

**INVESTIGATING THE EFFECTIVENESS OF MULTIMEDIA
PRESENTATION IN REDUCING COGNITIVE LOAD FOR PHYSICAL
SCIENCE LEARNERS**

By

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submitted in accordance with the requirements for the degree of

MASTER OF SCIENCE

in the subject

PSYCHOLOGY

at the

UNIVERSITY OF SOUTH AFRICA

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FEBRUARY 2012

Abstract

The purpose of the research was to investigate the effectiveness of using multimedia as a means of teaching physical science to learners. The underlying theoretical assumption was that a multimedia presentation would help to reduce the cognitive load experienced by learners when they learn physical science content, compared to a traditional mode of presentation, and that this reduction may have a positive effect on the ease with which they master the content.

Physical science learners in Grade 11 viewed a presentation consisting of multimedia screens and screens depicting the learning content in a traditional layout – in order to compare the level of knowledge gained as well as the cognitive load experienced for the multimedia and traditional instructions. Pre- and post-test questionnaires were used to determine the knowledge gained, while cognitive load was measured using a dual-task methodology.

A multivariate analysis of variance was used to analyse the data. The results did not reveal a statistically significant increase in knowledge gained via the multimedia approach when compared to the traditional mode of instruction, but when focussing the analysis on learners with a lower-knowledge base in physical science though, statistically significant results were found. However, no significant results were found to support the hypothesis that multimedia would help to reduce learners' cognitive load.

It was concluded that the multimedia design principles are more effective in increasing knowledge for physical science learners of low-knowledge than traditional instructional designs.

Key Terms

Cognitive Load Theory; Dual-task Methodology; Multimedia Learning; Physical Science Instruction

Declaration

Student Number: 45669104

I declare that '*Investigating the effectiveness of multimedia presentation in reducing cognitive load for physical science learners.*' is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

Signature (Miss J Reynolds)

Date

Acknowledgements

Many people, whether directly or indirectly, have guided and encouraged me on this journey from a one line topic to a now completed dissertation.

I would like to express my gratitude to my supervisor, Dr. HC Janeke, for his supervision and guidance, as well as my family, friends and colleagues for their on-going help and support.

List of Abbreviations

ANOVA	Analysis of Variance
CLT	Cognitive Load Theory
FET	Further Education and Training
GUI	Graphical User Interface
MANOVA	Multivariate Analysis of Variance
PDA	Personal Digital Assistants
TEPRs	Task-evoked Pupillary Responses
TIMSS	Trends in International Mathematics and Science Study

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CHAPTER ONE: Background

The development of programmes to improve scientific literacy is certainly an important endeavour in the South African context. According to *Science in Africa*, “South African learners are regularly outstripped in science and mathematics by pupils from much poorer African nations” (Science in Africa, 2007, para. 3). The impact of scientific illiteracy on the economy, employment opportunities for learners as well as the understanding of public policies (Science in Africa, 2007) has now been clearly established. For this reason it is becoming increasingly important to identify educational strategies and teaching methods that will empower educators to more effectively teach physical science to learners and thereby increase their level of scientific literacy. Scientific literacy requires a clear understanding of scientific concepts and methods and must be approached as a problem-solving process, not simply the rote memorisation of definitions. It requires meaningful learning.

Meaningful learning relies on active cognitive processing in the working memory of the learner who can only process limited amounts of information at one time. For this reason, Bruning, Schraw, Norby, and Ronning (2004) maintain that the focus of physical science educators should be on minimising extraneous and irrelevant information and on highlighting germane information in their presentation of the syllabus, so that the learners’ ‘cognitive load’ is not overtaxed and the learning process thereby impaired. The notion ‘cognitive load’ is clarified further down in this chapter, and discussed in much more depth in the next chapter.

This study attempts to address the current low level of scientific literacy in South Africa by exploring whether physical science learners’ understanding of the concepts of physics can be improved using a multimedia approach to encourage meaningful learning. The main postulate is that multimedia fosters a meaningful learning environment, and that this may facilitate the learners’ acquisition of core concepts in physical science. Before discussing the theoretical framework adopted in this study, it is pertinent to first elaborate on the notion of ‘multimedia learning’.

Multimedia Learning

Multimedia learning, as explained by Mayer and Moreno (2003), entails the combining of verbal and graphical material (i.e. words and pictures) to facilitate learning. *Multimedia instruction* involves the presentation of words (printed or spoken) and pictures (static or dynamic) to allow learners to organise and integrate the material in order to develop a deep understanding of the work (Mayer & Moreno, 2003). However, if multimedia presentations combine excessive visual and auditory elements the working memory of the learners can become overwhelmed while they are trying to deal with the often complex constellation of facts and theories in a discipline such as physical science. As a result, processing efficiency could be impaired, and the learning process could even disintegrate (Bruning et al., 2004; Paas, Renkl, & Sweller, 2003a). It is therefore necessary for educators using multimedia presentation designs to be aware of the learners' available cognitive resources, to ensure that the material actually enhances the learners' recall, and that it facilitates transfer of the subject material to new situations or problems.

This study investigates the effect of a multimedia presentation on the acquisition of concepts in physical science. It is situated in the framework of cognitive load theory (CLT) by Paas et al. (2003a), and also draws from Baddeley's (1992; 2001) theory of working memory.

Cognitive Load

Cognitive load theory (CLT) has been an area of much investigation and evaluation since it originated in the 1980s. Information processing and the use of cognitive psychology principles in generating new designs for instructional materials have since received much attention (Paas, et al., 2003a).

Brünken et al. (2003) describe three categories of cognitive load: *intrinsic cognitive load* which is caused by the inbuilt structure and complexity of the material and cannot be manipulated by the design of the presentation; *extraneous cognitive load* which is caused by a confusing presentation design and is not related to comprehension of the

material; and *germane cognitive load* which is related to the learners' motivation and is the effect of the learners' efforts to engage with the presented material.

Cognitive load cannot be observed directly, it is a theoretical construct which describes the internal processing of information (Brünken, Plass, & Leutner, 2003). The construct is situated within the information processing approach to human cognition, and closely linked to Alan Baddeley's (1986) model of working memory.

Working Memory

The working memory model consists of three components: a *central executive*, and two supplementary subsystems. The central executive is an attentional controller – coordinating the flow of information to and from the subsystems. These subsystems are the *phonological loop* which is concerned with speech-based information and the *visuospatial sketchpad* which is concerned with processing visual and spatial information (Baddeley, 2001, 1992). A fourth component - the *episodic buffer* - was later added to the model by Baddeley (2001). This third subsystem, which still requires extensive experimental assessment, is responsible for linking the central executive and other subsystems to long-term memory (Baddeley, 2001).

Central Executive

The central executive plays a critical role in the working memory model – being responsible for the control and regulation of cognitive processes (Baddeley 2001). Baddeley identifies the processes of the central executive to include the capacity to focus available attention, to divide attention between more than one task, to switch attention between tasks and to coordinate the phonological loop and visuospatial sketchpad (Baddeley 2001, 1992).

Phonological Loop

The phonological loop is assumed to consist of two components – a *phonological store* and an *articulatory control process*. The phonological store is capable of holding acoustic information for approximately two seconds, unless refreshed by rehearsal (Baddeley, 1992, 2001). The articulatory system is responsible for maintaining the traces of speech-based information within the phonological store through sub-vocal

repetition. Another function of the articulatory system is to transform visually presented information such as words or nameable pictures into phonological traces through subvocalisation and to encode these into the phonological store (Baddeley, 1992, 2001).

The function of the phonological loop is mostly considered as a system for the comprehension of speech under complex conditions, and more recently as playing a role in the acquisition of vocabulary in small children or when learning a second language (Baddeley 1992).

Visuospatial Sketchpad

The visuospatial sketchpad is important for spatial orientation and in the solution of visuospatial problems. This is achieved through the temporary storage and manipulation of visuospatial information (Baddeley, 2001). The visuospatial sketchpad forms an interface between visual information such as form and colour, and spatial information such as area and movement - whether received through the senses or long term memory (Baddeley, 2001).

The visuospatial sketchpad is active in spatial tasks such as judging distances or visual tasks such as pattern recognition (Baddeley, 2001).

Having presented a brief exposition of the general theoretical background associated with this study, it is now appropriate to describe the research problem and the method used to investigate the problem in more detail.

1.1 STATEMENT OF THE PROBLEM

This research study investigates the effect of onscreen multimedia presentations on the cognitive load of learners. The main aim of the study is to identify an effective way of presenting physical science information to learners to ensure that they comprehend the work and are also capable of using their knowledge to solve novel problems. The specific focus of the study is the effect of mode of presentation and consequently cognitive load, on learners' acquisition of the concept of 'frictional force' in physics.

1.1.1 Research Questions

An experimental research design was developed with the aim of answering the following research questions:

- Can an on-screen multimedia presentation, following Mayer and Moreno's (2003) nine ways to decrease cognitive load in multimedia presentations, reduce cognitive load for physical science learners?
- Can this multimedia presentation increase the learners' recall of the information?
- Can the dual-task method (Brünken et al., 2003) be used to measure both the primary task (the presentation) and secondary task (the reaction time to the distractor) simultaneously?

1.2 RESEARCH DESIGN AND METHODOLOGY

This pilot study implemented a quantitative, pre-test/ post-test design in order to investigate the effect of on-screen multimedia presentations on the cognitive load of learners. Control and experimental presentations were set to determine the effect of the multimedia presentation on learners' recall of the information presented. The study was designed to measure each learner's performance on the control against their own performance in the experimental presentation in order to account for differences in experience, cognitive capacity (Brünken et al., 2003), interpretation of the material, enthusiasm and anxiety.

Furthermore, a dual-task method was employed in order to measure the amount of cognitive load elicited by the different presentations— with the presentation as the primary task, and reaction time to a distractor on each of the presented screens, the secondary task.

1.2.1 Population and sample

The population of interest for this investigation was learners in the Further Education and Training (FET) Phase (Grade 10 – 12) who take physical science as a subject. Purposive, convenience sampling was used to select the sample for this pilot study.

Two participating classes of learners were selected. These classes were purposively identified due to all the learners currently taking physical science, with one year of experience in the subject. The sample used for analysis (n= 57) was made up of 42.1% males and 57.9% females all aged between 17 – 19 years. In terms of racial distribution, 42.1% of the learners were White, 33.3% Black, 12.3% Coloured and 12.3% Indian.

1.2.2 Research instruments

On-screen multimedia presentations were specifically developed for this study to best answer the research questions. Two different presentations were developed to present the work to the learners. The content of the presentations was derived from the reference material (Olivier, n.d.) to represent the control and were then converted into an experimental, multimedia equivalent incorporating Mayer and Moreno's (2003) *nine ways to reduce cognitive load*.

A distractor was included in the screens of both the control and experiment in order to measure the level of cognitive load elicited by the learning material. The output of the learners' reaction to the distractor was a text file (.txt) that could be used to deduce the necessary statistics. The text file included: the name of the learner, as well as a timestamp which could then be used to determine the duration of time spent on each screen as well as the time it took for the learner to react to the distractor.

A pre-test questionnaire was formulated by using questions relating to the content covered in the presentation, derived from the reference material (Olivier, n.d.). These questions were then re-ordered to form a post-test questionnaire.

1.2.3 Research variables

The independent variable in this study is the *type of presentation* (experiment or control), while the dependent variables are the *increase in test score* for the post-test when compared to the pre-test, as well as the *reaction time* of the learner to the presented distractor.

The score obtained by each learner for the pre-test questionnaire was subtracted from the score obtained for the post-test questionnaire, thereby giving results for the variable

increase in test scores. While the difference in time from when the distractor appeared on the screen to when the learner reacted was recorded in order to get the learner's reaction time to the distractor. The *average reaction time* per learner in response to the screens was calculated.

1.2.4 Data collection

The presentations were uploaded onto the computers in the computer lab, ensuring an equal number of computers would show the two, different presentations. Random assignment to the presentations was ensured by allowing learners to enter the computer lab at the beginning of the lesson and chose the computer at which they wanted to sit.

The lesson was facilitated by a physical science teacher who instructed the learners to answer the pre-test questions before viewing the presentation. They were told to watch for the distractor and to click on it when it changed from blue to yellow. It was also explained that they would be answering questions after the presentation, based on what was covered.

After the learners had completed the presentation they answered the post-test questions relating to the presentation. Once the class had left, the text files recording the necessary statistics were extracted for each learner.

1.2.5 Internal and external validity

Neuman (2007) outlines possible threats to internal and external validity. These were overcome in different ways in this study:

- An analysis of the difference in pre-test scores for the learners who viewed different presentations was used to rule out any selection bias, revealing no significant difference between the two groups of learners.
- A possible testing-effect was controlled for by the pre-test/ post-test design of the study. The pre-test affects both the experiment and the control equally; therefore, any increase in test score due to priming when learners answer the pre-test would affect both experiment and control equally.

- Examination of the pre-test scores showed that the learners were not previously aware of the topic of frictional force, and rules out possible statistical regression since the learners did not achieve near perfect scores on the pre-test. This implies that there was room for the learners to improve on the questionnaire scores after viewing the presentation.
- Diffusion of treatment/ contamination could not occur as the classes were scheduled directly after one another (as the one class left, the other class was waiting outside a different venue and were then directed to the computer room - leaving them no time to discuss what had happened in the lesson).
- To control for researcher expectancy a double blind experiment was used. The science teacher who marked the papers was not the same teacher who checked and administered the lesson and was therefore unaware of the details of the study or that it was pre- and post-test questions she was marking. She therefore had no expectations for the results.
- No instrumentation problems occurred during the experiment – all the programmes and hardware worked as planned.
- The research occurred in a naturalistic environment - where the learners are unaware that they are involved in research and behave in a natural way. This protects the ability to generalise experimental findings to events and settings outside the experiment itself (i.e. an average classroom environment).

The research design and methodology is covered in detail in Chapter 3.

1.3 DATA ANALYSIS

A multivariate analysis of variance (MANOVA) was used to analyse the data by testing the differences in mean increase in test score as well as the mean reaction time to the presented distractor for the experiment compared to the control. This technique was decided upon as it allows for the simultaneous testing of the differences in means for several dependent variables (SPSS South Africa, 2001) as well as its statistical power to detect true differences, and to control for Type 1 error (false positive results) that may occur when running separate multiple analysis of variance (ANOVA) tests (Tabachnick & Fidell, 2007, p. 244).

1.3.1 Interpretation of results

A difference was found in the percentage increase in scores between the experimental and control group - with the increase being greater for the experimental group. This increase was not statistically significant. Therefore, the null hypothesis (of no difference between the increase in score for the multimedia presentation and normal presentation) was accepted.

However, an evaluation of the difference in the percentage increase in scores for low-knowledge learners, between the experimental and control group showed to be statistically significant. This difference revealed a greater increase in scores for the questions pertaining to the multimedia presentation.

The difference in reaction time to the distractor between the control and experiment was found to be significant. Therefore, the null hypothesis of there being no difference in reaction time for the multimedia presentation and the normal presentation is rejected. However, this difference was due to a greater reaction time to the distractor for the multimedia presentation (experiment) and therefore the directional alternate hypothesis, which expected a smaller reaction time for the multimedia presentation, was rejected.

An evaluation of the difference in reaction time between the experimental and control group for the low knowledge learners revealed a greater reaction time to the distractor for the multimedia presentation, however, the difference was not found to be statistically significant.

The data analysis method and results are detailed in Chapter 4 of this document.

1.4 CONCLUSIONS

The results revealed a significant difference in reaction time between the experiment and control, however, a faster reaction time was revealed for the normal presentation (control) than for the multimedia presentation (experiment). The directional hypothesis was rejected and it is concluded that the multimedia presentation design used in this pilot study did not effectively reduce the learners' cognitive load.

The results revealed a greater increase in scores for the experiment than for the control. However, these results were not statistically significant and the null hypothesis was

accepted. Based on Mayer's (2009) expectation of multimedia design principles to have a greater effect on low-knowledge learners' understanding of the presented work, when compared to high-knowledge learners; the results for learners who had achieved less than 40% for their overall term mark, were analysed. These results revealed a significant difference in the increase in scores between the experiment and control, with a greater increase seen for the multimedia presentation (experiment) than for the normal presentation (control).

It is therefore concluded that the multimedia design principles were more effective in increasing the learners' knowledge on the topic than the standard, more traditional instructional methods. This effect is greater for learners with a lower knowledge of physical science than for those learners with a higher knowledge.

It is concluded that the dual-task methodology can be used with relative ease, to measure the primary and secondary tasks, however, more empirical research needs to be explored to evaluate the effectiveness of the dual-task methodology in measuring cognitive load.

Chapter 5 describes the conclusions of the study, the limitations and recommendations in more detail.

1.5 CHAPTER SUMMARY

The outline of the chapter in this document is presented below:

Chapter 2: Theoretical Background and Literature Review

Chapter two presents the theoretical framework guiding this study, as well as discussing and unpacking the key constructs.

Chapter 3: Research Design and Methodology

Chapter three covers the research approach and design, as well as the research questions and hypotheses. The sampling strategy, research instruments, data collection and data analysis procedures are also covered.

Chapter 4: Analysis and Results

Chapter four reports on the analysis of the data. The results that are presented offer a description for the demographics of the sample, the reaction times to the distractor as well as the increase in test scores.

Chapter 5: Conclusions, Limitations and Recommendations

Chapter five summarises the results and interprets them in the context of the background to the study. This chapter also discusses the limitations of the research as well as recommendations for future studies.

1.6 SUMMARY

This chapter has provided an introduction and orientation to the research. The problem, objectives of the research, research design and research methodology has been discussed.

A review and discussion of the research literature is provided in Chapter Two.

CHAPTER TWO: Theoretical Background and Literature Review

Computer technology has enabled an explosion in the availability of ways to present material - with a focus on web-based and multimedia instruction. The growing popularity of computer-based multimedia presentations can largely be attributed to the power of computer graphics and the capability of presenting text as either visual or auditory and pictures as either static or moving, as apposed to the one dimension of printed instruction (Mayer, 2009, p. 3; Hegarty, Narayanan, & Freitas, 2002). The call to expand instructional messages beyond the purely verbal and the constant need to generate new, effective instructional designs and techniques (Sweller & Chandler, 1991), has resulted in a strong focus on understanding the mental processes involved in learning through multimedia – where information is received through separate sensory channels (Mayer & Moreno, 2003). Cognitive load and modality in learning is one of the most popular topics in this area (Cook, 2009). Based on assumptions of the workings of human cognition, cognitive load is concerned with the ability to process information given the current capacity of the cognitive system. More complex learning tasks require more cognitive resources and as a result increase cognitive load (Xie & Salvendy, 2000). Therefore, to facilitate meaningful learning, instructional methods need to elicit the minimum cognitive load possible.

This chapter discusses: (1) multimedia learning and its cognitive assumptions regarding learners' information processes; (2) cognitive load theory and the variable types of load; (3) approaches to measuring cognitive load; and (4) reducing cognitive load in multimedia environments.

2.1 MULTIMEDIA LEARNING

Multimedia instruction makes use of different media - largely visual and auditory elements - to present educational content. The information is presented in verbal form (which includes spoken or printed text), together with pictorial form (static or dynamic graphics) in order to foster meaningful learning (Mayer, 2009, p. 5).

Mayer (2009, p11) identifies two approaches to designing multimedia material – a *technology-centred approach* and a *learner-centred approach*. The technology-centred

approach focuses on the latest technological advances available to determine which technology is the most effective to present information. However, this approach often fails to lead to long-term improvements in education. In contrast, the learner-centred approach is based on an understanding of human cognition and how it can be aided by the effective use of multimedia technology. The learner-centred approach emphasises that designs more in tune with how the mind works will enhance learning more effectively than those that are not.

