The effect of Computer Simulations on Grade 12 Learners' understanding of concepts in the Photoelectric Effect

By

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DECLARATION

I declare that

The effect of Computer Simulations on Grade 12 Learners' understanding of concepts in the Photoelectric Effect

is my own work and that all sources that I have used and quoted have been indicated and acknowledged by means of complete references.

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SIGNATURE DATE

(Mr B.J.Kunnath)

ABSTRACT

The study investigated the impact of computer simulations on the teaching and learning of photoelectric effect in Grade 12. The Grade 12 Physical Sciences curriculum has components of physics and chemistry. The photoelectric effect is a section in the physics curriculum and examination in the National Senior Certificate. In this case study, thirty learners were randomly divided into three groups in one rural school in the Frances Baard district in the Northern Cape Province. A randomised pre-test - post-test control group design was implemented. Data were collected through pre and post tests, by observation of the lessons and learner interviews. An analysis of variance performed showed that there was no significant difference on pre-test scores for the three groups. A paired -sample t-test on the post-test scores discovered that the Teacher-Centred Experimental Group (TCEG) performed better than the Learner-Centred Experimental Group (LCEG); (t statics, $t(9) = -6.135$, $p < 0.05$). In addition, the Control Group (CG) where the teacher used the traditional method of teaching performed even better than the Learner-Centred Experimental group. An analysis of covariance on the post-test scores with learners' pre-test scores as the covariate showed a significant effect on the instructional group favouring the TCEG ($F(2,29) = 52.763$, $p < 0.05$). The Hake's normalised gain, $\langle g \rangle$ was used to measure the effectiveness of the intervention. The normalised gain showed a high-g (0.794) for the TCEG, a medium-g (0.405) for the CG and a low-g (0.134) for the LCEG. The interview data also confirms that the TCEG learners benefited more than the LCEG learners. It is, therefore, suggested that the TCEG approach is a better method for the effective teaching of photoelectric effect.

KEY WORDS

Computer Simulation, Quantum Mechanics, Grade 12 Physical sciences, Inquiry-based Learning, Constructivist theory, Photoelectric effect, Frequency, Intensity, Work function, Threshold frequency, Stopping potential, Einstein's photoelectric equation.

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May the Lord almighty bless you all.

DEDICATION

This study is dedicated to my family: my father Joseph, mother Lillykutty, lovely wife Anita and our loving children Aaron and Rayan.

ACRONYMS

The following acronyms has been used in this study and is presented alphabetically:

ACEPT	Arizona Collaborative for Excellence in the Preparation of Teachers
ANOVA	Analysis of Variances
ANCOVA	Analysis of Covariance
CAPS	Curriculum Assessment Policy Statement
CCM	Conceptual Change Model
CG	Control Group
CLT	Cognitive Load Theory
DBE	Department of Basic Education
EFG	Evaluation Facilitation Group
FET	Further Education and Training
LCEG	Learner-Centred Experimental Group
MCQ	Multiple Choice Question
MKO	More Knowledgeable Others
NCDoE	Northern Cape Department of Education
PEAT	Photoelectric Effect Achievement test
PhET	Physics Education Technology
POE	Predict Observe and Explain
PT	Photoelectric Tutor
RAM	Random Access Memory
RTOP	Reformed Teaching Observation Protocol
SGB	School Governing Body
SPSS	Statistical Package for Social Sciences
STM	Scanning Tunnelling Microscope
TCEG	Teacher-Centred Experimental Group
VQM	Visual Quantum Mechanics
ZPD	Zone of Proximal Development

DEFINITION OF TERMINOLOGY

The following terminology has been used in this study and is presented alphabetically:

Curriculum: refers to the lessons, academic content taught and pedagogy in a school or in a specific course or program.

Computer: An electronic device that accepts input data and processes it to produce output data according to a set of instructions.

Dineledi School: Schools identified by the Department of Basic Education to promote mathematics and physical sciences. These schools get special funding from the Department for acquiring various learning and teaching support materials.

Experience: It is defined in terms of the number of years of teaching by a teacher in a secondary school teaching physical science.

Fermi energy: It is the maximum energy occupied by an electron at zero kelvin.

Photon: A photon is an elementary particle, the quantum of all forms of electromagnetic radiation including light.

Photoelectric effect: The phenomenon of ejection of electrons from the surface of certain metals when light of a certain frequency is incident on it.

Physical Science: is a broad discipline concerned with natural phenomena of the earth, atmosphere and space. In the South African curriculum, physical sciences is concerned with the study of physics and chemistry.

Quantum mechanics: the branch of mechanics that deals with the mathematical description of the motion and interaction of subatomic particles, incorporating the concepts of quantization of energy, wave–particle duality, the uncertainty principle, and the correspondence principle.

Simulation: Simulations can be defined as interactive multimedia with dynamic elements that are under user-control.

Software: Software is a generic term for organised collections of computer data and instructions.

Stopping potential: The potential difference that we must apply to stop the photoelectron from moving.

Work function: the minimum quantity of energy which is required to remove an electron to infinity from the surface of a metal.

Zone of Proximal Development: The distance between the actual developmental level, as determined by independent problem solving, and the level of potential development, as determined through problem solving under adult guidance, or in collaboration with more capable peers.

LIST OF TABLES

LIST OF FIGURES

TABLE OFCONTENTS

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Quantum physics, which is regarded as one of the most important discoveries of contemporary physics, started during the early twentieth century and was gradually manifested to the scientific world through inventions of the laser, the electron microscope, the microprocessor and nanotechnology. At the same time, it is widely accepted that quantum mechanics is the most difficult branch of modern physics. Feynman (1965) ironically supported this statement by saying "I think I can safely say that nobody understand quantum physics" (p.129). John Gribbin's (1984) *In Search of Schrödingers Cat*, included a famous quote from Niels Bohr about the complexity of quantum mechanics as "Anyone who is not shocked by quantum theory has not understood it" (p. 254). Even the pioneers who used quantum theory to explain the mysteries of science, agreed with this notion of difficulty and especially the idea of "quanta" of light. "All these fifty years of conscious brooding have brought me no nearer to the answer to the question, what are light quanta? Nowadays every Tom, Dick and Harry thinks he knows it, but he is mistaken." (Einstein 1951, p. 453). The researches that were carried out in the field of teaching quantum mechanics at the secondary level (Ireson, 2000; Müller & Wiesner, 2002) conclude that learning the concepts of quantum mechanics is hard, as it contains abstract ideas and requires strong mathematical tools. Falk (2007) commented that even though quantum mechanics is an extremely important and influential physics theory, the teaching and learning of quantum mechanics is a challenging task for both teachers and students. But the learning of quantum mechanics is vital for a learner of physics, as it is the torch when he or she studies phenomenon such as the photoelectric effect, the Compton effect or black body radiation, where classical physics fails to explain these phenomena.

To understand quantum mechanics, one has to understand the dual nature of light. But research shows that this is not easy, as learners go back to the corpuscular theory when referring to the particle nature of light or photons (Klassen, 2011, p.723). Armstrong (1983) says that photons "are not particles like baseballs or shot: and the photon is not a return to Newton's corpuscular theory of light" (p.102). Understanding the photoelectric effect is an important milestone in understanding the particle nature of light, one of the cornerstone of quantum mechanics.

According to McKagan, Handley, Perkins, & Wieman (2008), "the photoelectric effect is a powerful tool to help students build an understanding of the photon model of light, and to probe their understanding of the photon model" (p.1). Dyson (1992) commented that understanding of quantum mechanics takes the learner to the second stage of understanding science. This is why Sen (2000) emphasised that teaching quantum physics at high school level could bring important benefits. Hughes and Du Bridge (1932) state that Einstein's photoelectric equation is perhaps the most important single equation in the whole quantum theory. Wright (1937) argues that Einstein's equation for the photoelectric effect is the usual starting point for the presentation of quantum theory for physics students. So, it is of utmost importance that the photoelectric effect should be taught effectively to the learners, as it is one of the phenomenon that was explained by Einstein using quantum theory.

A number of studies explain the difficulty of teaching the photoelectric effect and some advantages on using simulations in Europe and the United States of America. (Steinberg *et al*. 1996; Ireson, 2000; Olsen, 2002; Wieman, Adams & Perkins, 2008; Klassen, 2011; Sokolowski, 2013). But a literature search using Jstore, ERIC, SpringerLink, WorldWideScience, Ebsco and Google Scholar, on the study of teaching photoelectric effect with simulations in Africa yielded only two results. The first one by Nadaraj (2012) was to explore the experiences of pre-service physics students, when simulations are used to augment hands-on practical experiments in the photoelectric effect. The second one was by de Beer (2013) to investigate the learning experiences of learners with different learning styles, when simulations are used to teach the photoelectric effect. Hence, this limited study seeks, therefore, to determine if computer simulations could be used to assist in the teaching and learning of the photoelectric effect in a high school in the province of Northern Cape in the Republic of South Africa.

1.2 CONTEXT OF THE STUDY

The Republic of South Africa is divided into nine provinces. Northern Cape, where this study took place, is the largest of them comprising 30.5% of South Africa. Population wise it is the least populated province in the country with only 2.2% of the country's population. It is also one of the provinces in the country where young people are more likely to go hungry than their counterparts in other provinces. (Statistics South Africa, 2016)

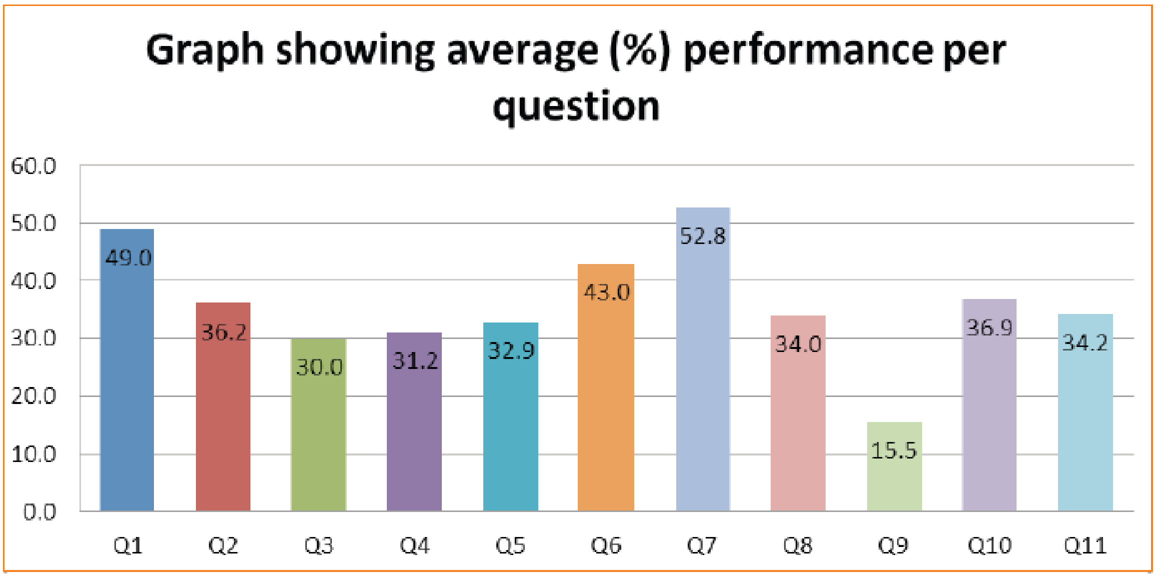
The Northern Cape Province is divided into 5 districts. For educational administration, the districts are further divided into circuits. The study took place in a secondary school in a rural community of circuit 2 of the Frances Baard District. The school is a co-educational school where 100% of the students are black.

The school is consistently performing well in the National Senior Certificate (NSC) physical science examination. This specific school is a Dineledi school and has a laboratory with essential equipment. All Dineledi schools receive good support from the district and provincial offices of the Northern Cape Department of education.

