain some difficult things, and he is a talented science teacher.*"

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[25] Sulphuric acid *"will eat your salad before you do"* because it is fully dissociated so it reacts quickly (Silberberg, 2000). Vinegar is a weak acid and so is not fully dissociated and therefore reacts more slowly. By comparing vinegar, which is always dilute (about 4 to 6 % acetic acid), to sulphuric acid, which can have a range of concentrations, students may make incorrect associations about strong and weak acids. For example, they might conclude that strong acids are corrosive while weak acids are not.

4.3 ANALYSIS OF QUESTIONS WHERE NO IMPROVEMENT WAS NOTED

This section aims to answer the third research question.

RESEARCH QUESTION 3:
What were the weaknesses of the videos?
(a) To what extent did students answer questions less successfully after watching the videos?
(b) What were some of the factors that may have led to this poor performance?

Only those questions where the there was no improvement or a decrease in the correct answer by the treatment group coupled with a relative increase of more than 7% in the percentage of students from the treatment group choosing the main distractor compared to the control group were analysed. (See Table B2 in Appendix B for a list of these questions.) The extent to which this occurred is discussed in section 4.3.1. Tactics identified on the video that were thought to have influenced students in the treatment group to answer questions incorrectly are described in the remainder of this section.

4.3.1 The extent to which questions were answered less successfully after watching the videos

Four questions out of a total of thirty questions appeared to have been affected negatively by the videos, just over 13% of the questions. One came from the *electrochemistry* test, one from the *acids and bases* test, and two from the *titrations* test. Two of these questions can be classified as diagnostic questions. Diagnostic questions are different to knowledge questions as they are used to determine the extent of commonly held misconceptions, and, according to Gay (1991), they can also be used to troubleshoot teaching strategies. (For more information on these types of questions see section 3.3.2.) These questions are Question 7 in the *electrochemistry* test, and Question 4 in the *titrations* test. The remaining two questions (Question 6 in the *acids and bases* test and Question 2 in the *titrations* test) were typical Senior Certificate *Physical Science* questions. Table 9 gives an indication of the task being tested in each question, lists the percentage of students selecting the main distractor in the pre-tests and post-tests along with the increase in the percentage of students selecting that option in the post-test by group. The final column in Table 9 lists the relative increase in selection of the main distractor by the treatment group compared to the control group.

Table 9: Table showing questions where the treatment group showed an increase in the main distractor compared to the control group

Topic	Question		Control (%)			Treatment (%)			Relative change by treatment group (%)
	No.	Task being tested	Pre-test	Post-test	Change	Pre-test	Post-test	Change	
Electrochemistry	7	Explain the purpose of the salt bridge	28	38	10	32	49	17	+7
Acids and bases	6	Identify the solution with the highest concentration of H_3O^+	25	25	0	33	44	11	+11
Titrations	2	Identify an incorrect titrimetric procedure	30	33	3	33	49	16	+13
	4	Identify the conditions at the end-point of a titration	39	28	–11	32	46	14	+25

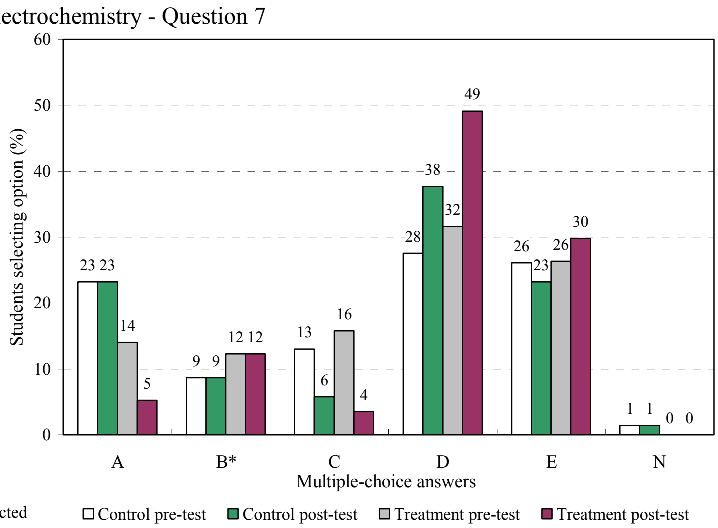
A statistical procedure that evaluated whether the increases noted in Table 9 were significantly different could not be found. The questions are discussed in the remainder of this section by type and by topic. The diagnostic questions are discussed first, and after that the typical Senior Certificate *Physical Science* questions are discussed.

4.3.2 Question 7, Electrochemistry test: The purpose of the salt bridge

Question 7, which is given in Figure 18 below along with a histogram of the results obtained, is a diagnostic question that probes students' understanding of the microscopic processes occurring at the salt bridge.

The purpose of a salt bridge in an electrochemical cell is to

A. provide a pathway so that the oxidising agent can reach the reducing agent
B. provide a pathway for charge carriers in solution
C. increase the resistance to the flow of current so that the cell maintains its potential
D. provide a pathway for electrons to complete the circuit
E. provide a connection between the two half-cells so that cations can reach the negative electrode



* = Correct answer N = No answer selected

Figure 18: Electrochemistry test: Question 7, and a histogram of the results obtained

According to Garnett and Treagust (1992b:1082) the purpose of a salt bridge is to provide "*a continuous path for the movement of ions between separate half-cells*". The reason that ions have to move between half-cells is because of the special construction of an electrochemical cell where the oxidation and reduction processes have been physically separated from each other (Silberberg, 2000). During oxidation metal atoms lose electrons to form aqueous cations in one half-cell, and during reduction aqueous cations gain the electrons released in the oxidation process to form metal atoms in the other half-cell. Since the same numbers of ions are produced in the one half-cell as are deposited in the other half-cell (assuming the charges of the ions are the same), the overall charge of the system is maintained but the physical separation means that charges in the individual half-cells are not balanced (Silberberg, 2000). Positive charge accumulates in the oxidation half-cell (because of cations formed by the oxidation process) and an equal amount of negative charge accumulates in the reduction half-cell[26] (because cations are removed by reduction and aqueous anions are left behind[27]). The movement

[26] This notion of charge accumulating in half-cells is a device that is used to teach the underlying principles. It does not actually take place. The potentials and equilibriums described are only established when all the components of the cell are connected but no current flows (Birss and Truax, 1990).

[27] The cations originally present in a reduction half-cell were components of a salt, for example $M^+X^-(aq)$. When metal cations deposit via reduction the following reaction takes place: $M^+(aq) + e^- \rightarrow M(s)$, this means that aqueous anions, $X^-(aq)$, are left behind.

of negatively charged particles (anions) from the reduction half-cell to the positively charged oxidation half-cell via the salt bridge corrects this imbalance in charge[28].

The correct answer for this question is option B (that the salt bridge provides a pathway for charge carriers in solution) and the results show that for both groups the same percentage of students chose the correct answer in the pre-test and post-test (see Figure 18). This was only a small percentage of the total (9% for the control group and 12% for the treatment group). The cross tabulation for this question shows how individual students answered the question in the pre-test and post-test, see Table 10 below. The rows in Table 10 indicate the choices that students made in the pre-test while the columns indicate the choices made in the post-test. From this table it can be seen that the perception that the same students choose correctly in both the pre-test and post-test is not valid. Instead, only two students selected the correct option in both the pre-test and post-test for both groups (see the highlighted portions of the cross tabulation).

Table 10: Cross tabulation for pre-test and post-test results by group

			Post-test / Frequency (percent)						
			A	**B**	**C**	**D**	**E**	**N**	Total
Control	Pre-test	**A**	6 (8.7)	1 (1.5)	1 (1.5)	4 (5.8)	3 (4.4)	1 (1.5)	16 (23.2)
		B	2 (2.9)	2 (2.9)	0 (0.0)	1 (1.5)	1 (1.5)	0 (0.0)	6 (8.7)
		C	2 (2.9)	0 (0.0)	1 (1.5)	4 (5.8)	2 (2.9)	0 (0.0)	9 (13.0)
		D	2 (2.9)	1 (1.5)	1 (1.5)	13 (18.8)	2 (2.9)	0 (0.0)	19 (27.5)
		E	3 (4.4)	2 (2.9)	1 (1.5)	4 (5.8)	8 (11.6)	0 (0.0)	18 (26.1)
		N	1 (1.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.5)
		Total	16 (23.2)	6 (8.7)	4 (5.8)	26 (37.7)	16 (23.2)	1 (1.5)	69 (100.0)
Treatment	Pre-test	**A**	0 (0.0)	0 (0.0)	0 (0.0)	4 (7.0)	4 (7.0)	0 (0.0)	8 (14.0)
		B	0 (0.0)	2 (3.5)	1 (1.8)	4 (7.0)	0 (0.0)	0 (0.0)	7 (12.3)
		C	1 (1.8)	2 (3.5)	1 (1.8)	4 (7.0)	1 (1.8)	0 (0.0)	9 (15.8)
		D	1 (1.8)	2 (3.5)	0 (0.0)	13 (22.8)	2 (3.5)	0 (0.0)	18 (31.6)
		E	1 (1.8)	1 (1.8)	0 (0.0)	3 (5.3)	10 (17.5)	0 (0.0)	15 (26.3)
		N	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
		Total	3 (5.3)	7 (12.3)	2 (3.5)	28 (49.1)	17 (29.8)	0 (0.0)	57 (100.0)

It must be noted that this question (which was taken from a local South African study) was not particularly well worded. Students may have avoided the correct answer because they did not know that the term "charge carriers" referred to aqueous ions. This question would have been less ambiguous had the correct scientific term (aqueous ions) been used in its place. Students may have selected distractor E (that the salt bridge provides a connection between the two half-cells so that cations can reach the negative electrode) simply because it was the only alternative that mentioned the term "cations". See Chapter 5 for a further discussion on the wording of the questions.

The histogram of the results (see Figure 18 on page 69) shows that nearly half of the students in the treatment group (49%) chose the main distractor, option D (that the salt bridge is used to provide a pathway for electrons to complete the circuit) in the post-test. This is an increase of 17% compared to the control group's increase of 10%. This increase was somewhat surprising because at no point in the

[28] This is the simplest explanation of the process. Oxidation and reduction processes are not independent so all of these processes (oxidation, reduction, electron and ion transfer) take place simultaneously. The individual anion does not physically move to the oxidation half-cell, instead an anion enters the salt bridge in the reduction half-cell and a different anion leaves the salt bridge and enters the oxidation half-cell. Cations also move through the salt bridge (and half-cell compartments) but in the opposite direction.

video is any statement made to this effect. The video presenter explains how the salt bridge functions on two separate occasions in the video: once during the introductory theory section, and a second time when working through examples. In both instances he states that his explanation has been simplified to such an extent that it is flawed because salt bridges are "*terribly complicated*". In the first instance he says that there are "*so many flaws in what I am about to tell you now, I'm embarrassed*" and in the second he says: "*Please, academics, accept that I have to make this one* (the explanation) *unbelievably simple*", and states that it contains "*lots of mistakes*". The first explanation is given in Transcript 9 below. (The video presenter was talking at a rate of about 150 words per minute during this explanation. This transcript represents a 62 second portion of the audio track.)

Transcript 9

"*Now the way a salt bridge works – by the way I'll be very honest very soon in this programme – these things are terribly complicated. But in a terribly simple way, what a salt bridge does is this: It allows the excess positive ions produced in this half cell* (he points to a sketch of the oxidation half-cell) *to go through the cotton wool plug into the salt bridge, and the ionic solution in the salt bridge neutralises the positives. On this side* (he points to a sketch of the reduction half-cell), *it allows the excess negative ions produced here to go through the cotton wool plug – by the way I often like to think like little tadpoles – that's why these plugs have to be cotton wool or fibreglass – they've got to be permeable. You've got to be able to get through them. You can't use a rubber cork. OK, right! These excess ions go through the salt bridge or cotton wool plug into the salt bridge and are neutralised again by the ionic solution.*"

In the second explanation the video presenter explains that the salt bridge is used to "*complete the circuit*" by preventing "*the build up of ... excess ions*" in the individual half-cells. He again states that the concentrated solution in the salt bridge "*neutralises*" the excess ions. Students were restless (talking and fidgeting) when this second explanation of the salt bridge was given.

Although there is no mention of electrons completing the circuit by travelling through the salt bridge in either explanation, it may be that by using the word "neutralise", students were somehow persuaded that electrons were involved in the process of eliminating ionic charge in the salt bridge. This may have occurred because the word "neutralise" had been used in a previous explanation to explain how electrons eliminated ("*neutralised*") excess positive charge that had accumulated on the copper cathode. The notion of a positively charged electrode is flawed (see footnote 20).

According to the video presenter a potential difference can develop at the electrode / electrolyte interface in a cathode "*half-cell*" that consists of a copper electrode and a copper(II) sulphate solution only. The video presenter stated that positive charge accumulates on the cathode because the "*copper* (he is referring to aqueous copper ions) *comes on to the rod* (electrode)*, becomes copper, and it drops its two pluses on the rod*". He reinforces this several times by stating that copper ions "*deposit on*" the electrode, that the "*copper ion drops itself as copper on the rod*", and that the copper ion "*being a metal will deposit its two positives on the rod*". This explanation is nonsensical for three reasons. Firstly, charge will only develop at the electrode / electrolyte interface of a half-cell when it is connected to another half-cell in an electrochemical circuit. Secondly, in this explanation the video presenter has stated that the copper ions deposit on the electrode through a process that does not involve the transfer of electrons. Copper ions cannot deposit without accepting electrons. Finally, the positive charges or "*pluses*" cannot be removed or "dropped" in any normal chemical reaction. The positive charges (protons) in a copper ion are located in its nucleus, if they are removed the identity of the ion changes. Once the concept of a positively charged copper electrode has been introduced, the video presenter explained how the positive charges (called "pluses" or positives") are "neutralised" by the electrons (called "minuses" or "negatives") produced in the oxidation half-cell, see Transcript 10.

(When involved with this explanation the video presenter makes a pushing gesture with his hands while stating that the zinc "*pushes*" electrons. He places his hand to his ear and adopts a quizzical look when saying, "*do I hear what I want?*", and smiles broadly when he says "*I do!*".)

Transcript 10

"*The zinc starts to shovel them* (the electrons) *out of the wire; it pushes them down the wire. It pushes them with a force, a pressure, a voltage. So the zinc, wanting to get rid of its electrons, starts to push them down the wire. On the other side, the copper, which is positive, says:*

'Hey (this wire that's just been attached to me), do I hear what I want? I do!'

Why?

'Because if I can import negatives, I can import electrons, they are going to neutralise all my positives, all my problems.'

Why?

'Because if I can neutralise all those (the video presenter points to the positive charges he has drawn on the copper electrode) *more coppers will start to arrive on the rod again.' So folks, this wire is a marvellous idea, it takes away all the minuses, it neutralises all the pluses. The zinc carries on ionising, making electrons. The copper carries on precipitating*[29]*, picking them up. The electrons keep going down the wire, and into this position here* (he places a cross on the wire in the same position as a voltmeter would be inserted into an electrochemical cell) *you put your radio, your torch, your tape recorder, etcetera. And folks, the electrons being forced down the wire will cause that thing* (the radio, torch or tape recorder) *to work.*"

It is possible that students may have assumed that because electrons had "*neutralised*" all the "*positives*" or "*pluses*" on the cathode, they may have been involved in the "neutralisation" process in the salt bridge. The video presenter seemed to avoid using accurate scientific terms for many scientific concepts and while there were some advantages to this strategy (see sections 4.2.4 and 4.2.5), there were also disadvantages. The colloquial terms "*negatives*" or "*minuses*" were used in the video to describe various entities, for example, electrons, anions, electrodes, solutions and various "$E^{\ominus}s$" (reduction, oxidation and cell potentials). Although transcripts of verbal text can appear complex and difficult to understand, according to Taylor (1988), inflections, body language and other cues that have not been recorded can convey meaning and aid understanding. The use of the term "neutralise" in this context, however, was inadvisable. Although the video presenter had probably intended to use this term in place of a more rigorous explanation, the term has a specific meaning in chemistry. It is used in acids and bases to describe either the process that occurs when an Arrhenius acid reacts with an Arrhenius base, or the process of adjusting the pH of a solution to 7 (Schmidt, 1991). It was unlikely

[29] The use of the term "precipitation" in this context is incorrect. According to Silberberg (2000:141), precipitation occurs when *"two soluble ionic compounds react to form an insoluble product"* and the chemical species that precipitates does not change its oxidation state. Oxidation and reduction reactions are always accompanied by a change in oxidation state (Silberberg, 2000).

that the use of this term would have persuaded students to believe that electrons travel over the salt bridge but it could have caused some confusion.

During the second *electrochemistry* video session a student from the treatment group asked the researcher to explain how the salt bridge worked. This incident occurred during the break immediately after the second explanation of the salt bridge had been given in the video. Instead of explaining, the researcher asked the student to make his ideas about the salt bridge explicit. He replied that he thought that the salt bridge was used to complete the circuit and to allow for the transfer of ions. As far as this student was concerned the video presenter's explanation had not been similar to his own understanding and he considered it to be wrong. Six of the 116 replies collected in Questionnaire 1, which asked students if any information they had received that day had been taught to them differently before, mentioned the salt bridge in answer to this question. The comments are listed below:

> "*Current through the cell.*"
>
> "*Flowing of current through the cell.*"
>
> "*Salt bridge section*"
>
> "*The section of the two solutions with the salt bridge.*"
>
> "*The explanation of the negative salt ions and where they end up going in the electrolyte or solution.*"
>
> "*The half-cell rules and the functioning of the salt bridge.*"

The researcher thought that a remedial intervention would be necessary to explain the functioning of the salt bridge because the lecturer had also stated that the salt bridge "neutralised" the excess charge that develops in half-cells. In addition to this several students from both groups had approached the researcher asking for an explanation of the salt bridge during the course of the study. A remedial intervention was devised by the expert who had made a cameo appearance in the *electrochemistry* video, and was given to both groups during the last lecture session by the lecturer. This expert was an academic member of staff in the Chemistry Department at the University of the Witwatersrand. His speciality was physical chemistry and he had demonstrated a functioning hydrogen half-cell (called a standard hydrogen electrode) in the video. He had a non-speaking role and was seen in the video checking the workings of the apparatus. He was named in the video by the video presenter.

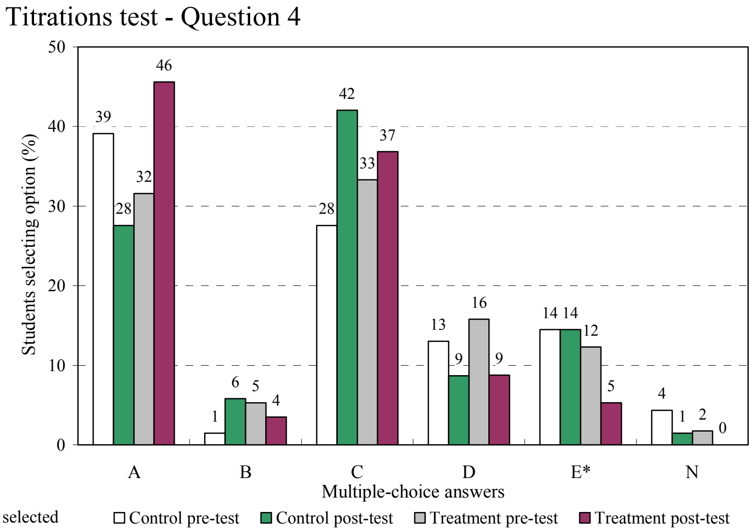
In the expert's opinion, students tend to think electrons travel over the salt bridge because they are not sure how electrons are used in electrochemical cells. They assume that electrons must complete the circuit as they do in electrical circuits. The expert felt that if students could grasp the concept that electrons were reagents, and that they were used up at a specific place in an electrochemical cell, then the problem with conduction in the electrolytes (aqueous salt solutions in the half-cells) and salt bridge could be solved. The expert explained that electrons are "made" at the anode via oxidation, that they travel through the external circuit (or wire), and that they are "used up" at the cathode via reduction. The purpose of the salt bridge is to provide a pathway for excess aqueous ions to complete the circuit. The expert had been asked by the researcher to introduce some anthropomorphic elements to his explanation since it was thought that the students might be more amenable to receiving the correct explanation in this way. The anthropomorphic notion that "electrons cannot swim" was introduced to reinforce the concept that electrons do not travel through the solutions. More information about this explanation can be found in Appendix E.