It has been found (Mayer, 2003a; Mayer, 2003c) that designs which effectively enhance learning using traditional resources (eg: a text book) will be equally effective when using electronic resources. Mayer highlights that “the same design principles that promote learning in traditional environments are likely to promote learning in electronic environments” (Mayer, 2003a, p. 298).

2.1.1 Multimedia learning outcomes

Two major goals of learning can be identified, namely, remembering and understanding. The ability to remember what has been learnt is assessed by means of retention tests (testing the learners’ ability to reproduce or recognise the material). Questions can test recognition (as in multiple choice, true-false, fill in the word type questions), or recall – where learners paraphrase information they can remember (Mayer, 2003b, p23; Bruning et al., 2004, p97). On the other hand, understanding is the ability to use what was learned to solve problems of a similar nature in different situations. This is assessed by means of transfer tests – where learners solve problems that are not explicit, but require an understanding of the material (Mayer, 2003b, p23; Bruning et al., 2004, p162; Mayer & Wittrock, 2006). Retention tests are primarily concerned with how much was learned (quantity), while transfer tests are more concerned with how well the learner can apply what was learned to other situations (quality).

Three outcomes to multimedia learning, based on the goals mentioned above, are described by Mayer (2009, p. 21). *No learning* occurs when a learner is unable to remember what was presented, as well as not being able to use the material in other, similar situations. That is, when the learner performs poorly on both the retention and transfer tests. A situation where a learner is able to remember what was presented

(does well on the retention tests), but is unable to use the information to solve different problems (performs poorly on the transfer tests) is described as *rote learning*. In this case, the learner has acquired fragments of information that can be remembered, but not used in novel situations. The third outcome is when a learner is able to remember what was presented, and can use that knowledge in other areas or to solve new problems. Mayer (2009) describes this as *meaningful learning*, and identifies it as the primary goal when designing multimedia instruction.

It is the intention of this study to adopt a learner-centred approach in the design of the multimedia presentation covering physical science as the learning area. Scientific literacy requires a clear understanding of scientific concepts and methods and must be approached as a problem-solving process, not simply rote memorisation of definitions (Vosniadou, & Kollias, 2003, p184; Graesser, León, & Otero, 2002; Bruning et al., 2004). Therefore, the intention will be to facilitate meaningful learning amongst the learners.

2.2 COGNITIVE THEORY ASSUMPTIONS AND MULTIMEDIA LEARNING

Multimedia learning, as described in the previous section, relies on three main assumptions of cognitive theory (Mayer & Moreno, 2003; Mayer, 2009, p60): the dual-channel assumption, limited capacity assumption, and active processing assumption. As Paas, Tuovinen, Tabbers, & Van Gerven, (2003b) describe it, "*Cognitive load theory is based on a cognitive architecture that consists of a limited working memory with partly independent processing units for visual and auditory information, which interacts with an unlimited long-term memory.*"

2.2.1 Dual-channel assumption

The dual-channel assumption is based on the working memory model described in the background in Chapter 1 (Baddeley, 1986, 1992, 2001) and assumes that there are separate processing channels responsible for visual and auditory material (Paivio, 1986, p53). The *phonological loop* is identified as being responsible for holding speech-based information and processing the narrations and sounds presented to the ears, while the *visuospatial sketchpad* is concerned with visuospatial imagery and processing the

material presented to the eyes - including illustrations, text, animations or videos (Baddeley, 1986, 1992, 2001; Mayer, 2009, p64).

Although the information may enter the working memory via one of the channels, when learners have adequate available cognitive resources, it is possible for them to be able to convert the representation of the material for processing in the other channel (Mayer, 2009, p65). For example, an experienced reader may be able to mentally convert presented text from images in the visual channel into verbal representations in the auditory channel. Alternatively, learners may use available resources to convert a narration describing an event from auditory representation into a corresponding mental image processed in the visual channel (Dehn, 2008; Mayer, 2009, p66).

2.2.2 Limited capacity assumption

Current research on human memory is based on the assumption that working memory has a limited capacity which restricts the amount of verbal or visual information that can be held and processed in this system at any particular moment in time (Baddeley, 1986, 2001). An implication of this capacity limitation is that learners may only be able to hold a few interacting elements simultaneously in working memory during conscious cognitive processing (Paas et al., 2003a; Sweller, van Merriënboer, & Paas, 1998).

An example of interacting elements and the pressure they place on working memory is evident when a learner attempts to balance a chemical equation (Plass, Moreno & Brünken, 2010). Learning the individual symbols for the chemical elements can occur independently from one another. This does not impose large pressure on the capacity of the working memory – since it is not necessary for the learner to understand the chemical elements in order to remember them. However, once the learner begins to balance the chemical equation, the learner needs to simultaneously focus on all the elements in the equation and how they interact with each other. This requires a level of understanding from the learner, and therefore places a strain on the limited capacity of the working memory system (Plass et al., 2010).

If each channel has limited capacity, it becomes important to understand how much information can be processed by the different channels at once. The limitations of working memory has great implications for instructional design - where anything more than the simplest cognitive activities can overwhelm the learners' working memory (Sweller et al., 1998). Learning in domains such as Computer Programming, Mathematics, and Science, which involve complex cognition, is constrained by the limited processing capacity of the working memory (Paas, & van Merriënboer, 1994). Baddeley's (1992, 2001) central executive is responsible for controlling the allocation, monitoring, co-ordinating and adjusting of limited cognitive resources.

2.2.3 Active processing assumption

The active processing assumption focuses on learners actively trying to make sense of presented multimedia material. The following processes are identified as essential for active learning (Mayer, 2009, p70; Cook, 2009): paying attention and selecting the relevant material, organising the information, and integrating it with existing knowledge. This process is depicted in *Figure 2.1* (Mayer, 2009, p. 61). By paying attention to the relevant words and visuals in the presentation, learners can select the appropriate material to bring into the working memory. The material then becomes organised by building relationships between the elements of the information within the working memory. By activating existing knowledge in the long term memory and bringing it into the working memory, connections can be made between the elements of information and prior knowledge in order to allow learning to take place (Mayer & Wittrock, 2006; Mayer, 2009, p70).

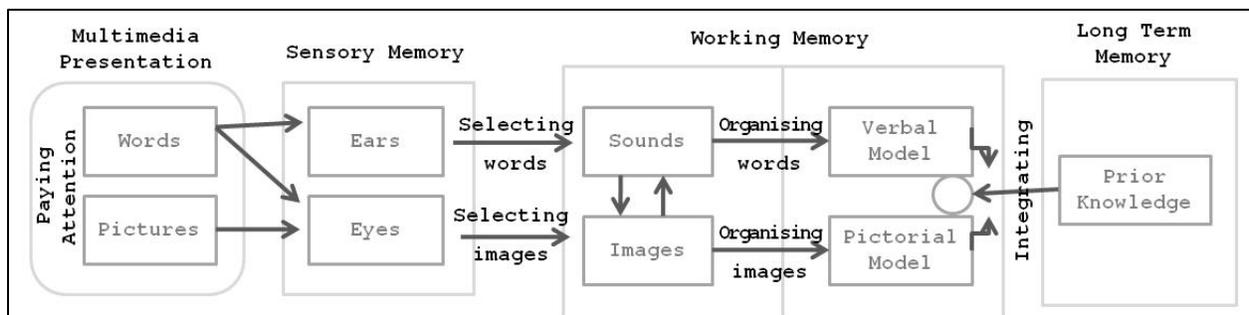


Figure 2.1 Cognitive theory of multimedia learning.

Long term memory expands the limited processing ability of the working memory by organising information in terms of knowledge structures such as schemas and categories - cognitive constructs that categorise multiple elements of information according to how they will be used, resulting in a single higher-order element subsuming elements sharing the same general function (Paas et al., 2003b; Sweller et al., 1998). For example, when reading, schemas of how letters are categorised into words and how the words are categorised into sentences allow the reader to derive meaning from the text. This automated function reduces the necessity of the working memory to process each individual mark on the page (Sweller et al., 1998).

Schemas provide the elements of knowledge (Sweller et al., 1998) and are processed in the working memory as a single element – so as not to exceed working memory capacity (Paas et al., 2003b). A schema has no apparent limit on informational complexity, with the automated function of storing and organising information in long term memory so as to reduce the working memory load. (Cook, 2009; Sweller et al., 1998; Paas et al., 2003b). Easing the processing of elements in working memory is the concern of cognitive load theory.

2.3 COGNITIVE LOAD THEORY

Cognitive load is defined as the demand a particular task places on the learners' working memory resources during learning (Paas, & van Merriënboer, 1994). Cognitive load theory (CLT) originated in the 1980s and has since been an area of much investigation and evaluation, facilitating the exploration of information processing and using cognitive psychology principles to generate new designs for instructional materials in order to enhance learning (Paas et al., 2003a; Sawicka, 2008; Cook, 2009). Sweller's (1988) focus on the limitation of the working memory during problem solving, facilitated the development of CLT with a focus on understanding the interaction between human cognition and instructional material to enhance learning. Cognitive load is not merely a result of the learning process but rather a major determining factor in the success of instructional interventions (Paas et al., 2003b; Elliott, Kurz, Beddow, & Frey, 2009).

High cognitive load and inappropriate direction of learners' attention is identified (Sweller, 1988; Xie & Salvendy, 2000) as one of the main reasons for instructional designs to fail in allowing learners to acquire adequate problem-solving skills (Paas & van Merriënboer, 1994). A high cognitive load is usually associated with tasks that are either new to the learners, performed under high time-pressure, or could result in punishment for mistakes made by the learners. Cognitive load can also be affected by learners' individual cognitive capabilities, prior knowledge, personal criteria of optimal performance, motivation or level of engagement with the material (Paas & van Merriënboer, 1994; Paas et al., 2003b).

The load on working memory can be influenced by the inherent complexity of the material (intrinsic cognitive load), by the presentation of the material (extraneous cognitive load) or by the activities required of the learners (germane cognitive load) (Sweller, 1999; Sweller et al. 1998).

2.3.1 Intrinsic cognitive load

Element interactivity (Paas et al., 2003a; Sweller et al. 1998; Sweller, 2010) refers to the amount of different types of information that need to be processed simultaneously in working memory in order to understand the material, and can be viewed on a continuum from low to high. Low element interactivity occurs when the elements can be learned in isolation, as they do not rely on each other to be understood. In instances of low element interactivity, the working memory load will be low due to the less complex nature of the task (Sweller et al., 1998). As previously mentioned in Section 2.2.2; an example of a task of low element interactivity is learning the chemical symbols. Although the task may be difficult due to the number of symbols to be learned, working memory is not heavily loaded, because each chemical symbol can be learned independently of the other symbols (Sweller, 2010).

On the opposite end of the continuum, material of high element interactivity can't be learned or understood until all of the elements and their interactions are manipulated simultaneously in working memory. For example, when manipulating algebraic equations each of the symbols act as an element and needs to be processed simultaneously in working memory (Sweller, 2010). As a result, high-element

interactivity material is difficult to understand (Paas et al., 2003a; Elliott et al., 2009). The complexity of the presented material increases as the element interactivity increases.

Intrinsic cognitive load is determined by an interaction between the inbuilt structure and complexity of the material being learned (element interactivity) and the learners' expertise. Intrinsic load cannot be directly influenced by the design of the instruction and therefore the intrinsic nature of the material could be enough to hinder learning (Sweller et al., 1998; Cook, 2009; Seufert, Jänen, & Brünken, 2007).

2.3.2 Extraneous cognitive load

Extraneous cognitive load is an unnecessary load caused by a confusing instructional design and is independent of the comprehension of the material (Sweller et al., 1998; Mayer, 2003b). Poorly designed material could make a difficult task even more difficult. Extraneous cognitive load occurs when designers do not take cognisance of the structure of human cognitive architecture and as a result working memory resources are used to process activities that are irrelevant to learning (Paas et al., 2003a; Mayer, 2003b).

For example, if the text is presented at the top of a screen and the animation at the bottom – the learner will have to scan between the words and animation, consuming much of the learners' cognitive capacity and leaving little for learning (selecting, integrating and organising the relevant elements) (Mayer, 2009, p80).

The loads imposed by element interactivity (intrinsic load) and instructional design (extraneous load) are additive. Therefore, the effect of extraneous cognitive load will be influenced by the intrinsic load of the material. When intrinsic load is low, extraneous cognitive load may be less important, as together, the total cognitive load might not exceed working memory capacity. Whereas, a combination of both high extraneous and high intrinsic load may substantially exceed working memory and in this way hinder learning (Paas et al., 2003a; Sweller et al., 1998). As a result, instructional designs focussed on reducing cognitive load are more effective for material with a high element

interactivity. When the material has low element interactivity, the designs may have little or no effect on reducing cognitive load (Paas et al., 2003a).

2.3.3 Germane cognitive load

Instructional designs to reduce overall cognitive load are only effective if learners use the available working memory capacity to actively engage with the material (Cook, 2009). Germane cognitive load is related to the learners' motivation and is the effect of the learners' efforts to engage in meaningful learning. Redirecting the learners' attention away from processes not relevant to learning, and towards constructive selection and integration of the important elements in the presentation, could increase germane cognitive load at the same time as decreasing extraneous cognitive load (Sweller et al., 1998; Sweller, 1999). The style in which information is presented, as well as the learning activities required, could facilitate the processing and learning of information and possibly increase available working memory resources (Paas et al., 2003a; Cook, 2009). While extraneous and intrinsic cognitive load impede learning, germane cognitive load enhances learning (Paas et al., 2003a).

The associations between intrinsic, extraneous and germane cognitive load are not symmetric (Elliott et al., 2009). Intrinsic cognitive load is the base load, which can only be reduced through previous experience and exposure to the material by allowing automation of existing schemas or, alternatively, the addition of new schemas. Working memory resources that are available after managing the intrinsic load can then be allocated to handle the extraneous and germane cognitive loads (Sawicka, 2008; Paas et al., 2003a). The relation between extraneous and germane cognitive load is such, that a reduced extraneous cognitive load through an effective instructional design, makes cognitive capacity available to increase germane cognitive load. This allows the learners to acquire knowledge and skills and thus improves learning (Paas et al., 2003a).

Therefore, a challenge for presentation designs is the limited available cognitive capacity for the intrinsic, extraneous and germane processing. Each of the different kinds of cognitive load presents a unique problem for instructional design: avoiding a

confusing layout and design of the material, overcoming the complexity of the material and using a motivating communication style (Mayer, 2009, p81).

2.4 MENTAL LOAD, MENTAL EFFORT AND PERFORMANCE

According to Paas and van Merriënboer (1994), cognitive load has two dimensions: a causal dimension representing the interaction between the learners' characteristics and the task at hand; and an assessment dimension of measurable concepts including mental load, mental effort, and performance.

Mental load allows an estimation of the expected demand on cognitive resources as it originates from the task or environmental factors and is constant for a certain task in a particular environment (Paas & van Merriënboer, 1994; Paas et al., 2003b). Mental effort comprises: task or environmental characteristics, the learners' characteristics, as well as an interaction between the two (Paas & van Merriënboer, 1994).

As a learner-centred dimension, *mental effort* refers to the cognitive capacity allocated to accommodate the demands of the task. It is measured while learners are busy working on an activity and can be considered a reflection of actual cognitive load. (Paas & van Merriënboer, 1994; Paas et al., 2003b).

Performance can be defined as the learners' ability to successfully complete the task - including error rate and speed - and can be measured during or after completion of the activity (Paas & van Merriënboer, 1994; Paas et al., 2003b).

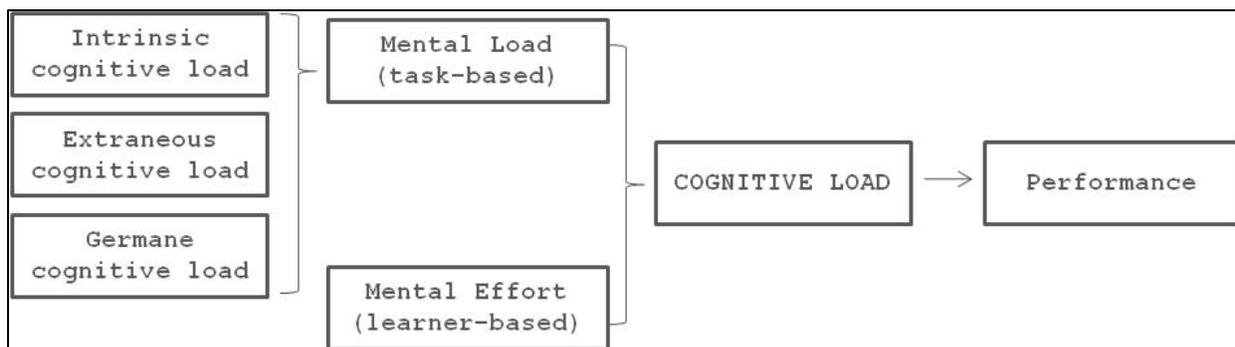


Figure 2.2 Schematic representation of the construct cognitive load.

Figure 2.2 depicts the relationship between the different types of cognitive load (causal factors) and the assessment dimensions. Mental effort is the key to a reliable estimate

of cognitive load, as it may yield information not necessarily reflected in mental load or performance measures (Paas & van Merriënboer, 1994). Instructional designs to decrease mental load will only be effective if the learners are motivated and invest mental effort in the tasks. Tasks based on cognitive load theory require less training time and less mental effort to achieve the same or better performance (Paas et al., 2003b). It is, however, possible for two learners to achieve the same performance levels on a task where the one learner needs to apply more effort than the other learner in order to arrive at the same answer (Paas & van Merriënboer, 1994).

2.5 MEASUREMENT OF COGNITIVE LOAD

Measuring cognitive load has long been a difficult area for researchers due to its multidimensional characteristics. By measuring mental load, mental effort and performance, cognitive load can be assessed (Paas & van Merriënboer, 1994; Tarmizi, Ayub, Bakar, Yunus, 2010). However, the interrelationships between these three elements are not consistent, as seen when learners compensate for an increased mental load by increasing mental effort in order to perform (Paas & van Merriënboer, 1994).

Measurements of cognitive load provide an empirical basis for the hypothetical effects of the instructional designs on learners' cognitive load; with existing measurements of cognitive load being categorised into analytical and empirical methods (Paas et al., 2003b; Xie & Salvendy, 2000).

2.5.1 Analytical methods

Analytical techniques are designed to estimate *mental load* without empirically measuring it or confirming it, by making use of subjective data such as expert opinion or analytical data including computer simulations, mathematical models and task analysis. (Paas et al., 2003b; Cook, 2009). Rating the difficulty of instructional materials is included in the analytical methods, and has been reported to show a high sensitivity to differences in instructions. However, these differences could possibly be attributed to the task difficulty, attention paid by the learners, or learners' competency (Brünken et al., 2003).

2.5.2 Empirical methods

Empirical methods are designed to estimate *mental effort* and *performance* by using subjective, physiological and performance-based techniques (Paas et al., 2003b).

Subjective Techniques

Rating scales are subjective techniques widely used by researchers to measure cognitive load because they are reliable, unintrusive, easy to use and relatively inexpensive (Cook, 2009; Paas et al., 2003b; Paas, van Merriënboer, & Adam, 1994). They are based on the assumption that learners are able to accurately report on the amount of mental effort spent on a task; mostly using the concept of overall load (Paas et al., 2003b). Most instruments make use of a questionnaire where the learners indicate their experienced level of mental effort or alternatively, the difficulty of the materials, on a scale - covering associated variables such as mental effort, fatigue and frustration (Paas et al., 2003b; Brünken et al., 2003). Rating scales have been found to be sensitive to relatively small differences in cognitive load (Paas et al., 1994) and it was highlighted by Gopher and Braune (1984) that learners are indeed capable of assigning numerical values, with relative ease and accuracy, to the imposed mental load or mental effort invested.