1.3 RATIONALE FOR THE STUDY

From 2008, since the photoelectric effect was introduced into the South African schools' curriculum, the last question in physical sciences paper 1 is always based on the photoelectric effect, even though the curriculum has been changed from the National Curriculum Statement (NCS) to the Curriculum Assessment Policy Statement (CAPS). This question carries a weight of ±10% of the whole paper. In the National Senior Certificate examination over the years, various diagnostic reports from the Department of Education showed that the learners performed poorly in the question on the photoelectric effect. (National Diagnostic Report, DBE, 2013, 2014 & 2015). (Tables 1.1, Table 1.2 and Table1.3)

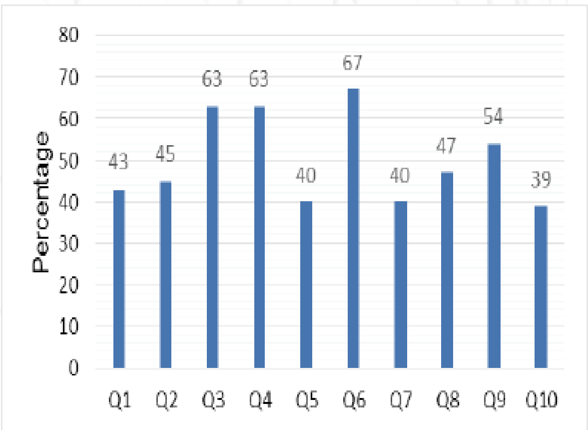
Table 1.1 Average marks per question expressed as a percentage for Paper 1 (NSC 2013)



Question	Content	Average Performance (%)
Q1	One-word items – all topics	49.0
Q2	Multiple choice questions – all topics	36.2
Q3	Vertical projectile motion	30.0
Q4	Momentum	31.2
Q5	Work, energy and power	32.9
Q6	Doppler effect	43.0
Q7	2D and 3D wave motion	52.8
Q8	Electrostatics	34.0
Q9	Electric circuits	15.5
Q10	Motors, generators & alternating current	36.9
Q11	Photo-electric effect	34.2

Source: National Senior Certificate Examination- Diagnostic report, (DBE), January, 2013

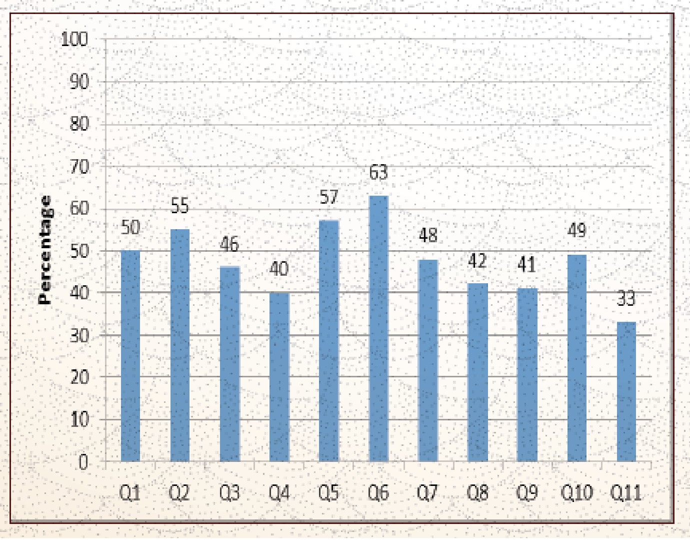
Table 1.2 Average marks per question expressed as a percentage for Paper 1 (2014 NSC)



Q1	Multiple choice questions
Q2	Newton's laws of motion
Q3	Vertical projectile motion
Q4	Momentum
Q5	Work, energy and power
Q6	Doppler effect
Q7	Electrostatics
Q8	Electric circuits
Q9	Motors, generators and alternating current
Q10	Photo-electric effect

Source: National Senior Certificate Examination- Diagnostic report, (DBE), January, 2014

Table 1.3 Average marks per question expressed as a percentage for Paper 1 (2015 NSC)



Q1	Multiple choice questions - all topics
Q2	Newton's Laws of Motion
Q3	Vertical projectile motion
Q4	Momentum
Q5	Work, energy and power
Q6	Doppler effect
Q7	Electrostatics (Coulomb's Law)
Q8	Electrostatics (Electric Fields)
Q9	Electric circuits
Q10	Motors, generators and alternating current
Q11	Photo-electric effect

Source: National Senior Certificate Examination- Diagnostic report, (DBE), January, 2015

There are questions in the National Senior Certificate, physical sciences examination that test the relationships between the photocurrent, kinetic energy of the ejected electrons, intensity of the incident radiation and its frequency. These questions are confusing to learners, as they cannot test that directly in a real experiment in a laboratory. This is why the National Diagnostic Report of the 2015 National Senior certificate examination, DBE, recommends the use of simulations to understand the experimental laws of the photoelectric effect (p.184).

As a teacher, the researcher also experienced difficulties in teaching this concept and the experimental laws, as most of the concepts are abstract. It was difficult to explain the relationships that lead to the experimental laws, which are important from an examination point of view. Learners cannot visualise the term intensity of light, since it is a new concept for them. This concept was not previously taught in any grades. Even when the term frequency is taught in grade 10, learners find it difficult to grasp it in relation to the photoelectric effect taught in grade 12. To visualise the concepts of intensity and frequency in the photoelectric effect, computer simulations were used.

1.4 AIM OF THE STUDY

The aim of the study was to determine the impact of computer simulations on the teaching and learning of the photoelectric effect in grade 12 physical science in one rural school in the Northern Cape province.

1.5 RESEARCH PROBLEM AND RESEARCH QUESTIONS

Many researches (Steinberg & Oberem, 1996; Johnston, Crawford & Fletcher, 1998; Gardner, 2002; McKagan, Handley, Perkins & Wiesman, 2008) show that learners hold a significant number of misconceptions in quantum mechanics, including the photoelectric effect, which is considered as the "starting point for the presentation of quantum theory". They propose alternative methods including the use of simulations for the teaching and learning of the photoelectric effect. This study is an attempt to evaluate the impact of computer simulations on students' science learning and understanding of the photoelectric effect. Considering the poor performance of learners over the past many years in the photoelectric effect in the National Senior Certificate examination, the research sought to answer the following questions:

1. What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive demonstration tool, manipulated by the teacher in the classroom?
2. What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive tool, manipulated by the learners in the classroom?

1.6 RESEARCH HYPOTHESIS

In order to suitably address the above-mentioned research questions, the following null hypotheses were formulated:

H_0 1 There is no significant difference between the mean pre-test and post-test scores for learners in the control group.

H_0 2 There is no significant difference between the mean pre-test and post-test scores for learners in the teacher-centred experimental group.

H_0 3 There is no significant difference between the mean the mean pre-test and post-test scores for learners in the learner-centred experimental group.

H_0 4 There is no significant difference between the mean post-test scores for learners in the control group, teacher-centred experimental group, and learner-centred experimental group after controlling the effect of pre-test scores.

1.7 SIGNIFICANCE OF THE STUDY

Research shows that there are many benefits of using technology such as computer simulations in the classroom, as students are increasingly technologically literate. But the use of computer simulations in the teaching of the photoelectric effect in schools is relatively under-reported. Most of the research about the use of simulations in the teaching of the photoelectric effect, focus on university students. (Steinberg, Oberem, & McDermott, 1996; Ireson, 2000; Olsen 2002; Wieman, Adams & Perkins, 2008; Klassen 2011; Sokolowski 2013). This study focuses on the effect of the use of simulations in a rural school on the topic of the photoelectric effect. The findings of this study could propose a new pathway for the teaching of photoelectric effect in the rural schools of South Africa, where science education is facing a serious crisis.

1.8 LIMITATIONS OF THE STUDY

The following are the limitations of the study:

1. The participants in the study were all black learners who are from an impoverished community but it can be assumed that these learners were reasonably representative of the rural learner population of South Africa. Some of the interventions were in the afternoon when they seem to be tired. Only one school was used for the intervention and therefore the present results should not be generalised to all sections of learners.

2. There are thirty-six secondary schools in Frances Baard district that offer Physical Sciences. Only few teachers agreed to participate in the study. But the number of learners doing physical sciences favours the current school.

3. The study was completed in three weeks. This short duration may have an impact on the study.

4. There might be a chance of contamination as the learners will talk to each other during the period of intervention. However, it was assumed that the contamination would be minimal because the classroom room experience could not be reconstructed without a computer.

5. The photoelectric simulation from PhET is not designed specifically for the South African curriculum. There are some features, for example, the stopping potential, different graphs of current versus battery voltage etc. are not fit for the learners doing physical science in the South African curriculum. This may have influenced the results, since there was a learner-centred group manipulating the simulation by themselves.

6. It is well known that the error in the statistical analysis can be decreased with a larger sample size. The small sample size of this study may have an effect on its general applicability.

7. The control group learners could have exposure to simulations after research so as not to disadvantage them. The plan to teach them using simulation could not be carried out due to some unexpected challenges experienced.

1.9 ORGANISATION OF THE STUDY

Chapter One

The background, context, rationale, research problem, research questions, and hypotheses are presented in this chapter. The significations and the limitations of the study are also discussed.

Chapter Two

The theoretical framework of the study is presented in this chapter with a detailed review of the literature available on the difficulties of teaching the photoelectric effect and the use of simulations.

Chapter Three

This chapter focuses on the research methodology, design, selection of participants, instruments for data collection and ethical issues considered in the study.

Chapter Four

This chapter explains the analysis of data collected from the study. The research questions were answered according to this analysis.

Chapter Five

The findings of the study are summarised in this chapter. The recommendations of the study as well as the implications of the study are also presented in this chapter.

1.10 SUMMARY

The study's orientation was outlined in this chapter. The background, the rationale, aim of the study, research questions and hypotheses were presented. The significance and the limitations of the study were also discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A literature review was conducted to present the current issues in the teaching and learning of the photoelectric effect, which is a quantum mechanical phenomenon. The literature that is relevant to the teaching and learning of the photoelectric effect spans many areas. They concern the misconceptions related to the interpretation of the photoelectric effect (Johnston *et al.* 1998; Ireson, 2000; Müller *et al*., 2002; Olsen, 2002; Hennessy, S., Wishart, J., Whitelock, D., Deaney, R., Brawn, R., La Velle, L., McFarlane, A., Ruthven, K. & Winterbottom, 2006; Wieman *et al.* 2008; Klassen, 2011; Yildiz & Büyükkasap, 2011; Wong, Lee, Shenghan, Xuezhou, Yan Qi, & Kit, 2011; Sokolowski, 2013); the teaching of the photoelectric effect and how it relates to difficulties in student understanding of the concept (Steinberg *et al.* 1996; Humphrey, 2000; Wieman *et al.* 2008; Wong *et al.* 2011; Sokolowski, 2013; Marshman & Singh, 2015; Taşlıdere, 2015; Taşlıdere 2016) and about university students' misconceptions and the solutions (Hobson, 1996; Müller & Wiesner, 2002; Knight, 2004; Singh *Et al.* 2006; Hennessy *et al.* 2006; Tsaparlis & Papaphotis, 2009; Koopman *et al.* 2009; Özcan *et al.* 2009; Yildiz & Büyükkasap, 2011; Greca & Freire, 2014; Marshman & Singh, 2015; Kizilcik & Yavaş, 2017).

Articles that are dedicated to the pre-university physics students (Steinberg *et al.* 1996; Ireson, 2000; Olsen, 2002; Wieman *et al.* 2008; Klassen, 2011; Sokolowski, 2013; Taşlıdere, 2015) deal with deeper contents associated with the photoelectric effect. Examples are wave-particle duality, photon model stopping potential and the relation between work function and the relation between the Fermi energy of the conduction electrons of the metal which do not have any importance in the Curriculum Assessment Policy Statement (CAPS).

In the CAPS, the photoelectric effect is introduced in Grade 12, to highlight the particle nature (photon model) of light (Curriculum Assessment Policy Statement, physical sciences, DBE, 2013 p.132).

The aim of this research is to establish in which way the use of simulations can help the learners to perform better in the photoelectric effect. The photoelectric effect plays an important role in understanding of the photon model of light (McKagan *et al.* 2009; Wong *et al.* 2011) and serves as a starting point to the quantum world (Uscinski and Larkin 2011). It is worth mentioning that the photoelectric effect was one of the phenomena that contradicted classical physics and paved the way for quantum mechanics, which is "an extremely important theory in physics, but the importance of quantum mechanics goes well beyond physics theories" (Falk, 2007 p.2).

2.2 QUANTUM MECHANICS

Quantum mechanics is the branch of physics relating to the very small (Coolman 2014) and has transformed the physicists' depiction of the world forever (Müller & Wiesner, 2002). According to these authors, it is not only a new theory but lays the framework for all of physics. Merzbacher (1998) presents quantum theory as a successful theory of physics that describes, correlates and predicts the behaviour of subatomic systems. Hobson (1996) also observes that quantum mechanics "is probably history's most successful scientific theory" (p.203). Özcan *et al.* (2009) argues that quantum mechanics "caused fundamental changes (a paradigm shift) in human ideas concerning the laws of nature and subsequently leads to immense technological revolution" (p.169). Singh *et al.* (2006) stressed the importance of quantum mechanics by saying that "the quantum theory has remained a cornerstone of modern physics" (p.43).