4.3.3 Question 4, Titrations test: The conditions at the end-point in a titration

Question 4, which is given in Figure 19 below along with a histogram of the results obtained, is a diagnostic question that probed students' understanding of the conditions at the end point of a general acid-base titration, as well as the extent of common misconceptions held. According to Silberberg (2000), the term end point is used to describe the stage in a titration where the indicator changes colour and so indicates the point at which the titration would be concluded. Although the end point is not identical to the equivalence point[30], for practical purposes the difference between the two is assumed to be insignificant (Silberberg, 2000). So, the following data would be known at the end point of an acid-base titration: the volumes of acid and base used in the titration, the concentration of one of the reagents, and the balanced chemical equation.

At the end point in an acid-base titration it is CORRECT to say that

A. the solution is neutral
B. the hydronium ion concentration is zero
C. the concentrations of the acid and base are equal
D. the amount of base added depends on its K_b
E. the volume of the base added depends on its concentration



* = Correct answer N = No answer selected

Figure 19: Titrations test: Question 4, and the histogram of the results obtained

The correct answer for this question is option E (that the volume of base added depends on its concentration). It must be noted that the answer to this question (which was taken from the University of the Witwatersrand's question bank) was not particularly well worded. Although the volume of base added would depend on its concentration, it is also dependent on the original amount of acid present. The results obtained (see Figure 19) show that for both groups only a small percentage of students answered the question correctly. The proportion of correct answers given by the treatment group remained constant at 14% while the control group decreased from 12% to 5%.

Two factors were thought to have persuaded the treatment group to choose the main distractor, option A (that the pH at the end point is neutral). The first was the introduction in the video of a made-up term called the "*neutral point*". This term was used to describe the end point in the first titration demonstrated in the video. In this titration a strong acid was titrated against a strong base so the end point was neutral (pH 7) and the term was appropriate. The same term was then applied by the video presenter to all subsequent titrations irrespective of whether the end point was neutral or not. The term

[30] The equivalence point in an acid-base titration is the point where the number of moles (or amount) of acid is stoichiometrically equivalent to the original number of moles (or amount) of the base. The difference in volume between the end point and the equivalence point is known as the titration error.

was usually used in conjunction with the scientifically accurate term "end point", for example, the video presenter might say "*we get to the end point, the neutral point*". So it seemed that the video presenter used this "made-up" term to explain the scientific term. Ogborn *et al.* (1997) call this type of explanation "rephrasing" and there were many instances where this occurred. (For a further discussion on this see section 4.4.3.) The second factor that may have persuaded students that the end point was always neutral was that he often used the term "*neutralises*" in both this and the *acids and bases* video, for example, he stated that "*an acid neutralises a base, and a base neutralises an acid*". The fact that "*a pH of 7 is neutral*" is also stressed repeatedly, particularly in the acids and bases video. According to Schmidt (1991), although acid-base reactions are often called neutralisation reactions, the meaning of the term neutral (and hence neutralise) has shifted since it was originally introduced in the 17^{th} century. When first introduced the term "neutral" [which is derived from the Latin term "neutralis" meaning neither one thing nor the other (Oxford English Dictionary online, 2008)] was used to indicate that acids and bases lost their distinctive properties on reacting. Since the introduction of pH in 1909 (Brock, 1992) however, the meaning attached to the term "neutral" has changed and according to Schmidt (1991), it is commonly interpreted by students to mean pH 7. Schmidt (1991) states that since students are often unaware of the earlier meaning of the term, they interpret the terms "neutral" and "neutralisation" to mean pH 7. For this reason he recommends that teachers use these terms with caution, or alternatively that they make the intended meaning of the terms explicit.

The histogram in Figure 19 shows that many students from both groups selected option C (that the concentrations of the acid and base are equal at the end point) in the post-test. Although the percentage increase of 4% by the treatment group was smaller than the control group's increase of 14%, the increase suggests that the video was not successful at eliminating this misconception. Students who select this option have confused the term "concentration" with "number or moles (amount)". Only a limited amount of video time (about 20 minutes) was devoted to discussing the conditions at the end point of a titration and performing calculations on the data collected during titrations. This was thought to have reduced the impact of this video. (About 60% of the time in this video was spent demonstrating practical work using voice-over. The preparation of a standard solution, three titrations, and the preparation of several cups of coffee – the analogue task used to explain molarity – were demonstrated.)

The slight decrease (from 5% to 4%) in the percentage of students in the treatment group selecting option B in the post-test compared to the increase (from 1% to 6%) by the control group, may result from these students selecting the main distractor in the post-test. According to Silberberg (2000), the concentration of hydronium ions at the end point are considered to be negligible and are often ignored when discussing acid-base titrations. Autoprotolysis (also known as autoionisation or autodissociation) of water means that very small concentrations of hydronium ions will be present.

The similar decrease in the percentage of students from both groups selecting option D was probably due to the fact that there were no discussions about the dissociation constants of bases (K_b). It must be noted that during the video no explanation about the special meaning chemists give to the word "amount" was given. In chemistry the word "amount" means "number of moles" however, the video presenter had used the term synonymously with the term "volume". For example, during the first titration (which had taken 30 minutes) the video presenter had used the word "amount" to describe the volume of base that he was pipetting into the flask (or reaction vessel). He made the following comment once he had finished pipetting: "*Alright, I've added a fixed amount of base ... from the* *pipette*". Although only one instance of the use of the word "amount" was identified in the video, it was speculated that it may have been possible to identify other instances of it occurrence during the banter that accompanied the titrating process. The process of listening to the audio track to identify the frequency with which the word "amount" was used was found to be unsuccessful[31] and this example was obtained through the process of transcription.

4.3.4 Question 2, Titrations test: Recognition of correct titrating procedures

Question 2, which is given in Figure 20 below, along with histograms of the results obtained, asked students to identify the procedure that would lead to inaccurate results when titrating.

Titrations test - Question 2

A student standardises an approximately 0,1 mol dm^{-3} sodium hydroxide solution against a standard solution of oxalic acid. Which one of the following procedures will lead to INACCURATE results?

A. The student rinses the burette with the oxalic acid solution before filling it to the zero mark with acid.
B. The student rinses the pipette with the sodium hydroxide solution before using it to pipette sodium hydroxide solution into the flask.
C. The student rinses the conical flask with the sodium hydroxide solution before pipetting in the sodium hydroxide.
D. The student uses water from the wash bottle to wash drops of chemicals on the sides of the conical flask during the titration.
E. The student adds three drops of indicator to the pipetted sodium hydroxide solution in the conical flask before beginning the titration.

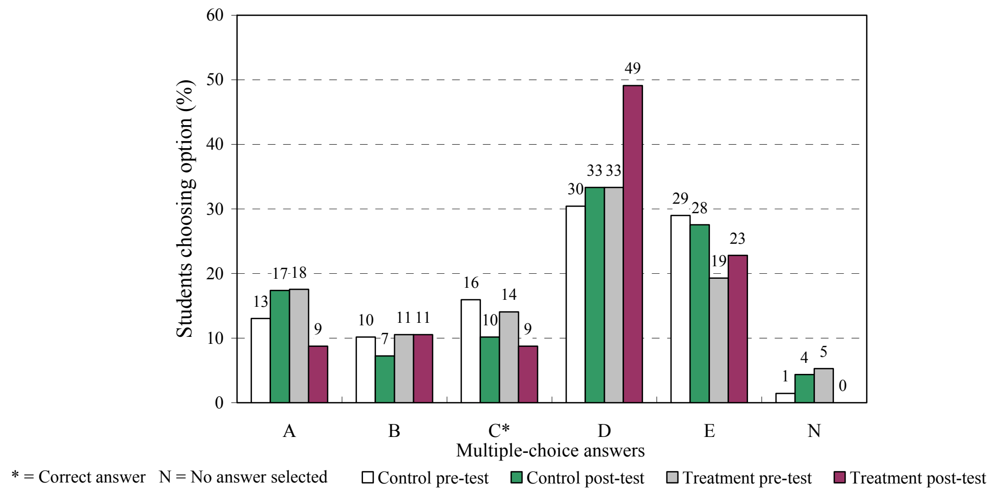


Figure 20: Titrations test: Question 2, and histograms of the results obtained

This question was a typical Senior Certificate *Physical Science* examination question. The correct answer to this question is option C (the student rinses the flask with sodium hydroxide before pipetting in the sodium hydroxide). The histogram shows that only a small percentage of students got this question correct in the post-test (9% for the treatment group and 10% for the control group.)

[31] It was almost as if familiarity with the word as an English first-language speaker somehow rendered the word invisible when listening to the audio track.

The results obtained for this question are of interest not because students selected the main distractor (since no specific distractor could identified as a main distractor) but because there was a 16% increase the percentage of students in the treatment group choosing option D (using water to wash down the sides of a conical flask) compared to an increase of just 3% for the control group. It is therefore possible that this increase by the treatment group may be due to the video.

Practical work was not carried out at the part-time school, and the Biographical Questionnaire showed that the majority of students (65% of the treatment group and 59% of the control group) had not seen or done any practical work at school. So in this study, only the treatment group had exposure to a practical demonstration of a titration. The lectures had covered the theory of acid-base titrations but had not included any details about titrating technique. As a result, the control group was not expected to choose differently in the post-test (although they may have altered their choices through the process of guessing the answer). The histogram (see Figure 20) shows that similar responses were obtained in the pre-test and post-test for the control group

Three titrations were performed by the video presenter in the video and in each one he demonstrated how the apparatus was cleaned and rinsed. So options A (rinsing the burette) and B (rinsing the pipette) were demonstrated. Option E (adding indicator before starting the titration) was also demonstrated and the video presenter had demonstrated how the flask (or reaction vessel) should be rinsed with water. He had discussed how the procedure stated in option C would lead to inaccurate results. The only procedure that had not been demonstrated during the titrations was the procedure outlined in option D, (rinsing the side of the flask with water to wash any chemicals on the sides of the flask during the titration). According to Kenkel (1994), this procedure is considered to be good practice when titrating. Students may have eliminated this option on the basis that it had not been demonstrated in the video but it was not possible to confirm if this was the reason why students had selected this option. If this was the case then it would seem to lend support to the contention of Meyer (1997) that individuals are able to recall and process certain types of visual information more readily than verbal information.

4.3.5 Question 6, acids and bases test: Identifying the solution with the highest hydronium ion concentration

Question 6, which is given in Figure 21 along with a histogram of the results obtained, is a typical Senior Certificate *Physical Science* question. To calculate the solution with the highest hydronium ion concentration, students would multiply the molarity of the acid by the number of ionisable hydrogens in the acid. In this question HCl (hydrochloric acid) and HNO_3 (nitric acid) are monoprotic acids so have one ionisable hydrogen, and H_2SO_4 (sulphuric acid) is diprotic so has two ionisable hydrogens. Option B is the correct answer, and 5% of the treatment group selected this answer in the post-test, a decrease of 11%, whereas for the control group the same percentage of students selected the correct answer in the pre-test and post-test.

Acids and bases test - Question 6

Which one of the following solutions has the highest concentration of hydronium ions (assume total ionisation)?

A. 1,0 dm^3 of 6 mol dm^{-3} HCl
B. 0,4 dm^3 of 10 mol dm^{-3} H_2SO_4
C. 0,5 dm^3 of 10 mol dm^{-3} HNO_3
D. 2,0 dm^3 of 2 mol dm^{-3} HCl
E. 0,5 dm^3 of 5 mol dm^{-3} H_2SO_4

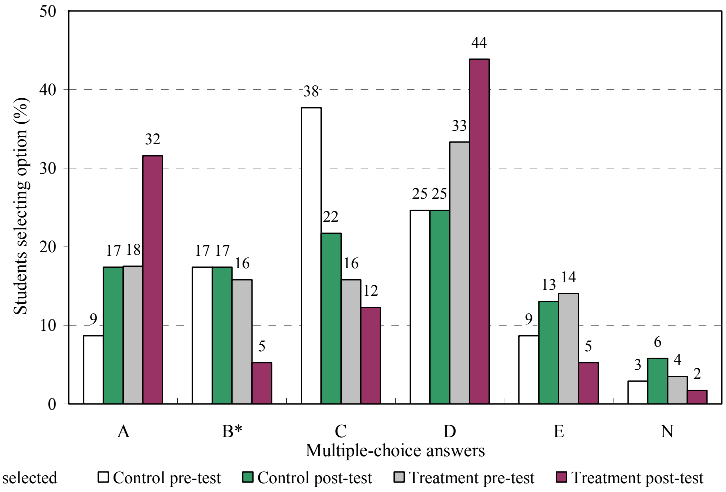


Figure 21: Acids and bases test Question 6, and a histogram of the results obtained

The increase in option A was thought to have occurred because this option has the highest molarity and students who selected this option may have simply forgotten to multiply the answers by the number of ionisable hydronium ions. The 11% increase in option D (the solution that had the largest volume and lowest concentration) in the post-test by the treatment group was somewhat surprising especially since the control group had no similar increase. This suggests that after watching the video, some students in the treatment group linked large volumes of hydrochloric acid with a low concentration to high hydronium ion concentrations. This is in direct contrast to the findings of Johnstone (1980). When this author gave a group of students similar questions in the United Kingdom, many of them selected the option with the smallest volume, irrespective of its molarity. He concluded that the students in his study were influenced by the colloquial meaning of the word "concentration", namely "small volume".

The selection of option D (and to a certain extent the selection of option A) may have arisen because of an experiment that was performed by the video presenter where changes in pH when diluting a strong acid (hydrochloric acid) were compared to changes in pH when diluting a weak acid (vinegar). Although the experiment involved a comparison between strong and weak acids (and all the acids in the question are strong acids), it was suspected that this experiment was responsible for persuading students that dilute solutions of hydrochloric acid contain higher concentrations of hydronium ions.

This experiment had little scientific or explanatory value because of two flaws. Firstly, the concentrations of the acids were not specified at the start, and secondly, the dilutions were not accurate. If carried out accurately the video presenter would have been able to demonstrate that pH of the strong acid would be lower than the pH of a weak acid at each dilution, because weak acids do not dissociate fully. Table 11 overleaf, gives the values obtained by the video presenter (shaded in grey) followed by the theoretically calculated pH values for this experiment, based on the researcher's own calculations using an acid dissociation (or ionisation) constant (K_a) for acetic acid of 1,7 x 10^{-5}.

Table 11: Comparison of the pH values of dilute strong and weak acids

Concentration of acid (mol dm^{-3})	pH of acetic acid	pH of HCl
Unknown	2.33	1.00
Unknown diluted to about 50 cm^3	2.44	1.23
0,10	2.7	1.0
0,010	3.0	2.0
0,0010	3.5	3.0
0,00010	4.2	4.0

Experimental results obtained in the video are shaded grey and the remaining results have been calculated theoretically

Two points were stressed by the video presenter during this experiment. Firstly, hydrochloric acid was singled out as being a "*strong acid*" that forms "*a very, very acidic solution*". This point was stressed repeatedly and it is possible that students may have concluded that hydrochloric acid was stronger than any other acid. Although the video presenter had often stressed that various acids were strong, this was the only occasion when he had reinforced the concept. These reinforcements seemed to have been introduced because the video presenter was filling in time as he waited for the pH meter to stabilise before taking the reading. Secondly, instead of using the experiment to explain how the pH differs between weak and strong acids when solutions of the same concentrations are compared as described above, the video presenter gave a more esoteric explanation, namely that dilution causes weak acids to dissociate to a greater extent and so produce more hydronium ions.

The esoteric explanation was based on theory that was not covered in the Senior Certificate *Physical Science* syllabus. During this explanation the video presenter attributed the difference in pH between the two acid solutions to the fact that weak acids dissociate to a greater extent as their dilution increases (due to Le Châtelier's principle). Although weak acids do behave in this way (for more information see Masterton and Slowinski, 1977, 456-457) the demonstration did not provide any evidence of this effect. (However, it can be seen from the readings listed in Table 11. This effect explains why the pH of the acetic acid tends towards the pH of the hydrochloric acid with increasing dilution.) A portion of this explanation is given in Transcript 11. The shaded sentence in this transcript was thought to have persuaded students that larger volumes of acid have more hydronium ions, even though this sentence had been spoken about acetic acid and not hydrochloric acid. This portion of the explanation was spoken at 167 words per minute, and because it was so fast, it was difficult to follow.

(This explanation was given during a voice-over portion of the video and the video presenter was pointing to the dissociation equations for these acids.)

Transcript 11

"*Remember in the strong acid you had almost none of that in solution (the HCl), it was all those two (H^+ and Cl^-). It happened before you diluted. So whether you diluted or not, you still have the same number of moles of H plus in solution. And by diluting, you just increased the volume, and therefore the change (in the pH) is big. But in a weak acid you don't have that much in solution (the hydrogen ions). A lot of it is still here (in the acetic acid molecule). So by diluting you make the acid ionise more. So you do produce more hydrogen ions and at the same time you do increase the volume. Now, if I increase the number of moles of hydrogen ions – at the same time I increase the volume. By doing so then my pH isn't going to change as much as if I increase the volume and I don't increase the number of moles, which is the case with a strong acid. Well, I hope that you got all that – because we certainly proved it – and that's the story.*"

According to Kozma (1991), the ease with which new information, particularly verbally relayed information via television or video, can be processed by the viewer depends not only on the pace with which this information is relayed, but also on the viewer's prior knowledge. If the pace is too fast and the viewer has insufficient prior knowledge, viewers can suffer from "*comprehension failure*" (Kozma, 1991). It would seem from the results obtained that the treatment group had missed many of the salient points of this presentation and had incorporated the new knowledge incorrectly.

4.3.6 Summary of the factors thought to have impacted negatively on students' performance

A number of factors seem to have persuaded students from the treatment group to answer these questions incorrectly. Firstly, it was speculated the inadequate use of scientific vocabulary may have increased the difficulty of the explanations given in the videos, and may have reinforced some incorrect notions about the science. In addition to this the inappropriate use of scientific vocabulary seems to have introduced confusion. Although there seemed to be some advantages in rendering vocabulary down into a simplified form (see sections 4.2.4 and 4.2.5), the choice of alternate vocabulary needs to be done with greater care. Secondly, oversimplification of some explanations seemed to have introduced or reinforced existing misconceptions. Thirdly, because the videos were not scripted and information was delivered at an extremely fast pace, some unqualified statements were made, and portions of inappropriate theory were introduced. As a result students seemed to be faced with the prospect of either reaching the wrong conclusions or suffering "*comprehension failure*". Fourthly, it was speculated that students chose the incorrect answer because a valid practical procedure had been omitted, so ensuring that the accompanying visual footage was accurate seemed to be important. Finally, the limited number of tutorial questions (examples) for some topics seems to have hindered students' ability to grasp and reinforce the concepts taught in the videos.

4.4 STUDENTS' REACTIONS TO THE VIDEOS

This section discusses students' reactions to the videos, and only reports on those reactions that have not been reported elsewhere in this chapter. Most of the incidents reported were recorded when the treatment group watched the videos. An overview of the control groups' reactions to the video is given in section 4.4.8. The most comprehensive information about the treatment group's reactions to the videos was collected during the *electrochemistry* video sessions since questionnaires were only given out during two of the three sessions when this video was screened. The quality of the videos varied and this was expected to impact on students' reactions. The *electrochemistry* video seemed to be newer, as its presentation was more professional than the *acids and bases* and *titrations* videos. For example, it used a more sophisticated "screen blackboard" (see section 4.4.2) and the pacing in this video seemed to be more appropriate (see section 4.4.4).

4.4.1 General reactions to the videos

The treatment group's response to the videos was generally positive and attendance at the video sessions was always over 70%. Three factors seemed to influence students' reactions to the videos. Firstly, students tended to be more responsive to the videos during the first hour of each video session, and they were more likely to answer questions posed in the videos by the video presenter during this hour. The questions asked fell into two categories: firstly, questions that teachers would typically ask in class like: "*Are you happy?*", "*Do you understand?*". Students generally answered "*yes*" in unison to these questions[32]. Secondly, questions that students would typically ask in class like: "*Isn't that difficult?*", "*How am I going to answer that?*". Students would not answer these questions and they tended to be rhetorical.

Secondly, the duration of the segments seemed to have an effect on students' attentiveness. Each video was divided up into several segments of uneven duration. The majority were 15 to 25 minutes long, but some were over 30 minutes long, and others were short (3 to 6 minutes). (Figure 3 on page 35 gives the duration of each of the 15 segments in the *electrochemistry* video.) Both long and short segments were not particularly well received. Students always muttered at the end of the short segments and became restless during long segments. In general, students' attention started to wane after about 20 minutes, and the introduction of a new segment at this point seemed to increase their attentiveness. According to Koumi (1991), one of the advantages of using regular segment lengths is that it introduces an element of routine to video watching, and this enables students to anticipate the end of each segment. From the researcher's perspective having segments of regular length would have made the video sessions easier to plan and run.