A limitation of the rating scales is the reliability on self-report which may be influenced by social desirability bias and errors in judgment (Cook, 2009). Furthermore, it is not clear how the reported mental effort relates to cognitive load, when a low invested effort could be due to a low-cognitive load or, alternatively, of such a high load that the learner decreased the mental effort used to engage with the material (Brünken et al., 2003; Cook, 2009). This issue, in turn, applies to the other measurements of cognitive load.

Physiological Techniques

Physiological techniques assume that changes in cognitive functioning may also be reflected in changes in physiological variables such as heart rate, brain activity, and pupil dilation (Paas et al., 2003b; Brünken et al., 2003). Measuring pupil dilation by means of task-evoked pupillary responses (TEPRs) measurements is a popular and useful technique. TEPRs are sensitive to fluctuating changes in cognitive load and are a

more objective measurement as they are measuring changes that occur without the learners' conscious control (Paas et al., 2003b; Cook, 2009). Another physiological technique which is gaining popularity is eye tracking – which records learners' eye movements and fixations while they are involved in processing visual information. As cognitive load increases, fixations will increase in number and duration, while learners may also return to an area in the presentation to reprocess confusing information (Cook, 2009; Holsanova, Holmberg, & Holmqvist, 2009).

However, physiological changes (pupil dilation, heart rate, brain activity) may also reflect emotional factors, including: anxiety, interest or motivation. These emotional factors could affect the results and, as in the case of eye tracking, the learners may continue to process information after they have looked away (Cook, 2009). Another identified drawback of physiological techniques is the expensive equipment that is intrusive and often difficult to use (Paas et al., 2003b; Cook, 2009).

Task and Performance Based Measures

Task and performance measures can be categorised into primary and secondary tasks. Primary task measurements are based on *performance* and would include accuracy scores on assessments of information learned (typically recall or recognition and transfer tests) (Paas et al., 2003b; Cook, 2009; Brünken et al., 2003). Secondary task methodology is based on performance in a secondary task *concurrent* to the primary task (Dual-task method) (Brünken, Steinbacher, Plass, & Leutner, 2002). Typically, secondary tasks would comprise simple activities requiring sustained attention, such as an auditory or visual signal to which learners are instructed to respond as quickly and accurately as possible (Paas et al., 2003b; Cook, 2009). Dual-task measures work on the assumption that available capacity from the primary task will be used to process the secondary task – as the difficulty of the primary task increases, performance on the secondary task will decline. Common performance variables include reaction time, accuracy and error rate (Paas et al., 2003b; Cook, 2009; Brünken et al., 2003; Brünken et al., 2002).

Dual-task methodology appears to be promising as a direct means to measure cognitive load induced by multimedia instruction (Brünken et al., 2002; Brünken et al., 2003).

When the amount of load induced by the design of the material is assessed, performance on the secondary task should differ for different designs of the same content. Furthermore, measuring the cognitive load induced by different instructional designs for the same learner will account for individual differences in abilities, interest and prior knowledge (Brünken et al., 2003; Brünken et al., 2002). A suitable measure identified by Brünken et al. (2003) is that of reaction time to a specific signal during a continuous monitoring task. The monitoring task uses only a few cognitive resources and therefore will not suppress the primary memory task, while the reaction time design limits interference between the primary and secondary tasks - maximising the use of the available cognitive capacity (Brünken et al., 2003). The speed of the reaction is directly dependent on the available cognitive resources, which is dependent on the capacity required by the primary task. Therefore, the reaction time (secondary task) in a dual-task measurement is a valid estimation of cognitive load elicited by the multimedia presentation (primary task) (Brünken et al., 2003).

Although dual-task methods may be more sensitive and reliable than analytical methods, rating scales or primary task methodologies, it can be difficult to be certain that outcomes achieved are purely due to cognitive load associated with the primary task and not a combination of load induced by both the primary and secondary tasks. Secondary tasks can interfere with the primary task, especially in instances when the primary task is complex and cognitive capacity is limited (Paas et al., 2003b).

Combining measures of the mental effort applied by learners (learning effort), together with the level of test performance is the best estimator of the efficiency of the instructional design in reducing cognitive load (Cook, 2009; Sweller et al., 1998; Dutke & Rinck, 2006).

2.6 REDUCING COGNITIVE LOAD

Cognitive load theory's increasing importance in instructional design has led to the development of theories and applications to lessen cognitive load elicited by instructional materials (Brünken et al., 2002; Mayer 2009, p278).

Mayer and Moreno (2003) present a theory of how learners engage with multimedia presentations and describe potential areas for cognitive overload in cases where learners' intended cognitive processing exceeds their available cognitive capacity. They suggest that for each overload scenario, a strategy should be presented for the design of multimedia instructions so as to reduce the chance of cognitive overload. Through research carried out over 12 years, Mayer obtained positive results, with high effect sizes, to support these recommendations for multimedia designs (Mayer, 2009).

2.6.1 Split-attention effect

The first type of cognitive overload described by Mayer and Moreno (2003) is a situation identified by Sweller (1999, p106) as the split-attention effect, which occurs when a learner's attention needs to be divided between the presented text and the corresponding visual representation or animation (specifically for multimedia presentations). For example, when an animation is presented at the top of the screen, but the corresponding text is presented at the bottom of the screen the learner uses resources to devote attention to both sources simultaneously, and then to integrate the animation and text (Mayer & Moreno, 2003; Sweller 1999; Sweller et al., 1998). The eyes receive the information from the words and the pictures (as depicted in Figure 2.1) at the same time, with only some of the information being able to be processed in the working memory, due to its limited capacity (Mayer & Moreno, 2003; Sweller et al., 1998; Sweller & Chandler, 1991). To overcome this overload, a solution of *off-loading* is proposed.

Offloading involves moving some of the essential processing from the visual channel to the auditory channel – which can be achieved by presenting the text as narration in order to reduce the processing demands on the visual channel. This technique allows for a better understanding by the learners and is referred to as the *modality effect* (Mayer & Moreno, 2003; Ginns, 2006; Nelson & Erlandson, 2008).

Increasing the capacity of the working memory by making use of both the visual and auditory streams is a widely accepted technique, and an area of much research (Sweller et al., 1998; Moreno, & Mayer, 1999; Kalyuga, Chandler, & Sweller, 2000). Although there has been some criticism regarding the explanations of the modality

effect (Rummer, Schweppe, Fürstenberg, Seufert, & Brünken, 2010; Guan, 2002), this effect does seem to have implications regarding the limitations of working memory, and provides evidence that working memory capacity can, to some extent, be increased. Presenting information to both the visual and auditory streams, to increase the capacity of working memory, has widely been adapted for instructional designs which have led to a decreased cognitive load and increased learning (Sweller et al., 1998; Schmidt-Weigand, Kohnert, & Glowalla, 2010).

2.6.2 High intrinsic load

When material is innately complex and both the auditory and visual channels are overloaded with essential processing demands, the presented material elicits high intrinsic load (Mayer & Moreno, 2003; Sweller 1999; Sweller et al., 1998). Although the complexity of the material cannot be altered, instructional designers can allow learners time to understand one section of information before proceeding to the next (Mayer & Moreno, 2003; Seufert et al., 2007). Two possible solutions are presented to help learners digest the complex information, namely *segmenting* and *pre-training*.

By allowing learners the time to process the presented material in between successive segments of the presentation, they are able to effectively select the relevant words and images and take the time to integrate them before moving on to the next section (Mayer & Moreno, 2003; Ibrahim, Antonenko, Greenwood, & Wheeler, 2011). An obvious way to achieve this is to allow learners to control the pace of the presentation themselves (by clicking for the next screen/ section of material to appear). This is referred to as the *segmentation effect* (Mayer & Moreno, 2003; Nelson & Erlandson, 2008).

Pre-training is another technique that can be used when the material is high in element interactivity. It involves giving the information regarding the components that make up the causal system, prior to the presentation. The learner is therefore familiar with the separate components of the system before trying to understand the causal link between them (Mayer & Moreno, 2003; Nelson & Erlandson, 2008). This *pre-training effect* occurs when learners, who have been exposed to the components before the presentation, have a better understanding of the multimedia presentation.

2.6.3 High extraneous load

In a presentation, where interesting but unnecessary information is added by designers, the learners may use up their limited cognitive resources on secondary processing and therefore have less resources available for essential processing (Mayer & Moreno, 2003). The addition of extraneous material thereby prevents learners from engaging in meaningful learning. *Weeding* and *signalling* are two techniques presented by Mayer and Moreno (2003) to overcome the extraneous overload.

Eliminating the interesting, but extraneous material, such as background music or irrelevant video clips, is called weeding and results in a multimedia presentation that is concise and coherent (Mayer & Moreno, 2003; Nelson & Erlandson, 2008; Ibrahim et al., 2011). A concise presentation encourages the learners to engage in essential processing only and results in the coherence effect. The *coherence effect* occurs when students understand a multimedia presentation without extraneous elements, better than an embellished one (Mayer & Moreno, 2003).

In instances when extraneous material cannot be removed, signalling learners' attention to the relevant material is effective in enhancing learning (Mayer & Moreno, 2003; Nelson & Erlandson, 2008; Ibrahim et al., 2011). This involves the provision of cues to the learner - advising on how to select and organise the relevant information. The *signalling effect* is exhibited when learners' understanding of a multimedia presentation is enhanced by the addition of cues on how to process the material (Mayer & Moreno, 2003).

2.6.4 Confusing presentation design

A confusing presentation design or layout can also result in high extraneous cognitive load for the learners.

Presenting words and visuals in separate windows or in an illogical layout, results in learners needing to scan the screen in order to align the text with the corresponding animation. This causes an increase in incidental processing which uses up the learners' limited resources unnecessarily and thus hinders learning (Mayer & Moreno, 2003; Moreno & Mayer, 1999).

An *integrated presentation* – one which aligns text with the graphic it is describing – results in a better understanding of the material, by reducing the learners' extraneous cognitive load. This is known as the *spatial contiguity effect* (Moreno & Mayer, 1999; Schmidt-Weigand et al., 2010; Holsanova et al., 2009; Ginns, 2006).

Another effective technique used to reduce extraneous cognitive load is to present words as narration only, as opposed to presenting words as both narration and text (Mayer & Moreno, 2003; Holsanova et al., 2009). Situations where words are presented simultaneously as narrations and on-screen text, are redundant and result in incidental processing by the learners to enable them to integrate the narration with the text. By presenting the words as narration only, learners will develop an increased understanding of the material. This is commonly known as the *redundancy effect* (Mayer & Moreno, 2003; Sweller et al., 1998; Sweller & Chandler, 1991).

2.6.5 Holding information in working memory

A presentation consisting of a narration followed successively by the corresponding animation, can increase cognitive load by requiring learners to hold the verbal presentation in working memory while the animation is presented (Mayer & Moreno, 2003). Cognitive resources allocated to holding the mental representation in working memory decrease the available capacity for the processing of the animation.

Synchronising the narration with the presentation is a technique used to lessen this effect. By simultaneously presenting the narration and animation, cognitive load is reduced, since the auditory channel effectively deals with the narration, while the visual channel handles the animation (Moreno & Mayer, 1999). However, this *temporal contiguity effect* is less effective in situations where the presentation alternates between only a few seconds of narration and animation. In these situations only a small amount of information needs to be held in the working memory and will therefore not overload it (Mayer & Moreno, 2003; Moreno & Mayer, 1999; Ginns, 2006).

The final technique identified by Mayer and Moreno (2003) is to match the instructional designs relevant to the expertise of the learners (Kalyuga, Ayres, Chandler, & Sweller, 2003). Learners who are capable of manipulating mental images with minimum mental

effort have been found - due to their cognitive abilities - to benefit more from the effects of a simultaneous presentation (Mayer & Moreno, 2003). It has also been found that more experienced learners may find some instructional techniques redundant and as a result place unnecessary load on their cognitive resources (Kalyuga et al., 2003). Therefore, the *spatial ability effect* is seen when individualisation (matching the type of learner to the presentation) is used to reduce cognitive load.

These nine methods of reducing cognitive load in multimedia presentations, as identified by Mayer and Moreno (2003), form the basis of this study, where the effectiveness of the techniques in an on-screen environment in a South African high school is evaluated.

2.7 SUMMARY OF THEORIES OF COGNITIVE LOAD AND MULTIMEDIA LEARNING

With much development in the fields of cognitive load theory and multimedia designs, the researchers and theorists have developed many approaches, definitions and methods. Those mentioned in this chapter have been summarised in Table 2.1 below.

Table 2.1 Summary of theories of cognitive load and multimedia learning.

TWO APPROACHES TO MULTIMEDIA DESIGN	
Technology based approach	Focus on the latest technological advances available to determine which technology will be the most effective.
Learner based approach	Focus on understanding how the mind works and how learning can be aided with technology.
THREE OUTCOMES OF MULTIMEDIA LEARNING	
No learning	Perform poorly on retention and transfer tests.
Rote learning	Perform well on retention tests and poorly on transfer tests.
Meaningful learning	Perform well on both retention and transfer tests.

THREE ASSUMPTIONS OF MULTIMEDIA LEARNING	
Dual-channel assumption	Assumes there are separate processing channels responsible for processing visual and auditory material.
Limit capacity assumption	A limited amount of information can be processed by each channel at one time.
Active processing assumption	Paying attention and selecting the relevant material, organising the information and integrating it with existing knowledge to actively try and make sense of the material.
THREE TYPES OF COGNITIVE LOAD	
Intrinsic	Influenced by the inherent complexity of the material.
Extraneous	Influenced by how the material is presented.
Germane	Influenced by the motivation of the learners.
THREE MEASURABLE DIMENSIONS OF COGNITIVE LOAD	
Mental Load	Estimation of the demand on cognitive resources due to the task at hand.
Mental Effort	Cognitive capacity allocated to accommodate the demands of the task.
Performance	Learners' ability to successfully complete the task.
TWO MEASURES OF COGNITIVE LOAD	
Analytical	Designed to estimate mental load without empirically measuring it.
Empirical	Designed to estimate mental effort and performance by using subjective (eg: rating scales), physiological (eg: TEPRs) and performance based techniques (eg: reaction time, accuracy and error rate).
FIVE TYPES OF COGNITIVE OVERLOAD	
Split attention effect	Produced when learners' attention needs to be divided between the presented text and the

	corresponding visual representation or animation.
High Intrinsic Load	Innately complex material combined with overloaded auditory and visual channels.
High Extraneous Load	Learners use up limited cognitive resources on secondary processing of interesting, but unnecessary information added by designers.
Confusing Presentation Design	Increased incidental processing due to presenting words and visuals in separate windows or an illogical layout resulting in learners needing to scan the screen to align text and animation.
Holding Information in Working Memory	Increased cognitive load by requiring learners to hold the verbal presentation in working memory while the successive animation is presented.
NINE WAYS TO REDUCE COGNITIVE LOAD	
Offloading	Moving some of the essential processing from the visual channel to the auditory channel.
Segmenting	Allowing learners sufficient time to process presented material in between successive segments of the presentation.
Pre-training	Providing instruction on the components that make up the causal system, prior to the presentation of the system.
Weeding	Eliminating interesting but extraneous material.
Signalling	Signalling learners' attention to the relevant material (when extraneous material cannot be removed).
Aligning	Aligning text with the corresponding graphic.
Eliminating redundancy	Presenting words as narration only as opposed to narration and text.
Synchronising	Simultaneously presenting narration and animation.
Individualising	Matching instructional designs relevant to the expertise of the learners.

CHAPTER THREE: Research Design and Methodology

This chapter provides an overview of the research design, the sample and the research instruments used. The data collection and data analysis procedures are also discussed.

3.1 RESEARCH DESIGN

This pilot study, which implemented a quantitative, pre-test/ post-test design, was used to investigate the effect of on-screen multimedia presentations on the cognitive load of learners. Control and experimental presentations were set up in order to determine the effect of the multimedia presentation on learners' recall of the information presented.

Learners' existing knowledge on the topic was assessed by means of a pre-test. A post-test was administered after they had viewed the presentation in order to assess the knowledge they had gained. The pre-test/ post-test design (*Figure 3.1*) controls for learners' existing knowledge on the subject of frictional force, before they view the presentation (Babbie, 2008; Neuman, 2007). It was expected that a higher level of knowledge would be gained for the experimental presentation than for the control presentation.

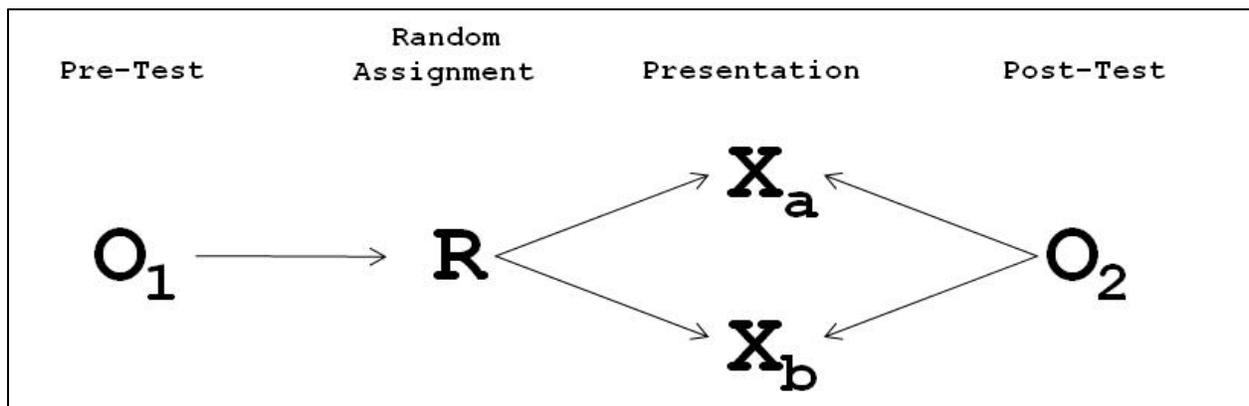


Figure 3.1 Illustration of the research design.

This pilot study was carried out in order to show the validity of the design of the study, the research instruments used, as well as the system used for recording the data obtained (Neuman, 2007). The study was designed to measure each learner's

performance on the control against their own performance in the experimental presentation.

Furthermore, a dual-task method was employed – with the presentation as the primary task, and reaction time to a distractor on each of the presented screens, the secondary task. A quicker reaction time was expected for the experimental presentation – due to available capacity from the primary task which can be used to process and react to the distractor (secondary task).

3.2 RESEARCH QUESTIONS

The research design was intended to answer the following research questions:

- Can an on-screen multimedia presentation, following Mayer and Moreno's (2003) nine ways to decrease cognitive load in multimedia presentations, reduce cognitive load for physical science learners?
- Can this multimedia presentation increase the learners' recall of the information?
- Can the dual-task method (Brünken et al., 2003) be used to measure both the primary task (the presentation) and secondary task (the reaction time to the distractor) simultaneously?

A comparison between the learners' increase in performance on the experiment and the control was used to determine whether the multimedia presentation was successful in increasing recall of the information. Analysis of the reaction time to the distractor for the experiment and the control helped to determine the learners' available cognitive capacity and ultimately to infer the cognitive load elicited by the multimedia presentation.

An assessment of the effectiveness of the dual-task method is achieved by analysing the reaction times to the experimental and the control task, as well as qualitatively determining whether the method was successful - by considering the ease of setting up and carrying out the methodology.

3.3 HYPOTHESES

The following two hypotheses were postulated. To investigate whether:

- The reaction time to the distractor for the multimedia presentation (experiment) will be smaller than for the normal presentation (control).
- The increase in the test scores will be greater for the multimedia presentation than for the normal presentation.

3.4 POPULATION AND SAMPLE

The population of interest for this investigation are learners in the Further Education and Training (FET) Phase (Grade 10 – 12) who take physical science as a subject. Grade 11 learners were selected because they would have had at least one year of exposure to physical science in the FET phase (in Grade 10) and will be progressing to Grade 12 the following year. Purposive, convenience sampling was used to select the sample for this pilot study.