The applications of quantum mechanics are not limited just to physics. All over, in our daily life, its applications can be seen. There would not have been computers, microprocessors, cell phones, LCD displays, and most of the electronic equipment without quantum mechanics. A medical doctor would add that among other things, there would be no magnetic resonance imaging and computer tomography; robust tools used for imaging the inside of a human body. Without quantum mechanics, a molecular biologist could not have made it possible to stimulate how medical substances interact with the proteins of the body- an efficient and safe method in testing new medical substances. (Falk, 2007). The same sentiment is echoed by Garritz (2012) by reporting "without quantum mechanics, there would be no global economy to speak of, because the electronic revolution that brought us to the computer age is a child of quantum mechanics"(p. 1787). Quantum mechanics has changed the world into a better place.

Kizilcik & Yavaş (2017) regarded quantum theory as the theory that consists of the most basic laws of nature, since it applies to both the sub-microscopic and microscopic worlds. They further observed, "although these laws attract little attention from most people, they explain facts that directly affect our life and are used in areas such as computing, laser technology and nuclear energy. For this reason, the teaching of quantum physics, which has a history of over one hundred years, is quite important" (p. 101).

The importance of the teaching and learning of quantum mechanics was also emphasised. For example, Faye (2002) observes that the learning of quantum mechanics is important, as it provides the ability to make calculations and conduct experiments and therefore to create new technologies. Marshman and Singh (2015) noticed that. "a solid grasp of the fundamental principles of quantum physics is essential for many scientists and engineers" (p.1). Johnston *et al.* (1998) argue that the learners need a lot of time and reflection to properly grasp quantum mechanical ideas and, hence, it would be beneficial for students to meet these ideas early in their career, if possible even in high school.

Olsen (2002) underlines the importance of teaching quantum mechanics in schools. He calls quantum mechanics as the "physics of the 20th century" (p. 571). He argues that it is important that the students should at least have some understanding of how quantum physics differs from classical physics. "We should in our teaching search for at least some anecdotal evidence that our students are experiencing how quantum physics presents to us an alternative world view, which challenges some of the fundamental assumptions underlying classical physics" (p.573). Therefore, it is vital for a physics learner to study quantum mechanics. This is why the photoelectric effect, which is the "stepping stone of quantum mechanics", is included in the CAPS curriculum in South Africa (Curriculum Assessment policy statement, DBE, 2013).

2.2.1 DIFFICULTIES IN LEARNING QUANTUM MECHANICS

Even though quantum mechanics is a very important branch of physics, it is considered as a very difficult subject. Quantum physics is difficult to understand, misunderstandings and misconceptions are common among students and they often considered it as difficult (Kizilcik & Yavaş, 2017). Based on the research reviewed by Falk *et al.* (2007), findings in quantum mechanics education research exposed that students grapple with the subject. Falk *et al.* (2007) reported that “qualitative studies show that many students have considerable problems in depicting a vast array of quantum mechanical topics in an accepted way” (p. 92). Koopman *et al.* (2009) observed that quantum mechanics is a difficult subject and even after instruction, students still seem to clinch onto a deterministic worldview. They express an impression that students do not have consistent ideas on quantum mechanics. Gardner (2002) reported that learners found quantum mechanics difficult because quantum mechanics was "all mathematics" (p.10). This confirms the findings of Johnston *et al.* (1998) stating "this means that the mental modes they are working with are tenuous constructs... where many elements of the constructs are nothing but isolated mathematical deductions, balancing precariously on one another" (p.443). The interesting fact is that "students' difficulties associated with the understanding of quantum mechanics is universal" (Johnson *et al.*,1998) and it is hardly surprising that students do not like quantum mechanics and non-physics students try to dodge it (Greca & Freire , 2014).

Quantum mechanics is conceptually dense, and it takes time for students to sort and assimilate the ideas and concepts involved. (Gardner, 2002). Understanding quantum mechanics requires students to reject some preconceived perceptions that they are brought up with, and which originate from their experience of the macroscopic world. However, students are educated mostly in the model of classical physics, and key concepts, such as determinism, causality, etc are very influential. After accepting the key concepts of classical physics, they find it problematic and difficult to amend considerations to those concepts of quantum mechanics (Ayene, 2014).

Marshman and Singh (2015) noticed that "because the quantum mechanics paradigm is radically different from the classical paradigm, students must build a knowledge structure for quantum mechanics essentially from scratch, even if they built a robust knowledge structure of classical mechanics" (p. 5). Furthermore, due to the abstract nature of quantum mechanics the study of quantum mechanics has always conferred enormous learning challenges on the students (Ayene, 2014). Greca and Freire (2014) commented that the difficulties learners encounter with quantum mechanics in advanced courses are renowned, and many studies have shown that the difficulties are much greater in introductory courses in quantum mechanics in all scientific careers. This finding is consistent with that of Ayene (2014), who noted that quantum mechanics "is widely acknowledged as an exceptionally academically demanding subject to understand, particularly for students who study the area of physics for the first time" (p.21). This is why the learning and teaching of the photoelectric effect is important in a South African context. The photoelectric effect is the only quantum phenomenon that the learners in secondary schools are exposed to in South Africa (Curriculum Assessment policy statement, physical sciences, DBE, 2013).

2.2.2 MISCONCEPTIONS IN QUANTUM MECHANICS

Several research findings unearthed the different difficulties and misconceptions among learners in mastering quantum mechanics and the concepts associated with quantum mechanics. In his study, Ireson (2000) identified the following conflicting quantum thinking among pre-university students in Europe. (a) The atomic structure is similar to the planetary system. (b) It is possible for a single photon to have constructive and destructive interference with itself. (c) During the emission of light from atoms, the electrons follow a definite path as they move between energy levels.

Olsen (2002) noticed a misconception among the pre-university students that light is a particle and photons have mass. The conception of a particle being massive is at the root of this misconception. Due to this prevalent misconception, Olsen questions the introduction of quantum theory by reference to wave-particle duality. He noticed that even for the university students, wave-particle duality is a complex concept to comprehend. Lewerissa *et al*. (2017) also echoed the same sentiment. They noted "the wavelike behaviour of electrons is hard to define, for electrons appear as bright spots on fluorescent screens in most of the textbook experiments. The wavelike behaviour of electrons only appears in the distribution of these bright spots. Quantum mechanics does not describe an electron’s path, only the probability of finding it at a certain location" (p.3).

Johnson *et al.* (1998) in their study among the undergraduates in Australia identified the following misconceptions. (a) A particle is made of "stuff". (b) A particle is made of "stuff" and it travels along a well-defined path. (c) A particle is made of "stuff" and it travels along a well-defined path and it also responds to external forces. They commented that "school physics has a strong Newtonian flavour, in the sense that, although most students' initial experience of physical models of reality may be somewhat counter-intuitive, these models do explain the behaviour of objects within the range of normal sensory experience" (p.428). Compared to Newtonian physics, learning quantum mechanics includes a fundamental reconcentration of or shift in intellectual activity in many different areas. Johnston *et al.* argues that "in thinking about quantum mechanics, students must move beyond models based on sensory experience towards models that encapsulate theoretical sets of abstract properties" (p. 429). For students learning quantum mechanics, the mental models they have used before, wave or particle, were pictorial models. They learned to design images, or draw pictures, to help conceptualise different ideas. However, the new quantum mechanical model is very different from what they are used to and requires another level of abstraction that makes it very difficult.

As the learners find it difficult to learn quantum mechanics, the instructors also find it very difficult to teach.

2.2.3 DIFFICULTIES IN TEACHING QUANTUM MECHANICS

Greca and Freire Jr. (2014) observed that because of its technically and philosophically sensitivity, teaching quantum physics is not an easy task. Zollman *et al*. (2001) noticed that many physics instructors believe that quantum mechanics is a very abstract subject and students cannot understand it until they have studied adequate classical physics. Hence, many instructors do not believe that quantum mechanics should be introduced to the students in the early years of their courses.

Marshman and Singh (2015) noticed that the subject matter in quantum mechanics makes instruction quite challenging for instructors, and even gifted students constantly battle to develop competence and master basic concepts. Lewerissa *et al*. (2017) claimed that quantum mechanics education is facing several challenges, since its teaching is entirely different from that of other physics topics. Johnston *et al.* (1998) expresses the same concern by saying "unfortunately, quantum mechanics is also a subject which most students traditionally find very abstract and difficult, and its teaching has not changed much since it was invented early this century. It is an area which has not, until recently, attracted much pedagogical research and it is timely that university teachers should be investigating ways in which it might be taught more effectively" (p. 427).

2.2.4 MODEL FOR QUANTUM MECHANICS TEACHING

Many researchers put forward different models for the effective teaching and learning of quantum mechanics. It is worth mentioning some of the important ones.

Garritz (2013) advocated the teaching of quantum mechanics through a philosophical approach, especially through controversies. This is a contradiction to a purely historical approach. Garritz noted that historical presentation, beginning with blackbody radiation, photoelectric effect, and Bohr's hydrogen atom model could be disadvantageous to learners, as these cases need classical behaviour at the outset, which confuses them. In their model, historical episodes are recreated, and the analysis of controversies (the Copenhagen interpretation of quantum mechanics and its strong opposition, Schrödinger's Cat) and rivalries (Einstein Versus Bohr-Born Debate) among scientists is presented as very important features.

deSouza & Iyengar (2013) presented a course for the first-year undergraduates that introduces students to chemistry through a conceptually detailed description of quantum mechanics. This physically oriented course stresses the fundamental concepts that underline chemistry. They commented, "by presenting chemical concepts through quantum mechanical description in the first year, faculty teaching the course are forced not to rely principally on mathematics and thus can focus on how the quantum world behaves. When students re-encounter quantum mechanics more formally as upperclassmen, they already have an exposure to the fundamental concepts" (p.717). They found another advantage of this approach, such as those students who are inclined towards the more physical side of the discipline become interested later in quantum mechanics.

Kohnle *et al.* (2014) for the Institute of Physics developed an introductory quantum mechanics course with two-level systems (two-level atoms, spin 1/2 particles, interferometers, qubits). The fundamental philosophy of their approach to the curriculum is to present the quantum mechanics as a method of reasoning about physical systems that is based on a few *gedanken* (thought) experiments. They developed many interactive simulations for their course, which are freely available online.

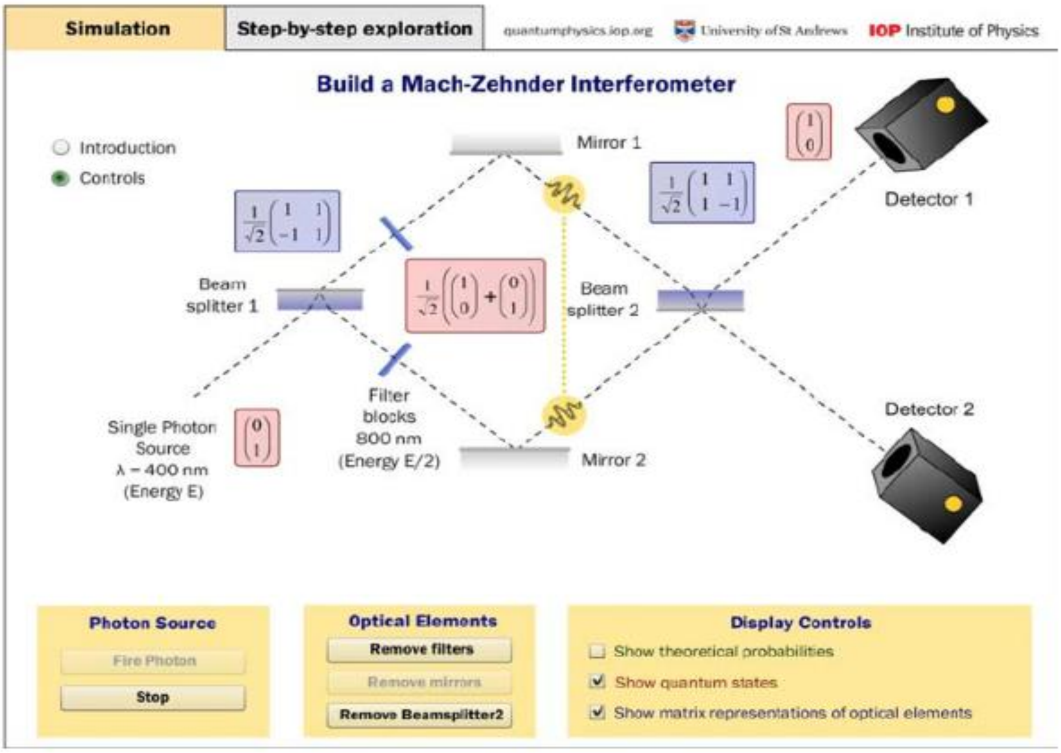


Figure 2.1: A screenshot of 'Build a Mach-Zehnder interferometer' simulation. Extracted from Kohnle *et al.* (2014, p 6).