Finally, the content of the segment influenced students' response. Students seemed to be more attentive if information pertinent to the Senior Certificate *Physical Science* examination was disclosed, irrespective of whether this information was relevant to the topic. For example, students were attentive when standard solutions were prepared in the *electrochemistry* video, even though the preparation of these solutions forms part of an allied topic and not *electrochemistry*. When similar footage of the preparation was screened on the appropriate video (namely the *titrations* video) students seemed less interested. This seems to suggest that footage of practical demonstrations should probably be topic specific and viewers could be referred to the appropriate video to find out information about allied content. Students became restless and started talking when non-contextualised information was introduced. This happened in the *electrochemistry* video when the video presenter performed off-task demonstrations using commercial dry-cell batteries, and when he gave off-task explanations on non-related topics such as how neon lights worked.

4.4.2 Reactions to unintended visual cues

Unintentional visual cues occurred when footage of certain objects such as rulers, ruled diagrams, graph paper and tables was screened for the first time, as students seemed to be preoccupied about copying the information on the screen as accurately as possible. So, if the video presenter used a ruler or the pre-drawn diagram had been done using a ruler, then students also used rulers. A considerable amount of commotion ensued after these unintentional cues were first screened because students would rummage around in their suitcases to retrieve whatever apparatus they needed to copy the diagram exactly. This commotion would last for about two minutes, by which time the visual footage was often no longer on the screen. Students would then talk to each other to find out what had been on the screen, so they could complete the diagram. (One of the drawbacks of incorporating talking-head footage into the video was that it restricted the amount of time available for students to copy down information from the screen.) Koumi (1991) warns that unintentional visual cues can give rise to unanticipated responses from viewers, for example, they may turn off the video. He suggests using

[32] Students had reacted in the same way to many of the questions asked by the lecturer during lectures.

various visual or aural cues (for example, icons or spoken introductions) to pre-warn viewers so that they can anticipate the introduction of specific footage. According to Koumi (1991:133), these strategies help to increase the "legibility" of the videos. One possible way of ensuring that viewers can anticipate diagrams and keep pace with the video would be to provide printed copies of these diagrams and graphs that viewers could fill in.

In general, students appeared to keep pace with most of the notes and diagrams written during the videos because they were usually written or drawn by hand from scratch by the video presenter. Johnstone (1997) reported similar findings when he conducted an investigation into the types of notes taken by university students in the UK during lectures. In this study Johnstone (1997) noted that students were able to keep pace with information written on the blackboard by the lecturer. The disadvantage of using hand-drawn diagrams, however, was that many of the presentations done on the "screen blackboard" [33] were untidy. The diagrams tended to deteriorate as the videos progressed because new information was added to the screen blackboard without deleting old, irrelevant information. As a result the footage became difficult to decipher. This problem was aggravated by the video presenter's habit of using an uncapped pen to point out salient features on the screen blackboard so that several dots were accidentally added to the text or diagrams and this worsened the appearance of the written presentation.

4.4.3 Reactions to the language used

The video presenter narrated the videos in colloquial English using many simplified terms and as a result his delivery appeared almost conversational. In Questionnaire 3, one student cited the video presenter's conversational way of speaking as a reason for selecting his videos instead of another teacher's videos, stating: "*He explains clearly he speaks as if you are next to him*".

The video presenter used a number of colloquial phrases and terms such as: "*what a pleasure*", "*watch quickly*", "*superdoopa*", "*tricky-wicky*", and "*goodie*", and he used the term "*folks*" repeatedly when addressing the viewers. He often used a simple phrase instead of a more complicated term, for example, instead of saying "*identical*" he used the phrase "*exactly the same as*". He also often explained words by giving a brief, one-phrase explanation within the sentence, for example: "*notation, the way of writing it*". Ogborn *et al*. (1997) call this type of explanation "rephrasing".

According to Lemke (1990), one advantage of using colloquial words instead of a high science register is that students are more likely to be attentive to this talk. Within the South African context, where most students are likely to be English second-language speakers, the use of colloquial English would probably ensure that the verbal text was accessible to most students. For this assumption to be valid the colloquial language must be relevant to the students' experience, and the following incident indicates that this may not have always been the case. This incident occurred immediately after the first segment of the *electrochemistry* video had been screened. Students were asked if there was

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[33] The "screen blackboards" used in the videos were either sheets of paper or an opaque screen that looked similar to the writing surface of an overhead projector. Of the two, the opaque screen was the most effective because it gave a sharper image. To get the same visual impact with paper the camera needed to be closer so the frame of the paper blackboard was smaller – this meant that equations were split across two lines. Although sheets of paper were used in all the videos, the opaque screen blackboard was only used in the *electrochemistry* video, giving the impression that this video was more recent.

anything they did not understand and a student asked the following question: "*Where are the foxes he is talking about?*" As an English first-language speaker the researcher was unable to understand the question and sought assistance from the rest of the group. They discussed the problem in the vernacular and the entire class started laughing when it was established that this student had never heard the term "*folks*" before, and thought that the video presenter was referring to "*foxes*". The video presenter used this term sixteen times during this segment, which was 30 minutes long.

Feedback from Questionnaires 1 and 3 seemed to indicate that the video presenter's English was generally pitched at an appropriate level. Questionnaire 1 used a three-point Likert scale to establish what students thought of the words the video presenter used. Fifteen percent thought they were "*too easy*", 83% thought they were "*OK*", and only 2% thought that they were "*too difficult*". In Questionnaire 3, four students (out of 73 respondents) specifically cited the video presenter's English as their reason for choosing his videos instead of someone else's. Their comments are listed below:

> "*He explains very clearly with pure English and straightforward.*"
>
> "*He uses a simple English and also his explanations.*"
>
> "*He explains clearly with perfect English and is very fascinating when explaining his work.*"
>
> "*He is very good explanation and his English not so difficult, and he shows things very clearly. Really he is very good.*"

4.4.4 Reactions to the speed of the verbal delivery

Questionnaire 1, which was given during the first video session, used a three-point Likert scale to establish students' opinions of the rate at which the video presenter spoke. The results showed 4% thought he spoke "*too fast*", 95% thought the rate was "*OK*", and 1% thought he spoke "*too slowly*". Since this questionnaire had been given out during the first video session the results imply that the rate at the start of this video was acceptable to English second-language speakers. However, a number of students complained that the video presenter spoke too quickly at subsequent video sessions.

In Questionnaire 2, three students (out of 108 respondents) complained that the video presenter had spoken too fast when dealing with Example 5, an explanation of the hydrogen half-cell. This questionnaire had asked students if they were confused about any section in electrochemistry, and during this explanation the video presenter had been speaking at a rate of 146 words per minute.

> "*Example 5, I didn't understood it, he was very fast.*"
>
> "*He does not explain example 5 well, he was too fast*"
>
> "*In example 5 he explained too fast and it was confusing*"

Students did not complain, however, about the rate at which the video presenter had spoken during the anthropomorphic explanation that occurred immediately prior to this explanation, even though it was spoken at a faster rate, namely 154 words per minute. This suggests that the degree of difficulty of the content may have influenced students' perceptions of the rate, or alternatively students may have focused their complaints on this aspect of the explanation instead of criticising other aspects. Evidence collected elsewhere (see Transcript 11 which was spoken at 167 words per minutes) suggests that the video presenter may have spoken more quickly when dealing with difficult subject matter.

Some students complained that the video presenter spoke too quickly at the start of the *acids and bases* video and approximately ten minutes into this video a number of audible sighs could be heard that were interpreted by the researcher to be a sign of frustration. Analysis of a one-minute transcript taken from this part of the video showed that he was speaking at a rate of 168 words per minute. The video presenter seldom spoke at these fast rates for longer than a minute and often the preceding sentence was spoken at about 110 to 120 words per minute. In total fifteen one-minute portions of this video were transcribed (called rates of commentaries) and the average number of words spoken per minute in these transcripts was 127. According to Kozma (1991), one of the disadvantages of a fast delivery rate is that much of the information is likely to be lost since students will not be able to interpret, synthesise and record what they are hearing. Johnstone (1997) found that university students encounter these types of encoding problems during lectures spoken at a considerably slower delivery rates, namely 100 words per minute. One possible way of ensuring a more regular rate of commentary would be to script the videos. Copies of the rates of commentaries taken from the videos can be found in Appendix F.

4.4.5 Reactions to the video presenter's explanations

Students commented on the video presenter's explanations in all three questionnaires. In Questionnaire 1 two students made the following comments in reply to the question which asked whether any of the information they had received that day had been taught to them differently before:

> "*Yes, the presenter explain better and we understood clearly.*"
>
> "*Yes, because it is more understandable than before.*"

Questionnaire 1 used a three-point Likert scale to establish what students thought of the video presenter's explanations and 16% (or $^{18}/_{116}$) thought they were "*very good*", 82% (or $^{95}/_{116}$) thought they were "*OK*" and 2% (or $^{2}/_{116}$) thought they were "*no good*". The same question was asked in Questionnaire 2 during the third video session and by this stage 70% of the 108 respondents thought they were "*very good*", 29% thought they were "*OK*", and only 1% thought they were "*no good*". In Questionnaire 3, 26 students (of 73 respondents or 36%) listed the quality of the video presenter's explanations as the reason they would choose his videos instead of someone else's. Some of their comments are listed below:

> "*He explains clearly, and he uses relevant examples to make pupils understand.*"
>
> "*When he explains, I understand.*"
>
> "*He explains in detail and he is not boring.*"
>
> "*He explains in a slow, simple and understanding way.*"
>
> "*He explains everything clearly and understandable. What he teaches is great and not forgettable.*"
>
> "*The way he is teaching is very good, he explains very well, even if you did not understand you end up understanding more.*"
>
> "*I understand him better because he does everything step by step, he explains better than any other teacher. I've attended their classes.*"
>
> "*He explains thoroughly before tackling the question and gives examples of things we did in our daily lives.*"
>
> "*He explains everything in full and clearly. He explains all the important examination questions which a student meets in the exam.*"

The last two comments seem to suggest that in the first case this student could identify with the analogues used in the analogies, and in the second case that this student liked the tutorial questions. The following two comments were also made in answer to the same question in Questionnaire 3:

"*He knows how to explain, BUT HE EXPLAINS TOO MUCH!*"

"*Although he is time consuming but to the point.*"

Not all of the students were enthusiastic about the video presenter's explanations. One student made the following negative comment in Questionnaire 1 (which asked students if any of the information they had received that day had been taught to them differently before).

"*The lesson they showed was too difficult since it was not clearly explained.*"

4.4.6 Reactions to the practical demonstrations

Observational evidence collected in the first two video sessions indicated that students seemed to enjoy watching the practical demonstrations that were given in the *electrochemistry* video. The video presenter had taken about one hour to show how to prepare all the components of an electrochemical cell (two standard solutions had been prepared along with the salt bridge) and the cell had been connected and the voltage had been read off the voltmeter. Questionnaire 2 used a three-point Likert scale to establish whether students thought the preparation and functioning of the experimental electrochemical cell was interesting. The results showed that the majority of students (76%) thought that it was "*very interesting*", 21% thought it was "*OK*", and only 3% thought it was "*boring*". This questionnaire also asked students if they had seen this experiment or a similar experiment before. Of the 108 respondents, 78 (76%) stated that they had not seen this type of experiment before.

Although this evidence suggests that students found these practical demonstrations interesting, they became restless watching the practical demonstrations of titrations in the *titrations* video. Three factors were thought to have contributed to this. Firstly, they were very time consuming, (two were over 30 minutes long). Secondly, the visual impact of this footage was less interesting than footage that had accompanied the preparation of the electrochemical cell or talking-head footage. Thirdly, the verbal commentary that accompanied the titrations was not particularly informative. The video presenter merely commented on the various activities that he was involved with, for example, how much titrant had been added from the burette and the colour of the solution in the flask.

Students also became restless during the *titrations* video when the preparation of several cups of coffee to which different quantities of sugar were added was being demonstrated. This task was used to explain the concept of molarity and was about 30 minutes long. The following three reasons were thought to account for the students' restlessness during this demonstration. Firstly, the visual impact of the footage was limited. Secondly, the links between the sweetness of coffee to molarity were not adequately explained at the start, and finally the video presenter's explanation about how to calculate the "sweetness" in coffee used fractions and was difficult to understand (see Transcript 12).

Transcript 12

"*A half a spoon of sugar in a tenth of a decimeter cubed. What am I going to get? Well, a half in a half would give me one, um-hum, and a half in a tenth, now look I've got more sugar than I've got coffee. Surely it's going to be five sweetnesses, five times as sweet. Why? Because one spoon in a tenth of a cup will be ten times as sweet as normal, so a half a spoon will be half of ten which is five. Happy?*"

There were two drawbacks with the practical demonstrations in the videos. Firstly, the large amount of video time devoted to practical demonstrations in the *titrations* video severely restricted the amount of time available for discussions about the theory. Only about 20 minutes of this video was used to discuss the calculations associated with titrations. Secondly, it was speculated that the unscripted commentary that accompanied the demonstration may persuade students to make incorrect assumptions (see section 4.3.4). An investigation into the commentary that accompanied the practical was not carried out during this study.

4.4.7 Evidence of confusion

Evidence of confusion was obtained from observation, from the questionnaires, and via discussions initiated by students. Questionnaire 2 asked students to state whether they were confused about any sections in electrochemistry and the majority (72% or $^{78}/_{108}$) stated that they were not confused. Of the 28% who stated that they were confused, the majority stated that they were confused about the hydrogen half-cell and the construction of the standard reduction potential table that had been explained that day in Example 5. Some of the comments made are listed below:

> "*That of 0,00V*"
>
> "*How they establish the standard electrode potential.*" (4 students had made this comment)
>
> "*About the way he says about potential table.*"

This reaction was to be expected since the video presenter's explanation about why the hydrogen half-equation has a reduction potential of 0,00V was incorrect. He had stated the standard reduction potential of hydrogen was "*exactly zero*" (see Transcript 13) and that "*the energy of hydrogen ions is exactly the same as hydrogen in diatomic gas form*"[34] because of the special conditions under which the hydrogen half-cell operates. Garnett and Treagust (1998b) list this as a commonly held misconception.

> Transcript 13
>
> *How do they know this reaction is absolutely zero? And the answer is they don't, that's my belief anyway. As long as it's nearly zero ... it doesn't matter ... the error cancels out. I'm sure there are some academics that might want to shot me down but I don't believe that it is exactly zero as long as it's close and it is close and that is all that really matters.*"

By oversimplifying the theory in this way, the video presenter was able to make two other oversimplifications. Firstly, the **relative** nature of the standard reduction potentials did not need to be explained. Secondly, the standard reduction potential table could be used to predict which direction was "*downhill*" for each half-equation.

These oversimplifications may have enabled students to understand specific examples of electrochemical cells (for example, a zinc / copper cell), and this may have given them the beginnings of understanding in this topic. However, the oversimplifications were expected to impact negatively on

[34] The standard reduction potential of the hydrogen half-cell is arbitrarily set at zero (Moran and Gileadi, 1989)

students' future learning in the topic. The following comment made in Questionnaire 2 (in answer to the question about whether students were confused about anything in electrochemistry) suggests that this student has been persuaded that the video presenter's version of the science is correct and that the textbook is wrong: "*The presenter is moderate rather than the textbook which is confused.*"

One of the ramifications of this oversimplification was the explanation about the microscopic processes that occur at the copper electrode in a copper half-cell. This explanation is given in Transcript 14 below. According to this explanation, dynamic equilibrium is reached between copper metal and aqueous sulphate ions, which is nonsensical. Equilibrium can only occur if the same chemical species are present on both sides of the equation. The upshot of this explanation was that students became confused about the concept of "*dynamic equilibrium*" and how it varied from "*equilibrium*". During a subsequent lecture session, a group of students asked the lecturer to go over the concept of equilibrium, and to explain the difference between these terms.

Transcript 14

"*Now the copper pluses have been going onto the rod to make the rod very positive and they're leaving behind the two minus sulphate ions. In other words your solution now has got far more sulphate ions than its got copper pluses because the copper pluses have gone on to the rod. So, your solution now has become extremely minus with all the sulphate ions left behind. And once again you've built up an electric pressure between the positive rod and, this time, the negative solution. We've built up a voltage. Now folks, once again, as in dynamic equilibrium, once it's been reached, you've built up the pressure. The pressure's holding, right, you know that's what a cell does, a cell holds the pressure, the volts, you're going to see nothing more, it will sit there, it will go internally dynamic, yes, but you won't see it.*"

4.4.8 The control group's reactions to the videos

A limited amount of data was collected about the control group's response to the videos because only the first two hours of this six-hour session were observed by the researcher (for the reasons discussed on page 38).

The control group seemed less enthusiastic about the videos than the treatment group had been, and they responded to fewer incidents in the video. For example, they did not laugh at the "*nobody runs uphill…*" comment reported in section 4.2.4, and they did not answer as many of the video presenter's questions (see section 4.4.1). It therefore seems likely that part of the treatment group's enthusiastic response to the videos may have been attributed to the halo effect (see section 5.1.2 for a discussion on this).

4.5 CONCLUDING REMARKS

This chapter reported on the findings from the study. The success of the videos as a supplementary learning aid was reported in the first section and the strengths and weakness of the videos were reported in the following two sections. Students' reactions to the videos were reported in the final section.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 LIMITATIONS OF THE RESEARCH

Before the findings of this study are summarised, it is important to evaluate any factors that may threaten the validity of the findings. This is done so that readers can draw their own conclusions about the validity of the findings given in this research report. According to Sanders and Mokuku (1994:481), researchers need to be *"able to claim with confidence that their data-gathering tools and techniques measure what they purport to measure, and that their research provides an authentic interpretation of reality."* To do this the limitations of the *"data-gathering tools and techniques"* need to be evaluated and the inferences that the researcher draws from these tools and techniques also need to be discussed.

Creswell (2002) states that educational research is a complex endeavour because it involves human participants. He adds that researchers are often required to make practical decisions to facilitate the conclusion of their studies and these may compromise or threaten the validity of their research. This study used a pragmatic design constructed around a quasi-experiment. Although steps were taken to improve the validity of the research design, it was not possible to control for all threats as they can arise from a numerous sources that cannot always be controlled.

5.1.1 The non-random assignment of students to the treatment group

Since the students who participated in this study were attending a non-traditional, part-time school where attendance at classes was recommended but not enforced, it was not possible to randomly assign students into groups. Furthermore it was not possible to allocate intact classes to the treatment or control groups as students were allowed to attend either one of two alternate classes, and they switched between classes at whim. Instead, the intention was to use a self-selected sample of students drawn from both classes, using the "first come, first served" basis. However, since more than the required number of students volunteered and they were all present at the venue well before the start, the planned selection criterion could not be used. An impromptu selection process was implemented by the lecturer, as described in Chapter 3, page 40. Although this selection process may have introduced a certain amount of randomness, the sample was still made up of volunteers. This selection strategy introduced four possible threats to the validity of the study.

- Firstly, a treatment group composed of volunteers is expected to respond differently to the treatment than would a non-volunteer group since volunteers are likely to be more enthusiastic.
- Secondly, the groups may have differed with respect to variables other than the dependent variable (namely the tests on the selected topics) investigated in the study. For example, the groups may have had different intellectual abilities, language skills or motivational levels. These variables may have altered each group's performance in unanticipated ways. For example, more

motivated students would probably extract greater benefits from any learning situation, regardless of the treatment, than less motivated students.

- Thirdly, the groups may have been different at the start with respect to the dependent variable under investigation, in this case the test scores. Data obtained in this study seems to indicate that any differences were small as the average pre-test scores for each test varied by less than two percent. Nevertheless, analysis of covariance was used in this study to adjust for any differences in the dependent variable between the groups at the start.
- Finally, the possibility existed that because the two groups attended class together, students from the treatment group may have discussed the treatment with students from the control group. These discussions may have artificially improved the control group's post-test scores. This effect is known as *experimental treatment diffusion*. According to Mertens (2005) it cannot be controlled, but it was hoped that by giving the control group the opportunity to watch the videos at the end of the study the amount of discussion about the treatment between the two groups would be reduced.

According to Creswell (2002), it is not possible to control all the variables in research situations and so such limitations must be considered when the results of the study are evaluated.