Convenience sampling was used to select a local high school that was available to participate in the research. The high school that participated is comprised of 44.3% males and 55.7% females aged between 13 – 20 years (Figure 3.2). The racial distribution of the learners is 38.2% White, 46.6% Black, 9.1% Coloured and 6.1% Indian (Figure 3.3). The high school is representative of the population of learners in South Africa in terms of gender (Statistics South Africa, 2010) with the slight majority of learners being female. The racial representation of the school is adequate when compared to the learner population (Department of Basic Education, 2010) – with the majority of the learners being Black. However, higher proportions of White, Coloured and Indian learners are enrolled at the participating high school as compared with the learner population of South Africa.

The two participating classes of learners were selected by the teacher and the multimedia lesson took place during their allocated Science lesson. These classes were purposively identified due to all the learners currently taking physical science, with one year of experience in the subject. The sample used for analysis ($n= 57$) was made up of 42.1% males and 57.9% females all aged between 17 – 19 years. 42.1% of the learners were White, 33.3% Black, 12.3% Coloured and 12.3% Indian.

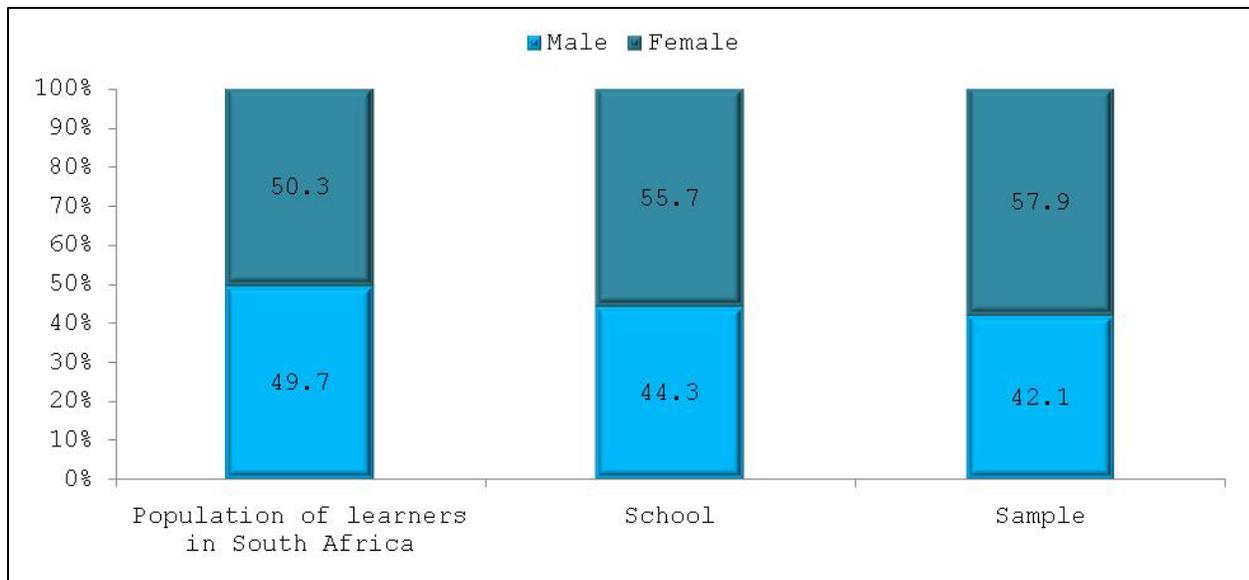


Figure 3.2 Gender representation of sample.

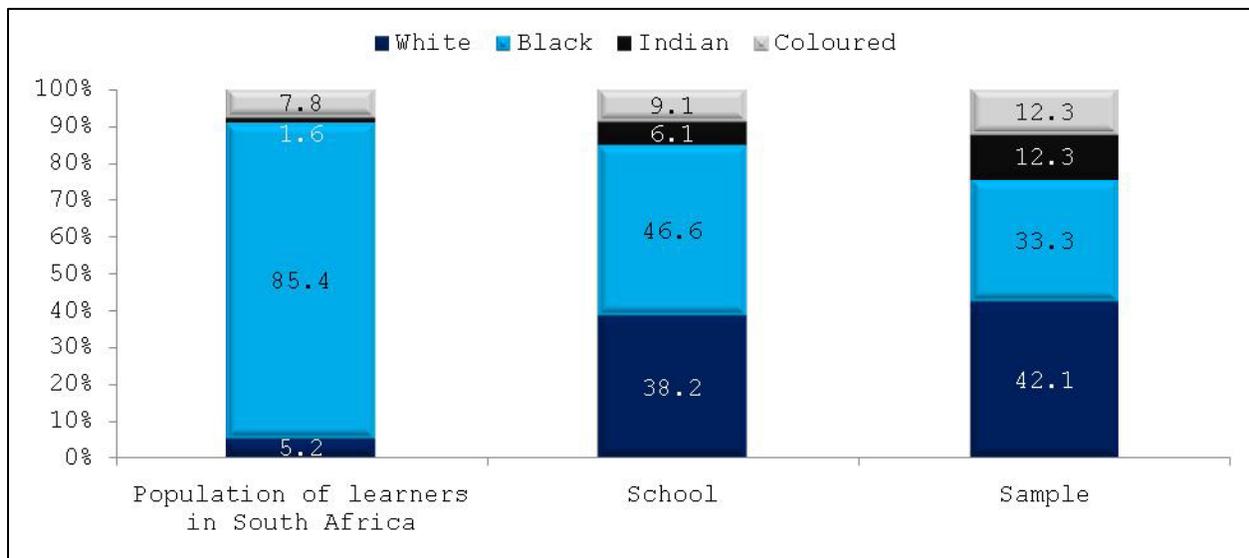


Figure 3.3 Race representation of sample.

3.5 RESEARCH INSTRUMENTS

The on-screen multimedia presentations were specifically developed for this study to best answer the research objective. Two different presentations (APPENDICES A and B) were developed to present the section of work to the learners that cover frictional forces. Specifically, the learners were required to answer questions covering definitions, concepts, equations and real-world applications relating to static and kinetic friction.

This section of work was selected because it was scheduled to be taught by the physical science teacher. The content of the presentations was derived from the learners' study material (Olivier, n.d.) and was perused and approved as appropriate by the physical science teacher.

3.5.1 Questionnaires

The pre-test questionnaire was formulated by using questions relating to the content covered in the presentation, derived from the reference material (Olivier, n.d.) (APPENDIX C). These questions were then re-ordered to form the post-test questionnaire (APPENDIX D). The physical science teacher perused and approved both the pre-test and post-test questionnaire.

3.5.2 On-screen multimedia presentations

To create the control screens (in line with traditional teaching resources used at the school), content derived from the reference material (Olivier, n.d.) was transferred in its original format into an electronic representation. These screens were then converted into a multimedia equivalent, incorporating Mayer and Moreno's (2003) *nine ways to reduce cognitive load* (Figure 3.4).

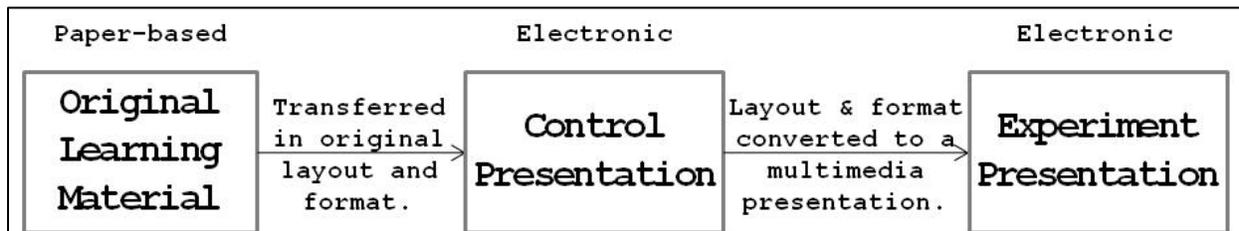


Figure 3.4 Creation of control and experiment presentation.

This resulted in equivalent control and experiment presentations with regards to content. The only difference between the presentations was the mode of presentation - a standard presentation for the control and a multimedia presentation for the experiment. Table 3.1 below outlines how these principles for reducing cognitive load were incorporated into the multimedia presentation.

Table 3.1 Incorporating principles for reducing cognitive load.

<p>NINE WAYS TO REDUCE COGNITIVE LOAD (MAYER & MORENO, 2003).</p>	<p>INCORPORATION INTO THE MULTIMEDIA PRESENTATION.</p>
<p>Offloading</p>	<p>Where appropriate, the written text was converted into a narration - to reduce processing by the visual channel.</p>
<p>Segmenting</p>	<p>Learners controlled the movement between the screens - allowing sufficient time to process the presented material between successive segments of the presentation.</p>
<p>Pre-training</p>	<p>Learners received training on basic physics principles in Grade 10 science lessons.</p>
<p>Weeding</p>	<p>Extraneous and unnecessary information was eliminated - resulting in a concise presentation requiring only essential processing.</p>
<p>Signalling</p>	<p>Where appropriate, key aspects were highlighted to attract learners' attention.</p>
<p>Aligning</p>	<p>Text was presented in alignment with the corresponding graphic to reduce extraneous processing due to a confusing layout.</p>
<p>Eliminating redundancy</p>	<p>Redundancy was avoided by ensuring information was presented either as narration only or text only.</p>
<p>Synchronising</p>	<p>Narrations were presented simultaneously with the corresponding animations - to reduce the amount of information learners needed to hold in working memory.</p>

Individualising	Purposive selection of learners who have experience and an appropriate level of expertise in physical science was implemented.
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Grouping of screens

The screens for the different presentations were grouped into two groups according to the specific concepts covered in each screen. The corresponding questions were also grouped accordingly. This grouping was to ensure the answers to those questions could only come from that group of screens. The allocation of screens and questions to the different groups is outlined in APPENDIX E. A t-test (Table 3.2) revealed no significant difference between the two groups of screens and questions (*p value = .057*).

Table 3.2 T-test: percentage increase in score for Group 1 and Group 2.

Group	N	Mean	Std. Deviation	Std. Error Mean
1	57	.4269	.32877	.04355
2	57	.3224	.24657	.03266

Levene's Test for Equality of Variances		t-test for Equality of Means						
F	Sig.	t	df	Sig. (2tailed)	Mean Diff	Std. Error Diff	95% Confidence Interval Difference	
							Lower	Upper
5.448	.021	1.920	112	.057	.10453	.05443	-.00332	.21238

The presentations were then drafted to contain one group of screens that were control screens and another group of screens which were experimental (multimedia) screens. Because the experimental presentation did not have the same number of screens as the control presentation once it was converted to a multimedia presentation, great care

was taken to ensure that the correct, corresponding screens were allocated to each group (Figure 3.5).

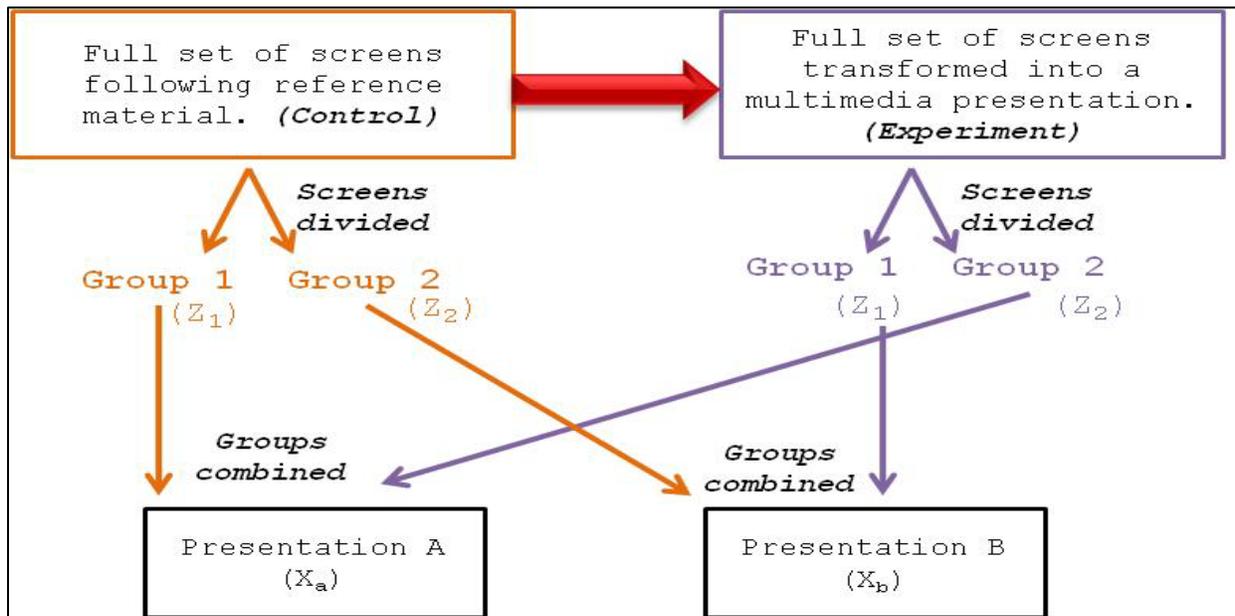


Figure 3.5 Grouping of screens into presentations.

This resulted in Group 1 containing 10 screens for Presentation A, 12 screens for Presentation B and a total of 12 marks for the questionnaire. Group 2 contained a total of 7 screens for Presentation A, 8 screens for Presentation B and a total of 8 marks for the questionnaire (Table 3.3).

Table 3.3 Total number of screens and questions per group.

Group	Presentation	Experiment/Control	Number of Screens	Total marks for questionnaire
1	A	Control	10	12
	B	Experiment	12	
2	A	Experiment	7	8
	B	Control	8	

Programming of presentations

The presentations were programmed in C# using *Visual Studio 2010*¹. Visual Studio and C# were chosen because the majority of the program relies on graphic representation and multimedia; and the selected technologies have excellent support for multiple media formats and Graphical User Interface (GUI) development (Deitel, Dietel, Listfield, Nieto, Yaeger, & Zlatkina, 2002). After the completion of programming of the presentations, the executable file (.exe) was used to run the presentation on a computer without the need to install any additional files.

Execution of presentation

Once the learners clicked on the executable file and launched the presentation, the start screen appeared (*Figure 3.6*). This screen was designed to obtain the learner's name and surname - in order to link the results to the correct learner - as well as to provide them with the necessary instructions for executing the task.

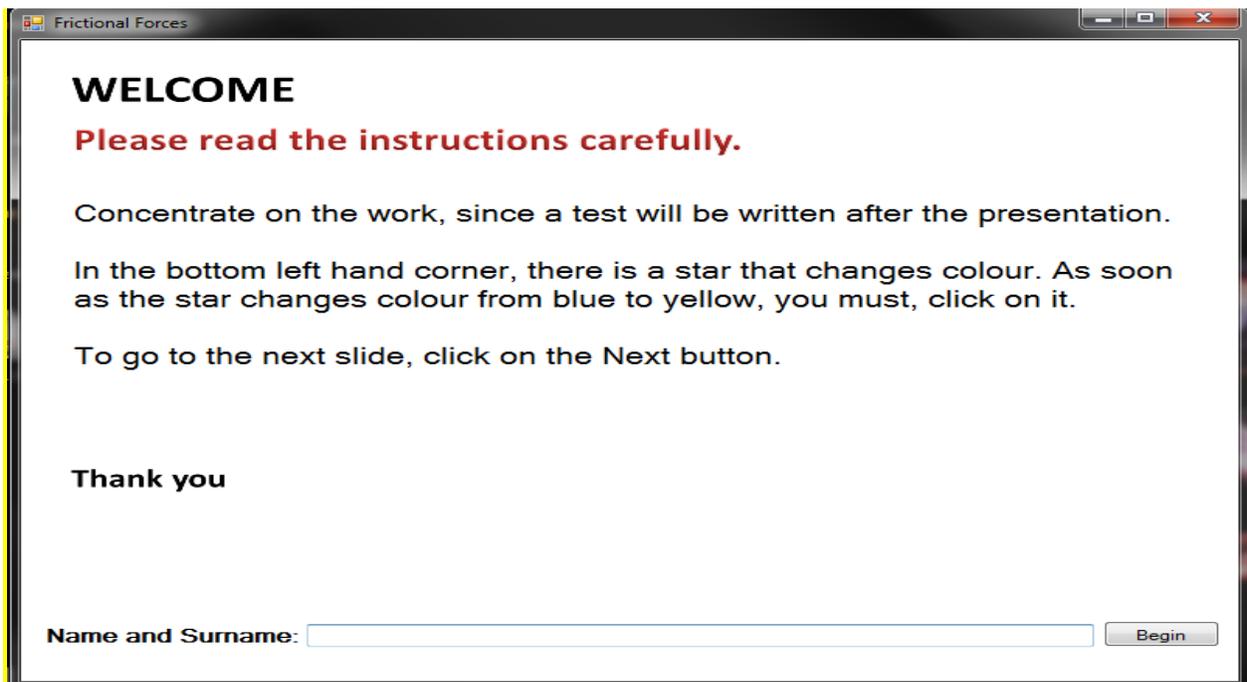


Figure 3.6 Start screen of the presentation.

¹ Visual Studio is an Integrated Development Environment (IDE) developed by Microsoft and is used to develop console and graphical user interface applications for mobile, desktop and web-based applications (Deitel, Dietel, Listfield, Nieto, Yaeger, & Zlatkina, 2002).

Each screen of both the control and experimental presentations had a blue star in the left hand corner (*Figure 3.7*). This star was used as the distractor – the secondary task – in the dual-task method. The learners were instructed to click on the star when it changed to yellow. The time it took for the colour of the star to change was randomised. The colours (blue changing to yellow) were decided upon to account for possible deficits in the learners' ability to discriminate between colours. Arditi (2010) advises on the use of colours that differ dramatically in hue, lightness and saturation to compensate for any colour perception deficits.

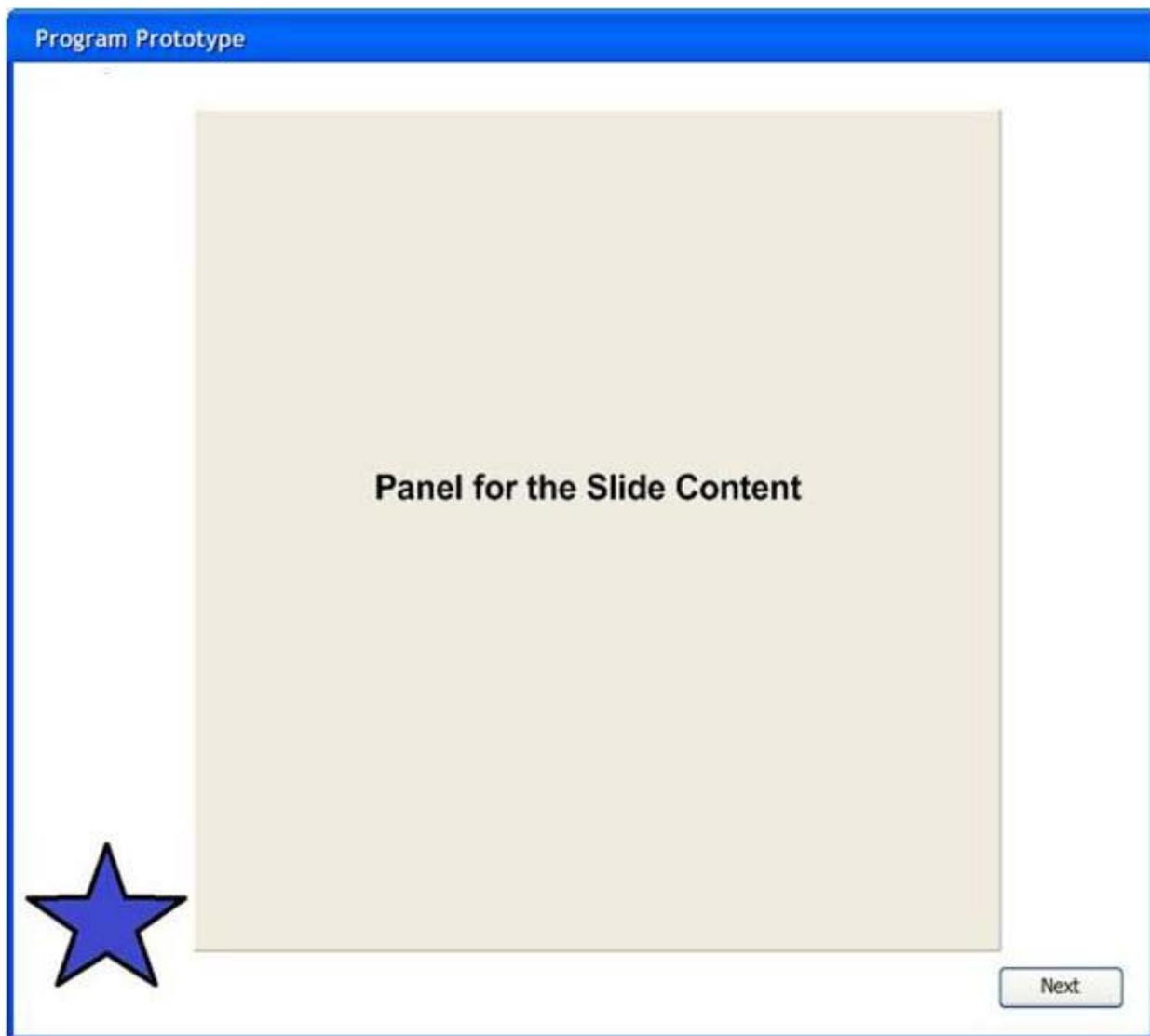


Figure 3.7 Basic layout of each screen.