In this course, each of the simulations proceeds with an activity. "Activities aim to promote guided exploration and sense-making, with scaffolding to help students progress from simpler to more complex situations. Activities aim to help students to link different representations, use the simulations to compare and contrast situations, collect data and interpret outcomes of their calculations" (Kohnle *et al. (*2014, p.5)).

The simulations aim to help students make connections between multiple representations such as graphical, mathematical and physical representations. Kohnle *et al.* (2014) pointed out the following advantages of this approach. (1) It engages students in the inherently quantum-mechanical aspects of physics by using experiments that have no classical explanation. (2) It allows straight discussion of the critical facets of quantum mechanics. (3) It allows an inclusion from the start of aspects of quantum information theory. (4) Instead of solving integrals and differential equations, it requires only basic linear algebra, and manipulation of 2 x 2 matrices which makes it mathematically less challenging.

Singh, Belloni, & Christian (2006) propose tutorials as effective supplements to traditional instruction in quantum mechanics. This tutorial approach consists of three components. Firstly, carefully designed tasks to elicit difficulties that students have. Secondly, the tutorials guide students through tasks that help them overcome those difficulties and organise their knowledge. The final component is a gradual reduction in tutorial support as students develop self-reliance. Some of the features of tutorials that make them suited for the teaching of quantum mechanics are "(a) They are based on research in physics education and pay particular attention to cognitive issues. b) Visualisation tools help students build physical intuition about quantum phenomena. (c) Students remain actively engaged, since they are asked to predict what should happen in a particular situation and receive appropriate feedback" (p.47).

Singh *et al.* (2006) further noted that "the teaching and learning of quantum mechanics currently stand at the fortuitous crossroads where advances in experimental, theoretical, computational, and educational research meet" (p.49). The important observation made by Singh *et al.* (2006) is that the guidance provided by research-based learning tools has the potential to increase the competence and number of students who pursue advanced degrees and careers in physical sciences and engineering. Computer simulation is one such important tool in this era of information technology.

Kizilcik & Yavaş (2017), in their study among the pre-service physics teachers, reported that the mathematics associated with quantum mechanics makes the subject difficult for the students. They proposed a model in which the students use visualizations and animations for the better understanding of the subject. They also mention the importance of referring to mathematics less often, since it will reduce the number of difficulties experienced in quantum physics courses. Quantum mechanics should be discussed in terms of experiments rather than merely depending on theoretical ideas (Kizilcik & Yavaş, 2017). They found that the use of thought experiments helped to reduce the abstract nature of the subject.

Nashon *et al*. (2008) proposed the teaching of quantum mechanics in a historical perspective. They commented that teaching students about scientific revolutions and change is important to demonstrate the uncertain nature of scientific knowledge. Their model is based on the theory of conceptual change model (CCM). According to them, conceptual change will only occur when the learner becomes discontented with the existing conception. This happens through a situation or experience that questions the existing conception by raising doubts in the learner's mind about his or her own concepts. They further stressed the fact that this approach will enable the students to develop a more complex scientific literacy by including both situational and cultural factors, accompanying the cognitive development, that helps in the understanding of the abstract nature of quantum mechanics.

Greca and Freire (2014), in their quest for the new didactics for introductory quantum theory, reviewed 43 articles published between 2000 and 2013 and presented a "spectrum" of options that are based on the history and philosophy of science and teaching experience as,

- "The inclusion of philosophical interpretations and their defence: According to them conceptual and interpretational issues are indissoluble in quantum mechanics and any research into quantum mechanics in science education must declare its interpretational choice, which has to be justified and defended". (p.298)
- The emphasis on strict features of the systems under study: The discussion of quantum features is important to all learners to prevent them from establishing unwanted associations with classical concepts.
- "An emphasis on formalism, without worrying about the ultimate ontological status of mathematics:" (p.299). The teaching of quantum mechanics may emphasise formalism, without considering the ultimate ontological position of mathematical expressions.
- "The incorporation of quantum mechanics applications to real problems: The inclusion of applications of quantum mechanics to real simplified problems is not only important for the understanding of quantum mechanics, but will also motivate students to continue their studies in this subject"(p.299).
- "The use of images to assist with conceptual understanding: use of images such as simulations help make the quantum mechanical concepts more understandable. It helps to visualise the abstract mathematical structure to grasp quantum concepts" (p.299).
- "The controversy over its foundations and interpretations can serve as the basis for the teaching of historical and philosophical aspects of science: Teaching of quantum mechanics must be informed by the history and philosophy of science" (p.300).

Müller and Wiesner (2012) proposed an introductory quantum mechanics course to construct a proper quantum mechanical understanding that avoids classical misconceptions. They concentrate mostly on those features of quantum mechanics which are entirely new compared with classical mechanics. Therefore, the course involves a focus on the following aspects:

- *Born's probability interpretation* is introduced early and used throughout the course. Wave-particle duality is often stated as the main puzzle of quantum mechanics in introductory courses. But, they point out that once a proper understanding of probability interpretation has been achieved, there is nothing mysterious in wave-particle duality.
- Classically well-defined dynamic properties like position, energy or momentum cannot always be attributed to quantum objects. An electron does not possess momentum if it is not in a momentum *eigenstate.* Similarly, an electron in an atomic orbital (an energy *eigenstate*) does not possess the property "position". Müller and Wiesner consider this aspect as the core element of quantum mechanics and therefore its discussion takes a prominent place in the course.
- The *measurement process* is one of the most controversial topics in quantum mechanics. In classical mechanics, measurement is considered as a passive reading of pre-existing values. In quantum mechanics, measurement is an active process. "There is a difference between "to possess a property" and "to measure a property". The special role of the measurement process becomes known in the process of state reduction and is illustrated e.g. by Schrödinger's cat paradox". (Müller & Wiesner, p.223)

Zollman and Rebello (1999) proposed the Visual Quantum Mechanics (VQM) project that makes quantum mechanics more appealing to high school and introductory college students, by minimizing the use of mathematics. In this project, computer visualizations, hands-on activities and written worksheets are integrated. The curriculum is organised into different instructional units that can each be completed in 6-12 hours of classroom teaching. The units can be integrated into any existing curriculum, because the requirements for this course are topics covered in a standard physics curriculum. The instructional units are:

- *Solids & Light* - To understand the concepts of energy levels and energy bands, transitions, and spectra, students use LEDs and gas lamps.
- *Luminescence: It's Cool Light* - Some overlap exists between this unit and the *Solids & Light* unit. Students use fluorescent and phosphorescent materials to understand the metastable states and the effects of impurities on energy bands.
- *The Waves of Matter* - Here the students create a model to explain the discrete energy states. Applying aspects of the model to the Star Trek transporter and the electron

microscope, students learn about the wave nature, wave functions, Schrödinger equation and wave packets. The Schrödinger equation is treated only qualitatively to reduce the mathematical load.

- *Seeing the Very Small: Quantum Tunnelling* - Students learn about quantum tunnelling and the various influencing factors associated with it, using a simulation of the Scanning Tunnelling Microscope (STM).
- *Potential Energy Diagrams* - Zollman and Rebello use magnets placed on a Pasco dynamics track or Hot Wheels cars to create and explore potential energy diagrams of different shapes. Potential energy diagrams are robust representation that is very effective in quantum mechanics.
- *Making Waves* - "This unit treats classical waves and introduces just those concepts that are needed for the study of *The Matter of Waves* unit." (p.253)

Zollman and Rebello (1999) reported that all VQM units were field-tested at various high schools and results show that students seem to have acquired a good general understanding of some important concepts of quantum mechanics that are usually not dealt at the introductory level. Even though the VQM project was a success in many parts of the world in teaching introductory quantum mechanics, it cannot be used in South African schools. This is because most of the instructional units are not prescribed in the South African school curriculum. The researcher mentioned the VQM project to highlight the success of visual methods in teaching quantum mechanical concepts.

2.3 PHOTOELECTRIC EFFECT

The photoelectric effect is a process where electrons are ejected from the surface of a metal by the action of light or electromagnetic radiation (Humphrey, 2000). A German physicist, Heinrich Hertz, discovered this phenomenon in 1887. All attempts to explain this phenomenon based on classical theory failed, since light was considered as a wave. Lorentz and Maxwell had solidly established the wave nature of electromagnetic radiation. Many experiments on the diffraction, interference and scattering of light had proved the wave nature of light. In 1905, Albert Einstein explained the phenomenon because of quantum theory. Einstein explained that under certain circumstances, light behaves not as continuous waves but as discrete, individual particles. These particles, or "light quanta," (what are called today "photons.") each carried a "quantum" or fixed amount of energy. The total energy of the light beam is the sum of the individual energies of these discrete "light quanta". Theories of matter and electromagnetic radiation in which the total energy is treated as "quantized" are known as quantum theories. Historically, the photoelectric effect was one of the first phenomena that was explained successfully using quantum mechanics.

2.3.1 LEARNING OF PHOTOELECTRIC EFFECT

McKagen *et al. (*2009) noted "understanding the photoelectric effect is a crucial step in understanding the particle nature of light, one of the foundations of quantum mechanics. The photoelectric effect is a powerful tool to help students build an understanding of the photon model of light and to probe their understanding of the photon model" (p.86). Wong *et al. (*2011) also underlined the fact that the photoelectric effect plays a very important role in guiding students in developing their understanding of the photon model of light. Fletcher and Johnston (2006) also stressed the importance of the photoelectric effect in understanding the particle model of light. Zollman *et al.* (2001) identified the photoelectric effect as one of the historically important experiments that the students must learn for the successful understanding of the basics of quantum mechanics. Rutten *et al.* (2012), in their study, noted the correlation between improved ability to predict the results of experiments on the photoelectric effect and the students' success in quantum mechanics.

2.3.2 DIFFICULTIES AND MISCONCEPTIONS IN PHOTOELECTRIC EFFECT

Researches shows that students have serious difficulties in understanding even the basic aspects of the photoelectric effect such as the experimental setup, experimental results, and implications about the nature of light (Steinberg *et al*., 1996, 2000; De Leone & Oberem, 2003; Knight, 2004). Steinberg *et al.* (1996, 2000) carried out studies regarding the learning of the photoelectric effect and they summarised the specific difficulties as:

- A belief of V = IR applies to the photoelectric effect.
- An inability to differentiate between frequency of light (and hence photon energy) and intensity of light (and hence photon flux).
- Students were not able to make any prediction of an I-V graph for the photoelectric effect.

- An inability to give any explanation linking photons to the phenomenon of the photoelectric effect. (Steinberg & Oberem, 2000)

Some of these difficulties were mentioned again by Wong *et al.* (2011), Nadaraj (2012), McKagen *et al.* (2009) and Taslidere (2015). Taşlıdere (2015) found that most of the students from different educational levels have serious learning difficulties in understanding the basic aspects of the photoelectric effect. He claimed that traditional presentation of the photoelectric effect did not provide students with sufficient functional and conceptual understanding.

For the high school students, most of the experiments in physics and their mathematical representations involve mostly the manipulation of two variables. However, the photoelectric effect involves a number of variables, such as photon energy, plates from which electrons are emitted, work function, kinetic energy of the ejected electrons and the external potential difference. Hence, Sokolowski (2013) claims that another difficulty in understanding the photoelectric effect is the involvement of these several variables. According to him, the multiple variables involved in the photoelectric effect makes the process of comprehension difficult for students.

One of the researches conducted by Wieman *et al.* (2008) on the use of PhET simulations in the teaching of the photoelectric effect, explained two misconceptions that are most prevalent among the learners. The most common error, made by nearly half (42%) of the students in the study was the misapplication of Ohm's law. Learners believed that a voltage is necessary or adequate for current flow or to overcome the work function of the metal. The second most common error, made by 5% of the learners, is associated with the quantum theory of light. Learners claimed that it is possible to eject the electrons from the metal even though the photon energy is less than the work function. They believed that it could be achieved by increasing the intensity of light alone.