5.1.2 Characteristics of the students

The fact that all the students involved in this study were rewriting the Senior Certificate *Physical Science* examination, and that the study took place in the last ten weeks of the academic year (just before the start of the Senior Certificate examinations), increases the likelihood that these students may have been more motivated than the general student population. Their motivation may have been heightened by the extra attention expended on them as a result of their involvement in a research study, and this may have spurred students from both groups to apply themselves and work harder. This increased application may have resulted in increased performance by both groups.

According to Mertens (2005), this type of participant reactivity, known as the Hawthorne effect, is unavoidable and cannot be quantified, although steps can be taken when designing a study to minimise it and other types of participant reactivity. The following two steps were intended to curtail participant reactivity during this study. Firstly, video sessions were scheduled for 4pm on Friday afternoons as fewer students were expected to volunteer at this time. And secondly, a "first come, first served" selection strategy was intended to be used. Although this strategy was considered to be both reasonable and fair by the participants, it had to be abandoned for the reasons stated above (in section 5.1.1). The impromptu selection process caused a considerable amount of discontent amongst members of the control group[35], and probably increased participant reactivity in this study. Participant reactivity could have manifested itself in the following ways: Firstly, members of the treatment group may have felt that they had been specially selected and so may have engaged with the treatment more enthusiastically than they would have otherwise, known as the halo effect (Mertens, 2005). Secondly,

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[35] One student wrote the following comment on the biographical questionnaire alongside the question that asked whether students had watched any educational science programmes on television: *"I'm worried, I did not see the videos"*. Several students also spoke to the researcher during the study to express their disappointment at not being selected to watch the videos. The control group watched the videos on the Saturday immediately after this questionnaire was administered, see Figure 1 on page 23.

the control group may have either tried harder than they would have normally, known as compensatory rivalry (Mertens, 2005), or tried less hard, known as resentful demoralisation (Mertens, 2005). Readers must therefore bear these considerations in mind when considering the findings reported in this study.

5.1.3 Student attrition during the study

The study had been designed to make allowances for student attrition since anecdotal evidence from the lecturer had indicated that student attendance was erratic. Nonetheless, by using only those students who met the attendance requirements imposed during the study, attrition of students could impact on the findings in three ways. Firstly, the elimination of some students may mean that the sample was no longer representative of the group studied, so the findings may not give an accurate reflection of the actual situation. This may have impacted on the internal validity of the study. For example, the students who were analysed may have different abilities to the original group. Secondly, the eliminated students may have deliberately "dropped out" because they were less able and wanted to avoid writing tests. If this was the case then bias may have been introduced into the sample. Finally, a non-representative sample impacts on the external validity of the study and means that the findings should not be generalised. Readers must recognise this limitation.

5.1.4 Possible problems with the design of the study

A number of variables were introduced into the study because it was designed around the durations of the videos, which varied per topic. This meant that students had different exposure to the topics and, because the tests were written before and after each video topic, different time intervals existed between tests. The *electrochemistry* video was the longest and three video sessions were allocated to it; two video sessions were allocated the *acids and bases* video (but the video was faulty so an extra session had to be scheduled), and one video session was allocated to the *titrations* video. The following time interval occurred between pre- and post-tests: four weeks for the *electrochemistry* tests, three weeks for the *acids and bases* tests, and two weeks for the *titrations* tests. These different exposures to the topics and differing time intervals between pre-tests and post-tests could have affected students' performance. For example, the treatment group's improvement in the *electrochemistry* post-test may have merely been due to the longer exposure students had to this topic. Alternatively, the improvement could have arisen because these students used the four weeks between the *electrochemistry* tests to practice the tasks demonstrated in the video. Similarly, the poor performance on the *titrations* test may have been due students' shorter exposure to the topic, and the shorter time interval between tests. If students' performance had been altered as a result of these factors, then the test results may not have been an accurate reflection of the research situation and this would affect the internal validity of the study. There was no way to quantify the extent to which this may have happened, and the possibility that this design might introduce these variables was not considered when the study was designed.

On reflection it was considered that a better design would have resulted if the *acids and bases* and *titrations* videos been considered as a single topic. Not only was the division between these two topics artificial in the first place (there was overlapping content between the videos), but the duration of the combined videos was similar to the duration of the *electrochemistry* video. Combining the videos would have had the advantage of regulating the study, and of reducing the number of tests that had to be written. Anecdotal evidence collected during the study seemed to suggest that in general students' enthusiasm for test writing flagged as the study progressed.

5.1.5 Possible problems with the research instruments

Three different instruments were used to collect data in this study and the limitations associated with each instrument are discussed separately below:

Tests: A number of problems with the tests were identified that may have influenced students' performance, and so may have threatened the internal validity of the study. Firstly, according to Haladyna (2004), the format of multiple-choice tests can affect students' performance. For example, the use of an incomplete stem can increase the difficulty of a question, and all three tests contained at least one question of this type. The use of a negative stem can add to the difficulty of questions as students often forget to reverse the logic, and both the *acids and bases* and *titrations* tests had one question of this type. Wordier questions such as those used in the *titrations* test are also considered to be more difficult, particularly for English second-language students, and this may have contributed to the generally poor performance obtained for this test.

Secondly, because the tests were set before the videos were viewed, they may have lacked what Paris, Lawton, Turner, and Roth, (1991:12) term *"instructional validity"*. Paris *et al.* (1991) use this term to describe the correspondence between the scope of the test and content taught in class. Of the three tests, only the *titrations* test lacked instructional validity. This problem arose because the researcher had interpreted the topic *titrations* to include the theory, calculations and techniques surrounding titrations only. The video presenter, on the other hand, had included the preparation of standard solutions and various associated calculations, and over 50% of the video was devoted to this topic. This test also lacked what Paris *et al.* (1991) term *"curricular validity"*. Paris *et al.* (1991) use this term to describe the extent to which content of the test matches the prescribed syllabus. One of the diagnostic questions about the conditions at the end point in a titration was based on content that was not in the Senior Certificate *Physical Science* syllabus. As a result the *titrations* test focused on a narrow portion of the content, and tested only a limited amount of theory, some of which was tested repeatedly. For example, there were five diagnostic questions that investigated students' knowledge of various aspects of the theory surrounding the conditions at the end point of a titration, and two titrimetic calculations. This meant that the possibility existed that students knew the correct answers, so got all the questions correct, or did not know them and so got all the questions wrong. This could have skewed the results from this test, and by not testing all the content divulged in the video, the test did not accurately reflect the amount of learning that took place. This could have impacted on the internal validity of the findings as this test was unlikely to give an authentic representation of the situation investigated in the study.

Thirdly, the decision to only face-validate, and not pilot, the tests was considered on reflection to be ill-advised. At the time of the study the researcher believed that since all the test questions had been used on previous occasions, the process of face validation would be sufficient to identify problems with the tests. However, this was not the case as a number of problems were identified when the test results were analysed. It is possible that these problems may have been identified had the test been piloted, and could have been eliminated prior to the main study. Problems that may have been identified by piloting the tests include some of problems with "instructional" and "curricular validity" mentioned above, and the problems with the wording of the questions. Inaccurately worded questions may have caused some students to make incorrect choices. (For example, see section 4.3.2 for an instance where this may have happened). Piloting the tests would also have enabled the researcher to test the assumption that students could perform the simplified calculations given in the tests using mental arithmetic.

Questionnaires: Although the questionnaires were face-validated before being used, they were not piloted, so potential problems with the wording of the questions were not assessed prior to administration. Although no problems with the wording were highlighted during the analysis, it is possible that piloting could have led to the development of better formulated questions with fewer potential ambiguities. Data collected from incorrectly worded or structured questionnaires may result in validity problems. Another unanticipated problem that may have affected the internal validity of the questionnaires was that some students seemed concerned about possibly hurting the video presenter's feelings when filling in the questionnaires. Although students were repeatedly assured that their confidentiality was going to be respected, this reaction suggests that the aims of the questionnaires (namely to identify the strengths and weakness of the videos) should have been reiterated. Although students usually expressed these concerns immediately before they handed in the completed questionnaire (which suggests that they had been candid), the possibility exists that some students may not have expressed their true feelings about the videos.

Observational techniques: Two factors may have reduced the internal validity of data collected using observational techniques in this study. Firstly, the researcher's lack of skill in using these techniques at the start of may have meant that important observations during the early stages of the research were either not recorded accurately or not noticed. Secondly, monitoring only five types of routine activities in the observation schedules may have meant that other routine activities may have been overlooked throughout the study. For example, no information was recorded when the practical demonstration discussed in section 4.3.5 was being screened. This was because students were not involved in the routine activities recorded in the observation chart (namely answering questions, laughing, talking, fidgeting or sighing) and no other special incidents occurred.

5.1.6 Experimenter effects

In educational research it is recognised that the researcher has an effect on the participants in a study. This effect may be unintentional, and consequently the researcher may not even be aware of its occurrence (for example, a researcher's style of dress, gender, or attitude may affect participants' responses). Alternatively, the effect may be intentional, for example the researcher may intentionally treat participants differently.

The researcher attempted to treat all the participants equally in this study and the large number of students attending the lecture sessions aided in this process. About 450 students attended lectures during the course of this study and as a result the researcher was unable to recall specific students from week to week. But the smaller student numbers (about 100) attending the treatment group's video sessions meant that some of these students became well known to the researcher. These students often involved the researcher in discussions, some of which concerned the videos but most of which were concerned with career guidance. Students wanted to know what various professionals did at work, along with information about pursuing these careers. Although individual students had asked these questions, the requested information was divulged to the group. Students were eager to receive this information and it is possible that these discussions may have affected their attitudes to the researcher. This changed attitude may have affected their attitude to the treatment and so their performance in the tests may have changed. This would impact on the internal validity of the study.

5.1.7 Limitations arising from data-analysis and reporting procedures

Purposive sampling of the videos was used in this study to provide evidence for the findings from the test, and it is possible this deliberate sampling did not give an accurate description of the content of the videos. This may have impacted on the internal validity of the study. For example, the decision to use short transcripts may have given an incorrect impression of the actual explanation. Similarly, it is possible that the incidents selected on the video to describe these findings, may not actually have been responsible for the findings. Although attempts were made to triangulate data from as many different sources as possible, corroborating evidence from these sources could not always be found. Where applicable, the existence of corroborating evidence from the different sources is mentioned in the research report.

Purposive sampling can also introduce bias as the researcher may deliberately report information that supports a specific point of view. While Creswell and Millar (2000) recommend that researchers clarify their bias at the start, according to Charmaz (2003), the perspective of the researcher is often made explicit to readers when they read the report. Charmaz (2003:271) states: *"The researcher composes the story; it does not simply unfold before the eyes of an objective viewer. This story reflects the viewer as well as the viewed."*

5.2 SUMMARY AND CONCLUSIONS

The limitations discussed in section 5.1 must be taken into consideration when reviewing the findings and conclusions recorded in this research report.

The purpose of this study was to evaluate how effective videos were at supplementing learning when watched in the same way as a television broadcast. The results obtained are summarised below:

- ***Comparison of group mean scores showed no significant differences as a result of the treatment:*** Three tests were written during the course of the study, and in one test (the *electrochemistry* test) the treatment group improved to a greater extent than the control group (improving from 34% to 43% compared to 36% to 41%, respectively). In the second and third tests (the *acids and bases* test and the *titrations* test) both groups improved to the same extent although the control group's performance was slightly better that the treatment group's in the *titrations* test. (In the *acids and bases* test the treatment group improved from 35% to 47% and the control group from 34% to 46%, and in the *titrations* test the treatment group improved 17% to 20% and the control group from 20% to 23%). The improvements between the groups were not statistically significant, implying that no effect can be attributed to the videos.
- ***The treatment group made large gains in 20% of the test questions:*** In six questions out of 30 (10 questions per test), the treatment group made large improvements compared to the control group. These relative improvements ranged from 9% to 23% and could have been attributed to the video.

- In Question 5 in the *electrochemistry* test, the treatment group's 9% greater improvement in identifying the anode correctly could have been due to either a mnemonic used in the video to help students remember the naming conventions at electrodes, or an analogy used by the video presenter, or a combination of the two. The analogy effectively communicated the source of electrons in an electrochemical cell and their movement between electrodes in the external circuit.
- In Question 9 in the *electrochemistry* test, the 19% greater improvement by the treatment group in successfully identifying a reduction half-equation could have occurred because the examples asked in the question, namely zinc and copper, had been used to illustrate the theory in the video. The large amount of time spent in the video (about 40 minutes) to explain how these elements typically react, coupled with the extensive use of anthropomorphic and teleological explanations could have helped students in the treatment group to recall the correct answer to this question.
- In Question 10 in the *electrochemistry* test, the 23% greater improvement of students from the treatment group calculating the cell potential correctly could have resulted from the application of an algorithm in the video. A narrative that made use of specific vocabulary enabled the steps associated with the algorithm to be recalled and applied. This vocabulary was derived from a complex analogy that linked the characteristics associated with the way water flows out of a tank to a simplified interpretation of the theory of electrochemical cells. The vocabulary was drawn from the analogue and was used to describe concepts in the scientific domain. In this way both the scientific vocabulary and associated scientific concepts were simplified, which could have reduced the cognitive load on the students. This simplified way of thinking about the electrochemical cells could have helped students from the treatment group to grapple with certain aspects of theory.
- In Question 4 in the *acids and bases* test, the relative improvement of 12% by the treatment group in selecting the chemical species behaving as a Brønsted-Lowry base could be the result of repeated exposure to these types of problems or to the simplification of the vocabulary in the video. The vocabulary associated with each species in a Brønsted-Lowry reaction was reduced from two to one term per species by the video presenter and this could have reduced the cognitive load of the theory and enabled students from the treatment group to grapple with the principles instead of the vocabulary.
- In Question 7 in the *acids and bases* test, the 13% greater improvement by the treatment group in calculating the pH correctly could have been due to the manipulated formula for pH that was derived in the video.
- In Question 10 in the *acids and bases* test, the relatively greater improvement of 12% of students from the treatment group correctly selecting a basic salt from a list could have been due to an analogy used in the video, in combination with a number of short explanations about strong acids. The analogy exploited the semantic links between people and acids and bases. However, the analogue was linked to a simplified interpretation of the science. As presented the analogy enabled students to answer the question successfully without them needing to understand the underlying chemical principles. The inclusion of a number of entertaining and predominantly anthropomorphic explanations about strong acids and their

characteristics could have helped students in the treatment group to recall the identity of some strong acids and this could have helped them apply the analogy.

- ***The treatment group made noticeably more errors than the control group in 13% of the questions:*** In four of the 30 questions in the post-tests, the treatment group selected the main distractor to a much greater extent than the control group. These relative increases ranged from 7% to 25%, and the treatment group students' choice of these distractors could have been influenced by the videos.
  - In Question 7 in the *electrochemistry* test, the 7% greater choice of the main distractor (that the purpose of the salt bridge is to allow for electrons to complete the circuit) by the treatment group could have resulted from a combination of oversimplified explanations and inadequate use of scientific vocabulary in the video. Oversimplified explanations that included many inaccuracies were given about the processes that occur at electrode / electrolyte interfaces, and about the function of the salt bridge. The inadequate use of scientific vocabulary within these explanations could have caused confusion that resulted in several treatment group students drawing the wrong conclusions. For example, students could have mixed up electrons with anions because the same generic descriptors were used to describe them, namely *"negatives"* and *"minuses"*.
  - In Question 4 in the *titrations* test, the relative increase of 25% more students from the treatment group than the control group selecting the main distractor (that the end point of an acid-base titration is neutral) could have occurred because of the introduction of the made-up term *"neutral point"* in the video. This term was linked to the term "*end point*" and the two terms were used together whenever the end point of a titration was discussed. The intended meaning of made-up term *"neutral point"* was never made explicit in the video.
  - In Question 2 in the *titrations* test, the relative increase of 13% by the treatment group of a specific distractor (that washing down the sides of the reaction vessel with water would cause inaccurate results) could have resulted from footage of titrations performed in the videos. This valid practical procedure was not demonstrated in the video and its omission could have caused students to conclude that it would lead to inaccurate results.
  - In Question 6 in the *acids and bases* test, the 11% greater selection by the treatment group of an incorrect answer (that large volumes of dilute acids have higher concentrations of hydronium ions) could be due to the verbal text that accompanied practical demonstration in the video. This demonstration showed how the pH changes when strong and weak acids are diluted. Students could have drawn the wrong conclusion either because the explanation about how the pH of weak acids change on dilution was too complicated or because the explanation was delivered at too fast a rate. Alternatively, the commentary that accompanied the footage of the demonstration could have been incorrectly interpreted by the students.
- ***The responses of the students to the videos were very positive and attendance at the video sessions was always over 70%.*** The following facets of the videos were commented on or reacted to positively by students:
  - **Effective use of language:** The language used by the video presenter on the *electrochemistry* video was considered by 83% (or $^{96}/_{116}$) of the students from the treatment group to be "*OK*". One student commented that "*He explains clearly he speaks as if you are next to him*". Students also commented on the standard of his English, for example, one student stated: "*He*

explains very clearly with pure English and straightforward". However, anecdotal evidence indicated that one student had difficulty understanding a relatively simple word, namely the word "folks".

  - **The rate of presentation:** The rate at which the video presenter spoke was considered to be "*OK*" by 95% of the students. One student commented: "*He talk slow and talking the truth and I can understand him*". However, evidence was collected that indicated that the video presenter spoke too fast during some portions of the videos (see comments in next main bullet).
  - **The quality of the explanations:** The explanations used by the video presenter in the *electrochemistry* video were initially considered to be "*very good*" by 16% (or $^{18}/_{118}$) of the treatment group. This percentage increased to 70% (or $^{75}/_{108}$) by the end of this video. The quality of the video presenter's explanations was cited by 36% of the control group once they had viewed the videos as their reason for choosing these videos in preference to other similar products. One student stated: "*He explains everything clearly and understandable. What he teaches is great and not forgettable*". Another student commented specifically on the examples used to explain the theory: "*He explains thoroughly before tackling the question and gives examples of things we did in our daily lives*".
  - **The inclusion of tutorial questions:** The number of tutorial questions tackled in the *electrochemistry* video was considered to be "OK" by 86% (or $^{93}/_{108}$) of the students. This video had 9 tutorial questions and one student commented: "*the more examples, the more we understand*". Another commented: "*He explains everything in full and clearly. He explains all the important examination questions which a student meets in the exam*".
  - **The inclusion of practical demonstrations:** Anecdotal evidence indicated that students enjoyed watching the practical demonstrations and findings suggested that students were able to recall specific aspects of the visual footage. The preparation and functioning of an electrochemical cell was considered by 70% (or $^{76}/_{108}$) of the students to be "*very interesting*".

- ***Some negative comments were made about the videos***:
  - **Students were confused by some explanations:** Some of these had been oversimplified in the videos, and were found to be confusing by some students, and 28% (or $^{30}/_{108}$) of students in the treatment group stated that they were confused about some aspects of electrochemistry. Students sought clarification from outside sources on various oversimplifications for example, the functioning of the salt bridge.
  - **Restlessness occurred on a number of occasions:** firstly, if the duration of the segments was either too short (less than ten minutes) or too long (more than 25 minutes). Students responded most positively to regular segments of about 20 minutes duration. Secondly, if the rate of commentary was too fast or if it was on content that was not considered by the students to be relevant to the syllabus. Thirdly, if the educational significance of the footage was not made explicit. For example, students complained after viewing one instance of such footage that they had come to the videos "*to learn more about chemistry not water*". Finally, if video footage of certain objects or graphics was screened. For example, if a ruler was used to draw a diagram in the video then students also used a ruler and a commotion ensued as students tried to find rulers.

- **The fast rate at which the video presenter spoke, for some portions of the videos:** Students complained that they had difficulty deciphering one complex explanation because it was too fast (the relevant explanation was spoken at a rate of 146 words per minute). One student commented: "*He does not explain example 5 well, he was too fast*". In another instance anecdotal evidence was collected that the majority of the students found another section (spoken at a rate of 168 words per minute) too fast for notes to be taken.

5.3 RECOMMENDATIONS

The recommendations in this research report fall into two categories. First a number of recommendations for the video presenter are discussed. Second, a number of suggestions for future research are proposed.