Once the learners had read through and understood the information on the screen they proceeded to the following screen by clicking the “Next” button in the bottom right hand corner of the screen. The presentation allowed the learners themselves to control the speed at which they could move from one screen to the next screen in order to allow for learners who may be slower or faster than others.

File to record reaction time

The output of the application is a text file (.txt) that could be used to compute the necessary statistics. The text file included: the name of the learner, as well as the timestamp of: when the test started and ended; when the star changed colour; when the star was clicked on and when the next screen appeared. The timestamp could then be used to determine the duration of time spent on each screen as well as the time it took for the learner to react to the colour change.

3.6 DATA COLLECTION PROCEDURE

The presentations were uploaded onto the computers in the computer lab. One row of computers was loaded with Presentation A, the other row with Presentation B, resulting in an equal number of computers with Presentation A and Presentation B. Learners entered the computer lab at the beginning of the lesson and chose the computer at which they wanted to sit, ensuring a quasi-random assignment of the learners to the different presentations. Of the 57 learners, 26 viewed Presentation A and 31 viewed Presentation B. Random assignment is important to ensure the two groups of learners are comparable and do not differ on aspects that may offer an alternative explanation for the research findings (Babbie, 2008; Neuman, 2007).

The lesson was facilitated by the physical science teacher who instructed the learners to answer the pre-test questions before viewing the presentation. They were told to watch for the distractor and to click on it when it changed from blue to yellow. It was also explained that they would be answering questions after the presentation, based on what was covered. This was to encourage them to concentrate on the content of the presentation and not to focus only on the changing colour of the distractor. Each

computer had its own headphones for auditory output – so as not to distract the learners around them.

After the learners had completed the presentation they answered the post-test questions relating to the presentation. Once the class had left, the text files recording the necessary statistics were extracted for each learner.

3.6.1 Internal and external validity

Neuman (2007) outlines possible threats to internal and external validity. These were overcome in different ways in this study:

- An analysis of the difference in pre-test scores for the learners who viewed Presentation A and those who viewed Presentation B was used to rule out any **selection bias**. A t-test (Table 3.4) revealed no significant difference between the two groups of learners (*p value = .427*).

Table 3.4 T-test: pre-test for Presentation A and Presentation B.

Presentation	N	Mean	Std. Deviation	Std. Error Mean
A	26	5.50	2.140	.420
B	31	5.03	2.243	.403

Levene's Test for Equality of Variances		t-test for Equality of Means						
F	Sig.	t	df	Sig. (2tailed)	Mean Diff	Std. Error Diff	95% Confidence Interval Difference	
							Lower	Upper
.004	.950	.801	55	.427	.468	.584	-.703	1.639

- A possible **testing-effect** is controlled for by the pre-test/ post-test design of the study. The pre-test affects both the experiment and the control equally; therefore,

any increase in test score due to priming when learners answer the pre-test will affect both experiment and control equally.

- Examination of the pre-test scores (Table 3.5) shows that the learners were not previously aware of the topic of frictional force, and rules out possible **statistical regression** since the learners did not achieve near perfect scores on the pre-test (*mean score of 5.25 out of a total of 20 (26%)*). This implies that there was room for the learners to improve on the questionnaire scores after viewing the presentation.

Table 3.5 Analysis of the pre-test scores.

N	Minimum	Maximum	Mean	Std. Deviation
57	1	10	5.25	2.190

- **Diffusion of treatment/ contamination** could not occur as the classes were scheduled directly after one another (as the one class left, the other class was waiting outside a different venue and were then directed to the computer room - leaving them no time to discuss what had happened in the lesson).
- To control for **researcher expectancy** a double blind experiment was used. The science teacher who marked the papers was not the same teacher who checked and administered the lesson and was therefore unaware of the details of the study or that it was pre- and post-test questions she was marking. She therefore had no expectations for the results.
- No **instrumentation problems** occurred during the experiment – all the programmes and hardware worked as planned.
- The research occurred in a **naturalistic environment** - where the learners are unaware that they are involved in research and behave in a natural way. This protects the ability to generalise experimental findings to events and settings outside the experiment itself (i.e. an average classroom environment).

3.7 ETHICS

The teacher voluntarily agreed for the scheduled lesson to be presented as an on-screen presentation and to participate as the facilitator. The study was a non-intrusive observation of the classroom and there was no manipulation of the learners' emotions, thoughts or feelings. Learners were not told that they were participating in a study - the work covered in the presentation forms part of the physical science syllabus and the setting is naturalistic - as the physical science teacher still presented the lesson in the computer lab in their usual science lesson. No one was placed in physical danger or in embarrassing or anxiety-inducing situations and no deception, misleading or lying occurred. Once the post-test was completed, the learners were informed about how the lesson fits into the research study, and gave their consent for the results to be analysed and used as part of the study (Esomar, 2009).

The on-screen multimedia presentation enhanced the topic which was scheduled to be covered by the physical science teacher. Physical science learners could benefit from this method of teaching, should it be revealed that the on-screen multimedia presentations are a more effective method of instruction.

The results of the pre- and post-test questions did not influence the learners' term marks or their progress in the grade as the teacher re-taught the section of work by means of the lesson format that is typically used. This was done to ensure that no one was disadvantaged due to the topic being presented in a different format to what they are used to.

3.8 DATA ANALYSIS PROCEDURES

3.8.1 Reaction time to distractor

The difference in time from when the star changed colour to when the star was clicked on by the individual learner was recorded in order to get the learner's reaction time to the distractor. The average reaction time per learner in response to the screens of Group 1 and the average reaction time per learner in response to the screens of Group 2, were calculated.

If a learner exited a screen before the distractor changed colour, no time was assigned to that screen neither was it added to the average reaction time for the learner for that group. However, if the learner did not click on the distractor for a particular screen, it was assumed that most of the learner's cognitive capacity was used to process the presented screen, with little or no resources remaining to process the distractor. Therefore the time the learner spent on the screen was recorded as the reaction time (as opposed to not including the time in the average) – to ensure that a lower average was not reported.

3.8.2 Questionnaires

The questionnaires were marked by an independent science teacher, who was unaware of the study as well as the different pre- and post-tests. To reduce bias, the pre- and post-tests were sent as a single pack for marking, and the learners' names were removed from the questionnaires with only identifying numbers being allocated.

The score obtained per question by each learner for the pre-test questionnaire was subtracted from the score obtained per corresponding question for the post-test questionnaire. Likewise, the overall test score for the pre-test was subtracted from the overall score for the post-test, thereby giving results for the variable *increase in scores*. The questions were grouped together according to the screens to which they corresponded. The increase in scores for the questions in Group 1, as well as the increase in scores for the questions in Group 2 was calculated for each learner.

3.8.3 Assignment of results to experiment and control

The experiment was made up of Group 1 results for learners who viewed Presentation B and Group 2 results of learners who viewed Presentation A. Therefore the whole learner group was represented in the experiment. The control was made up of Group 1 results for learners who viewed Presentation A and Group 2 results for learners who viewed Presentation B. Therefore the whole learner group was represented in the control (Table 3.6).

Table 3.6 Assignment of results to experiment and control.

	Group 1	Group 2	Total
Experiment	Presentation B (n=31)	Presentation A (n=26)	57
Control	Presentation A (n=26)	Presentation B (n=31)	57
Total	57	57	

Therefore each individual learner's performance in the standard on-screen presentation (control) was compared to their own performance in the multimedia on-screen presentation (experiment). This was done in order to control for differences in experience, cognitive capacity (Brünken, et al., 2003), interpretation of the material, enthusiasm and anxiety.

The results for the control group as a whole was compared to the experimental group as a whole with both groups containing results for the full set of learners.

3.8.4 Multivariate analysis of variance

A multivariate analysis of variance (MANOVA) was used to analyse the data. This technique was decided upon as it allows for the simultaneous testing of the differences in means for several dependent variables (SPSS South Africa, 2001, p. 9-2). The independent variable in this study is the type of presentation (experiment or control), while the dependent variables are the increase in test score for the post-test when compared to the pre-test, as well as the reaction time of the learner to the presented distractor.

3.9 SUMMARY

This chapter has outlined the research design and methodology. The analysis of the data as well as the results and findings will be discussed in detail in Chapter Four.

Extensive time was invested in the planning and preparation of the experimental work as well as in the handling of the data in order to carry out the research in the most efficient and effective way, with the highest possible degree of accuracy.

CHAPTER FOUR: Analysis and Results

This chapter reports on the analysis of the data, using the IBM SPSS statistical package (version 19). The results that are presented offer a description for the demographics of the sample, the reaction times to the distractor as well as the increase in test scores.

4.1 DESCRIPTION OF THE SAMPLE

A total of 65 learners from an English medium school participated in the lesson. After the data cleaning process, 57 learners' results remained; 8 results had to be removed due to incomplete data sets as well as the reaction times not writing to the text files correctly.

Of the results that were used, 26 learners viewed Presentation A (45.6%) and 31 viewed Presentation B (54.4%). The sample of 57 was made up of 42.1% (24) males and 57.9% (33) females all aged from 17-19 years. Furthermore, 42.1% (24) of the learners were White, 33.3% (19) Black, 12.3% (7) Coloured and 12.3% (7) Indian.

4.2 REACTION TIME TO DISTRACTOR

The research questions: *“Can an on-screen multimedia presentation following Mayer and Moreno’s (2003) nine ways to decrease cognitive load in multimedia presentations, reduce cognitive load for physical science learners?”* and *“Can the dual-task method (Brünken et al., 2003) be used to measure both the primary task (the presentation) and secondary task (the reaction time to the distractor) simultaneously?”*, are answered by analysing the learners' reaction time to the distractor in the presentation. The star changing colour is the distractor while the learners' reaction to the colour change (clicking on the star) is the secondary task in the dual-task method.

The reaction time to the distractor was calculated by subtracting the time it took the learner to click on the star from the time at which the star changed from blue to yellow. If a screen was exited by the learner before the distractor changed colour, no time was assigned to that screen. Whereas, if the distractor for a particular screen was not clicked on by the learner, the time they spent on the screen was used as the reaction time.

Due to the grouping of screens (as outlined in APPENDIX E), the average reaction time was calculated for the screens that form part of a particular screen category. The reaction times for each individual learner for these screen categories were then grouped together to form an average reaction time for the Group 1 screens as well as an average reaction time for the Group 2 screens. Depending on which presentation the learner viewed, Group 1 will either be the control or the experiment, and likewise with Group 2. The data arrangement process for the reaction times is depicted below in *Figure 4.1*.

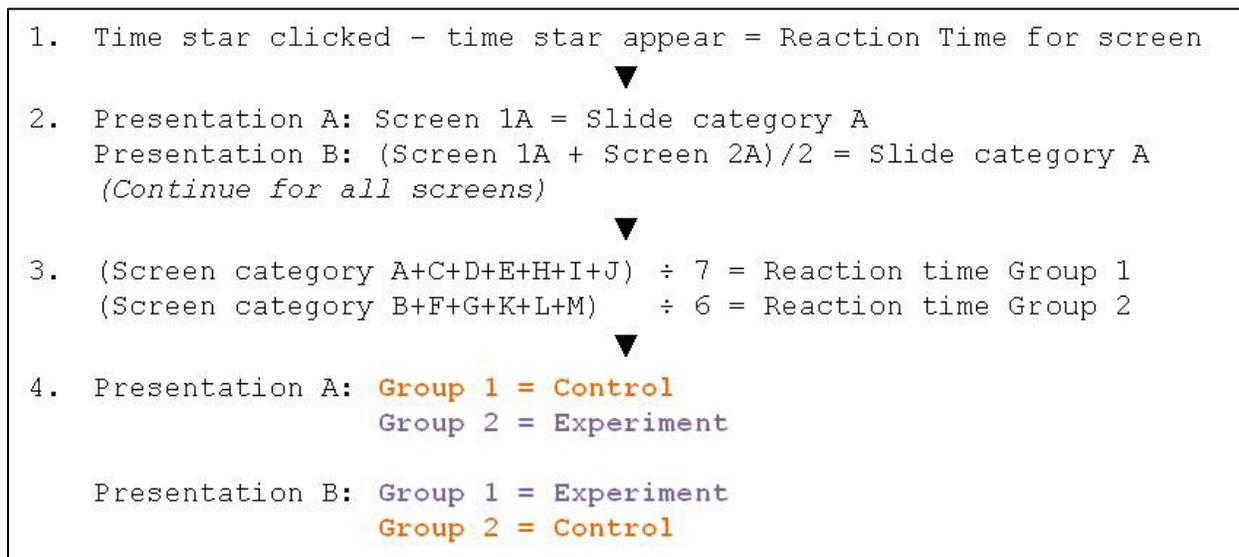


Figure 4.1 Data arrangement for calculating the reaction time to the distractor.

4.3 INCREASE IN TEST SCORES

The research question: “*Can this type of multimedia presentation increase the learners’ recall of the information?*” is answered by analysing and comparing the pre-test and post-test scores for the questionnaires.

The increase in test scores was calculated by subtracting the score the learner obtained for a question on the pre-test from the score obtained for the corresponding question on the post-test. As with the reaction times, the grouping of the questions (outlined in APPENDIX E) resulted in an average score for the learner being obtained for the Group 1 and Group 2 questions. The data arrangement process for the increase in test scores is outlined in *Figure 4.2* below.

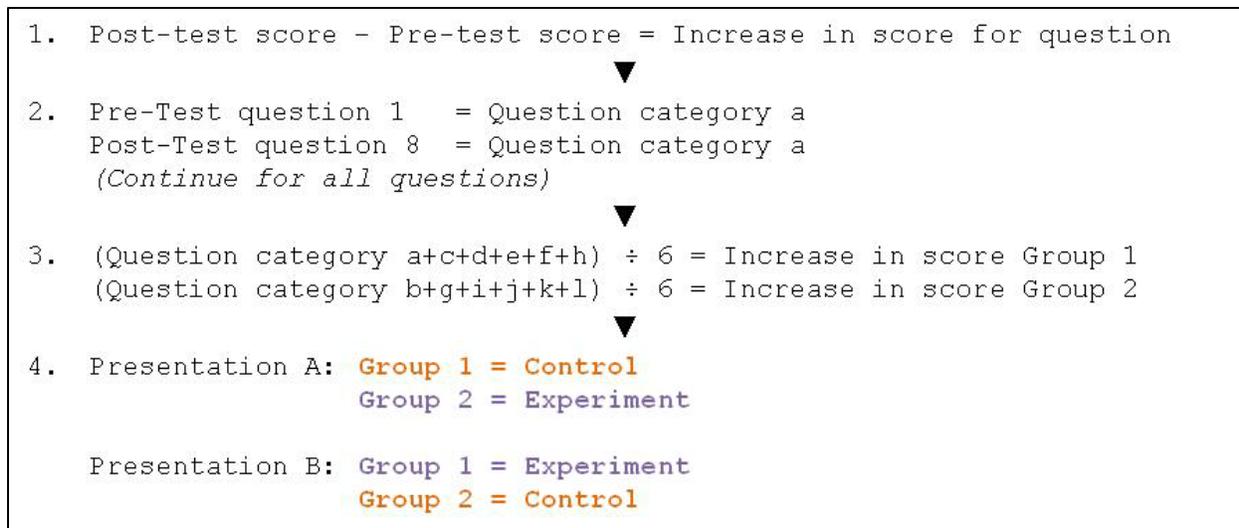


Figure 4.2 Data arrangement for calculating the increase in test scores.

4.4 COMBINING GROUP RESULTS FOR EXPERIMENT AND CONTROL

In order to compare the differences in reaction times between the control and experiment as well as the increase in scores for the control and experiment, the results for the different groups needed to be combined. Group 1 results for learners who viewed Presentation A were combined with Group 2 results for Presentation B to form the data set for the control. To form the experimental data set, Group 2 results for Presentation A were combined with Group 2 results for Presentation B.

4.5 DETERMINING THE DIFFERENCE BETWEEN EXPERIMENT AND CONTROL

A multivariate analysis of variance (MANOVA) was used to test the differences in mean increase in test score as well as the mean reaction time to the presented distractor for the experiment compared to the control. There are typically two reasons why a MANOVA would be used, namely statistical power to detect true differences, as well as to control for Type 1 error (false positive results) that may occur when running separate multiple analysis of variance (ANOVA) tests (Tabachnick & Fidell, 2007, p. 244).

4.6 DESCRIPTIVE STATISTICS

The experiment and control group each had 57 results – representing the whole learner group - with each learner having participated in both the experiment and the control.

The total possible increase in score for Group 1 is 12, while the total possible increase in score for Group 2 is 8. The increase in score was therefore compared in percentages. The frequencies of the overall percentage increase in scores are represented in Table 4.1 and graphically displayed in *Figure 4.3*.

Table 4.1 Increase in scores for the control and experiment.