2.3.3 TEACHING OF PHOTOELECTRIC EFFECT

To make the quantum mechanics appealing for the teachers and the learners, Ireson (2000) proposed a sequence of instruction that allows the learner to develop a conceptual framework for a subject that is often unreasonable to common sense or normal reasoning. He recommended the following approach, put forward by Fischer and Lichtfeldt (1992) in teaching the quantum physics. (1) Reference to classical physics should always be avoided. (2) Teaching of the photoelectric effect must begin with electrons rather than photons. Due to the strong influence of Newtonian physics in high schools, it is very likely that the learners refer to the corpuscles or classical particles when they hear about photons as a particle. Therefore, to avoid this temptation of students, it is better to introduce the photoelectric effect by considering light as a quantum object rather than photons.

Taşlıdere (2015) in his motivation for a new model for the teaching of the photoelectric effect reported that the photoelectric effect is one of the important quantum physics topics that plays crucial role in understanding the photon model of light. This study was conducted in Turkey, with a sophomore level of pre-service science teachers. Lewerissa *et al.* (2017), in their study, using three data bases such as Scopus, Web of Science, and ERIC reported that some students confused the photoelectric effect with ionization. Their study also reveals that students have difficulty with fully understanding how light and electrons interact, and how various aspects such as work function, cut-off frequency, kinetic energy, and material properties together constitute the photoelectric effect. This hinders their further understanding of quantum mechanics.

The course, outlined in section 2.2.4, by Müller & Wiesner (2002) starts with the photoelectric effect. deSouza & Iyengar (2013) wanted to start their quantum mechanics course by introducing the photoelectric experiments that shattered the classical interpretation of the world in the beginning of the twentieth century. This shows the importance of ensuring that learners understand the concept of the photoelectric effect properly, as it is the stepping- stone for the teaching and learning of quantum mechanics.

This finding is very important in the South African context, as is evident from the various diagnostic reports by the Department of Basic Education. All the reports show that the learners are struggling with the photoelectric effect in the different National Senior Certificate examinations (National Diagnostic Report of 2013, 2014, 2015 & 2016, National Senior certificate examination, DBE). Thus, there is a good opportunity for the researcher to find a better way of teaching the photoelectric effect in the South African context.

Zollman and Rabello (1999), Singh *et al*. (2006), Kohnle *et al*. (2014) and Greca and Freire (2014) (see section 2.2.4) all highlighted the success of simulations in teaching quantum mechanics. It is also noted that simulations can help students to engage with and delve into physics topics through interaction, immediate feedback and multiple representations of physical concepts (Kohnle *et al*. (2014)). They provide students' visual representations of abstract concepts and microscopic processes, such as the photoelectric effect that cannot be observed directly. Therefore, the use of simulations is explored.

2. 4 SIMULATIONS

A computer simulation is an interactive program that contains a model of a natural or artificial system or process (Eckhardt, Urhahne, Conrad, & Harms, 2013).

2.4.1 ADVANTAGES OF USING SIMULATIONS

Stephens and Clement (2015) emphasised the fact that simulations provide learners an opportunity to personalise their own modelling tools. They also noticed that simulations can increase engagement and teachers can use them to "help students make their thinking visible" (p. 138). Chao, Chiu, DeJaegher, and Pan (2016) commented that simulations of scientific phenomena will help students develop better conceptual understanding.

According to Jimoyiannis and Komis (2001), "simulations are open learning environments that provide learners with the opportunity to:

- develop their understanding about phenomena and physical laws through a process of hypothesis-making, and ideas testing;
- isolate and manipulate parameters, thereby helping them to develop an understanding of the relationships between physical concepts, variables and phenomena;
- employ a variety of representations (pictures, animation, graphs, vectors and numerical data displays) which are helpful in understanding the underlying concepts, relations and processes;
- express their representations and mental models about the physical world; and
- investigate phenomena which are difficult to experience in a classroom or lab setting, because it is extremely complex, technically difficult or dangerous, money-consuming or time-consuming, or happens too fast" (p.185).

Other interesting advantages of simulations is well explained by Rutten *et al.* (2012). They found that a learning environment with a computer simulation has the following advantages and attracts the teachers to use them in their classrooms.

- Students can methodically explore hypothetical situations.
- They can interact with a simplified version of a process or system
- Students can change the time-scale of events, and
- Practice tasks many times and solve problems in a realistic environment without stress.

In their study reviewing the articles on simulations, Rutten *et al.* (2012) found that all reviewed studies that compare conditions with or without simulations report positive results for the simulation condition for studies in which simulations were used to replace or enhance traditional lectures. This confirms an earlier finding by Bozkurta and Ilika (2010) who reported that the groups who study with the aid of computer simulations are more successful than those who study with traditional methods.

Khan (2008) asserted that computer simulations are particularly valuable for science teachers because they help to visualise aspects of science that are too large or too small for to view. It also affords the quick testing of ideas, show the results through graphs or other representations, and provide extreme situations to support through experiments and "what if" scenarios. Simulations help students to generate initial relationships between variables and to assess the validity of the relationships. It creates an environment to make comparisons between data and helps to visualise this using graphs and animations (Ceberio *et al.*, 2016).

Bozkurta and Ilika (2010) found that with the help of a powerful simulation many of physics contents which are difficult to teach, and transfer can be made simpler and clearer and many computer simulations allow students to learn physics concepts and let them have manual skills in virtual environments that can only be acquired in real laboratories. Using simulation, time changes can be speeded up or slowed down. Abstract concepts can be made concrete and implied processes made visible. When real-world environments are simplified, teachers can focus students' attention on learning objectives, causality of events is better explained, and the extraneous cognitive load is reduced through the simulation. Allowing the flexibility to explore ideas together and prompting students to justify their actions and providing prompt feedback, are further factors that may have promoted the use of simulations (Smetana & Bell, 2012).

Simulation speeds up teachers’ educational potential and students’ learning in an active ma nner. It also provides options for modelling notions and processes, and acts as a bridge in learning new physics notions by using prior knowledge. As a result of using simulations, students also pointed out that as a science, physics is used in daily life and has a connection with real life. (Hursen, 2015). Hence, the use of simulations was suggested while teaching physics to make the contexts more easily understandable. Therefore, it is very important that the physics curriculum and instruction should include them.

2.4.2 SIMULATIONS AND VARYING ABILITY STUDENTS

One of the biggest challenges the teachers face is the instruction of students with varying ability levels. Any step to help the slow learners or the less able learner should be welcomed in all forms of instruction. Teaching with simulation is one of those steps. Hennessy (2005) noticed that the biggest beneficiary of the use of simulation is the less able group, since the power of simulation increases their scope of experience through visual representation. Simulations allow them to repeat experiments as often as necessary, which could not be done practically. This points to the fact that students can learn at their own pace.

Ceberio *et al.* (2016) mentioned a very important feature of simulation that helps the slow learners. Each simulation focuses on a single or minimal number of physical concepts and omits all the other unnecessary details, to give the user a simple and controllable program. This feature is very important as students often lack the expertise needed to make the precise distinctions between what is needed and what is unnecessary within these problems. By using simulations, results are simplified by removing the unnecessary details and allowing the students to focus on important concepts. (Anderson & Wall, 2016).

2.4.3 REDUCTION OF COGNITIVE LOAD USINF SIMULATIONS

There are different theories that try to understand and explain how people learn. Cognitive Load Theory (CLT) (Sweller, 1988) is one of such theory. Cognitive load theory regards information processing as a procedure, similar to that of a computer (Reedy, 2015). New information for an individual is regarded as a Random Access Memory (RAM) which is the working memory of the computer. Reedy (2015) pointed out that there is a limit to how much information people can process together, and this influences how information is stored. Too difficult a task or too much information, presented in an unstructured or unreasonable way, can result in cognitive overload for a learner.

Reedy (2015) notices that cognitive load theory is very helpful to design learning tasks and environments. It is of paramount importance that the developers and designers of computer simulations and other teaching and learning support materials keep in mind the importance of reducing the cognitive overload. Different researches on the teaching and learning of photoelectric effect (McKagen *et al.*, 2006 and Adams *et al.*, 2008) show that students learn best when reducing their cognitive load by eliminating unnecessary details. Sokolowski (2013) recommended that simulations such as PhET simulation have the ability to reduce the cognitive load. Kaheru and Kriek (2016) also pointed out that the cognitive load could be reduced by simulations when they investigated Grade 11 learner understanding in geometrical optics.

2.4.4 DISADVANTAGES OF SIMULATIONS

Although there are many advantages in the use of simulations, limitations and disadvantages are also presented in the literature. Guy and Jackson (2015) reported that the simulations impede learners' development of interpersonal skills due to the minimum use of face-to-face interaction between the learners and the teacher. Frederking (2005) and Shellman (2006) questions the reporting of positive learning outcomes using simulations citing that they lack a high standard of rigour. Teach and Patel (2007), and Wolfe and Luethge (2003) believe that simulations perpetuate continuous guessing and hence student performance using simulations is not valid or reliable.

The use of simulations as an alternative to experimentation is also questioned. Greca and Freire (2014) reported that simulations are not comparable to experiments, because simulations lack materiality. In experimentation, there is a theory and then experimentation and the experimental results will be confronted by the theoretical calculations. Greca and Freire (2014) argue that this is not the case with simulations. Hence, experiments have a superior epistemological status compared to simulations.

2.5 TEACHING USING SIMULATIONS

One of the aims of any instruction is addressing students' misconceptions or alternative conceptions. Simulations are tools for addressing the misconceptions (Köseoğlu, 2015). Zietsman & Hewson (1986) reiterated this idea by reporting that "simulations are credible representations of reality, capable of producing significant conceptual change in students holding the alternative conception" (p.34). Jimoyiannis and Komis (2001) claimed that simulations provide a bridge between students' prior knowledge and the learning of new physical concepts, helping students develop scientific understanding through an active reformulation of their misconceptions.

According to Richards, Barowy and Levin *(*1992), teaching using properly designed simulations can bridge the gap in any content among the students. He argued that students are willing to spend more time and effort necessary to undergo conceptual change because the simulations engage them in a very interesting manner. Since simulations are based upon scientific models, they provide students with a set of rational experiences that challenge the way they see the world. When coupled with hands-on activities, the computer simulations facilitate students to construct and test their own account for the various physical phenomena.

The process of teaching by simply telling students about a scientific theory is inadequate, for it fails to engage the students in reflecting upon and modifying their own view of the way they think the world works (Richards *et al.* 1992). Jimoyiannis and Komis (2001) found that the use of simulations reinforces students' conceptual change in a gradual process which is represented below.

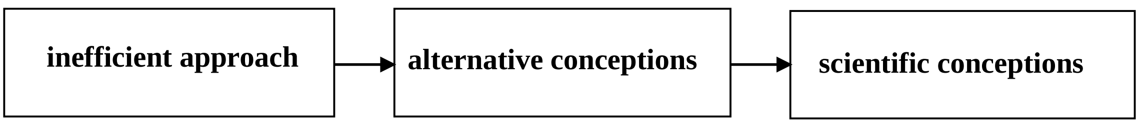


Fig 2.2: Taken from Jimoyiannis & Komis (2001) p. 201

The inefficient approaches of teaching and learning lead to alternative conceptions. That is why several teaching strategies, such as creating conflicts, having students work in groups and performing experiments, the use of simulation etc. are proposed. This helps the learners develop the right conception by themselves in a gradual manner.

2.5.1 SIMULATIONS AND INQUIRY BASED TEACHING

Inquiry-based teaching is a way of learner-centered teaching and learning. Rutten *et al*. (2015) reported that there is no agreement in the research literature about the definition of inquiry-based learning. According to them, there are several approaches that exist in inquiry- based learning and teaching. The most general model of learning starts with posing questions and developing hypotheses in a concept. This process continues with investigation and ends with conclusions and then evaluation.

Various studies revealed that simulation helps inquiry-based teaching. Rutten *et al*. (2015) proposed the use of an inquiry cycle comprising prediction, observation and explaination (POE model) in which the students manipulate different simulations. Teachers' use of computer simulations provides an opportunity to stimulate their students in expressing their ideas about a given concept or phenomenon and speculating on how to solve a problem (Smetana & Bell, 2013). One of the approaches in inquiry-based teaching is the problem-solving methodology. Ceberio *et al.* (2016) reported that the use of problem-solving methodology together with simulations can improve students' problem-solving abilities. Simulations give both teachers and students, more flexibility to perform authentic scientific inquiry and it serve as scaffolds for helping students to solve complex tasks that are often inherent in authentic inquiry.