- ***Recommendations for the video presenter:***
  - Instead of using the same generic descriptor to describe several entities, use the scientific name for each, instead. For example, avoid using the terms "negatives" and "minuses" to describe "anions" and "electrons".
  - Make more judicious selection of some of the explanatory terms to rephrase ideas about chemical processes, and make the meaning of the selected explanatory terms explicit. Avoid using in general situations terms that have specific meanings in science. For example, avoid using the term "neutralise" to describe the processes that occur in the salt bridge and the term "neutral point" to describe the end point in titrations.
  - Where applicable, discuss how the specific meaning of scientific terms differs from the everyday usage of the same term and limit the use of such terms to those instances where the specific scientific meaning applies. For example, confine the use of the term "neutral" to situations where it means pH 7. Alternatively, highlight the intended meanings of term when it is used in a different context.
  - Vary the sketches drawn of the electrochemical cells so that the anode is not always drawn on the left.
  - Give viewers adequate warning about any graphics that will be used because sudden appearance graphics such as pre-drawn diagrams and graphs caused unpredictable responses from the viewers. Alternatively, supply printed copies of these graphic with the videos.
  - Monitor the verbal commentary in the videos so that a more even rate of verbal delivery is attained. This could be possibly be achieved by scripting. Scripting would also help to make the footage that accompanies the practical demonstrations more informative.
  - Include more error recognition strategies in the videos so that students can recognise and troubleshoot their answers to problems.
  - Replace any explanations based on content that is not included in the syllabus with more appropriate explanations.
  - Highlight those instances where the scientific content has been oversimplified, and eliminate any claims these oversimplifications represent a valid version of the science.

- ***Recommendations for future research:***
  - Interviews could be conducted to establish whether students had been persuaded (by the video) that the anode is always on the left in any sketch of an electrochemical cell because it was always represented in this way in the video.
  - Interviews could be used to confirm if the practical demonstration in the *acids and bases* video was in fact the source of the incorrect notion that large volumes of dilute acids contained more hydronium ions.
  - Interviews could be used to determine whether students had used guesswork to answer the question on pH. If this was the case then a study could be conducted to establish the extent to which students use guesswork to answer multiple-choice questions. Alternatively, a study could be conducted to establish if students perceive multiple-choice questions to be non-demanding and so assume that they can be answered using mental arithmetic.
  - An investigation could be conducted to establish the extent to which students can eliminate options or use other test-wiseness strategies when answering multiple-choice questions.
  - Interviews could be conducted to establish the extent to which students found the visual footage memorable and whether specific topics were more memorable than others.
  - The extent to which the diagnostic questions used in the study gave a valid interpretation of the misconceptions held about the topics could be established using interviews.
  - Students could be interviewed to establish whether the commentary that accompanied the practical demonstrations was a potential source of wrong ideas.
  - A study could be conducted to establish whether South African students' understanding of common words, like the word "amount", and how their understanding of this word differs from the special meaning given to this term in chemistry, namely "number of moles".
  - An investigation could be carried out to determine whether a strategy could be devised that would integrate the oversimplifications presented in the *electrochemistry* video into a more realistic interpretation of the theory.
  - The extent to which students at tertiary institutions hold misconceptions similar to those introduced as a result of the oversimplification in the videos could be investigated.
  - The strengths of the videos could be exploited to construct videos that taught the same introductory principles based on the correct scientific principles. The success of these videos could be evaluated.

5.4 CONCLUDING REMARKS

This study endeavoured to articulate the strengths and weaknesses of the selected videos from a number of different standpoints. Educational and technical issues were discussed along with information about how students (who were representative of the target audience) reacted to the videos. The report also provided suggestions for the video presenter and proposed a number of possible avenues for future research.

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APPENDIX A: Topic content

Conceptual and Propositional Knowledge Statements about Electric Circuits and Electrochemical Cells.

Source: Garnett and Treagust (1992a:124-125).

Electric circuits	
1	Charged particles include electrons, negative ions and positive ions.
2	Electrons and negative ions have been designated a negative charge. Positive ions have been designated a positive charge.
3	Like charges repel each other and unlike charges attract each other.
4	An electric current involves the movement of charge. In a metallic conductor the moving charge is electrons and in solution the charges are positive and negative ions.
5	An electric circuit is a closed path through which charges move.
6	Electrons move from regions of low potential to regions of high potential.
7	The electromotive force of a cell[1] (e.m.f. or $E^{\ominus}_{cell}$) gives an indication of the capacity of the cell to do electrical work, and indicates the tendency of a cell reaction to go in a specific direction.
8	The unit for e.m.f. is the volt.
Oxidation-Reduction	
9	*Oxidation can be defined as*
(a)	the gain of oxygen
(b)	the removal of electrons
(c)	an increase in oxidation state
10	*Reduction can be defined as*
(a)	the removal of oxygen
(b)	the gain of electrons
(c)	a decrease in oxidation state
14	*Half-reactions and half-equations*
(a)	Oxidation-reduction reactions can be represented separately as oxidation and reduction half-reactions by the use of half-equations.
(b)	An oxidation half-reaction is represented by a half-equation which shows the removal of electrons and an increase in oxidation number.
(c)	A reduction half-reaction is represented by a half-equation which shows the gain of electrons and a decrease in oxidation number.
(d)	Half-equations include the oxidised or reduced species and electrons.
(e)	Half-equations are balanced according to a set procedure. In aqueous solutions the procedure differs slightly depending on whether an acidic or basic environment is required.
(f)	Half-equations are written to show the half-reactions which occur at the anode and cathode.
15	*Oxidation-reduction (redox) reactions and equations*
(a)	Oxidation-reduction (redox) reactions involve simultaneous oxidation and reduction processes.
(b)	Oxidation-reduction (redox) reactions involve the transfer of electrons from one species to another (or more accurately: from the species that is oxidised to the species that is reduced).
(c)	Oxidation-reduction (redox) equations may be identified by changes in the oxidation numbers of the reacting species.
(d)	Oxidation-reduction (redox) equations may be derived from the addition of oxidation and reduction half-equations. The half-equation are first multiplied by factors so that the number of electrons transferred in each half-equation are the same.
(e)	Oxidation-reduction (redox) equations can be separated into oxidation and reduction half-equations.

[1] According to Shriver *et al.* (2006:144), the International Union of Pure and Applied Chemistry (IUPAC) recommend that the term e.m.f. be avoided as no force is involved, the recommended term is *"zero-current cell potential"*.

Conceptual and propositional knowledge statements about electrochemical cells

Source: Garnett and Treagust (1992b:1081-1083) using the numbering suggested by Garnett and Treagust.

Four additional knowledge statement have been included namely, 5(j), 6(a), 6(b), 6(c).

Electrochemical cells	
1 In an electrochemical cell:	
(a)	there is a spontaneous chemical reaction which converts stored chemical energy into electrical energy,
(b)	the oxidation-reduction reaction which takes place is controlled and the oxidation and reduction half-reaction usually occur in separate compartments called half-cells,
(c)	a cell e.m.f. is spontaneously produced and an electric current results,
(d)	the relative tendencies of the reactants to be oxidised or reduced determines the resulting oxidation-reduction reaction,
(e)	the e.m.f. generated depends on the nature of the half-cell reactions and the concentration of the electrolyte,
(f)	the cell e.m.f. generated indicates the capacity of the cell to do electrical work,
(g)	the e.m.f. of the cell is measured in volts.
2 Half-cells	
(a)	are compartments in which separate oxidation and reduction half-reactions occur,
(b)	consist of an electrode immersed in an electrolyte,
(c)	are linked by a salt bridge which allows the transfer of ions in the internal circuit,
(d)	enable the transfer of electrons from one reactant to another to take place through an external circuit or metallic conductor which links the electrodes,
3 Electrodes	
(a)	Electrodes are electrical conductors that are placed in an electrolyte to provide a surface for oxidation or reduction reactions. (They may be reactive, undergo reduction or oxidation, or they may be inert.)
(b)	The nature of the electrodes and the electrolyte determine the oxidation or reduction reactions which occur.
(c)	Inert electrodes, such as graphite and platinum, are made from substances which conduct electricity and are not chemically altered in cell reactions. When reactive electrodes undergo reduction or oxidation they increase or decrease in size respectively (Birss and Truax, 1990) When diatomic gases form at an inert electrode, it is a two-stage process: first the ions lose electrons and form an atom and then two atoms combine to form the diatomic gas (Ogude, 1992).
(d)	The labelling of the electrodes as the anode or cathode depends on the site of the oxidation and reduction half-reactions. The electrode at which oxidation occurs is called the anode while the electrode at which reduction occurs is called the cathode.
(e)	The anode is labelled (–) while the cathode is labelled (+).
4 Transfer of charge	
(a)	If the anode is oxidised (called a reactive anode), electrons move directly from the anode to the cathode through the external circuit and positive ions are released into solution around the anode as it dissolves. At the cathode the substance being reduced accepts electrons.
(b)	If the anode is inert, electrons are transferred directly from the oxidised substance onto the anode and then through the external circuit to the cathode. At the cathode the substance being reduced accepts electrons.
(c)	An electrolyte conducts electricity in a cell by the movement of dissolved positively and negatively charged ions. The movement of ions completes the circuit and maintains electrical neutrality.
(d)	Negative ions are called anions and positive ions are called cations.
(e)	Anions move through the electrolyte to the anode and cations move through to the cathode.
(f)	A salt bridge contains ions in solution and provides a continuous path for the movement of ions between separate half-cells.

Electrochemical cells continued	
5 Reduction potentials, standard reductions potentials, and the standard reduction potential table	
(a)	Reduction potentials indicate the relative tendency of substances to be reduced by listing half-equations in order of decreasing tendency to be reduced (decreasing strength as oxidising agents).
(b)	Standard reduction potentials are determined in relation to the $2H^+(aq) + 2e^- \rightarrow H_2(g)$ half-cell reaction which is **assigned** an $E^\ominus$ of 0,00 V. Substances more readily reduced than hydrogen ions are listed above hydrogen and have positive $E^\ominus$ values while those which are more difficult to reduce are listed below and have negative values. Metals that do not react with acids are listed at the top of the table while metals that react with acids have negative values of $E^\ominus$ and are listed under hydrogen in the table (Moran and Gileadi, 1989).
(c)	Standard reduction potentials assume conditions of 1 mol dm^{-3} concentration, 101,3 kPa pressure and usually 25°C temperature.
(d)	Standard reduction potentials can be read as standard oxidation potentials if the sign of the $E^\ominus$ is changed and the equation is read in the reverse direction (from right to left).
(e)	Standard reduction tables list oxidising agents in decreasing strength from the top to the bottom left hand side of the table and reducing agents in decreasing strength from the bottom to the top right hand side of the table.
(f)	Standard reduction potential tables can be used to predict whether or not oxidation-reduction reactions are likely to occur, either in a cell or by direct mixing of reagents.
(g)	Standard reduction potential tables can be used to predict the oxidation and reduction half-reactions that may occur at the anode and cathode, and the half-equations for the half-reactions can be combined to determine the cell reaction and equation.
(h)	Standard reduction potential tables can be used to predict the site of the anode and cathode in an electrochemical cell.
(i)	Standard reduction potential tables can be used to predict the e.m.f. of an electrochemical cell. Predictions should be interpreted with caution since they provide no information about the rate of the reaction, and the concentration of the reacting species and other factors which affect reduction potentials. When the reaction proceeds spontaneously the reaction must be written so that the $E^\ominus_{cell}$ is positive. It is the universally accepted contention that all spontaneous reactions are associated with a decrease in free energy (Moran and Gileadi, 1989).
(*j*)	*"In 1953 the International Union of Pure and Applied Chemistry (IUPAC) decided that all* (standard reduction potential) *tables should be compiled with the sign of the potential corresponding to the reduction reaction"* (Moran and Gileadi, 1989:913).
6 Equilibrium in electrochemical cells	
(*a*)	The first equilibrium is established when the circuit is connected but "*no current is permitted to flow, no electrochemical reactions can occur"* (Birss and Truax, 1990:404). In the case of reactive metal electrodes: equilibrium is established on the metal / electrolyte interface and either a trace amount of metal atoms deposit on the electrode or a trace amount of metal atoms dissolve in the electrolyte. A potential develops that prevents further charge transfer but it cannot be measured, and is not related to potential recorded in the Standard Reduction Potential Table (Birss and Truax, 1990)
(*b*)	The second equilibrium is established when the half-cells have been *"allowed to react with each other ... (and) the cell voltage as read on the voltmeter is zero"* (Birss and Truax, 1990:404). A second equilibrium is established at the metal / electrode interface.
(*c*)	The cell is not in equilibrium when it operates, *"net electrochemical reactions occur at each electrode, the concentrations in each compartment change, and the cell voltage will decrease with time"* (Birss and Truax, 1990:404).

Students' misconceptions about electrochemical (galvanic) cells

These misconceptions were initially reported by Garnett and Treagust, (1992b:1087), and the version listed here has been paraphrased by Sanger and Greenbowe (1999:854).

	Common student misconceptions about electrochemical cells
1	In an ordered table of reduction potentials the species with the most positive $E^{\ominus}$ value is the anode.
2	Standard reduction potentials list metals by decreasing reactivity.
3	The identity of the anode and the cathode depends on the physical placement of the half-cells.
4	Anodes, like anions, are always negatively charged: cathodes, like cations, are always positively charged.
5	The fact that the $E^{\ominus}$ for the H_2 (1atm)/H^+ (1*M*) is zero is somehow based on the chemistry of H^+ and H_2.
6	There is no need for a standard half-cell.
7	Half-cell potentials are absolute in nature and can be used to predict the spontaneity of the half-cells.
8	Electrons enter the solution from the cathode, travel through the solutions and the salt bridge, and emerge at the anode to complete the circuit.
9	Anions in the salt bridge and the electrolyte transfer electrons from the cathode to the anode.
10	Cations in the salt bridge and the electrolyte accept electrons and transfer them from the cathode to the anode.
11	Cations and anions move until their concentrations are uniform. .
12	Electrons can flow through aqueous solutions without assistance from the ions.
13	Only negatively charged ions constitute a flow of current in the electrolyte and the salt bridge.
14	The anode is negatively charged and releases electrons; the cathode is positively charged and attracts electrons.
15	The anode is positively charged because it has lost electrons; the cathode is negatively charged because it has gained electrons.
16	Cell potentials are derived by adding individual reduction potentials.
17	Half-cell potentials are not intensive properties.

Knowledge statements about acids, bases, and pH

Source: Silberberg (2000) unless indicated otherwise.

Aqueous solutions
Concentration also known as amount-of-substance concentration or molar concentration and given the symbol *c*. It is defined to be the amount of substance divided by the volume of solution (International Union of Pure and Applied Chemistry, 1997).
Concentration is an intensive quantity so is independent of volume.
Molarity is the number of moles (amount) of solute per litre (or dm^{-3}) of solution.
Amount = number of moles (The term amount is derived from the definition for a mole, namely: a mole is the amount of atoms of carbon in exactly 12,000g of carbon–12, International Union of Pure and Applied Chemistry, 1997).
Macroscopic properties – acids and bases
Acids taste sour. Acids are corrosive. Acids have a pH < 7.
Bases sometimes taste bitter. Bases feel slippery. Bases have a pH >7.
Acids and bases affect the colour of indicator dyes differently.
Microscopic properties - Arrhenius
Acids donate hydrogen ions (H^+).
Bases donate OH^- ions.
Limitations of Arrhenius
Many bases that generate aqueous OH^- ions do not have OH^- in their formulas.
The solvent has to be water.
Microscopic properties – Brønsted-Lowry
A Brønsted-Lowry acid is any species that donates a proton (which is a more accurate term for a hydrogen ion, represented as H^+). Protons cannot exist as free ions (H^+) because they are very small and have a very high charge density. In aqueous solution they bind to water molecules via dative covalent bonding to form hydronium ions (H_3O^+).
A Brønsted-Lowry base is any species that accepts a proton. To bind a proton a base must have a lone pair of electrons (so metal cations cannot be Brønsted-Lowry bases).
Advantages of Brønsted-Lowry Definition
Accounts for the basic properties of bases that do not have hydroxide ions in their formulas.
Expands the number of bases to include water, ammonia, amines and the conjugate base of any weak acids.
Applies to any solvent including reactions that have no solvent i.e. solid phase acid-base reactions.
Conjugate acid-base pairs
An acid and a base must work together to enable proton transfer to take place. One species will only behave as an acid if another species will simultaneously behave as a base.
Once an acid has donated a proton, what remains is known as its conjugate base. A conjugate base has one less H and one more negative charge than its acid.
Once a base has accepted a proton, it is known as its conjugate acid. A conjugate acid has one more H and one less negative charge than its base.
The term conjugate acid-base pair can be applied to an acid and its conjugate base or to a base and its conjugate acid.
The net direction of an acid-base reaction depends on the relative strengths of the acid and base involved. The reaction proceeds predominantly in the direction in which the stronger acid and stronger base form the weaker acid and the weaker base.
Brønsted-Lowry reactions are equilibrium reactions so reagents and products exist simultaneously. Equilibrium is established very quickly.

Amphiprotic substances
"Amphi" means "on both sides" and "protic" refers to protons so an amphiprotic substance can fit both Bronsted-Lowry definitions, by either donating or accepting protons.
Examples of amphiprotic substances include H_2O, HSO_4^-, HCO_3^-.
Amphiprotic substances are sometimes called amphoteric substances but this term is more commonly applied to substances that will react with either an acid or a base. An ampholyte is a species that exhibits amphiprotic behaviour, derived from the terms *"amphoteric electrolytes"* (Vogel, 1969:10). (Ampholyte = noun, Amphiprotic = adjective/adverb.)
Autoprotolysis of water
Autoprotolysis (also called autoionisation or autodissociation) of water is the name given to the dissociation of water into H^+ and OH^-.
The reaction is temperature dependent and at 25°C $[H^+] = [OH^-] = 1{,}0 \times 10^{-7}$ mol dm^{-3}.
The dissociation constant of pure water at 25°C is $K_W = 1{,}0 \times 10^{-14} = [H^+][OH^-]$
The value of K_W is maintained, so if $[H^+]$ changes, then $[OH^-]$ undergoes an inverse change.
In acidic solution $[H^+] > [OH^-]$ In basic solution $[H^+] < [OH^-]$ In neutral solution $[H^+] = [OH^-]$
The pH and pOH scales
pH uses a negative logarithmic scale to convert the very dilute concentrations of H^+ into manageable numbers.
$pH = -\log[H^+]$ and $pOH = -\log[OH^-]$
$[H^+]$ is calculated from pH, and $[OH^-]$ is calculated from pH by manipulating the equation pH + pOH = 14. A low pH indicates a high pOH, and vice versa. If a solution has a pH of 1 then $[H^+] = 0{,}1$ mol dm^{-3}, and it is 10 times more concentrated than a solution with a pH of 2, $[H^+] = 0{,}01$ mol dm^{-3} and so on.
The pH and pOH of pure water at 25°C is 7.
Strong acids and bases (solvent = water)
Strong acids or bases dissociate completely into ions when they dissolve in water.
In the case of strong acids they are fully deprotonated. Or more rigorously: strong acids or bases dissociate to give a stoichiometric amount of ions in aqueous solution. So, a 1 molar solution of a strong monoprotic acid will give 1 mole of hydronium ions, a 1 molar solution of a strong diprotic acid will give 2 moles of hydronium ions. Examples of strong acids: Hydroiodic, HI; perchloric, $HClO_4$; hydrobromic, HBr; hydrochloric, HCl; sulphuric, H_2SO_4, nitric, HNO_3.
Strong bases dissolve completely. Examples of strong bases: hydroxides and oxides of Group 1 and 2 metals only. Group 1 oxides and hydroxides dissolve completely, Group 2 oxides and hydroxides are not very soluble but the portion that dissolves will dissociate completely.
Symbolic representation of the dissociation of some strong acids and bases. $HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$ $H_2SO_4(aq) + 2H_2O(l) \rightarrow 2H_2O^+(aq) + SO_4^{2-}(aq)$ $O^{2-}(aq) + H_2O(l) \rightarrow 2OH^-(aq)$ N.B. It is not useful to represent these reactions using equilibrium equations as there is virtually no undissociated acid or base.
The acid dissociation constants (K_a) for strong acids are large, ranging from 1 to 10^{11}

Weak acids and bases (solvent = water)
Weak acids and bases dissociate to such a small extent that most of their molecules remain intact in aqueous solution.
Examples of weak acids: Hydrofluoric HF, hydrocyanic HCN, nitrous. HNO_2, phosphoric H_3PO_4, chlorous, $HClO_3$ and organic acids (more correctly termed carboxylic acids) RCOOH
Examples of weak bases Ammonia, NH_3; Amines with the general formula RNH_2, R_2NH; R_3N. Symbolic representation of the dissociation of some weak acids and bases.
$H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + H_2PO_4^-(aq)$ $RCOOH(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + RCOO^-(aq)$ $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ The symbol $\rightleftharpoons$ is used to indicate that these are equilibrium reactions so both reagents and products are present in solution.
The acid dissociation constants of weak acids (K_a) and of weak bases (K_b) are small ranging from 10^{-1} to 10^{-12}. Although the term "dissociate" is applied to Brønsted-Lowry bases, no bases dissociate, they gain protons instead.
Since every base has a conjugate acid, the dissociation constant of a base can also be expressed in terms of the dissociation constant of its conjugate acid.
Dissociation constants of strong and weak acids and bases
The dissociation constants of any Bronsted-Lowry acid and its conjugate base in aqueous solution are related to each other in the following way: $K_a \times K_b = K_w$ Since acidity constants cover a very wide range they are often reported as their common logarithms using the formula: pK = –log K, so for any acid at 25°C $pK_a + pK_b = pK_w$. The stronger the acid, the weaker its conjugate base. Strong acids ($pK_a < 0$) have very weak conjugate bases ($pK_b > 14$). Weak acids ($pK_a > 0$) will have weak conjugate bases ($pK_b < 14$). For example, the pK_a of acetic acid is 4,77 and the pK_b is 9,23.
Acid and base dissociation constants are intrinsic properties and are independent of dilution effects. The theoretical pH values for HCl, a strong, monoprotic acid, compared to acetic acid with the same concentration are higher because the weak acid does not dissociate completely but the fraction that dissociates increases as the acid is diluted (Masterton and Slowinski, 1977). This can be explained using Le Châtelier's principle and can be confirmed using theoretical calculations. As dilution increases, differences between the pHs become negligible so both HCl and acetic acid will have a pH of 6 at concentrations of 1,0 x 10^{-6} *M* . At infinite dilution will have pHs of 7,0 as long as the temperature is maintained at 25°C.
It is not possible to turn an acid into a base by dilution and vice versa.
The pH of any acid or base at infinite dilution will be 7,0 at 25°C. According to Brock (1992:383) it was *"Arrhenius' finding that at infinite dilution the molar conductivities of all acids were the same"* that was the foundation for pH.
Polyprotic acids
"Poly" means "many" and "protic" is derived from protons so polyprotic acids donate more than one proton. If an acid only has only one ionisiable hydrogen, then it is a monoprotic acid ("mono" means "one"). If an acid has two ionisable hydrogens, then it is a diprotic acid ("di" means "two").
Polyprotic acids lose protons in succession and each deprotonation step is progressively less favourable. Consider phosphoric acid: First deprotonation step: $H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + H_2PO_4^-(aq)$ Second deprotonation step: $H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HPO_4^{2-}(aq)$ Third deprotonation step: $HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + PO_4^{3-}(aq)$

Neutral, basic and acidic ions

Ions are classified as being neutral, basic or acidic ions depending on how they react with water.