Increase in Score	Frequency Control (%)	Frequency Experiment (%)
-25%	7.0	3.5
-17%	1.8	-
-8%	3.5	1.8
0%	10.5	14
8%	10.5	5.3
13%	5.3	5.3
17%	-	5.3
25%	19.3	12.3
33%	10.5	14
38%	10.5	8.8
42%	1.8	1.8
50%	12.3	14
58%	-	1.8
63%	5.3	1.8
67%	-	3.5
75%	-	5.3
83%	-	1.8
100%	1.8	-

	N	Minimum	Maximum	Mean	Std. Deviation
Control	57	-25	100	23.39	25.195
Experiment	57	-25	83.33	29.60	24.971

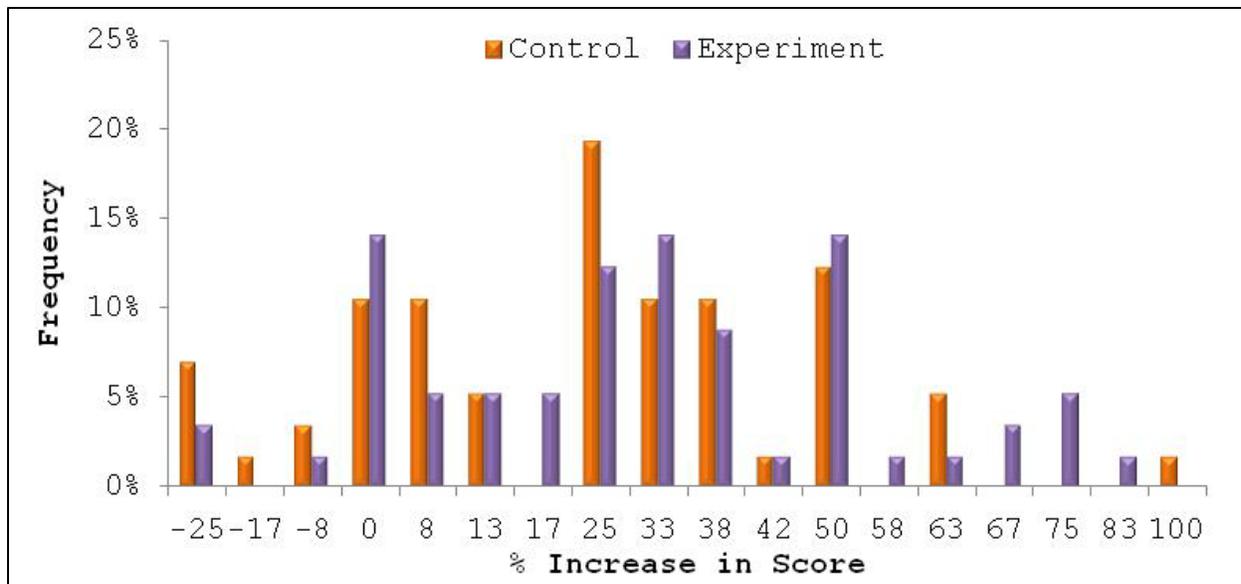


Figure 4.3 Percentage increase in scores for the control and experiment.

Overall, 8.8% of learners (7 in the control group and 3 in the experimental group), showed a decrease in scores from the pre-test to the post-test. This could possibly be due to fatigue, rushing to complete the post-test, concentrating more on the distractor than the presentation or a lack of interest. No increase in score between the pre- and post-test was seen for 10.5% of the control group, compared to 14% of the experimental group. The majority (54.4%) of the control group showed an increase of between 25% and 50% in score, while the majority of the experimental group (64.9%) showed an increase of between 25% and 83% in score. The mean increase in score for the control group is 23.4% while the mean increase in score for the experimental group is 29.6%.

The learners' reaction times per screen to the distractor are represented in Table 4.2 and graphically displayed in *Figure 4.4*. These times range from 1.1429 seconds to 37.2857 seconds. For the majority of the control group (75.4%), the reaction time per screen is less than 16 seconds while the reaction time for 75.4% of the experimental group is greater than 10 seconds per screen. The mean reaction time for the control is 11.4442 seconds while the mean reaction time for the experiment is 15.0176 seconds.

Table 4.2 Reaction time for the control and experiment.

Average Reaction Time (Seconds)	Frequency Control (%)	Frequency Experiment (%)
< 2	7.0	-
2-4	14.0	7.0
4-6	10.5	5.3
6-8	8.8	5.3
8-10	8.8	7.0
10-12	5.3	5.3
12-14	8.8	14.0
14-16	12.3	17.5
16-18	5.3	3.5
18-20	1.8	10.5
20-22	5.3	12.3
>22	12.3	12.3

	N	Minimum	Maximum	Mean	Std. Deviation
Control	57	1.1429	31.8571	11.4442	7.8759
Experiment	57	2.1429	37.2857	15.0176	7.3985

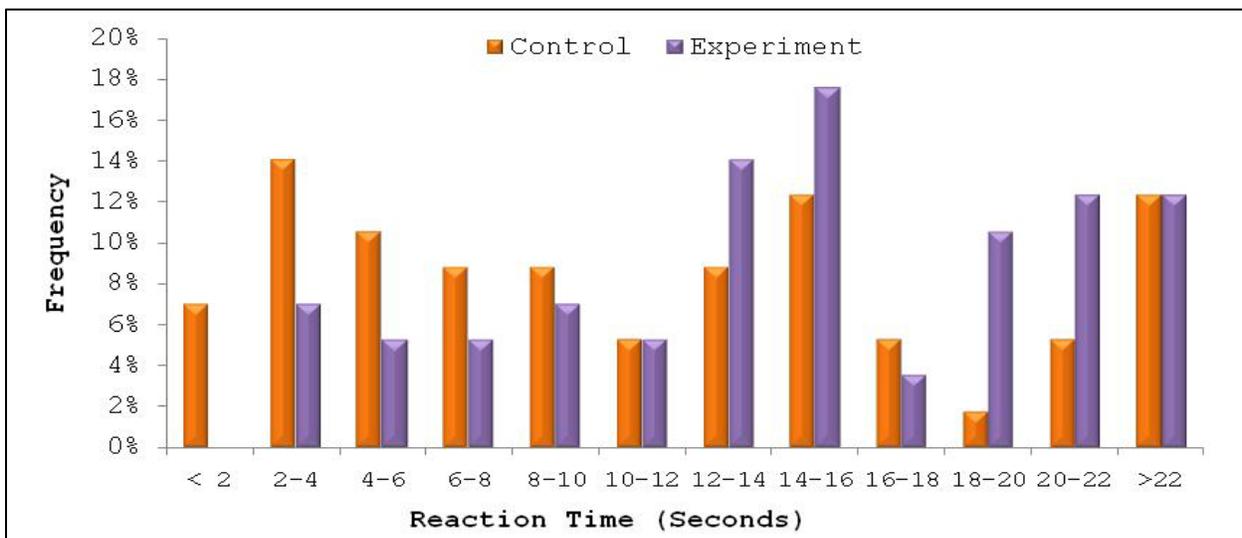


Figure 4.4 Reaction time to distractor for the control and experimental groups.

4.7 MULTIVARIATE ANALYSIS OF VARIANCE

A *between-subjects multivariate analysis of variance* was conducted on two dependent variables, namely *percentage increase in score* and *reaction time to distractor*. The independent variable is *type of presentation* (experiment or control). The significance level was set to .05.

When conducting a MANOVA, an assumption is made that there is a multivariate normal distribution in the population and homogeneity of variance. If the sample size is large enough (greater than 30), the normality of the distribution would not have an effect on the results.

Box's M test can be used to test the assumption of homogeneity of variance (SPSS South Africa, 2001). Since there are the same number of subjects in the experimental and control group in this study, the homogeneity assumption is less of a concern. Nonetheless, both Box's M test ($p = .225$) (Table 4.3) and Levene's test of homogeneity of variance (Table 4.4) were performed ($p = .923$; $p = .395$). Both revealed no significant differences in variances of the groups.

Table 4.3 Box's test of Equality of Covariance Matrices.

Box's M	F	df1	df2	Sig.
4.444	1.453	3	2257920.000	.225

Table 4.4 Levene's test of homogeneity of variance.

	F	df1	df2	Sig.
% Increase in Score	.009	1	112	.923
Average Reaction Time	.729	1	112	.395

Significant differences were found for the interaction of the increased scores and reaction time between the control and experimental group, $F(2,111) = 4.014$, $p = .021$

(Table 4.5). In order to evaluate effect size, the Partial Eta Squared results were considered. The partial eta squared value of .067 showed that 6.7 % of the variance in dependent variables could be explained by the type of presentation. This is a weak effect, so despite the result being significant – it is not of much practical significance (Cohen, 1988).

Table 4.5 Wilks' Lambda results of the control and experiment groups.

Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Observed Power
.933	4.014	2	111	.021*	.067	.707

Significant differences between the control and experiment for the reaction time are noted ($p = .014$), whereas no significant differences between the control and experiment are noted for the percentage increase in score ($p = .189$) (Table 4.6).

Table 4.6 Comparison of means.

Dependent Variable	Experiment / Control	Mean	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
% Increase in Score	Control	23.391	3.322		16.808	29.974
	Experiment	29.605	3.322		23.022	36.188
	Experiment /Control	6.214 (mean difference)	4.699	.189	-3.096	15.523
Reaction Time	Control	11.442	1.012		9.437	13.447
	Experiment	15.015	1.012		13.010	17.020
	Experiment /Control	3.573 (mean difference)	1.431	.014*	.738	6.409

4.7.1 Race and gender differences

A MANOVA using two dependent variables - percentage increase in score and reaction time to distractor, with race as the independent variable was conducted. No significant differences between the races for the interaction of the increased scores and reaction time for either the control $F(6,104) = 1.020$, $p = .417$ or experimental group was revealed, $F(6,104) = 1.225$, $p = .299$ (Table 4.7). The Partial Eta Squared values of .056 and .066 suggest a weak effect for race.

Table 4.7 Racial differences on the experiment and control.

Wilks' Lambda	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Observed Power
Control	.892	1.020	6	104	.417	.056	.387
Experiment	.872	1.225	6	104	.299	.066	.463

Similarly, no significant differences between the males and females were found for the interaction of the increased scores and reaction time for either the control $F(2,54) = .603$, $p = .551$ or experimental group, $F(2,54) = .461$, $p = .633$ when using gender as the independent variable (Table 4.8). The Partial Eta Squared values of .017 and 0.022 suggest a small effect for gender – of almost no practical significance.

Table 4.8 Gender differences on the experiment and control.

Wilks' Lambda	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Observed Power
Control	.978	.603	2	54	.551	.022	.145
Experiment	.983	.461	2	54	.633	.017	.121

4.7.2 Effect of academic level on results

Mayer (2009) expects the implementation of the multimedia design principles to have a greater increase in low-knowledge learners' understanding of the presented work, when compared to the understanding of the high-knowledge learners. When analysing the results for learners with a lower knowledge in physical science (identified as those who achieved less than 40% for their overall term mark) no significant differences were found for the interaction of the increased scores and reaction time between the control and experimental group, $F(2,23)=2.132$, $p=.141$ (Table 4.9). The Partial Eta Squared value of .156 suggests a small effect for the type of presentation.

Table 4.9 Results of control and experiment groups for low knowledge learners.

Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Observed Power
.844	2.132	2	23	.141	.156	.392

Significant differences between the control and experiment for the percentage increase in score for the low-knowledge learners are noted ($p=.046$). Whereas no significant differences between the control and experiment are noted for the reaction time to the distractor ($p=.621$) (Table 4.10).

Table 4.10 Comparison of means for low knowledge learners.

Dependent Variable	Experiment / Control	Mean	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
% Increase in Score	Control	16.987	6.125		4.346	29.628
	Experiment	35.256	6.125		22.615	47.897
	Experiment /Control	18.269 (mean difference)	8.662	.046*	.392	36.146

Reaction Time	Control	15.891	2.062		11.634	20.147
	Experiment	17.351	2.062		13.094	21.608
	Experiment /Control	1.460 (mean difference)	2.917	.621	-4.559	7.480

4.8 SUMMARY OF RESULTS

Although there is a difference in the percentage increase in scores between the experimental and control group - with the increase being greater for the experimental group - this increase is not statistically significant. Therefore, the null hypothesis (of no difference between the increase in score for the multimedia presentation and normal presentation) is accepted.

However, an evaluation of the difference in the percentage increase in scores for low-knowledge learners, between the experimental and control group showed to be statistically significant. This difference revealed a greater increase in scores for the questions pertaining to the multimedia presentation.

The difference in reaction time to the distractor between the control and experiment is found to be significant. Therefore, the null hypothesis of there being no difference in reaction time for the multimedia presentation and the normal presentation is rejected. However, this difference is due to a greater reaction time to the distractor for the multimedia presentation (experiment) and therefore the directional alternate hypothesis, which expected a smaller reaction time for the multimedia presentation, is rejected.

An evaluation of the difference in reaction time between the experimental and control group for the low knowledge learners revealed a greater reaction time to the distractor for the multimedia presentation, however, the difference was not found to be statistically significant.

CHAPTER FIVE: Conclusions, Limitations and Recommendations

This chapter discusses the conclusions drawn from the results of the study, the limitations of the research as well as recommendations for physical science instruction and directions for future research.

5.1 CONCLUSIONS

Conclusions are drawn about the research in accordance with the outlined research questions:

- Can an on-screen multimedia presentation, following Mayer and Moreno's (2003) nine ways to decrease cognitive load in multimedia presentations, reduce cognitive load for physical science learners?
- Can this multimedia presentation increase the learners' recall of the information?
- Can the dual-task method (Brünken et al., 2003) be used to measure both the primary task (the presentation) and secondary task (the reaction time to the distractor) simultaneously?

5.1.1 Reducing cognitive load

As discussed in Chapter 2, the abstract nature of cognitive load together with the multidimensional characteristics of the concept of cognitive load makes it a complex area for researchers. More specifically, the influences of interventions on cognitive load are difficult to isolate, measure and report on (Cook, 2009).

This study employed an empirical task and performance-based measure to assess the amount of information learned as well as the cognitive capacity available to process the secondary task. The secondary task in this study was the reaction time to a presented distractor, with the assumption that performance on the secondary task should differ in accordance with the amount of cognitive load induced by the design of the material (Brünken et al., 2002; Brünken et al., 2003).

It was expected that the multimedia presentation (experiment) would decrease the learners' cognitive load, thus freeing up their cognitive resources, which in turn would

allow them to react more quickly to the distractor as compared with the reaction time to the distractor in the normal presentation (control). The results did reveal a significant difference in reaction time between the experiment and control, however, a faster reaction time was revealed for the normal presentation (control) than for the multimedia presentation (experiment). The directional hypothesis was rejected and it is concluded that the multimedia presentation design used in this pilot study did not effectively reduce the learners' cognitive load.

It is possible that the content of work that was covered in the presentations is not very high in element interactivity and therefore the multimedia design may not have had much of an effect. Designs have less of an effect or no effect on reducing cognitive load for material of low element interactivity (Pass et al., 2003a).

5.1.2 Increase in learners' knowledge

The intention of this study was to evaluate the effectiveness of multimedia instruction as a method of presentation in facilitating meaningful learning amongst physical science learners. Learners' performance on a test administered before they viewed the presentation (pre-test) was used to measure their existing knowledge of the topic and was subtracted from their performance on a test administered after they viewed the presentation (post-test). This was used to indicate the amount of knowledge the learners had gained from the presentation.

It was predicted that the multimedia presentation (experiment) would result in a greater increase in knowledge gained by the learners when compared to the normal presentation (control). As expected, the results revealed a greater increase in scores for the experiment than for the control. However, these results were not statistically significant and the null hypothesis was accepted.

Based on Mayer's (2009) expectation of multimedia design principles to have a greater effect on low-knowledge learners' understanding of the presented work, when compared to high-knowledge learners; the results for learners who had achieved less than 40% for their overall term mark, were analysed. These results revealed a significant difference in the increase in scores between the experiment and control, with

a greater increase seen for the multimedia presentation (experiment) than for the normal presentation (control).

It is therefore concluded that the multimedia design principles were more effective in increasing the learners' knowledge on the topic than the standard, more traditional instructional methods. This effect is greater for learners with a lower knowledge of physical science than for those learners with a higher knowledge.

Furthermore, it is concluded that future research or follow up studies of this pilot study using a larger sample size will be likely to show significant results for the increase in score for experiment vs. control.

5.1.3 Evaluation of the dual-task methodology

A dual-task method was used in this study as it has been identified in several publications as a more sensitive and reliable methodology when compared to analytical methods - despite little empirical research being done using this methodology (Smith, 2007). The primary task consisted of learners viewing the presentation, and the amount of knowledge they gained from the presentation was assessed by means of a difference in performance on a pre- and post-test. The secondary task was the learners' reaction to a distractor on the screen and was assessed by means of a reaction time.

The methodology was relatively simple to set-up, but explaining to the learners what they were required to do was more complex. The explanation of the distractor and the necessary response may have confused the learners and this could have affected their reaction time to the distractor. Therefore, it cannot be said with certainty that the results of the reaction times are purely due to the cognitive load of the primary task (presentation) and not to a combination of load induced by the primary task together with the secondary task (Paas et al., 2003b).

A rating scale questionnaire where learners report on the mental effort they employed to complete a task should be used jointly with the dual-task methodology. This will provide an indication of the level of mental effort experienced by the learner, as well as their fatigue and frustrations (if included in the questionnaire). For this study, the results revealed that the learners had gained more knowledge from the multimedia

presentations - but it could have required them to apply more mental effort to achieve such results.

It is concluded that the dual-task methodology can be used with relative ease, to measure the primary and secondary tasks, however, more empirical research needs to be conducted to explore the effectiveness of the dual-task methodology in measuring cognitive load.

5.2 LIMITATIONS OF THE RESEARCH

The limitations of this pilot study, as well as suggestions for overcoming them in follow up studies are outlined below.

5.2.1 Methodological design

The difficulty of isolating and measuring cognitive load was experienced in this study. Although the dual-task methodology was effective in measuring the primary and secondary tasks, it is difficult to attribute the results to the level of cognitive load experienced by the learners. The combination of mental effort and performance measures are likely to reveal more information about cognitive load than when using one of the methods in isolation (Paas & van Merriënboer, 1994). Future studies could make use of a rating scale questionnaire together with the dual-task methodology in order to allow learners to report on the mental effort they employed

5.2.2 Sample

The sample size used in this pilot study has a 9.18% margin of error at a 95% confidence interval. Future research or follow up studies of this pilot study should make use of a larger, more robust sample size in order to improve the precision of the results.

5.2.3 Measuring instruments – reaction time

The greater reaction time to the distractor for the multimedia presentation could possibly be attributed to factors other than the cognitive load elicited by the presentation. The novelty of the presentation, as well as the explanation of the required response to the distractor may have overwhelmed and possibly confused the learners – resulting in a higher reaction time. Future studies could make use of a practice lesson to allow the

learners to become familiar with the type of presentations as well as the reaction required to the distractor in order to avoid overwhelming the learners.

The multimedia presentation could possibly have elicited a higher germane cognitive load for the learners. This may have resulted in the learners being more motivated to understand the material and focussing more attention on the multimedia screens in an effort to engage with the presentation and thus reacting more slowly to the distractor. The corresponding higher increase in scores for the overall test for the multimedia presentation reveals that the learners were concentrating on the content of the presentation and did absorb the presented information.

Colour coding of text with the corresponding diagram has been found by Kalyuga, Chandler and Sweller (1999) to reduce working memory load and increase test performance. Different colours were used in the multimedia screens in the research, but the colours were not applied to corresponding elements and were used in order to make the screens bolder and more interesting. The use of colour may have made it more difficult for the learners to see the change in colour of the distractor. The change in colour may have been more noticeable in the less elaborate, monotone screens of the control presentation which could have contributed to a quicker reaction time to the distractor. Future studies could test the effect of the colour of the distractor in order to determine the impact this may have on the reaction time to a distractor.

5.3 RECOMMENDATIONS

Based on the outlined conclusions and limitations, recommendations for physical science instruction as well as for future studies which investigate the effectiveness of multimedia methods are discussed below.

5.3.1 Recommendations for physical science instruction

The results of the study indicate the promise of multimedia design principles in increasing learners' retention of physical science information. The greater increase in scores seen in questions pertaining to the multimedia presentation, although not statistically significant, warrant further investigation into the feasibility and effectiveness of incorporating multimedia design principles in lessons.

It is noted that major barriers to the adoption of computers for teaching include a lack of confidence and a lack of competence for learners and teachers, as well as a lack of access to resources (Bingimlas, 2009). Few schools in South Africa will have access to computer laboratories, which is likely to limit the development of on-screen multimedia design as standard teaching practice. It will still be beneficial for schools to make use of the basic design principles, as investigated in this study, when constructing their paper-based workbooks and worksheets.

5.3.2 Recommendations for future research

Further research in this field should expand on this pilot study by conducting research with larger sample sizes, in order to improve the generalisability of the results.

It is recommended for future studies to investigate the effect of the multimedia presentations on reducing cognitive load and increasing recall of the information for different learning areas, and not only physical science. By employing the multimedia principles on different learning areas, the correlation between element interactivity and a reduction in cognitive load could possibly be established.