Rutten *et al*. (2015) found "four relations between pedagogical aspects related to inquiry-based teaching and with computer simulations:

1. Active student participation during implementation of computer simulations in teaching relates to students' positive attitude about its contribution to their motivation.
2. Implementation of computer simulations in teaching that resembles the inquiry cycle relates to students' positive attitude about its contribution to their insight.
3. Active student participation during implementation of computer simulations in teaching relates to low resemblance to the inquiry cycle, and *vice versa*.
4. Learning goal congruence between a teacher and his/her students relates to the teacher's positive attitude about inquiry-based teaching with computer simulations." (p.1241).

Rutten *et al.*'s findings agree with those of Zacharia (2005). According to Zacharia (2005), effective physics instruction must encourage the type of learning that advances conceptual understanding. Such learning occurs when physics instruction focuses on creating classroom interactive learning that facilitates individual self-direction in constructing better physical science ideas. Rutten *et al*. reported that such interactive learning can be provided using simulations, together with the application of the POE model. They commented that the important attribute of simulations is the provision of a learning environment that is exploratory and enables the student to inquire into the presented event. Simulation allows a change in variables, the probing of conditions and the observation of the effect of these actions.

The National Research Council of Canada (2002) is calling for scientific inquiry teaching and learning. Computer simulations offer a great opportunity for conducting scientific inquiry, allowing students to develop their own scientific knowledge (Rutten *et al.* 2015). The use of simulations in the classroom is a powerful tool not only for aiding student learning, but also for allowing inquiries that are analogous to authentic science practice. Simulations have the potential to enrich students' learning about the different presented contents, whilst meanwhile scaffolding authentic science inquiry and helping students better understand science practices (Peffer *et al*., 2015).

2.5.2 SIMULATIONS AND EXPERIMENTS

Simulation offers ideal visual representations of physical phenomena and experiments that would be dangerous to carry out, costly in a school laboratory or generally difficult or impossible to investigate experimentally (Richards *et al.* 1992). Nordlund and Stein (1988) underlined this fact by giving an example, as they report, "through simulations, scientists have been able to extend their experiences to otherwise unobservable phenomena, such as the processes occurring beneath the surface of the sun" (p. 702). Osborn (2003) claimed that the simulations release students from tiresome manual processes and enable teachers and learners to focus on the most important issues without distraction. Bozkurta and Ilika (2010) also agrees with this by reporting "some experiments which are difficult to make or hard for the students to understand in a real laboratory, can be made much simpler with the help of simulations". This finding is important in teaching the photoelectric effect in South African schools, because they do not have the necessary equipment to verify the experimental laws of the photoelectric effect.

There are several reasons influencing teachers use of computer simulations over experiments. One is the saving of time. Simulations allow teachers to dedicate more time to the students instead of, to the setting up and supervision of experimental equipment. Another advantage is the ease with which experimental variables can be manipulated in a simulation. Taşlıdere (2015) reported that simulations allow students to arrange the independent variables and observe the impacts immediately. Simulations allow the articulation and testing of hypotheses and provide ways to support understanding with varying representations, such as diagrams and graphs (Rutten *et al*., 2012).

Anderson and Wal (2016) report a better performance on the pre-test for learners exposed to the program compared to learners exposed to traditional experimental laboratory experience. Simulations minimize the high cost of laboratory equipment, shorten the duration for experiments as there is no need for setting up of the equipment that usually takes a long time. In a South African context, this is very important as many science schools do not have a working laboratory. It also provides a safe environment for dangerous experiments such as nuclear reactions and high voltage electricity experiments.

2 5.3 TEACHING PHYSICS WITH SIMULATIONS

Yigit *et al.* (2005) proposes one of the methods that needs to be applied to students for them to comprehend physics as a subject which is hard to understand and memorise and is also abstract, is using visuality to make a relationship between recently learned notions and those previously learned. Giving visual education in physics lessons can eliminate many problems associated with the teaching and learning of physics. Simulations could help to make the abstract notions in physics concrete and allow learning at the learners' own pace. (Adiguzel, Gurbulak & Saricayir, 2011; Celen, Celik & Seferoglu, 2011; Akkagit & Tekin, 2012). In addition, using multimedia techniques makes education effective and interesting, addressing students' personal differences in learning (Adiguzel *et al.*, 2011). Hursen and Asiksoy (2015) pointed that simulations speed up teachers' educational potential and students' learning in an active way.

Ceberio *et al.* (2016) defines physics simulations as computer programs that enable one to depict a particular physical phenomenon dynamically. Many examples of teaching physics using simulations can be found in the literature. (Anderson & Wall 2016; Ceberio *et al.* 2016; Chao *et al.*, 2016; Ulukök & Sari, 2016); Hursen & Asiksoy, 2015; Krobthonga, 2015; Peffer et al., 2015; Rutten *et al.* 2015; Taub *et al.*, 2015; Darrah, Humbert, Finstein, Simon & Hopkins, 2014; Sarabando *et al.* 2014; Anderson & Barnett, 2013; Eckhardt *et al.* 2013; Civelek *et al.* 2013; Akkagit & Tekin, 2012; Wieman et al, 2008; Richards *et al.*, 1992). In most cases, it is reported that computerised labs or simulations helped to increase the understanding of the concepts and provide many benefits over traditional teaching and laboratory activities. Sarabando *et al. (*2014) in their study, reported that the learners who used simulation-assisted learning on the concept of mass and weight gained 40-58% compared to 20-37% by the learners who were exposed to traditional teaching. Taub *et al.* (2015) provided evidence that computer simulations were effective in developing different learning processes than the usual physics tasks. Ceberio *et al*. (2016) observed that in recent years, interactive computer simulations have been constantly integrated into science teaching and have contributed substantial improvements in its teaching–learning process.

The approach helps to change students' perception of physics as a 'difficult' subject. Hursen and Asikoy (2015) observed that, by using the simulation supported method, students' feelings, thoughts and interest towards physics have changed in a positive way. Their results suggested that this method should be included in the education process. Chao *et al.* (2016) also underlined this finding by noting that computer simulations are effective tools to support students to develop a better understanding of physics concepts. Simulations help to facilitate necessary conditions that would promote students' active engagement in learning and functional understanding of physics (Jimoyiannis & Komis, 2001).

Hursen and Asiksoy (2015) pointed out that simulations motivate students, and lead to an active participation. Simulations provided a pleasant learning environment, even in difficult physics topics such as quantum mechanics; increased recognition of experiment tools and materials; increased attention; and positive attitude and motivation, thus enabling students to enjoy the lesson (Ulukök, & Sari, 2016) which is very important for teaching and learning of a subject such as physics, which is perceived as a difficult subject by many students.

2.6 PhET SIMULATIONS

Physics Education Technology (PhET) is an interactive physics simulation software which was developed by a group of researchers from the University of Colorado in the United States of America. Its development is based in research on how students learn and their conceptual difficulties and misconceptions. The PhET project's goals are "increased student engagement, improved learning and improved beliefs about and approach towards learning" (Wieman, *et al.*, 2008, p.394). PhET simulations have a very good global acceptance, due to its simple presentation, simplicity, versatility and its availability in the internet as freeware. In developing the simulations, researchers made use of "student interviews and classroom testing to explore issues of usability, interpretation and learning" (Wieman *et al.*, 2008, p.394)

In PhET simulations, the visual display and direct interaction features help answer students' questions and develop their understanding of the various concepts. Wieman *et al.* (2008) assert that interacting with the simulation helps users in developing their own mental models and better understanding of the science. They noticed that students find the simulations enjoyable and intellectually engaging and students (and teachers) spontaneously play for hours with some simulations in educationally constructive and productive ways. They have identified several characteristics that make PhET simulation very engaging. These characteristics include (i) dynamic visual environments that are controlled by the user, (ii) challenges that are not too hard or too easy, and (iii) enough visual complexity to create curiosity.

An advantage of PhET simulations, as noted by Weiman *et al*., is "students who used the PhET simulations repeatedly commented that it was easier to see what was happening with the simulations and that they were more fun than the real equipment" (p 683). Wieman *et al.* (2008) mentioned the success of PhET simulations in at least two courses. Learners who used the "Circuit Construction Kit", which is a PhET simulation, demonstrated a higher mastery of the concepts of current and voltage on the final examination compared to their peers who did a laboratory exercise with real electrical equipment. In another instance, 80% of learners doing a quantum mechanics course using PhET "Photoelectric Effect" simulation, demonstrated mastery of the concepts compared to 20 % that underwent traditional instruction. Many learners found the PhET "simulations to be fun and intellectually engaging" (p. 683). Weiman *et al.* noted that any simulations that are carefully developed and tested, encourage authentic and productive investigation of scientific phenomena, and provide believable animated models that usefully navigate learners' thinking.

The success of PhET simulations is also reported in recent studies as well. In a 2015 study with PhET simulations, Hursen & Asiksoy (2015) reported that simulation-supported physics education has a positive effect on students' academic success. They also established from the findings obtained from students' ideas that simulation-supported physics education also helps in overcoming fear and anxiety towards physics lessons and it is effective in increasing interest and motivation. Ceberio *et al.* (2016) reported that the simulations that are available from the website http://phet.colorado.edu/en/simulations/category/new are the most outstanding examples of the interactive simulations that offer a great visualisation of a particular phenomenon. In a study among the pre-service teachers by Ulukök and Sari (2016), regarding the different simulations, it was found that the pre-service teachers considered the PhET programs as most effective. They reported that the pre-service teachers found that the PhET simulations are easy to use, are life-like and enjoyable, able to concretise information, strengthen conceptual understanding and able to make learning easy and enjoyable.

2.7 SIMULATIONS IN PHOTOELECTRIC EFFECT

There are a number of simulations are available online. Some of the websites that provide these simulations are given below.

- http://www.thephysicsaviary.com/Physics/Programs/Labs/PhotoelectricEffect/index.html www.kcvs.ca/site/projects/physics_files/photoelectric/photoelectricEffect.swf

- www.opensourcephysics.org/items/detail.cfm?ID=10272
- electron6.phys.utk.edu/phys250/Laboratories/photoelectric%20effect.htm

Most of these simulations are free and can be used only online, but cannot be used in many rural areas of South Africa. Also, the efficacy of these simulations could not be verified in any of the literature reviewed. In the literature, there are two important simulations mentioned regarding the teaching and learning of the photoelectric effect. They are Photoelectric Tutor (PT) and PhET simulation on the photoelectric effect. These simulations are constructed after years of research and are discussed below.

2.7.1 PHOTOELECTRIC TUTOR

In response to difficulties when teaching the photoelectric effect (see section 2.3.2), Steinberg and Oberem developed a computer tutorial called Photoelectric Tutor which was written in the programming language cT. The main focus of their tutorial was on drawing and interpreting I-V graphs for the electric circuit in the photoelectric experiment. Steinberg and Oberem (2000) reported that they "believed that having students draw I-V graphs would be a context for an instructional tool on the photoelectric effect" (p.3).

Photoelectric Tutor was designed in a way that it enters into a dialogue with the student to keep the student engaged intellectually. The structure of PT is shown in the diagram below.

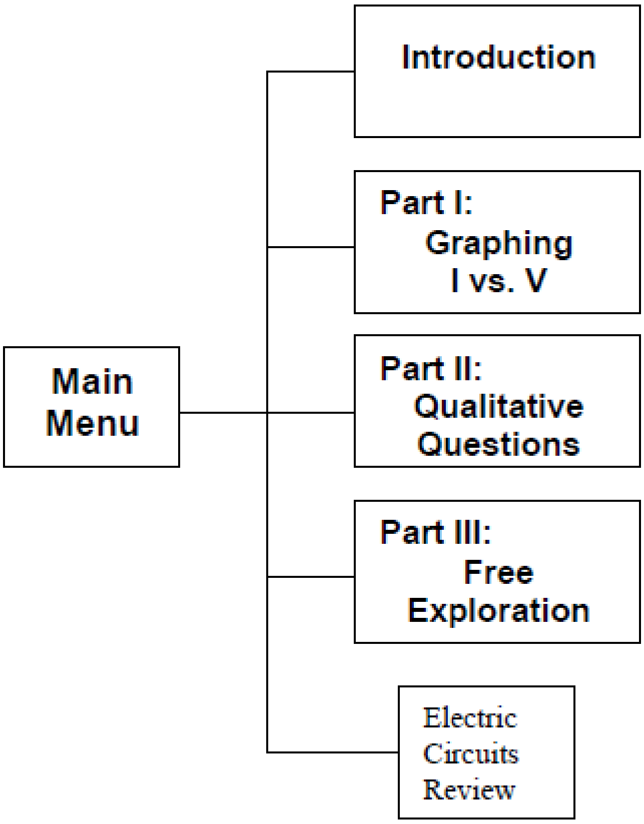


Fig. 2.3: Structure of Photoelectric tutor. Taken from Steinberg & Oberem (2000) p.118.