Acidic anions are formed from weak bases like ammonium because the anion reacts with water to reform the base and H^+ ions.

Ions that do not react with water to form H^+ or OH^- ions are neutral.

Neutral anions are derived from strong acids. It is thermodynamically unfavourable for these ions to accept protons.

Neutral cations are derived from strong bases. These bases contain Group 1 or 2 metals – they do not interact with water as they have no lone pair of electrons.

Basic anions are formed from weak acids and they react with water to reform the acid and OH^- ions.

Basic cations – there are no basic cations, see neutral cations above.

Acidic cations – these exist but are Lewis acids.

Acid-base reactions

In a titration, H^+ from the acid reacts with OH^- from the base to form $H_2O(l)$ (strong acids and bases).

Both Arrhenius and Brønsted-Lowry bases (which do not have OH^- in their structures) can be used in titrations.

The identity of the acids and bases used in a titration can be determined from the salt formed.

The anion (negative ion) is derived from the acid and the cation (positive ion) is derived from the base.

The salt formed can have a range of pHs depending on whether the cation or anion react with water.

The salt formed when a strong acid reacts with a strong base will be neutral because neither ion reacts with water.

The salt formed when a weak base such as ammonium hydroxide reacts with a strong acid will be acidic because the cation of the weak base (ammonium) reacts with water to re-form hydronium ions as shown below:

$$NH_4^+(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NH_3(aq)$$

The salt formed when a weak acid reacts with a strong base will be basic because the anion of the weak acid reacts with water to re-form hydroxide ions as shown below:

$$CH_3COO^-(aq) + H_2O(l) \rightleftharpoons CH_3COOH(aq) + OH^-(aq)$$

It is not possible to determine whether the salt formed when a weak acid reacts with a weak base will be acidic, basic or neutral without performing a calculation using the dissociation constants of each.

Acid-base titrations (aqueous solutions only)

A titration is a quantitative chemical technique that uses a carefully monitored process (titration) and a solution of known concentration (standard solution) to establish the concentration of an unknown solution.

A standard solution is a reagent of known concentration commonly prepared by accurately weighing a mass of reagent and diluting to a fixed volume in a volumetric flask.

The accuracy with which the concentration of a standard solution is known limits the accuracy of the titration.

Common practical procedures used during titrations:

One solution, known as the titrant, is added in a metered way via a burette.

The burette is rinsed with the titrant before filling.

An accurately known volume of the other reagent is pipetted into a flask.

The pipette is rinsed with reagent before pipetting into the flask.

The flask may be rinsed with deionised water before the reagent is added to the flask.

A few drops of indicator are added to the flask before titrating.

The walls of the flask are washed down with water just before the end point is reached to ensure that reagents that may have adhered to the walls of the flask are included when determining the end point.

Dilute solutions of acids are prepared from concentrated acids by adding small portions of acid slowly to a large volume of water until all the acid is added. The mixture should be cooled down after each addition of acid.

An indicator is a weak organic acid and has a different colour from its conjugate base. Either one or both forms are intensely coloured so only a small amount needs to be added.

The colour change occurs over a small pH range, typically a 2 unit pH range.

Acid-base titrations (aqueous solutions only) continued
The end-point is the term used to describe the stage in the titration at which the indicator changes colour so the titration would be concluded. The equivalence point is where the number of moles of species added from the burette is stoichiometrically equivalent to the original number of moles of the other species. The end point and the equivalence point are not identical due to limitations imposed by the indicator. For practical purposes the difference between the two is assumed to be insignificant so the end-point ≡ the equivalence-point.
Weak acids, like strong acids, react fully when titrated. Weak bases, like strong bases, react fully when titrated.
Information obtained from a titration: The accurate concentration (mol dm^{-3}) of one reagent: either $Molarity_{base}$ or $Molarity_{acid}$. The accurate volume of the pipetted reagent: $Volume_{base}$ or $Volume_{acid}$. The accurate volume of the titrant: $Volume_{acid}$ or $Volume_{base}$. Information obtained from the chemical equation associated with the reaction: stoichiometric between the acid and base.
Calculations performed on information obtained uses the following relationship: $Volume_{base}$ x $Molarity_{base}$ = $Volume_{acid}$ x $Molarity_{acid}$ taking stoichiometry into account.
When titrating an acid with a base the following microscopic changes occur: The $[H^+]$ decreases. The pH decreases (and pOH increases). $H^+(aq)$ reacts with $OH^-(aq)$ to form $H_2O(l)$. When titrating a base with an acid: The $[OH^-]$ decreases. The pH increases (and pOH decreases).
When titrating a strong acid with a strong base: The starting pH is low. When titrating a strong base with a strong acid: The starting pH is high. The pH at the end point is about 7,00.
When titrating a weak acid with a strong base: The starting pH is higher than a strong acid and dictated by its K_a value. The pH at the end point is greater than 7,00 because the weak conjugate base dissociates in water to form OH^- ions.
When titrating a weak base with a strong acid: The starting pH is lower than a strong base and dictated by its K_b value. The pH at the end point is less than 7,00 because the weak conjugate acid dissociates in water to form to form H_3O^+ ions.

APPENDIX B: Tests, Test results

ELECTROCHEMISTRY – PRE- AND POST-TEST STUDENT NUMBER: _________

INSTRUCTIONS: Study each question and the answers given by the letters A, B, C, D, and E. When you have decided which answer is correct, circle the appropriate letter on the question paper.

EXAMPLE				
Pure ice melts at				
A. – 4ºC	(B.) 0ºC	C. 0K	D. 373K	E. 4ºC

1. A redox reaction is a reaction in which:

A. only oxidation takes place
B. only reduction takes place
C. electron sharing takes place
D. *reduction and oxidation take place
E. none of the above

2. In which ONE of the following reactions is the underlined chemical species being reduced:

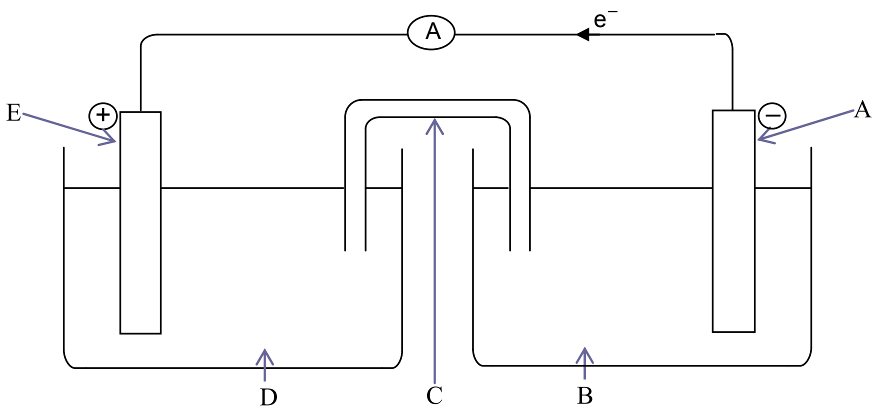
A. *$Mg + \underline{Cu}^{2+} \rightarrow Mg^{2+} + Cu$
B. $Cl_2 + 2K\underline{Br} \rightarrow 2KCl + Br_2$
C. $\underline{Pb}(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$
D. $MnO_2 + 4H\underline{Cl} \rightarrow MnCl_2 + H_2O + Cl_2$
E. $FeCl_3 + \underline{H}_2SO_4 \rightarrow 2FeCl_2 + 2HCl + S$

3. In the following reaction electrons are being transferred from

$2Al + 6H^+ \rightarrow 2Al^{3+} + 3H_2$

A. H to H^+ B. *Al to H^+ C. Al to Al^{3+} D. H^+ to Al E. H to Al

Questions 4 and 5 refer to the electrochemical cell which is illustrated below:



4. The cathode is:

A. B. C. D. *E.

5. When the electrochemical cell operates the reaction which takes place at the electrode A is:

A. *oxidation
B. crystallisation
C. neutralisation
D. oxidation and reduction
E. reduction

6. When an electrochemical cell operates, conduction though the electrolyte is due to

A. electrons moving through the solution attached to the ions
B. electrons moving from ion to ion in the electrolyte
C. *the movement of positive and negative ions
D. the movement of water molecules
E. electrons moving across though the solution from one electrode to the other

7. The purpose of a salt bridge in an electrochemical cell is to

A. provide a pathway so that the oxidising agent can reach the reducing agent
B. *provide a pathway for charge carriers in solution
C. increase the resistance to the flow of current so that the cell maintains its potential
D. provide a pathway for electrons to complete the circuit
E. provide a connection between the two half cells so that cations can reach the negative electrode

8. When chlorine gas forms at a graphite (carbon) electrode. Four possible events are given below. Which of these reactions is / are likely to occur?

1 $Cl^- \rightarrow Cl + e^-$ 2 $Cl^- + e^- \rightarrow Cl$
3 $2Cl^- \rightarrow Cl_2$ 4 $2Cl \rightarrow Cl_2$

A. 3 only   B. 4 only   C. *1 & 4 only   D. 2 & 4 only   E. 1 only

9. Which of the following reactions is a reduction half-reaction?

A. $Zn \rightarrow Zn^{2+} + 2e^-$
B. $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$
C. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$
D. $Cu + 2e^- \rightarrow Cu^{2+}$
E. *$Cu^{2+} + 2e^- \rightarrow Cu$

10. What is the cell potential for the following standard cell

$Sn / Sn^{2+} // Fe^{3+} / Fe$

		E^O
given:	$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+ 0,77 V
	$Fe^{3+} + 3e^- \rightleftharpoons Fe$	– 0,04 V
	$Sn^{2+} + 2e^- \rightleftharpoons Sn$	– 0,14 V
	$Fe^{2+} + 2e^- \rightleftharpoons Fe$	– 0,44 V

A. – 0,14V   B. – 0,18V   C. *+ 0,10V   D. + 0,34V   E. – 0,10V

ACIDS AND BASES – PRE- AND POST-TEST STUDENT NUMBER: ____________

INSTRUCTIONS: Study each question and the answers given by the letters A, B, C, D, and E. When you have decided which answer is correct, circle the appropriate letter on the question paper.

EXAMPLE				
Pure ice melts at				
A. – 4ºC	(B.) 0ºC	C. 0K	D. 373K	E. 4ºC

1. According to Brønsted-Lowry definition, an acid is

A. an electron pair acceptor
B. an electron pair donor
C. an hydroxide ion donor
D. *a proton donor
E. a proton acceptor

2. A substance is AMPHIPROTIC if

A. it is dissolved by an acid
B. it can be neutralised by an acid
C. it turns litmus paper red and blue
D. *it can act as both an acid and a base
E. it is insoluble in a base but soluble in an acid

3. A conjugate acid-base pair in this reaction is

$$CH_3COOH + NH_3 \rightleftharpoons CH_3COO^- + NH_4^+$$

A. NH_3 and CH3COO$^-$
B. *CH_3COOH and CH_3COO^-
C. NH_3 and CH_3COOH
D. NH_4^+ and CH_3COOH
E. NH_4^+ and CH_3COO^-

4. In which one of the following reactions does $H_2PO_4^-$ act as a base

A. $H_2PO_4^- + 2OH^- \rightarrow 2H_2O + PO_4^{3-}$
B. $H_2PO_4^- + HCO_3^- \rightarrow H_2CO_3 + HPO_4^{2-}$
C. $H_2PO_4^- + H_2O \rightarrow H_3O^+ + HPO_4^{2-}$
D. *$H_2PO_4^- + H_3O^+ \rightarrow H_2O + H_3PO_4$
E. $H_2PO_4^- + CO_3^{2-} \rightarrow HCO_3^- + HPO_4^{2-}$

5. Which ONE of the following statements is NOT TRUE of the following acid-base equilibrium?

$$HB(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + B^-(aq)$$

A. If HB is a strong acid the formation of the products is favoured.
B. Ka for HB will be larger if it is a strong acid than if it is a weak acid.
C. If HB is a strong acid the pH will be less than 7.
D. *The more dilute the acid, the smaller the Ka value will be.
E. If B^- is a strong base the formation of HB is favoured.

6. Which one of the following solutions has the highest concentration of hydronium ions (assume total ionisation)?

A. 1,0 dm^3 of 6 mol dm^{-3} HCl
B. *0,4 dm^3 of 10 mol dm^{-3} H_2SO_4
C. 0,5 dm^3 of 10 mol dm^{-3} HNO_3
D. 2,0 dm^3 of 2 mol dm^{-3} HCl
E. 0,5 dm^3 of 5 mol dm^{-3} H_2SO_4

7. What is the pH of a solution which has a hydroxide concentration of 0,001 (1×10^{-3}) mol dm^{-3}?

A. 3 B. 1 C. *11 D. 7 E. 13

8. What is the hydronium ion concentration of a solution with a pH of 5?

A. 1×10^5 mol dm^{-3}
B. 5 mol dm^{-3}
C. – 5 mol dm^{-3}
D. *1×10^{-5} mol dm^{-3}
E. 1×10^{-7} mol dm^{-3}

9. If the pH of an aqueous solution changes from 5,2 to 8,6; what has happened to the hydronium ion concentration?

A. It increased.
B. It became zero.
C. *It decreased.
D. It became less than zero.
E. It did not change.

10. Which one of the following salts is basic in aqueous solution?

A. NH_4Cl B. KI C. $CaBr_2$ D. *Na_2CO_3 E. K_2SO_4

TITRATIONS – PRE- AND POST-TEST STUDENT NUMBER: ____________

INSTRUCTIONS: Study each question and the answers given by the letters A, B, C, D, and E. When you have decided which answer is correct, circle the appropriate letter on the question paper.

1. The proper method for diluting concentrated sulphuric acid is to:

A. *add the acid to the water very slowly while stirring
B. add the water to the acid very slowly while stirring
C. pour the acid and water simultaneously into the container
D. add water drop by drop into the acid while stirring
E. add a large volume of water to the acid while stirring

2. A student standardises an approximately 0,1 mol dm^{-3} sodium hydroxide solution against a standard solution of oxalic acid. Which one of the following procedures will lead to INACCURATE results?

A. The student rinses the burette with the oxalic acid solution before filling it to the zero mark with acid.
B. The student rinses the pipette with the sodium hydroxide solution before using it to pipette sodium hydroxide solution into the flask.
C. *The student rinses the conical flask with the sodium hydroxide solution before pipetting in the sodium hydroxide.
D. The student uses water from the wash bottle to wash drops of chemicals on the sides of the conical flask during the titration.
E. The student adds three drops of indicator to the pipetted sodium hydroxide solution in the conical flask before beginning the titration.

3. Which of the following WILL NOT take place when a dilute solution of sodium hydroxide is added to a dilute solution of hydrochloric acid?

A. The hydronium ion concentration drops.
B. Water molecules are formed.
C. The pH of the solution increases.
D. Hydroxide ions combine with hydronium ions.
E. *The reaction $Na^{+}(aq) + Cl^{-}(aq) \rightarrow NaCl(s)$ takes place.

4. At the end point in an acid-base titration it is CORRECT to say that

A. the solution is neutral
B. the hydronium ion concentration is zero
C. the concentrations of the acid and base are equal
D. the amount of base added depends on its Kb
E. *the volume of the base added depends on its concentration

5. If 0,10 mol dm^{-3} potassium hydroxide is titrated with 0,10 mol dm^{-3} hydrochloric acid, which of the following statements about the solution at the end point is CORRECT?

A. The concentrations of potassium hydroxide and hydrochloric acid molecules will be equal.
B. The concentration of potassium hydroxide ions will be 0,10 mol dm^{-3}.
C. The hydronium ion concentration will be 0,10 mol dm^{-3}.
D. *The solution is equivalent to 0,05 mol dm^{-3} potassium chloride.
E. There will be no potassium hydroxide molecules remaining.

6. When titrating acetic acid with sodium hydroxide solution an indicator is used. The indicator is used to show when

A. all the hydronium ions have reacted with the base
B. *the amount of base added is equal to the original amount of acid
C. the concentration of the added base equals the original concentration of the acid
D. the pH of the solution reached 7
E. equilibrium has been reached

7. Which one of the following statements about indicators in acid-base titrations is CORRECT? An indicator

A. must be neither an acid nor a base
B. *must be intensely coloured in either its acid or base form so that it can be observed in low concentrations
C. is a spectator in the titration and takes no part in the reaction
D. changes colour when the solution is neutral
E. is chosen such that its Ka value is exactly equal to the pH at the end point

8. You have equal volumes of the following solutions:

Acid	Concentration in mol dm^{-3}	pH
Hydrochloric HCl	0,1	1,1
Acetic CH_3COOH (monoprotic)	0,1	2,9
Formic HCOOH (monoprotic)	0,1	2,3
Hydrocyanic HCN	0,1	5,1

The solutions are titrated using a standard base. Which solution will require the most base at the end point?

A. Hydrochloric
B. Acetic
C. Formic
D. Hydrocyanic
E. *All require the same volume of base.

9. 25 cm^3 of 1 mol dm^{-3} hydrochloric acid is neutralised by 20 cm^3 of a sodium hydroxide solution. What is the concentration of the sodium hydroxide solution?

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

A. 50,00 mol dm^{-3} B. 1,0 mol dm^{-3} C. 0,80 mol dm^{-3}
D. *1,25 mol dm^{-3} E. 5,00 mol dm^{-3}

10. What volume of 0,5 mol dm^{-3} sulphuric acid is required to neutralise 10 cm^3 of a 1 mol dm^{-3} solution of sodium hydroxide?

$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

A. *10 cm^3 B. 15 cm^3 C. 5 cm^3
D. 20 cm^3 E. 2 cm^3

Table B1: The percentages obtained for the correct answer along with the relative improvement obtained by the treatment group relative to the control group.