A study designed to compare learners of different academic levels is recommended in order to further investigate the effect of the learners' level of knowledge on their reaction to multimedia instruction.

The effect of the characteristics of the distractor was not investigated in this study, and is a recommended research topic for future studies. Measuring the position, colour, symbol used or other variations to a distractor, may help to improve the dual-task methodology in measuring cognitive load, by enabling a better understanding of the effect of the secondary task on cognitive load.

There has been an increased interest in making use of mobile technologies to move beyond classroom-bound teaching. However, little research has been done to investigate the efficiency of mobile technologies such as personal digital assistants (PDAs) and portable digital media players for learning (Ryu & Parsons, 2009). Therefore, it is recommended for future research to investigate the application of multimedia designs in mobile technologies, such as PDAs or tablets.

5.4 THEORETICAL IMPLICATIONS OF THE RESEARCH

The low level of scientific literacy in South Africa has many negative implications for the economy, for the creation of employment opportunities, as well as for the communication, understanding and adoption of public policies (Science in Africa, 2007). According to a report released by the Human Science Research Council (1996), key findings from South Africa's participation in the *Trends in International Mathematics and Science Study (TIMSS)* in 1995 include achievement scores that are very low in comparison to other participating countries, as well as no significant differences in achievement on subject knowledge for what had been taught in class and what had not been taught. South Africa participated in TIMSS again in 1999 and 2003 – where the results remained low (Human Science Research Council, n.d.).

It is apparent that a strategy to raise the standard of science education and science literacy in South Africa is required. This intervention needs to ensure the maximum impact in lieu of the limited resources available. The lack of access to teachers and other educational resources necessitates that the teaching that does occur be as effective as possible – transferring the maximum amount of information to the learners and increasing their science knowledge.

The promising results of this study regarding the use of multimedia design principles to increase learners' knowledge in physical science should encourage researchers to continue to investigate the most effective means of transferring scientific knowledge to learners. Increasing the number of science graduates will have a positive effect on the country as a whole and could contribute to the creation of a more skilled and productive workforce.

5.5 SUMMARY

This pilot study has shown promising results for the use of multimedia design principles in increasing learners' knowledge in physical science. Despite a few highlighted limitations in design, sample and measuring instruments, the effect of multimedia presentations is revealed. Recommendations for further studies have been described, and this pilot study should be considered as the beginning of much research into

methods for reducing cognitive load for learners, as well as investigations into the accurate and objective measurement of cognitive load.

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APPENDIX A – Presentation A

FRictionAL FORCE

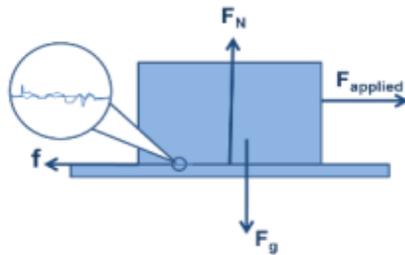
Frictional force is a resistance force that exists between two surfaces that are in contact with each other. Friction always opposes the relative motion between two surfaces. In opposition to the normal force, that is perpendicular to the surface, **the frictional force always acts along or parallel to the surface but in the opposite direction to the objects motion.** There are **two types of friction** namely, **static friction** and **kinetic (dynamic) friction.**



Next

Screen 1A

FRictionAL FORCE

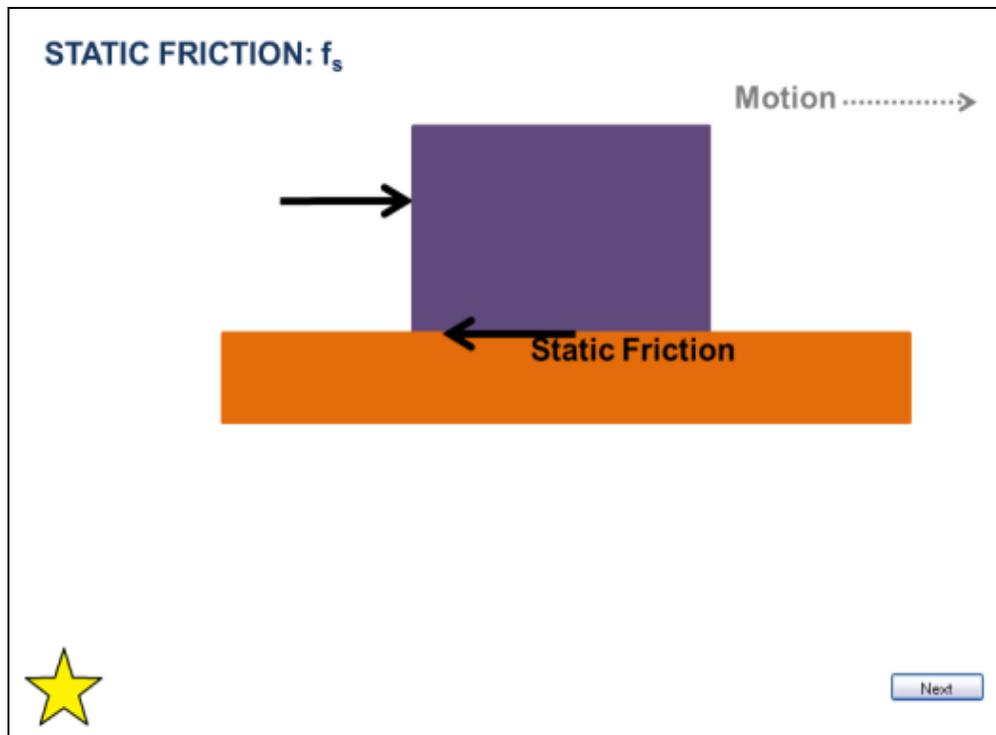


Frictional force is a resistance force that exists between two surfaces that are in contact with each other. Surfaces are not 100% smooth, they are slightly rough. The smoothest surface would be ice.



Next

Screen 2A



Screen 3B

The following figures explain the concept of static friction.

No motion (1)

No motion (2)

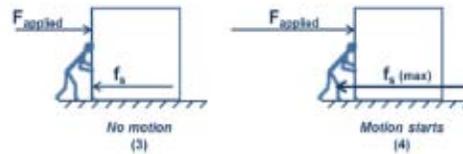
Figure (1) shows a large crate at rest on the floor. No applied force (push or pull) is exerted on the crate. There is no static friction as long as no attempt is made to move the crate.

In **Figure (2)** a person exerts a small horizontal force (F_{applied}) on the crate. The crate still does not move. The static friction (f_s) is equal in magnitude to the applied force (F_{applied}) but in the opposite direction

Next

Screen 4C

The following figures explain the concept of static friction.



In **Figure (3)** the applied force (F_{applied}) is increased slightly. As the applied force (F_{applied}) increases so the static friction (f_s) also increases, but the crate still does not move. When the applied force increases, so does the static friction and cancels the applied force.

In **Figure (4)** the applied force (F_{applied}) is increased even more until a point is reached where the object breaks away from the surface and starts moving. The magnitude of the applied force just before the object starts to move is called the maximum static frictional force and is indicated as $f_{s(\text{max})}$.



Next

Screen 5C

The maximum static frictional force between dry, unpolished surfaces has the following important characteristics:

•The maximum static frictional force [$f_{s(\text{max})}$] is independent of the contact area between the objects.

Irrespective if the block lies with its broad side or its narrow side on the surface, $f_{s(\text{max})}$ stays the same for the same surface that the object is in contact with.



Next

Screen 6D

•The maximum static frictional force $[f_{s(max)}]$ is strongly dependent on the nature of the two surfaces that are in contact with each other.

The type of material and the surface finish, have a huge influence on the maximum static frictional force. Well polished surfaces usually offer less friction than rough surfaces.

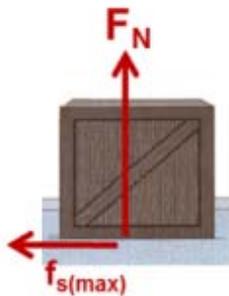
•The maximum static frictional force $[f_{s(max)}]$ acts in the opposite direction to the applied force.

•The maximum static frictional force $[f_{s(max)}]$ is directly proportional to the magnitude of the normal force (F_N) that the surface exerts.



Next

Screen 7E



Next

Screen 8F

The value of static frictional force can vary from zero to the maximum value and can be calculated from the equation:

the coefficient of static friction

- a proportionality constant
- depends on the nature of the surface and types of material that are in contact with each other

$$f_{s(\max)} = \mu_s \cdot F_N$$

maximum static frictional force
- in Newton (N)

normal force
- in Newton (N)

Because both $f_{s(\max)}$ and F_N are forces that are measured in N (newton), N is cancelled so that μ_s is just a number without a unit.

It is a measure of how "slippery" a surface is. A big number means the surface is not very "slippery", while a small number means a "very slippery" surface.



Next

Screen 9F

$$\mu_s = \frac{f_{s(\max)}}{F_N}$$



Next

Screen 10G

KINETIC FRICTION: f_k

Kinetic friction is the friction exerted by one surface on another when one surface moves over the other.

Static frictional force is no longer relevant as soon as an object starts to move over a surface. The surface then exerts a **kinetic** frictional force on the object.

The kinetic frictional force is smaller than the static frictional force thus, $f_k < f_{s(max)}$.



Next

Screen 11H

The kinetic frictional force, f_k , has the following characteristics:

•Kinetic frictional force (f_k) is independent of the area of contact.

Irrespective of whether the block rests with its wide or narrow end on the surface, f_k stays the same for the same surface in contact.

•Kinetic frictional force (f_k) is independent of the speed of the moving object if the speed is small.



Next

Screen 12I

•Kinetic frictional force (f_k) acts in the opposite direction to the direction of motion of the object.

•Kinetic frictional force (f_k) is strongly dependent on the nature of the surfaces that are in contact with each other.

The type of material and the surface finish, has a large influence on the kinetic frictional force. Well polished surfaces offer less friction than rough surfaces.

•The magnitude of the kinetic frictional force (f_k) is directly proportional to the magnitude of the normal force (F_N) that the surface exerts.



Screen 13I

The normal force indicates how hard two surfaces press against each other. The more the surfaces press against each other, the greater f_k is.

It follows that:

$$f_k \propto F_N$$

so that $f_k = \mu_k F_N$

Where: f_k = kinetic frictional force in Newton (N).
 μ_k = the coefficient of kinetic friction (that is a proportionality constant).
 F_N = normal force in Newton (N).



Screen 14J

$$\mu_k = \frac{f_k}{F_N} \quad f_k < f_{s(\max)} \quad \mu_k < \mu_s$$



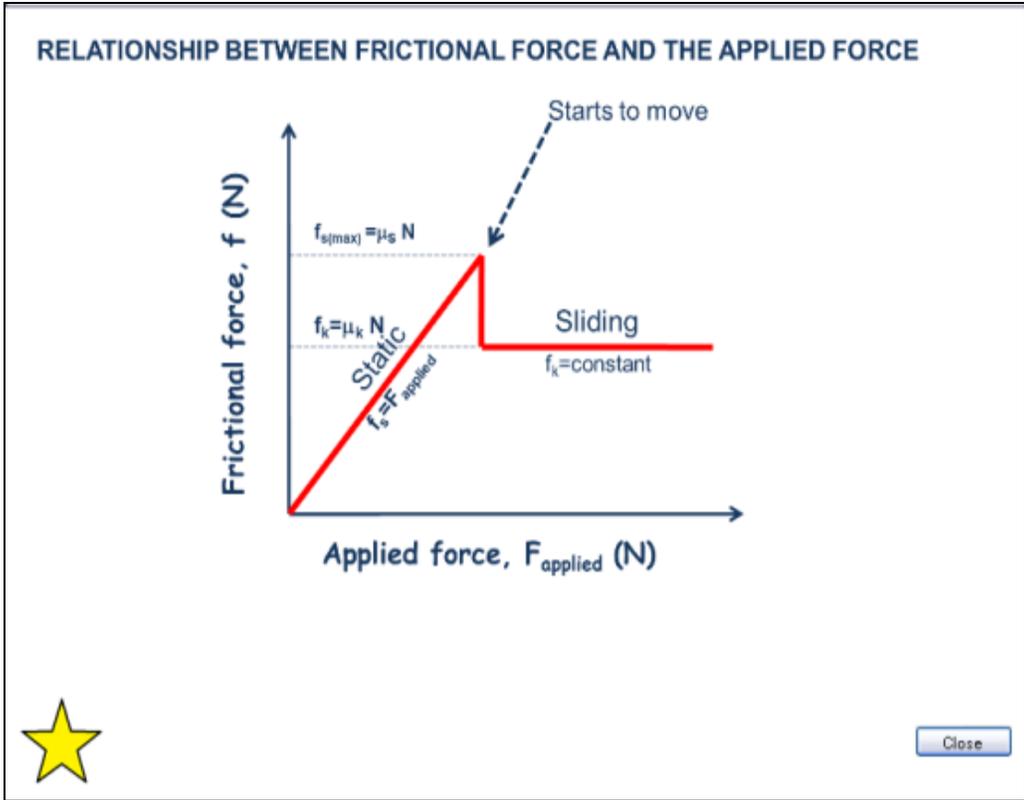
Screen 15K

The following table shows the coefficients of static μ_s and kinetic friction μ_k for a few surfaces in contact:

Surfaces	Coefficient of static friction (μ_s)	Coefficient of kinetic friction (μ_k)
Ice on ice 	0.1	0.03
Wood on wood 	0.4	0.2
Rubber on wet concrete 	0.7	0.5
 Steel on steel (hard, dry)	0.8	0.36
Rubber on dry concrete 	1	0.8

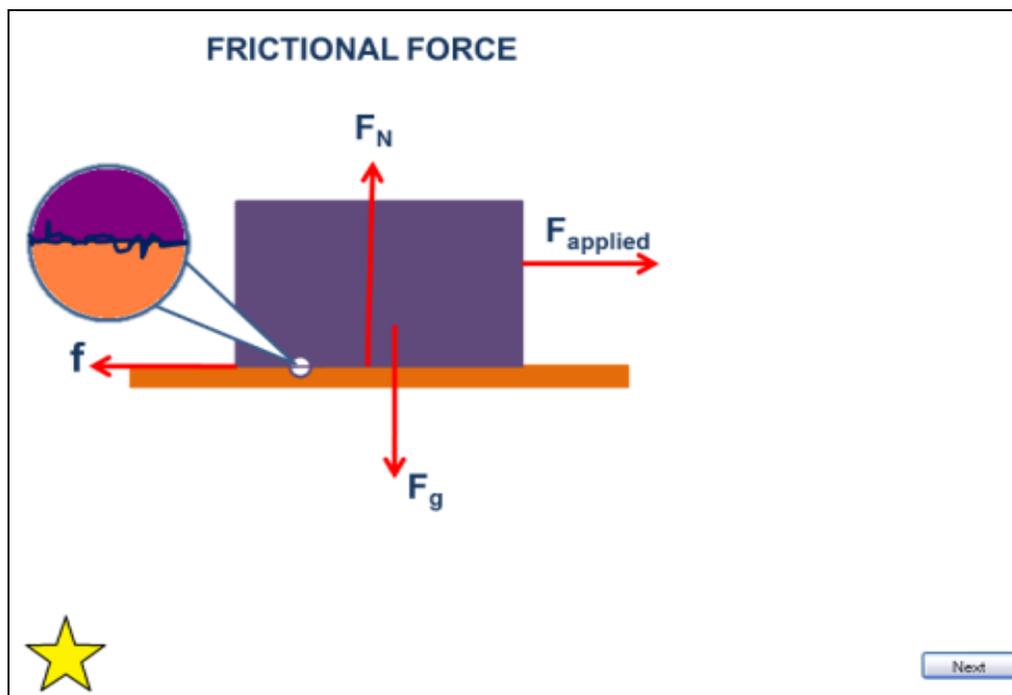



Screen 16L



Screen 17M

APPENDIX B – Presentation B



Screen 1A

STATIC FRICTION: f_s

*Static friction is the frictional force exerted by one surface on another surface when there is **no motion**.*

Static friction is therefore the frictional force that must be overcome in order for a stationary object to start moving.

A yellow star is in the bottom-left corner, and a 'Next' button is in the bottom-right corner.

Screen 2B

The following figures explain the concept of static friction.

Figure (1) shows a large crate at rest on the floor. No applied force (push or pull) is exerted on the crate. There is no static friction as long as no attempt is made to move the crate.



No motion
(1)



No motion
(2)

In **Figure (2)** a person exerts a small horizontal force (F_{applied}) on the crate. The crate still does not move. The static friction (f_s) is equal in magnitude to the applied force (F_{applied}) but in the opposite direction



Next

Screen 3C

The following figures explain the concept of static friction.

In **Figure (3)** the applied force (F_{applied}) is increased slightly. As the applied force (F_{applied}) increases so the static friction (f_s) also increases, but the crate still does not move. When the applied force increases, so does the static friction and cancels the applied force.



No motion
(3)



Motion starts
(4)

In **Figure (4)** the applied force (F_{applied}) is increased even more until a point is reached where the object breaks away from the surface and starts moving. The magnitude of the applied force just before the object starts to move is called the maximum static frictional force and is indicated as $f_{s(\text{max})}$.



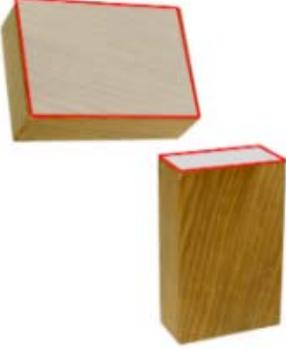
Next

Screen 4C

The maximum static frictional force between dry, unpolished surfaces has the following important characteristics:

- 1. The maximum static frictional force $[f_{s(max)}]$ is independent of the contact area between the objects.**

Irrespective if the block lies with its broad side or its narrow side on the surface, $f_{s(max)}$ stays the same for the same surface that the object is in contact with.



Screen 5D

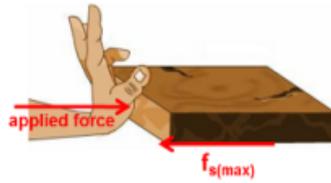
- 2. The maximum static frictional force $[f_{s(max)}]$ is strongly dependent on the nature of the two surfaces that are in contact with each other.**

The type of material and the surface finish, have a huge influence on the maximum static frictional force. Well polished surfaces usually offer less friction than rough surfaces.



Screen 6E

3. The maximum static frictional force [$f_{s(\max)}$] acts in the opposite direction to the applied force.



4. The maximum static frictional force [$f_{s(\max)}$] is directly proportional to the magnitude of the normal force (F_N) that the surface exerts.

$$f_{s(\max)} \propto F_N$$



Next

Screen 7E

By placing more masses onto the block, for example, the size of the normal force can be progressively increased and thus the maximum static frictional force $f_{s(\max)}$ is also increased. It follows that:

$$f_{s(\max)} \propto F_N$$

so that

$$f_{s(\max)} = \mu_s F_N$$

Where: $f_{s(\max)}$ = maximum static frictional force in Newton (N).

μ_s = the coefficient of static friction.

F_N = normal force in Newton (N).



Next

Screen 8F

The value of static frictional force can vary from zero to the maximum value and can be calculated from the equation $f_{s(max)} = \mu_s F_N$.

μ is the Greek letter "mu". μ_s , the coefficient for static friction, is a proportionality constant and depends on the nature of the surface and types of material that are in contact with each other. (You are never expected to know this as each surface has its own value. It is given to you in the question).

Because both $f_{s(max)}$ and F_N are forces that are measured in N (Newton), N(Newton) is cancelled so that μ_s is just a number without a unit.

It is a measure of how "slippery" a surface is. A big number means the surface is not very "slippery", while a small number means a "very slippery" surface.