PT consists of an introduction and Part I, Part II and Part III. "Part I begins with a screen layout that includes a set of axes on which I-V graphs can be drawn, the circuit diagram, and a dialogue box in which the computer poses questions and the student types responses". In part II, a computer-generated V-I graph is given, and the students are asked to modify the graphs if certain experimental parameters such as intensity and frequency of the incident beam of light and work function of the metal were to be changed. If the student makes an error, the computer initiates a dialogue box that asks some questions to help the student to recognise the error. The student responds by typing a short answer. The sequence of the question is determined by the students' response to the questions. The dialogue continues until the student draws a correct graph. These features are shown in figure 2.4 and 2.5 below.

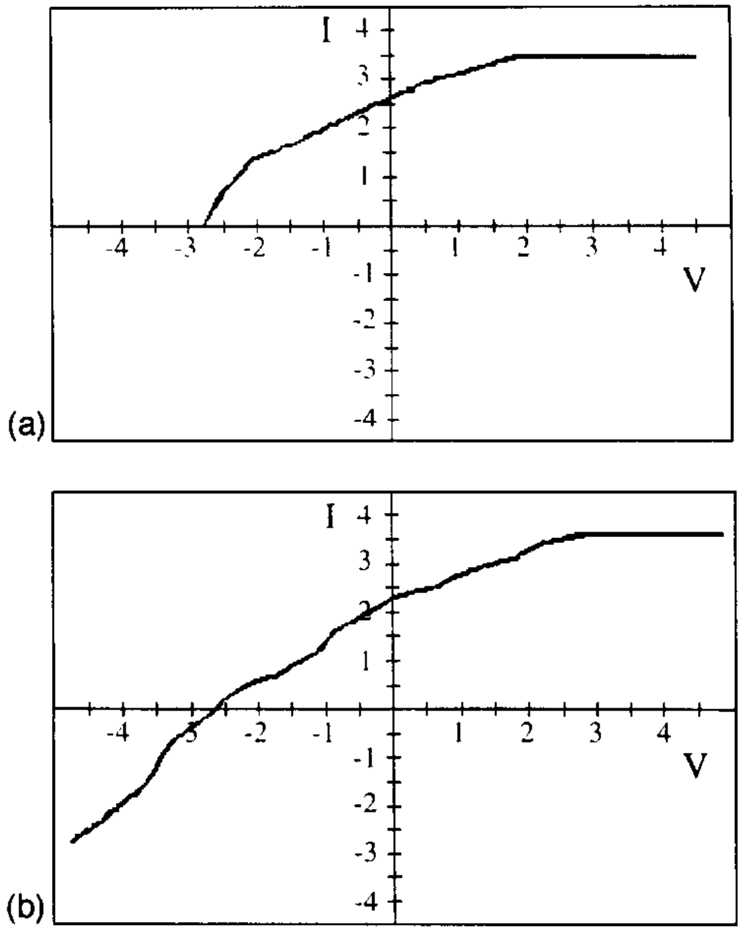


Fig 2.4: (a) An I-V graph drawn by a student. The graph appears qualitatively correct but does not explicitly show an essentially zero current when V is below the stopping potential (V_s). (b). The I-V graph by the same student after the student when V is below V_s. Instead of showing a current that is essentially zero, the graph shows a sizable negative current. Taken from Steinberg *et al.* (1996) p.1373.

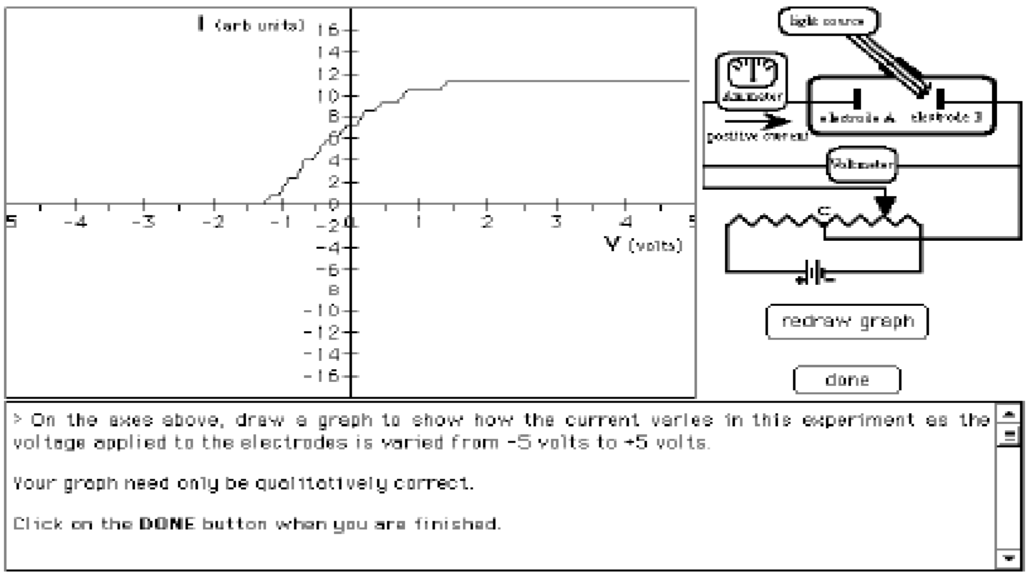


Fig. 2.5: A typical screenshot of Photoelectric Tutor that interacts with the students. Taken from Steinberg & Oberem (2000) p.118.

Part III is called *free exploration*. Here students can explore, on their own, the effect on the I-V graph of varying experimental parameters. A screenshot for part III is shown in the figure 2.6 below.

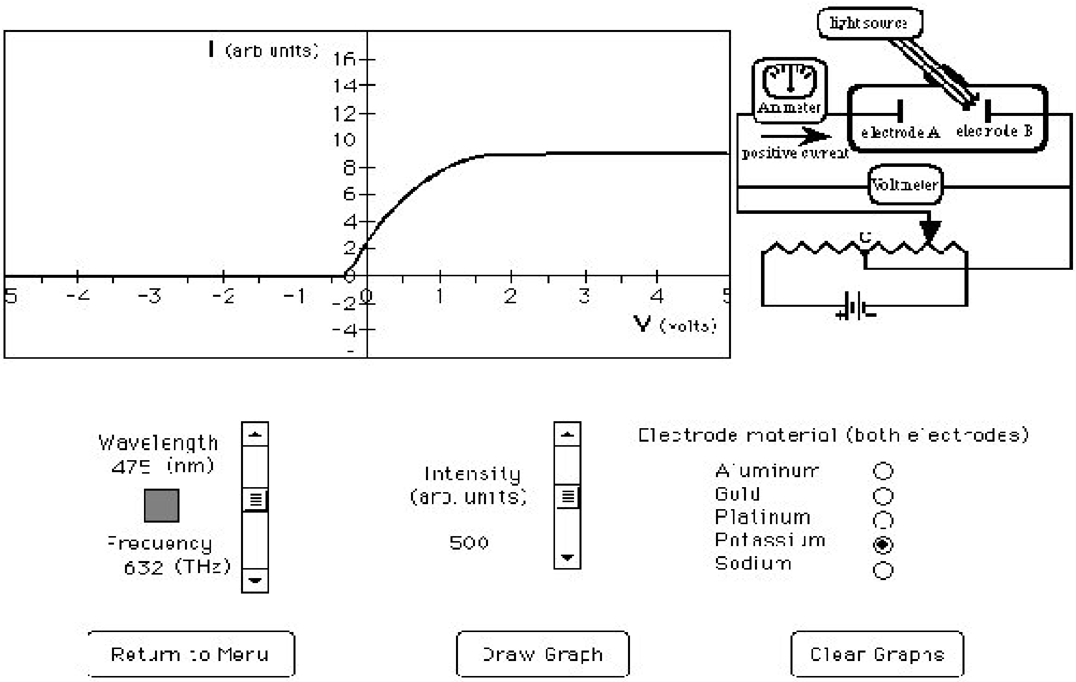


Fig 2.6: Layout of the screen for Part III of the Photoelectric tutor. Taken from Steinberg *et al.* (1996) p.1375.

Even though the instructional strategy used in Photoelectric Tutor- the drawing and interpretation of I-V graphs for the photoelectric experiment- was effective, it did not guarantee that the students understand all the aspects of the phenomenon. Steinberg *et al.* (1996) acknowledged that that the ability to draw an I-V graph does not necessarily guarantee that students have already developed a better understanding of the phenomenon of the photoelectric effect.

De Leone and Oberem (2003) conducted further studies using the PT and found that many learners lack the basic idea of the classical model of light, which is contrasted by the results of the photoelectric effect. They found that many of the learners could not differentiate the classical corpuscles with the photon model. McKagan *et al.* (2008) claimed after consulting with different tutors and authors that there are two main goals for teaching the photoelectric effect. (1) Correctly predict the results of experiments of the photoelectric effect and (2) describe how these results lead to the photon model of light. PT was designed mainly to address the first learning goal. This achieved substantial improvement, but not complete success, in achieving the desired goals. Around 60% of students, even after the PT tutorial, are still unable to correctly predict the effect of changing the voltage. The use of PT also failed in achieving the second goal of teaching the photoelectric effect. So, it was necessary for the physics education research community to look for an alternative. This search produced the PhET simulation, developed by the university of Colorado.

2.7.2 PhET SIMULATION ON THE PHOTOELECTRIC EFFECT

The researchers and developers associated with PhET wanted a simulation and supporting materials that are available online free, so that they were accessible to a wide audience. Their goals for the development of the simulation aimed to address the difficulties described in previous researches on the photoelectric effect (Steinberg *et al*., 1996 & 2000; De Leone & Oberem, 2003; Knight, 2004; McKagen *et al*, 2006; and Adams *et al.*, 2008). They also wanted to go beyond Photoelectric Tutor towards achieving the learning goals discussed in the last paragraph of section 2.5.1. Their intention was to create a simulation that could be saved and played offline, making it appealing to many teachers and learners.

PhET simulation offers a variety of exploration techniques to students. McKagan *et al.* noted that "the simulation allows students to control inputs such as light intensity, wavelength, and voltage, and to receive immediate feedback on the results of changes to the experimental set-up. With proper guidance (in the form of interactive lecture demos and homework questions), students can use the simulation to construct a mental model of the experiment." (p.2). The other important feature of the PhET photoelectric simulation is that it allows students to interactively construct the graphs commonly found in textbooks. These graphs are current vs. voltage, current vs. intensity, and electron energy vs. frequency. McKagan *et al.* mentioned this important feature as "by seeing these graphs created in real time as they change the controls on the experiment, students are able to see the relationship between the graphs and the experiment more clearly than when viewing static images". (p.2)

2.7.2.1 FEATURES OF PhET PHOTOELECTRIC SIMULATION

McKagen *et al.* (2008) explains the important features of photoelectric simulation in PhET as:

(1) *The circuit*: Previous researches (Steinberg, Oberem and Mc Dermott 1996, 2000 & De Leone and Oberem, 2003) have shown that students have difficulties in understanding the circuit diagrams. In PhET, the developers replace the circuit diagram with a cartoon-like picture of an actual experiment. They replace the variable voltage supply with a simple battery with a slider where the user can select negative and positive voltages. This design is based on suggestions from previous research (McKagen *et al.* 2006 and Adams *et al.,* 2008) on the photoelectric effect to reduce the cognitive load.

(2) *Electrons:* McKagen *et al.* (2008) calls the showing of electrons as the most controversial feature of the simulation. This is because in a real photoelectric experiment, it is not possible to see the movement of electrons from one plate to the other. However, the researchers have observed that this aspect of the simulation is very useful in helping students visualise the effect of voltage change. Students can see that increasing the voltage accelerates the electrons, making the voltage negative, and decelerates them in a very concrete way. The feature of seeing electrons also helps the learners to visualise the meaning of stopping potential. Previous research showed that this is one of the difficult concepts of the photoelectric effect. (Steinberg *et al.*, 1996)

(3) *Photons:* In contrast to the electrons, simulation does not show individual photons by default, but instead represents light as a beam. McKagen *et al.* pointed that it is better to keep an image that is consistent with both the wave or the particle nature of light. This is because understanding the experimental basis of the photon model of light was the biggest challenge experienced by the learners, as found in the researches of Steinberg, Oberem and Mc Dermott (1996) (2000), De Leone and Oberem (2003). PT failed to achieve this important goal. So as McKagen *et al.* noted, "PhET researchers want the simulation to aid students in constructing this model, rather than explicitly providing it" (p.4). The options menu in the simulation allows instructors to show photons in place of the beam view. McKagen *et al.* reported that the users rarely look in the options menu and use this important feature.