Results are listed in order of decreasing relative improvement. Those questions with a relative improvement of 9% or more were considered to be representative of the strengths of the videos and are shade grey in the table. Those questions where the treatment group showed no change or a decrease in the percentage choosing the correct answer are highlighted in yellow.

Test and Question number	Correct answer						
	Control group			Treatment group			Relative improvement
	Pre-test	Post-test	Change	Pre-test	Post-test	Change	
EQ10	26.1	33.3	7.2	28.1	57.9	29.8	22.6
EQ9	43.5	52.2	8.7	21.1	49.1	28.0	19.3
AQ10	37.7	34.8	-2.9	21.1	31.6	10.5	13.4
AQ7	8.7	11.6	2.9	7.0	22.8	15.8	12.9
AQ4	34.8	47.8	13.0	33.3	57.9	24.6	11.6
EQ5	29.0	39.1	10.1	24.6	43.9	19.3	9.2
TQ8	13.0	11.6	-1.4	7.0	14.0	7.0	8.4
TQ6	10.1	10.1	0.0	1.8	8.8	7.0	7.0
TQ7	15.9	15.9	0.0	10.5	17.5	7.0	7.0
EQ1	88.4	87.0	-1.4	86.0	91.2	5.2	6.6
TQ1	40.6	49.3	8.7	33.3	47.4	14.1	5.4
AQ5	20.3	34.8	14.5	21.1	40.4	19.3	4.8
AQ2	73.9	91.3	17.4	77.2	96.5	19.3	1.9
EQ6	24.6	14.5	-10.1	19.3	10.5	-8.8	1.3
AQ1	66.7	87.0	20.3	73.7	94.7	21.0	0.7
TQ2	15.9	10.1	-5.8	14.0	8.8	-5.2	0.6
EQ7	8.7	8.7	0.0	12.3	12.3	0.0	0.0
EQ4	59.4	60.9	1.5	54.4	54.4	0.0	-1.5
AQ3	26.1	50.7	24.6	21.1	43.9	22.8	-1.8
TQ3	14.5	18.8	4.3	17.5	19.3	1.8	-2.5
EQ8	17.4	13.0	-4.4	17.5	10.5	-7.0	-2.6
TQ5	14.5	20.3	5.8	21.0	22.8	1.8	-4.0
AQ9	26.1	36.2	10.1	29.8	35.1	5.3	-4.8
TQ10	15.9	18.8	2.9	15.8	12.3	-3.5	-6.4
TQ4	14.5	14.5	0.0	12.3	5.3	-7.0	-7.0
EQ2	50.7	66.7	16.0	59.7	68.4	8.7	-7.3
TQ9	31.9	47.8	15.9	38.6	45.6	7.0	-8.9
EQ3	11.6	31.9	20.3	19.3	29.8	10.5	-9.8
AQ6	17.4	17.4	0.0	15.8	5.3	-10.5	-10.5
AQ8	26.1	43.5	17.4	45.6	40.4	-5.2	-22.6

Where E = Electrochemistry test, A = Acids and bases test, T = Titrations test, and Q = Question number

Table B2: Graph showing those questions where there was either no change or a decrease in the percentages obtained for the correct answer (shaded in yellow), and the change in the main distractor by the treatment group relative to the control group.

Results are listed in order of decreasing relative change of the main distractor. Those questions where the treatment group either showed no change or a decrease in the correct answer coupled with a relative improvement of more than 7% or more in the main distractor were considered to be representative of the weaknesses of the videos and are shade grey in the table.

Test and Question number	Percent change in correct answer by Treatment group	Main distractor						
		Control group			Treatment group			Relative change
		Pre-test	Post-test	Change	Pre-test	Post-test	Change	
TQ4	-7.0	39.1	27.5	-11.6	31.6	45.6	14.0	25.6
TQ2	-5.2	30.4	33.3	2.9	33.3	49.1	15.8	12.9
AQ6	-10.5	24.6	24.6	0.0	33.3	43.9	10.6	10.6
EQ7	0.0	27.5	37.7	10.2	31.6	49.1	17.5	7.3
AQ8	-5.2	18.8	18.8	0.0	17.5	22.8	5.3	5.3
EQ8	-7.0	33.3	33.3	0.0	40.4	43.9	3.5	3.5
EQ4	0.0	31.9	33.3	1.4	36.8	38.6	1.8	0.4
TQ10	-3.5	31.9	42.0	10.1	26.3	28.1	1.8	-8.3
EQ6	-8.8	37.7	58.0	20.3	57.9	61.4	3.5	-16.8

Table B3: Averages and standard deviations obtained for tests

Topic	Test	Control		Treatment	
		Average	Std dev	Average	Std dev
Electrochemistry	Pre-test	3.29	1.34	3.42	1.38
	Post-test	4.07	1.70	4.28	1.72
Acids and Bases	Pre-test	3.38	1.75	3.46	1.33
	Post-test	4.55	1.63	4.68	1.34
Titrations	Pre-test	1.87	1.26	1.72	1.10
	Post-test	2.17	1.24	2.02	1.23

Table B4: Table showing the question type and source of the questions used in the tests

	Item	Question content	Question type	Source
Electrochemistry test	1	Definition of redox reaction.	Recall	Past paper
	2	Identification of species that is reduced in a redox equation.	Identification	Past paper
	3	Electron transfer between reagents in a redox reaction.	Diagnostic	Past paper
	4	Identification of the cathode in a diagram of a cell.	Identification	Ogude(1994)
	5	Reaction at an electrode (anode).	Diagnostic	Ogude(1994)
	6	Conduction in an electrolyte.	Diagnostic	Ogude(1994)
	7	Purpose of the salt bridge.	Diagnostic	Ogude(1994)
	8	Reactions occurring when diatomic gas forms at an electrode.	Diagnostic	Ogude(1994)
	9	Identification of a reduction half-reaction.	Identification	Past paper
	10	Calculation of cell potential.	Manipulative	Past paper
Acids and bases test	1	Definition of a Bronsted-Lowry acid.	Recall	Past paper
	2	Definition of an amphiprotic substance.	Recall	Past paper
	3	Identification of a Bronsted-Lowry acid-base pair.	Identification	Past paper
	4	Identification of a species acting as a Bronsted-Lowry base.	Identification	Past paper
	5	Relationship between Ka and dilution.	Diagnostic	UWQB
	6	Calculation of hydronium ion concentration.	Manipulative	Past paper
	7	Calculation of pH of a base.	Manipulative	Past paper
	8	Calculation of the hydronium concentration from pH.	Manipulative	Past paper
	9	Changes in the hydronium concentration with pH change.	Diagnostic	UWQB
	10	Identification of a basic salt.	Identification	Past paper
Titrations test	1	Technique for diluting concentrated acids.	Identification	Past paper
	2	Technique for titrating.	Identification	Past paper
	3	Reactions occurring during a titration.	Diagnostic	UWQB
	4	Chemical composition at the end point.	Diagnostic	UWQB
	5	Chemical composition at the end point.	Diagnostic	UWQB
	6	Function of the indicator in a strong base / weak acid titration.	Diagnostic	UWQB
	7	Properties of an indicator.	Diagnostic	UWQB
	8	Effect of strong and weak acids on volume of base.	Diagnostic	UWQB
	9	Calculation of the concentration of a base.	Manipulative	Past paper
	10	Calculation of the volume of acid used in a titration.	Manipulative	Past paper

Where: Past paper = taken from a previous Senior Certificate *Physical Science* examination,
UWQB = University of the Witwatersrand question-bank.

Question types are sorted according to the classification suggested by Haladyna (2004).
Recall = requires recall of a definition.
Identification = requires the identification of case.
Diagnostic = investigates microscopic understanding and explores misconceptions.
Manipulative = requires the recall and application of a formula.

APPENDIX C: Questionnaires

VIDEO QUESTIONNAIRE 1

First session – Treatment group

Administered in video session 1, after section 3 on Electrochemistry video 1.

This was where the theory section ended.

1. How did you find the speed at which the presenter spoke?

   A. Too fast B. OK C. Too slow

2. Were the words the presenter used:

   A. Too difficult B. OK C. Too easy

3. How did you find the speed at which the presenter explained chemistry?

   A. Too fast B. OK C. Too slow

4. How did you find the presenter's explanations?

   A. Very good B. OK C. No good

5. Was the information taught to you today new?

   A. Yes, all of it B. Some of it C. None of it

6. Was the information you received today taught differently to you before?

   A. Yes B. No

   If yes please state which section in the space below:

   ____

   ____

   ____

VIDEO QUESTIONNAIRE

Third session – Treatment group

Administered in video session 3 after section 3 on Electrochemistry video 2, see Figure 3 on page 35.

At this point the video presenter had been doing tutorial questions.

1. What do you think of the number of electrochemistry examples the presenter did?

   A. Too many B. OK C. Too few

2 What do you think of the speed at which the presenter did the examples?

   A. Too fast B. OK C. Too slow

3. How did you find the presenter's explanations?

   A. Very good B OK C. No good

4. What did you think of the preparation and functioning of the experimental electrochemical cell?

   A. Very interesting B. OK C. Boring

5. Have you seen this experiment or a similar experiment before?

   A. Yes B. No

6. Are you confused about any sections in electrochemistry? If yes, please explain:

   ____

   ____

   ____

VIDEO QUESTIONNAIRE

Saturday session – Control group
Administered after section 4, Electrochemistry video 1.
This was at the end of the first example.

1. How did you find the speed at which the presenter explained chemistry?

   A. Too fast B. OK C. Too slow

2 If you had a choice between the presenter's videos or videos of the same standard presented by someone else, which would you choose?

   A. The presenter's B. Someone else's C. Don't mind

   Why?____

   ____

   ____

BIOGRAPHICAL QUESTIONNAIRE

Please use the boxes to write your answers. Use Y for yes and N for no.

1. Student Number ☐
2. Age ☐
3. Sex ☐
4. Home language ☐
5. Are you currently attending full-time school? ☐
6. Do you have a job? ☐
7. What school did you attend last year?

   ____

8. Did you see or do any laboratory experiments at school? ☐
9. Are you studying any other subjects this year? ☐

   If so, how many? ☐
10. Will you write matric physical science in October / November this year? ☐
11. If you pass matric physical science, what are you planning to do next year?

    ____

12. If you fail matric physical science, what are you planning to do next year?

    ____

13. Do you think you understand physical science better now than you did before starting the ‘matric rewrite’ course? ☐
14. Have you watched any educational science programmes on the television? ☐

    If yes, which ones?

    ____

APPENDIX D: Observation schedule

Subject = *Electrochemistry* Tape = 1 Segment = 1 Time = 30 minutes

TIME (minutes) ⇨ ACTIVITY ⇩	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Answers questions									✓					✓												
Laughs				✓					✓					✓												✓
Talks																										
Fidgets																										
Sighs																										
COMMENTS ⇩ *"Verbatim quote from video"* Information about the content of the video – to explain either the student's reaction or the content of the video.	*"What is electrochemistry? Electrochemistry is difficult".*	*"Electrolysis … break up chemical bonds." "Electricity is difficult"*	New concept : *"electric pressure is volts"*	Analogy – water tank with tap. *"Tap says 'OPEN ME'" "Folks"*	*"Don't work with flows from cells. Need to calc pressure when chemicals are producing it"*	*"Consider a simple situation, a tank"*	*"The water in a tank pushes. It says 'tap open me up and let me come out'"*	Exaggerated facial expression.	*"Stick around I'll make you famous." "What does the pressure behind the tap depend on?"*	*"The difference in push."*	*"The energy of height is potential energy." "What is potential difference?"*	*"Potential difference = volts"*	*"A rubber tank".*	Compare foot in a bath and in ocean: *"is your foot crushed?"* Joke = *"tootsie"*	Fluorescein is used to colour the water.	Demonstates that the plunger compresses when pressure is increased	*"The voltmeter, the pressure gauge"*		Apparatus leaks. Shows beakers with different volumes taken to different heights versus the compression of the plunger.		*"Will the water flow from x → y or y → x?"* Direction in which water will flow in a pipe.	*"If your baby brother asked, how would you explain the direction of flow to him?"*				*"Some twit put the tap above the dam." "Energy at a point."*

APPENDIX E: The remedial explanation

THE REMEDIAL EXPLANTION

The author of the remedial explanation for the microscopic workings of an electrochemical cell was Doctor X, the expert who made an appearance on the electrochemistry video during Question 5 that showed a working Standard Hydrogen Electrode. It was a cameo, non-speaking role, and he was seen in a laboratory coat checking the workings of the apparatus. Dr X was an academic member of staff in the Chemistry Department at the University of the Witwatersrand whose speciality was physical chemistry. He was asked to explain the workings of an electrochemical cell to both the researcher and the lecturer and was then asked to simplify his explanation by introducing some anthropomorphic elements if possible. The researcher had requested this because the video presenter had relied heavily on anthropomorphisms when teaching this section and it was thought that the students might be more amenable to receiving the correct explanation in a similar way.

According to Dr X, students often have problems with the concept that electrons are reagents in an electrochemistry cell. A problem that arises because of the conventions involved in writing the oxidation half-equation. In these equations the ‘lost’ electrons are represented as products. Consider the reaction between copper and zinc as used in the video:

$Cu \rightarrow Cu^{2+} + 2e^-$ (oxidation half-equation: electrons are represented as ‘products’)
$Zn^{2+} + 2e^- \rightarrow Zn$ (reduction half-equation: electrons are represented as ‘reagents’)

Dr X felt that if students could grasp the concept that electrons were reagents: that they were “made” or generated at one place (anode) via oxidation and then “used up” at another place (cathode) via reduction then the problem with conduction in the electrolytes and salt bridge would be mostly solved. In an attempt to reinforce this, the anthropomorphic explanation that “electrons cannot swim” was introduced. The imagery of electrons “leaping” into the “arms” of cations at the cathode and thereby turning the cations into atoms that deposited at the cathode was introduced in class by the lecturer but not recorded in the written explanation.

The explanation was reduced into the following few lines by the lecturer for the students to copy down. N.B. as written it only explains the situation of an electrochemical cell containing reactive metal electrodes.

An electrochemical cell is a closed circuit.
Electrons are <u>reagents</u> in an electrochemical cell.
They are <u>made</u> at the anode by oxidation (atoms lose electrons).
The electrons flow towards the positive charge (cations), from anode to cathode via the external circuit – metal wire.
At the cathode the <u>electrons are used up</u> (ions gain electrons to become atoms), so reduction to take place.
Remember electrons <u>cannot swim</u>.
The circuit is completed by the movement of ions dissolved in the electrolytes and salt bridge.

APPENDIX F: Rates of commentary

RATES OF COMMENTARY

DISCLAIMER
While every attempt has been taken to ensure the accuracy of the transcripts, some inaccuracies may have been included inadvertently.

The rates of commentary were determined by transcribing a one-minute portion of the videos. The rate at which the video presenter spoke was dictated by the activity he was engaged in and generally he spoke more slowly when involved in writing on the screen blackboard than when involved in talking-head footage. The averages rates are given in the table below:

Topic	Number of one-minute segments analysed	Range (words per minute)	Average rate (words per minute)
Electrochemistry	19	98 – 155	130
Acids and Bases	16	91 – 168	127
Titrations	7	105 – 149	122
Overall	42	91 – 168	127,3

ELECTROCHEMISTRY

Rate of commentary 1: Segment 1 (talking head)

"I always feel that electricity is difficult because its one of these topics that we know exists but we don't, we can't work with it, we can't see it, we can't handle it, we can't experiment with it except in theory. What I now want to do, as I always do before I start any programme involved with electricity folks, and if you've seen this before please allow me , I must go through it for those who haven't, I want to once again start by understanding electricity. Now in this section, unlike circuits, we don't need a great deal of knowledge of electricity but we need one very important fact and that it that electric pressure is volts."

119 word per **70 seconds** (ca 102 words per minute)

Rate of Commentary 2:

"*I said to you that the pressure there depends on the difference in height between the top of the water and that point, in other words the height. Now, the energy of height, I think you'll agree is called potential energy. The energy of height is Ep. Let's call that position one and down here let's call it position two. In other words, the pressure there is the difference in energy which is dependant on the height between the top of the water and that point there. It's the difference in potential energy between that point and that point. The pressure depends on the potential difference between that point and that point and what is potential difference? (Volts)*."

117 words per minute

Rate of commentary 3: Segment 2

"*When the second zinc wants to leave the rod as two plus there are two minuses sitting on the rod from the first one and those two minuses say to those two pluses: 'Hey, where you going? I love you.' Plus attracts minus. And these two minuses over here say to those two pluses: 'Don't leave me, please don't leave me.' And the zinc two pluses, the second zinc pluses, say to the rod: 'Shut up junior. Keep quiet. I'm running downhill. This is man's work. Two electrons, I'm not even going to look at you twice.' The attraction is low. And the second zinc leaves the rod. And the third millionth zinc leaves the rod. But, folks, every time a zinc...*" 122 words per minute

Rate of commentary 4:

"*In your equilibrium, OK, what has happened? You've got a situation where the zinc running downhill to zinc ions equals the charge on your electrode pulling the ions back. As I said a moment ago, you have reached dynamic equilibrium. Now please see what you've done: You've started with a neutral zinc rod, there it is there, you've started with a zinc salt, the solution was neutral. You've left negatives behind on the rod, in other words the rod has become very negative, alright, and you have been pumping into the solution an equal number of positive charges. In other words, the solution has become equally positive. Do you realise what you have done*?"

114 words per minute

Rate of commentary 5: Segment 3

"*Now the copper pluses have been going onto the rod to make the rod very positive and they're leaving behind the two minus sulphate ion. In other words your solution now has got far more sulphate ions than its got copper pluses because the copper pluses have gone on to the rod, So, your solution now has become extremely minus with all the sulphate ions left behind. And once again you've built up an electric pressure between the positive rod and, this time, the negative solution. We've built up a voltage. Now folks, once again, as in dynamic equilibrium, once its been reached, you've built up the pressure, the pressure's holding, right, you know that's what a cell does, a cell holds the pressure, the volts, you're going to see nothing more, it will sit there, it will go (internally dynamic, yes, but you won't see it.*)"

139 words per minute

Rate of commentary 6:

"*Now the way a salt bridge works, by the way I'll be very honest very soon in this programme: these things are terribly complicated, but in a terribly simple way, what a salt bridge does is this: It allows the excess positive ions produced in this half cell to go through the cotton wool plug into the salt bridge and the ionic solution in the bridge neutralises the positives. On this side it allows the excess negative ions produced here to go through the cotton wool plug, by the way I often like to think like little tadpoles, that's why these plugs have to be cotton wool or fibreglass they've got to be permeable, you've got to be able to get through them, you can't use a rubber cork. OK, right, these excess ions go through the salt bridge or cotton wool plug into the salt bridge and are neutralised again (by the ionic solution)*."

151 words per minute

Rate of commentary 7: Segment 4

"*You will understand cells, that's a promise as long as you have an IQ more than fifty, hey that includes the women as well, right, of course, hey, and you work with me. Alright now, one thing I am going to say before we start, I'm not a scientist that believes in formulas, not at the simple level. There are formulas in cells, well there's one, and I'm going to show it to you, I'm not going to use it. I'm going to show you how to do cells. Probably one of the most difficult things you'll ever do in Chemistry, with a bit of brains but understanding how they work and folks, we are a long way down that path already of understanding how they work. Now let's turn to that workbook of ours and let's see, ooh, what example one has for us. Alright, question one*:"

148 words per minute

Rate of commentary 8: Segment 5

"*The magnitude of E theta, how big it is, is the difference in energy between the electrode which is the metal, and its electrolyte which is its ion. In other words the size of E theta, how big it is, is the difference in energy between the metal and its ion. It's the difference in the potential energy between the metal and its ion. It's the difference in potential between the metal, the electrode and its solution, its ion. It's the potential difference between the metal and its ion and if I'm telling you the truth what are the units of E theta? They are (volts)* "

105 words per minute

Rate of commentary 9:

"*Now look, let me very quickly tell you how this works: Here you've got your zinc and lead cell, don't worry about the rest (the presenter is referring to the fact that he has only drawn two beakers and two electrodes). Now your zinc is trying to make electrons, it's pushing them out with a force of 0,76 volts but your lead is also trying to make them with a force, it's trying to push them out, of 0,13 volts. Folks you've got a vector pushing this way in opposition with a vector pushing the other way, both trying to produce electrons. What's the resultant vector? 0,76 one way, 0,13 the other, 0,13 takes away. You end up with 0,63 volts in that direction which is exactly what you got as the voltage, the e.m.f., of the cell*."