Screen 9F

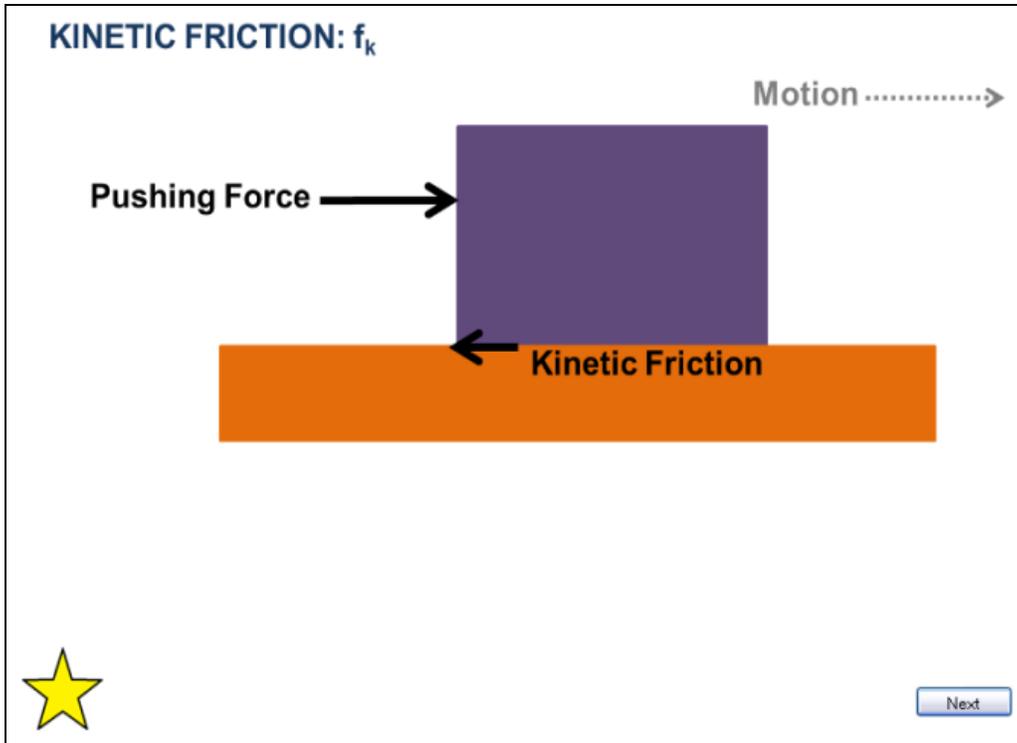
The coefficient of static friction (μ_s) shows the relationship between the maximum static frictional force and the normal force for the two surfaces in contact.

$$\mu_s = \frac{f_{s(max)}}{F_N}$$

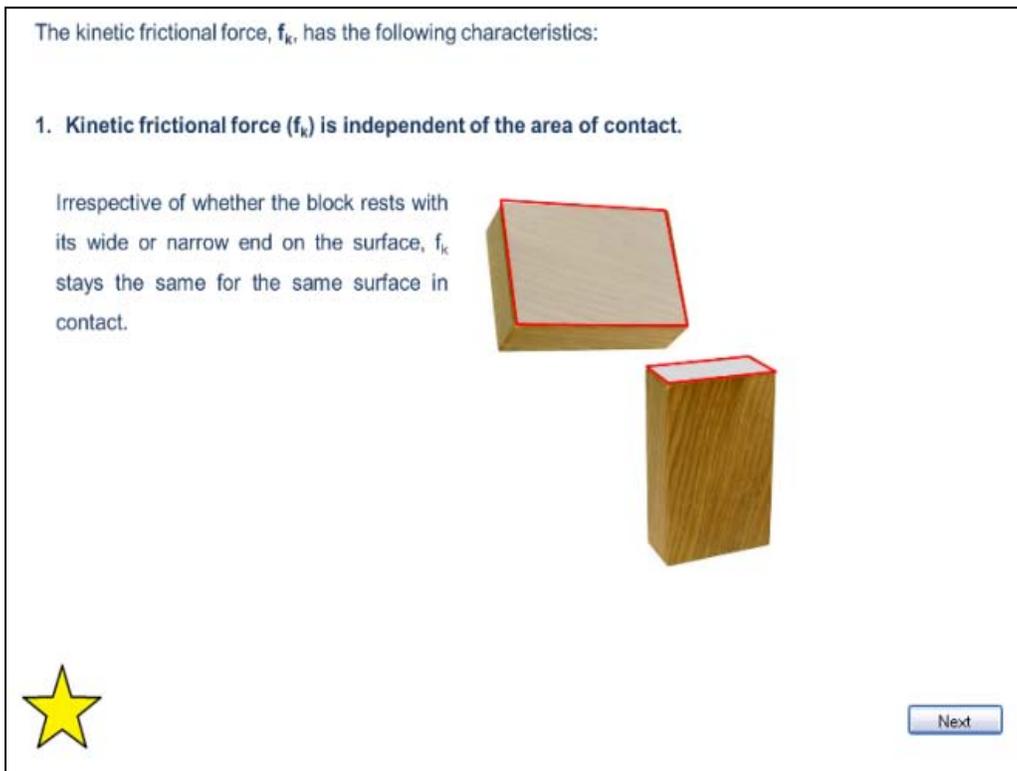
The greater the maximum static frictional force ($f_{s(max)}$) is in relation to the normal force (F_N), the greater the μ_s and the more difficult it will be for the two surfaces to move over each other. A smaller coefficient of static friction (μ_s), shows surfaces in contact that will move over each other more easily.



Screen 10G



Screen 11H



Screen 12I

2. Kinetic frictional force (f_k) is strongly dependent on the nature of the surfaces that are in contact with each other.

The type of material and the surface finish, has a large influence on the kinetic frictional force. Well polished surfaces offer less friction than rough surfaces.



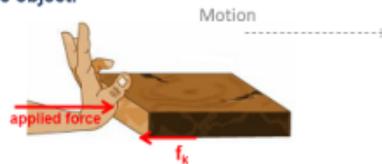
3. Kinetic frictional force (f_k) is independent of the speed of the moving object if the speed is small.



Next

Screen 13I

4. Kinetic frictional force (f_k) acts in the opposite direction to the direction of motion of the object.



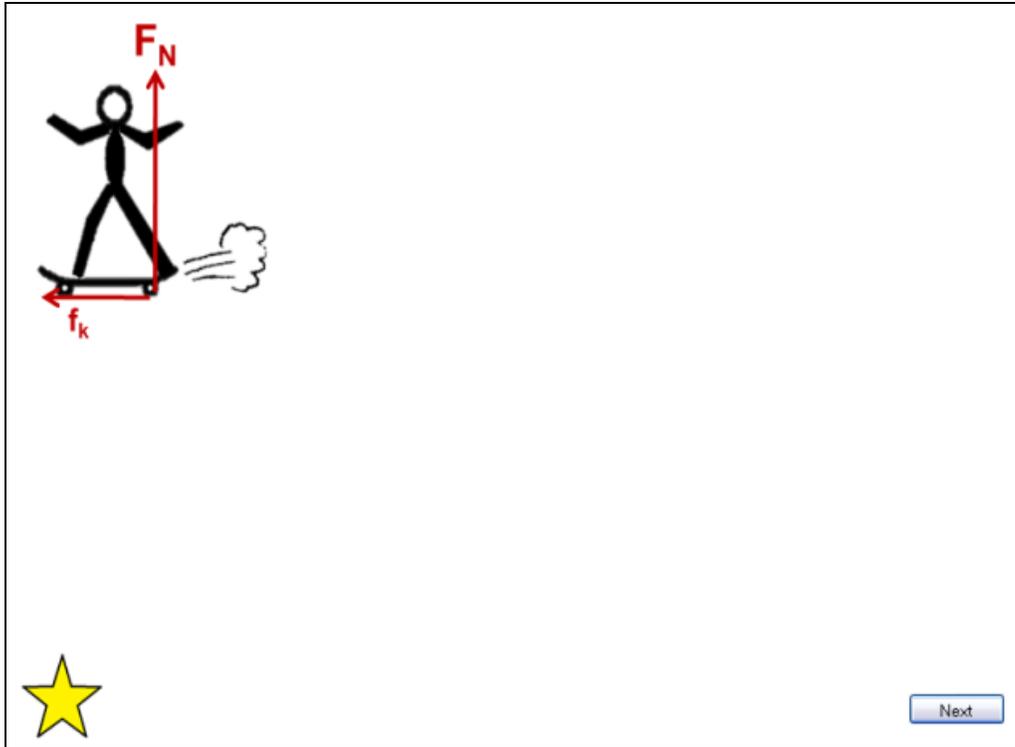
5. The magnitude of the kinetic frictional force (f_k) is directly proportional to the magnitude of the normal force (F_N) that the surface exerts.

$$f_k \propto F_N$$



Next

Screen 14I



Screen 15J

The value of kinetic frictional force can be calculated from the equation:

$$f_k = \mu_k \cdot F_N$$

kinetic frictional force
- in Newton (N)

the coefficient of kinetic friction
- a proportionality constant

normal force
- in Newton (N)

In the diagram, the equation $f_k = \mu_k \cdot F_N$ is shown. A green arrow points from f_k to the text "kinetic frictional force - in Newton (N)". A red arrow points from μ_k to the text "the coefficient of kinetic friction - a proportionality constant". A blue arrow points from F_N to the text "normal force - in Newton (N)". In the bottom-left corner, there is a yellow star. In the bottom-right corner, there is a button labeled "Next".

Screen 16J

The coefficient of kinetic friction (μ_k) shows the relationship between the kinetic or dynamic frictional force and the normal force for the two surfaces in contact.

$$\mu_k = \frac{f_k}{F_N}$$

Because f_k is smaller than $f_{s(max)}$, μ_k will also be smaller than μ_s for the two surfaces in contact.



Next

Screen 17K

COEFFICIENTS OF FRICTION

The coefficients of friction usually have values that are smaller than 1. Both the coefficients of static and kinetic friction are dependent on the types of surfaces that are in contact with each other. Lubrication makes surfaces smoother and reduces the coefficient of friction. (This also reduces the heating effect).



Next

Screen 18L

The following table shows the coefficients of static and kinetic friction for a few surfaces in contact:

Surfaces	Coefficient of static friction (μ_s)	Coefficient of kinetic friction (μ_k)
Wood on wood	0.4	0.2
Ice on ice	0.1	0.03
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Steel on steel (hard, dry)	0.8	0.36

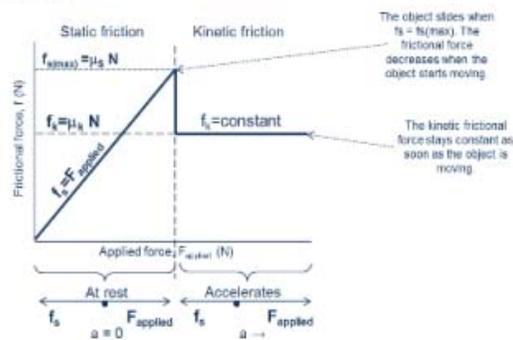


Next

Screen 19L

RELATIONSHIP BETWEEN FRICTIONAL FORCE AND THE APPLIED FORCE

When the horizontal applied force, F_{applied} , that is exerted on an object (e.g. a block) is increased slowly, the size of the frictional force, f , also increases as indicated in the graph below. The static frictional force increases and reaches a maximum value, $f_{s(\text{max})} = \mu_s F_N$ just before the object starts to move. After the object starts moving, the smaller, constant kinetic friction is present, $f_k = \mu_k F_N$.



Close

Screen 20M

APPENDIX C – Pre-test questionnaire

1. Explain what a normal force is. (1)

The normal force indicates how hard two surfaces press against each other. ✓ **OR** The force that is perpendicular to the surface. ✓

2. Provide a definition for static friction. (2)

Static friction is the frictional force ✓ exerted by one surface on another surface when there is no motion. ✓ **OR** Static friction is the frictional force ✓ that must be overcome in order for a stationary object to start moving. ✓

3. List two characteristics of the maximum static frictional force $f_{s(\max)}$. (2)

Is independent of the contact area between the objects (Irrespective if the block lies with its broad side or its narrow side on the surface, $f_{s(\max)}$ stays the same for the same surface that the object is in contact with.) ✓ **OR** Is strongly dependent on the nature of the two surfaces that are in contact with each other. (The type of material and the surface finish, have a huge influence on the maximum static frictional force.) ✓ **OR** Acts in the opposite direction to the applied force ✓ **OR** Is directly proportional to the normal force (F_N) that the surface exerts ✓

4. Provide a definition for kinetic friction. (1)

Kinetic friction is the frictional force exerted by one surface on another surface when one surface moves over the other. ✓

5. List two characteristics of kinetic frictional force f_k . (2)

Is independent of the contact area between the objects. (Irrespective if the block lies with its broad side or its narrow side on the surface, f_k stays the same for the same surface that the object is in contact with.) ✓ **OR** Is independent of the speed of the moving object if the speed is small ✓ **OR** Is strongly dependent on the nature of the two surfaces that are in contact with each other. (The type of material and the surface finish, have a huge influence on the kinetic frictional force). ✓ **OR** Acts in the opposite direction to the direction of motion. ✓ **OR** Is directly proportional to the normal force (F_N) that the surface exerts. ✓ **OR** The kinetic frictional force is smaller than the static frictional force thus, $f_k < f_{s(\max)}$. ✓ **OR** The kinetic frictional force stays constant as soon as the object is moving. ✓

6. Describe the direction of frictional force in relation to the moving object. (2)

Frictional force always acts along or parallel to the surface ✓ but in the opposite direction to the object's motion. ✓

7. The static frictional force (increases / decreases/ stays constant) when the object starts moving and the kinetic frictional force (increases/ decreases/ stays the same) as the object is moving. (2)

The static frictional force decreases ✓ when the object starts moving and the kinetic frictional force stays constant ✓ as the object is moving.

8. A man wants to move a cabinet, with a weight of 900N across the floor.

8a. What is the magnitude of the static frictional force before the man touches the cabinet, thus before any force is exerted on the cabinet? Explain your answer. (2)

0. ✓ **AND** There is no applied force, therefore there is no frictional force. ✓

8b. He now exerts a horizontal force of 250N, but the cabinet does not move. What is the magnitude of the static frictional force? Explain your answer. (2)

250N. ✓ **AND** The static frictional force is equal in magnitude to the applied force. ✓

9. Write down an equation for the coefficient of static friction. (1)

$$\mu_s = \frac{f_{s(\max)}}{F_N} \quad \checkmark \text{ OR } \quad f_{s(\max)} = \mu_s F_N \quad \checkmark$$

10. Which is smaller? The coefficient of static friction (μ_s) or the coefficient of kinetic friction (μ_k)? (1)

Because f_k is smaller than $f_{s(\max)}$, μ_k will also be smaller than μ_s for the two surfaces in contact ✓

11. Is the coefficient of static friction for *ice on ice* bigger or smaller than the coefficient of static friction for *rubber on concrete*? (1)

smaller: ice on ice (0.1) rubber on concrete (0.7-1.0). ✓

12. The greater the coefficient of static friction the (more difficult / easier) it is for two surfaces to move over each other. (1)

[more difficult] ✓

APPENDIX D – Post-test questionnaire

1. Describe the direction of frictional force in relation to the moving object. (2)

Frictional force always acts along or parallel to the surface ✓ but in the opposite direction to the object's motion. ✓

2. Provide a definition for static friction. (2)

Static friction is the frictional force ✓ exerted by one surface on another surface when there is no motion. ✓ **OR** Static friction is the frictional force ✓ that must be overcome in order for a stationary object to start moving. ✓

3. A man wants to move a cabinet, with a weight of 900N across the floor.

3a. What is the magnitude of the static frictional force before the man touches the cabinet, thus before any force is exerted on the cabinet? Explain your answer. (2)

0. ✓ **AND** There is no applied force, therefore there is no frictional force. ✓

3b. He now exerts a horizontal force of 250N, but the cabinet does not move. What is the magnitude of the static frictional force? Explain your answer. (2)

250N. ✓ **AND** The static frictional force is equal in magnitude to the applied force. ✓

4. List two characteristics of the maximum static frictional force $f_{s(max)}$. (2)

Is independent of the contact area between the objects (Irrespective if the block lies with its broad side or its narrow side on the surface, $f_{s(max)}$ stays the same for the same surface that the object is in contact with.) ✓ **OR** Is strongly dependent on the nature of the two surfaces that are in contact with each other. (The type of material and the surface finish, have a huge influence on the maximum static frictional force.) ✓ **OR** Acts in the opposite direction to the applied force ✓ **OR** Is directly proportional to the normal force (F_N) that the surface exerts ✓

5. Write down an equation for the coefficient of static friction. (1)

$$\mu_s = \frac{f_{s(max)}}{F_N} \quad \checkmark \quad \text{OR} \quad f_{s(max)} = \mu_s F_N \quad \checkmark$$

6. Provide a definition for kinetic friction. (1)

Kinetic friction is the frictional force exerted by one surface on another surface when one surface moves over the other. ✓

7. List two characteristics of kinetic frictional force f_k . (2)

Is independent of the contact area between the objects. (Irrespective if the block lies with its broad side or its narrow side on the surface, f_k stays the same for the same surface that the object is in contact with.) ✓ **OR** Is independent of the speed of the moving object if the speed is small ✓ **OR** Is strongly dependent on the nature of the two surfaces that are in contact with each other. (The type of material and the surface finish, have a huge influence on the kinetic frictional force). ✓ **OR** Acts in the opposite direction to the direction of motion. ✓ **OR** Is directly proportional to the normal force (F_N) that the surface exerts. ✓ **OR** The kinetic frictional force is smaller than the static frictional force thus, $f_k < f_{s(max)}$. ✓ **OR** The kinetic frictional force stays constant as soon as the object is moving. ✓

8. Explain what a normal force is. (1)

The normal force indicates how hard two surfaces press against each other. ✓ **OR** The force that is perpendicular to the surface ✓

9. Which is smaller? The coefficient of static friction (μ_s) or the coefficient of kinetic friction (μ_k)? (1)

Because f_k is smaller than $f_{s(max)}$, μ_k will also be smaller than μ_s for the two surfaces in contact ✓

10. Is the coefficient of static friction for *ice on ice* bigger or smaller than the coefficient of static friction for *rubber on concrete*? (1)

smaller: ice on ice (0.1) rubber on concrete (0.7-1.0). ✓

11. Circle the correct answer:

11a. The greater the coefficient of static friction the (more difficult / easier) it is for two surfaces to move over each other. (1)

[more difficult] ✓

11b. The static frictional force (increases / decreases/ stays constant) when the object starts moving and the kinetic frictional force (increases/ decreases/ stays the same) as the object is moving. (2)

The static frictional force decreases ✓ when the object starts moving and the kinetic frictional force stays constant ✓ as the object is moving.

APPENDIX E – Allocation of screens and questions to Group1 and Group2

Group 1	Screen Category	A	C	D	E	H	I	J
	Presentation A Screen Number	1A, 2A	4C, 5C	6D	7E	11H	12I, 13I	14J
	Presentation B Screen Number	1A	3C, 4C	5D	6E, 7E	11H	12I, 13I, 14I	15J, 16J
	Question Category	a, f	f, h	c, f	c, f	d	e, f	a
	Pre-Test Question Number	1, 6	6, 8	3, 6	3, 6	4	5, 6	1
	Post-Test Question Number	8, 1	1, 3	4, 1	4, 1	6	7, 1	8

Group 2	Screen Category	B	F	G	K	L	M
	Presentation A Screen Number	3B	8F, 9F	10G	15K	16L	17M
	Presentation B Screen Number	2B	8F, 9F	10G	17K	18L, 19L	20M
	Question Category	b	i	i, l	j	j, k	g
	Pre-Test Question Number	2	9	9, 12	10	10, 11	7
	Post-Test Question Number	2	5	5, 11a	9	9, 10	11b