121 words per minute

Rate of commentary 10: Segment 6

"*Now the way to remember this is, excuse me, the vowels go together. Anode – oxidation. If you like reduction takes place at the cathode, and by the way notice: Roman Catholic, taking a leaf out of a book of one of our very, very famous examiners, Johan Vermuelen. OK, Roman Catholic: reduction – cathode. So which is the anode? The anode is where oxidation takes place. Now that's all very well but what is oxidation? The answer is the loss of electrons. Sure, so all you now have to do is to go back to this here (the presenter returns to the half-reactions). Now be careful, not that one, I'm going to put a line through it because these are not the right way round. The right way...*"

121 words per minute

Rate of commentary 11:

"*The last question says the zinc is the anode and now I'm saying to you, the zinc is the negative electrode. Isn't there something wrong? Isn't there something wrong? Surely anodes are positive? How can anodes be negative? And you know if you can see that there's something wrong, it isn't actually wrong, you understand why we are trying to eliminate calling electrodes positive or negative. The answer is, when is an anode positive? In a thing like electrolysis, where the apparatus is taking in electricity and doing something with it: electronics, where you are taking electricity into it. Where you are making electricity, a cell is producing it, it's reversed. The anode is negative, (the confusion is there)*."

115 words per minute

Rate of commentary 12: Segment 8

"*One mole of solute, in this case zinc nitrate, in one decimeter cubed, now please remember, solution is going to give you a strength of one mole per decimeter cubed. Now, I want one mole per decimeter cubed because that's the standard for my cell. So, I want one mole per decimeter, in other words, if I was going to dissolve it in one decimeter I would need one mole which is 189,4 but I am dissolving it in a tenth of a decimeter and I want the same strength, therefore one tenth of a mole in one tenth of a decimeter of solution is going to give me the same strength...*" 112 words per minute

Rate of commentary 13: Tape 2, segment 1

"*Do you know what's happened? The copper said to the zinc, 'Zinc, I love you because your needs are my needs. I'm working with you, I want to go in this direction, I want to take your electrons. This is the way I'm designed to go.' So folks, all that's happening here is the two vectors, the two E standards, are working together. That's all that's happening. Don't think you've got to have one of them being a negative. No, why? These two are push me pull yous, they're working, two vectors working the same way, fantastic. Alright, the next step says if the electrons aren't the same multiply through to make them the same but they are the same, so all we have to do is cancel them before we add. OK, we now add, we say what is the overall cell reaction? Now there's...*"

146 words per minute

Rate of commentary 14: Segment 2

"*...I multiply the silver by three. Three there, three there, three there and what is 0,8 multiplied by three? No, please no, why? The E standard, the voltage, I've just shown you when I put those big electrodes into the last cell, doesn't change the E standard when I make my electrodes bigger. That stays 0,8 V. You do that and I'll divorce you even if you're a male and that says something. OK, no sir, don't touch the E standard value please. Alright, now why did I do this? For one very obvious reason, I can now (cancel out the electrons)*"

98 words per minute

Rate of commentary 15:

"*Now the loser, 'Yes' says Iron.*

Aluminium says, 'I'm the boss and I am producing electrons, I'm undergoing oxidation. Iron!'

'Yes boss'

'You are going, going to undergo reduction my electrons are on the right, yours are going to have to be on the left.'

And Iron says, 'They are already on the left.'

And Aluminium says. 'Just as well because this is the way you are going to react.'

So Iron says, 'Alright.'

Fe two plus plus two electrons is going to go to Fe. Now, I haven't turned him round so I don't change the sign.

So Iron says: 'But Aluminium, I don't want to go this way.'

And Aluminium says: 'Shut up junior, I'm the boss, and I'll tell you which way to go.'

Alright, there are your two half-cell reactions written in the direction left to right in the direction they're going to happen. Now, let's put them together."

153 words per minute

Rate of commentary 16: Segment 3

"*Now the hydrogen's bubbling up over that platinum and that is the surface on which the reaction is going to take place. Now, the way this works is as follows: Folks, you'll notice there's a wire coming out of the top that goes to the other half-cell through a voltmeter. Now what we do is this: You take this half-cell, you put another half-cell here and you link the two by the salt bridge. Then this wire goes to the electrode of the other half-cell, and a voltmeter goes into that position, and by reading the voltmeter we get the voltage of the other half-cell because this one has a voltage of zero. And can you* *see the platinum gauze, the hydrogen's bubbling over it, and it's on that platinum gauze, that acts as a catalyst, that this reaction takes place*."

141 words per minute

Rate of commentary 17: Segment 4

"*Now, in cells we have to end up with positive emfs. In spontaneous and non-spontaneous reactions we don't and, by the way that makes them easy. All we are going to do to work out whether a reaction is spontaneous or not as it's written left to right. We're going to take it and write it down and pretend that it is. Get the two half reactions, work out the E standard of both, add them up, and if the answer is positive it is spontaneous as written left to right, and if the answers are negative, what do you know? As written left to right its uphill, its non-spontaneous but were you to turn the reaction round then that uphill becomes that downhill. OK, you change the sign and the negative becomes positive, so it then becomes (a spontaneous reaction from right to left)*."

138 words per minute

Rate of commentary 18: Segment 5

"*If you've got two atoms bonded together, A bonded to B, to work out the formula when A bonds with B, take the valency of A and give it to B, over there. Take the valency of B and give it to A, over there. Simplify if you can and never write a one. Now, if you haven't been shown this, watch quickly and with lots of intelligence and ask your teachers to show you as well. Take a simple one: I want to know the formula when hydrogen bonds with oxygen. Oh, you'll say that's easy that's water, I want to show you the method. The valency of hydrogen is one, give it to oxygen, the valency of A you give to B. The valency of oxygen is two, give it to hydrogen. You can't simplify but you never write a one, H two O. Another one, carbon bonded to oxygen: What's the formula?* "

155 words per minute

Rate of commentary 19: Segment 7

"*If you're happy then I'm happy. Now you have handled what a lot of people believe to be the most difficult thing, at the school leaving level, in physical science. And if you're happy then I'm extremely proud of you, because you have handled something that's considered pretty tricky. You know something, I think, like everything else, once you understand it, it's easy to handle it. That's why chaps, you and I will never handle women, you'll never understand them and don't bluff yourself, you never will. And by the way girls, don't ever be normal. Imagine a normal woman, guys, how boring it would be? It would be terrible. No, let the woman be totally beyond understanding and then girls you'll be studied forever. OK, you'll puzzle us forever. Don't ever become human that would be a disaster*."

139 words per minute

ACIDS AND BASES

Rate of Commentary 1: Segment 1 (Given while demonstrating the topic)

"If an acid neutralises a base, tell me about a base. Well, maybe you know that a base, can you believe it, neutralises an acid. Sure, the one neutralises the other. So, the first thing we know about a base is a base neutralises an acid because an acid neutralises a base. Now the second thing we know about a base is. Now over here I've got a base, let's bring it in, here's the base. This is the acid, I'll take it away. If an acid – this one here – turns litmus paper red then what do you think a base is going

to do to red litmus paper? Turn it back to blue. Right, here's your base and you can't miss it, there it is. So the second thing a base does it makes red litmus blue again, here we go and by the way, the third thing that I think most of you will know about an acid and a base, folks, a base feels soapy."

168 words per minute

Rate of Commentary 2: Segment 1

"Now folks, remember ions in solution conduct electricity, and the more ions you've got in solution the more electricity that a solution can carry. So we can measure the amount of ionisation by the amount of current that a solution can carry. Think, lots of ions in solution, the ions can move through the solution carrying the current, very few ions in solution, they aren't enough to carry what has to be carried and the solution is a bad conductor. So strong acid, high ionisation, they make a lot of positive and obviously negative which don't come into the acid side, but they certainly produce a lot of hydrogen ions, protons and an equal number of negative ions."

118 words per minute

Rate of Commentary 3: Segment 2

"Because acids are on the acidic side of water and bases are on the basic side of water and, according to Arrhenius, remember he said that an acid donates hydrogen ions so this is your acid ion. He said that a base donates hydroxide ions, this is your basic ion, and you know an acid neutralises a base and a base neutralises an acid. When you get these two getting together, now you know they make H two O (H_2O). *It stands to reason that water is going to be neutral, it must be because every water molecule contains as much acid as it does base because H two O* (H_2O) *is an H plus* (1 minute) *added to an OH minus. So in other words because this is true, as much acid as base is in water, water is considered to be neutral."*

113 words per minute

Rate of Commentary 4: Segment 2

"…because water is neutral and water has a pH of 7, a pH of 7 is neutral. And because water has a pOH of 7 and water is neutral, a pOH of 7 is also neutral and that is where the 7 magic number comes from and it's not theory, they measure it. They measure water having a pH of 7 and a pOH of 7. So, based on water a pH of 7 is neutral and a pOH of 7 is neutral, but there is something else, for any solution (1 minute) *not just water, pH plus pOH always equals 14. Now that is another very valuable equation. For any solution pH plus pOH is 14. By the way, does it hold true for water? Yes it does, the pH is 7 and the pOH is 7, and by the way that is how we get the 14."*

91 words per minute

Rate of Commentary 5: *(36 seconds)*

"…many people believe that the pH range only runs from 0 to 14. The answer is: no, it doesn't. It actually goes below zero and she goes above 14. How far? Well, I don't think it goes anywhere beyond negative two and therefore think that formula where pH plus pOH equals 16, sorry 14, I'm saying 16. If the pH is negative two, and the total equals 14, then folks the pH can obviously go up to 16. So, in other words, you have a scale range and the normal range is between 0 and 14. The nearer 0, the more acidic, the nearer 14, OK, the stronger the base and remember, this is your pH scale. Your scale of acidity"

121 words in 36 seconds

Rate of Commentary 6: Segment 4

"So water is amphiprotic, it is amphoteric or you can say it's an ampholyte, L Y T E, it's an ampholyte. Depending on what you react it with, it can either react as a base or as an acid. Although, what's interesting here is why? Look, we've agreed that water's neutral so when you come with a big, strong acid like H Br (hydrobromic acid). *H Br says, 'me Tarzan, you Jane' and water says, 'alright I'll be Jane', remember water is either way. So when you come with a strong acid water is able to say, 'alright, alright, I'll be your base'. On the other hand when you come with a very strong base, water says, 'alright, alright, alright, I'll be your acid' and that is why it's both, and not all neutral things can do this but water can and that's why it's an ampholyte."*

143 words per minute

Rate of Commentary 7- 9: (3 minutes)

"If an acid is strong, it means it ionises easily, makes lots of ions, it produces protons like it's coming out of its ears. Alright, when its donated, given, its protons, which it does with pleasure, what's left of it is its conjugate base, in other words, let's come up here (he returns to a previous portion of the screen blackboard). *H Br is a strong acid, it gives protons readily and what is left of it is its conjugate base. Now, if the acid is strong, its conjugate base is weak. Let's assume you measured somebody's generosity, how generous are they, generosity in giving other people, in helping other people. So someone is very generous, they give, donate easily those people* (1 minute) *don't easily take something back, their whole joy in life is to help others. When an acid is strong it donates easily, what's left of it is its conjugate base and as a base its conjugate base does not take back easily, its conjugate base is weak. But on the other hand if you know somebody who's mean, who doesn't give easily, they'll, they, they, they, they might give a little bit, a weak acid. When it does give, and you offer it something, ngh!, it takes it back. Make sense? Of course! So in other words, when an acid is weak it doesn't donate protons easily, what's left of it when you do get a proton out of it,* (1 minute) *its conjugate base, is strong. It says: 'give it back'. OK, and that's why. So when you have these pairs if, for example, water is a weak acid, its conjugate base is strong. Ammonium plus is a strong acid or a weak acid, its conjugate base is the opposite. Now we know that in the case of ammonia that as a base it isn't that strong and it isn't that weak. In other words the acid now, the ammonium isn't that strong and it isn't that weak.* (This shaded portion was 'dropped-in', i.e. taped later and placed over the original audio-track.) *That's very important, that's very, very important to us, and that's why we have acid-base conjugate pairs. It's a yo-yo; it's a see-saw. One side strong, other side weak and, by the way, if an acid is fairly strong, its conjugate base is fairly strong. That's all it is. Part e what's the similarity between the Bronsted-Lowry theory of …"*

379 words in 3 minutes, average 131 words per minute (111, 122, 146)

Rate of Commentary 10: (*30 seconds*)

"By the way, I don't want to get into a controversy please, but those of you who know a lot about this'll say: 'hang on a minute, an organic acid donates' but I won't say it, but it doesn't donate the H. Um, um, um, alright. Let's just cool it there. Alright, this is called a monoprotic acid because only one of the hydrogens of the two are donate-able, give-able, and therefore its mono, one, protic."

76 words in 30 seconds

Rate of commentary 11-15: (5 minutes)

"I think the easiest way to explain is to use the idea of two people who get married or getting together anyway. Let's assume a real he-man marries a real she-woman, in other words as men go he's strong, as woman go she's strong. When they form one unit, a family, a partnership, the one compliments the

other and as a partnership they are about average because he does male things strongly and she does female things strongly. So when they get together the combination is about normal, it's about the normal things that people do.

If you get a wish-washy man, he's a man but not a very strong one (1 minute) *and he marries a wish-washy woman, she's a woman but she's not really a woman. When they form a partnership they also compliment each other. He does a bit of things that men do and she does a bit of things that woman do and as a result when they form a unit, as a unit they're also about average. They do in fact about much the same thing as the he-man married to the she-woman. OK, now that's easy.*

But what happens if a real he-man marries a wishy-washy woman. When they form a partnership, the he-man dominates and as a togetherness, as two people together, they tend to go and do things that men do (2 minutes) *rather than woman do because in the partnership you've got a real he-man and a very weak woman. But it works the other way round. If you have a wish-washy man, not a very strong man, and he marries a strong she-woman. When they form a partnership and they work together, the woman is going to dominate and as a partnership they will tend to do things that woman do, not that men do, because of the two partners, the woman is the strong one and I don't mean physically strong, I mean as womanly things go. Alright, that is exactly what happens when an acid reacts with a base to form a partnership, a salt* (3 minutes).

If you've got a strong acid and it reacts with a strong base as a salt, the strong acid compliments the strong base and the salt is in the middle, it's neutral, it's got a pH about 7, give or take. When you marry a weak acid to a weak base they form a partnership called a salt. The salt is also neutral, around 7, because neither partner is very strong and they are both weak and therefore they tend to do about average. So, strong acid, strong base tends to give a neutral salt; weak acid, weak base tends to give (4 minutes) *a neutral salt.*

But when you marry a strong acid to a weak base they form a partnership called a salt. The acid doesn't lose its habits, it's strong, the salt tends to be acidic, it tends to have a pH of lower than 7 more towards the he-man. Same way, if you marry a wishy-washy man to a strong woman, if you marry a weak acid to a strong base the salt that is formed is more base than acid and the salt tends to be basic. It tends to have a pH higher than 7 and you know something folks, that is exactly what is going on here. Let me show you.

560 words in 5 minutes: Average 112 words (111, 117, 116, 102, 114)

Rate of commentary 16-17: (given while pointing to various equations on the screen blackboard)

"*However, when you dilute this* (he points to the formula for acetic acid) *you lower the concentration of this* (he points to the hydrogen ions) *and if you like there are still plenty of these* (H^+) *still sitting here* (he points to the formula for acetic acid), *and dilution, you lower the concentration, and you'll learn if you haven't already, it's a man called Le Châtelier. What happens is: if you lower this concentration* (the acetic acid) *you favour towards the loss* (the forward reaction). *So by diluting a weak acid you cause it to ionise more. So what happens in the case over here* (he points to the definition for pH) *is that your weak acid's pH does not rise by the same amount as a strong acid's does because yes, you did increase the volume but at the same time you made more moles of hydrogen ions because by diluting a weak acid you favoured the reaction towards the H plus. Remember in the strong acid* (1 minute), *you had almost none of that in solution* (the HCl), *it was all those two* (H^+ and Cl^-). *It happened before you diluted. So whether you diluted or not you still have the same number of moles of H plus in solution and by diluting you just increased the volume and therefore the change is big. But in a weak acid you don't have that much in solution* (the hydrogen ions), *a lot of it is still here* (in the acetic acid molecule) *so by diluting you make the acid ionise more. So you do produce more hydrogen ions and at the same time you do increase the volume. Now, if I increase the number of moles of hydrogen ions at the same time I increase the volume by doing so then my pH isn't going to change as much as if I increase the volume and I don't increase the number of moles, which is the case with a strong acid. Well, I hope that you got all that because we certainly proved it, and that's the story. "*

286 words (119 words, 167 words)

TITRATIONS

Rate of commentary 1: Segment 1

"*Girls, admit it, you want to make something for supper, something, mmm, gorgeous, OK, and the recipe says that all the things you need are in the solid form. There's no liquid in this recipe at all, not even an egg to give it a kind of slush. Your heart sinks, why? Because you take solids, this solid, that solid, different size solids, and you put them in a dish and you stir and you stir and you stir and you shake and you wiggle and you know something, it is terribly difficult to get those solids in the dish to mix properly. A bit of a mistake, you've got too much baking powder on one side, too much salt on the other, right? Whereas if you're going to make something superdoopa for super and the recipe makes what you're mixing into a liquid form, oh what a pleasure (a couple of swirls, a couple of wiggles...)*"

149 words per minute

Rate of commentary 2:

"*Why because we had only a fixed amount of base, ten centimeters cubed from the pipette, but in the burette we had twenty centimeters cubed of acid. We just kept bring it in and bring it in and bring it in until we got to the end point, the neutral point, where from having an excess base in the beaker at that point, pH 7, neutral, there was no base and no acid in excess and we kept on adding acid so the beaker swung acidic. And folks the reason for this peculiar shape graph is the way pH is defined, the log. Now what is very important from this graph is as follows and that is folks all acid base titrations follow this particular shape ...*"

127 words per minute

Rate of commentary 3: Segment 2

"*A half a spoon of sugar in a tenth of a decimeter cubed. What am I going to get? Well, a half in a half would give me one, um-hum, and a half in a tenth, now look I've got more sugar than I've got coffee. Surely it's going to be five sweetnesses, five times as sweet. Why? Because one spoon in a tenth of a cup will be ten times as sweet as normal, so a half a spoon will be half of ten which is five, happy? Now folks if you can do this you've solved the strength of a solution. Now why is this so important to us, because remember what I said earlier. I said earlier ...*"

120 word per minute

Rate of commentary 4: Segment 3

"*Now, how many centimeters cubed in a decimeter cubed? Now folks, come on, centi, a hundred, deci, ten. How many hundreds in ten, if you like, and the answer is ten. So I'm working in volume it's ten by ten by ten, it's a thousand. So five hundred centimeters cubed is five hundred over a thousand, it's five hundred over a thousand decimeters cubed which is going to be half a decimeter cubed. Goodie, now let's take that fact and that fact and go back to our definition. We agreed that one mole of* *anything in one decimeter cubed solution is one mole per decimeter cubed, however we had a quarter of a mole ...*"

114 words per minute

Rate of commentary 5-6:

"Now the origin of that name, if I standardise something, I fix its size, its volume, its beauty, its something. The word standardise means to compare it so something else and thereby get a comparison between something which we take as a standard and the thing we are looking at. For example I want to know how long this ruler is, I compare it to the length of one meter kept in Paris, as the unit, the standard length, and compared to that I can find out the length of this ruler. I standardise the length of this ruler. Now in titrations we use solutions (1 minute), *the volumes of them, you saw me doing it just now with the pH meter, to work out the strength of one solution compared to another and we call that standardisation. So a standard solution is a solution whose strength is known to as many decimal points as possible, obviously within the realm of accuracy. And a standard solution is used to standardise another solution, to find out the exact strength, to as many decimal points as possible, the strength of the solution and that is all it is. So if I come along to you and I bring you a solution and I say to you this solution is one comma zero, zero, zero, zero (1,0000) moles per* dm^3, *concentration, sweetness, (it's a standard solution)."*

105 words per minute, 124 words per minute

Rate of commentary 7: Segment 6

"*I've got a fifth of a mole of solute in, here we go, a half a cup, ah-huh, in half a decimeter cubed of solution is, well this is not so easy, or is it? Look, a fifth in one cup is one fifth sweetness so a fifth in half a cup is going to be two fifths moles per decimeter cubed and, by the way, you know how to test this? Go back, two over five multiplied by one over two, the twos cancel, is one over five. Yes sir, OK, and that is what I've been asked. I've been asked to find the strength of that solution, which by the way...*"

113 words per minute