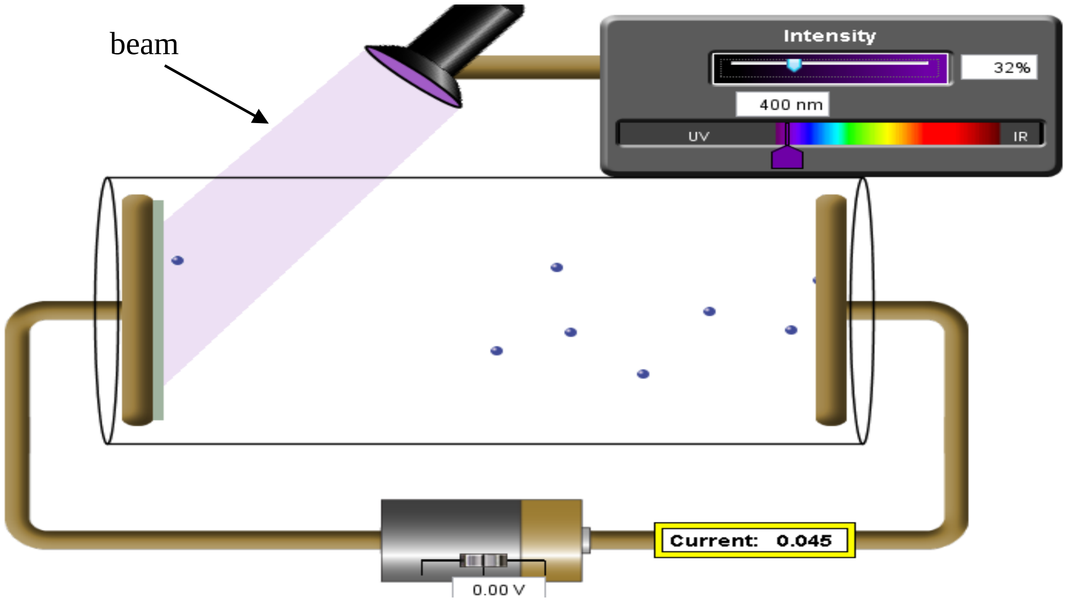


Figure 2.7. Screenshot from PhET interactive simulation showing the incident light beam.

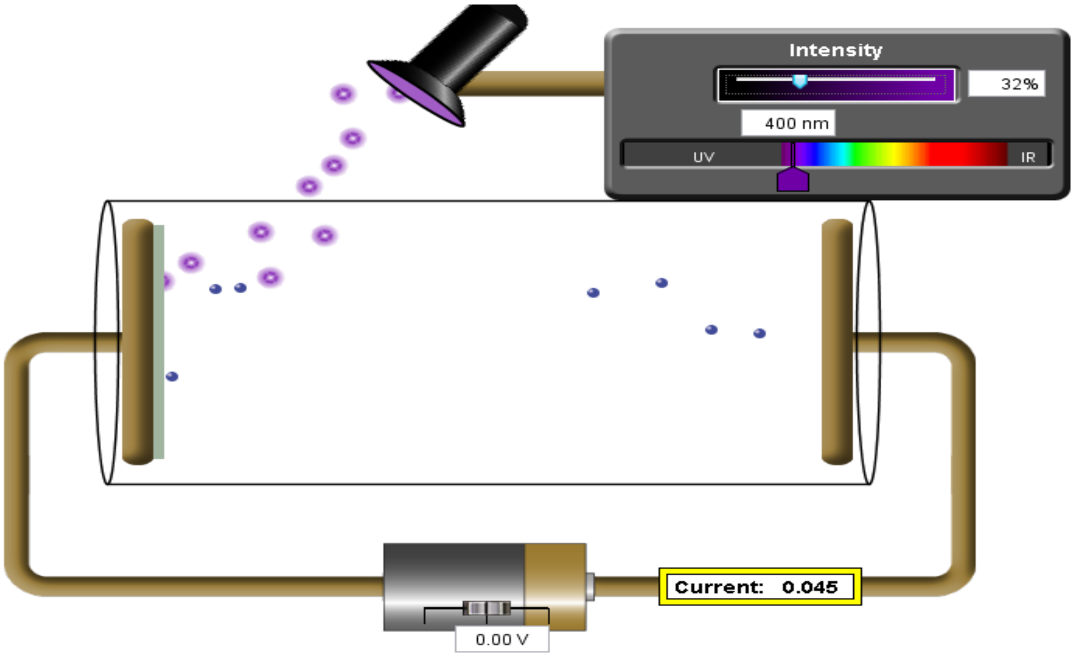


Figure 2.8: Screenshot from PhET interactive simulation showing the photons instead of light beam.

(4) *Simplifications:* Like any real experiment, the photoelectric effect experiment contains many delicate complications that are not relevant to the instruction. This includes the range of energies with which the electrons emit. The developers of PhET put a checkbox labelled "show only highest energy electrons." By default, when the simulation starts, the simulation shows the electrons are ejected with a range of energies. Nevertheless, if this is too difficult to follow for the learners the learner or teacher can select the option "show only highest energy electrons". In a real experiment, the electrons are ejecting at different angles from the plate or cathode. The developers of PhET simplified this by showing that all electrons are leaving perpendicular to the plate. Other advanced issues like the contact potential, thermionic emission, and reverse current are all ignored to make the simulation simple. In addition, there are provisions in the simulation to independently adjust the frequency and intensity.

The effectiveness of PhET simulations is mentioned in several articles. (Nadaraj, 2012; Taslidere, 2015; Krobthong, 2015; Supurwoko *et al.*, 2017). Nadaraj (2012) reported that students have great difficulty with the concept of work function of a metal, stopping potential, and interpreting the photoelectric effect graphs, so as to validate Einstein's explanations. The dependence of intensity and frequency on the photoelectric effect is also problematic. He further comments how PhET simulations help students "to visually comprehend concepts by animating what is invisible to the eye, through the use of graphics and intuitive controls such as click and drag manipulation, sliders and radio buttons". (p.453). He claimed that "concepts in light are abstract and light as a wave-particle duality can be confusing. While experiments in elucidating the wave nature of light can be done fairly easy and grasped, the particle nature and Einstein's explanation of the photoelectric effect is not easily assimilated and understood, even after tutorials and practicals" (p.452). He asserted that PhET simulation help learners to a great extent to grasp these concepts. Taslidere (2015) also established the positive effect of PhET on students' understanding of the photoelectric effect. Supurwoko *et al.* (2017) reported that, after using the demonstration method with the PhET simulation program, most of the students were able to explain the factors that influence the release of electron in the photoelectric effect.

The researcher favoured PhET over Photoelectric Tutor because of its simplifications and its ability to meet the second goal in teaching the photoelectric effect which is the understanding of the photon model of light. In the South African curriculum, the main aim of teaching this topic is to establish the particle nature of light (Curriculum Assessment policy statement, physical sciences, Department of Basic Education, 2013, p.132). Photoelectric tutor was focussing on the V-I graph, which is not prescribed in the CAPS syllabus for the Grade 12 learners. Stopping potential is also not mentioned in the syllabus. Another reason to opt for PhET simulation is its ability to solve the misconceptions in the photoelectric effect that will be detailed in the next section.

2.7.2.2 ADVANTAGES OF PhET PHOTOELECTRIC SIMULATION

Wieman *et al.* (2008) argues that using PhET simulation "is particularly helpful for students in quantum mechanics" (p.682). In a quantum mechanics course using a curriculum based on the "Photoelectric Effect" simulation, they found that 80% of the students demonstrated proficiency of the concepts, but only 20% did so in a course using traditional instruction. Wieman *et al. (*2008) states these results demonstrate that a curriculum based on PhET simulation provides a considerable improvement over traditional instruction that leads to many students who cannot describe the basic experimental set-up or conclusions of the photoelectric effect, as shown in previous research. Krobthong (2015) also reports that the PhET interactive simulations contribute to the students' better achievement when it is used together with the lectures, laboratory activities and homework.

2.7.2.3 ADDRESSING DIFFICULTIES AND MISCONCEPTIONS

To eliminate the difficulties and misconceptions discussed in section 2.3.2, Sokolowski (2013) proposes the following two main components in the scaffold approach (1) remove the external battery in the initial stage of the analysis of the experimental setup and (2) apply a thorough contextualisation during the process of introducing and explaining the mathematical model for the phenomenon. PhET simulation has a provision to change the external potential difference to negative, zero or positive. Sokolowski (2013) also claims that emphasising a direct proportionality between the intensity of the external light source and the intensity of the ejected electrons before taking the learners in the complete process of the analysis of the photoelectric effect will help eliminate this deficiency.

Sokolowski (2013) also commented that the concept of work function is also problematic for the learners. This is because the concept of work function is usually introduced simultaneously with the entire mechanism of the photoelectric effect. Sokolowski suggests that the concept of work function should be extracted and debated separately before going deeper into the phenomenon. He argues that comparing the binding energy with the photon energy is the best way to introduce the work function of the metal plate. After introducing the concept, students can be given the work functions of commonly used metal plates and determine which metal will eject electrons, given the frequency of light. PhET is very useful in this, since it has the feature where anyone can select a particular metal plate from a list of common metals.

Sokolowski (2013) proposes that in teaching the photoelectric effect, teachers must keep some variables as constant and change the others. For example, initially, one can keep the type of plate ejecting the electrons along with the external potential difference constant and change the frequency and intensity. When using the PhET simulations all these steps proposed are possible. That is why Sokolowski (2013) commented how PhET can be used in this way to help the students in understanding the relationship between frequency and kinetic energy and also between intensity and photocurrent.

PhET's proven ability to eliminate the common misconceptions in the photoelectric effect is another important highlight and one that also forced the researcher to select PhET as the simulation in this research. Another plus point is the feature that can be selected or deselected such as showing the light as a beam or photons, the kinetic energy *vs* frequency graphs, showing the high energy electrons etc.

Different approaches can be used to facilitate the teaching and learning of any subject matter. Constructivism is one of the most important approaches that gained momentum globally in recent years. (Komulainen & Natesheh, 2008)

2.8 CONSTRUCTIVISM

According to Cirik *et al.* (2015), constructivism can be defined as a learning approach in which students subjectively construct, construe and reorganise their knowledge. Constructivism is a theory of how the learner constructs knowledge from experience, which is unique to each individual (Singh & Yaduvanshi, 2015). Constructivism is a view that emphasises the active role of students in building, understanding and making sense of the information. Constructivist teaching is a learner-centred approach where students are actively involved in the construction of the knowledge rather than being mere passive listeners (Thakur, 2014). Knowledge is constructed individually by the learner, based on what the learner brings through prior experience or collaboratively by participating with peers. According to Nashon *et al.* (2008), constructivism suggests that knowledge shapes in the mind of the learners. Yaduvanshi and Singh (2015) asserted this idea by commenting "the constructivist epistemology assumes that learners construct their own knowledge and create their own understanding, based upon the interaction of what they already know, believe and the phenomena or ideas with which they come into contact. Thus, constructivism focuses on knowledge construction, not on knowledge reproduction" (p.166).

2.8.1 DISTINCTION BETWEEN THE CONVENTIONAL AND CONSTRUCTIVIST CLASSROOM

To highlight how constructivism envisages the learner-centeredness, it is worth mentioning how a constructivist classroom differs from the conventional one. The following table (Table 2.1) provides a comparison of conventional and constructivist science classrooms.

Table-2.1. Comparative study of conventional and constructivist science classrooms

Conventional Science Classroom	Constructivist Science Classroom
A. Curriculum It is presented part to the whole, with emphasis for inculcating basic skills among the learner. Materials are primarily text book and related work books.	 Curriculum emphasises big concepts, beginning with the whole and expanding to include the part. Materials include primary sources of material and manipulative material.
B. Learning It is based on repetition. It can enhance only the memory level and contributes little towards the understanding of scientific concepts or enhancement of reflective thinking.	 Learning is interactive, building on what the student already knows. Here, there is major scope for the development of higher cognitive facilities, such as problem solving abilities, critical thinking and reflective thinking.
C. Teacher / Facilitator They serve as transmitters of knowledge Their role is **directive**, rooted in **authority**.	 Teacher's role is shifted towards a mentor or facilitator who helps the students' in constructing their knowledge. Teacher's role is **interactive**, rooted in **negotiation**.
D. Student/ Learner Students are the **passive recipient** of bits of information (knowledge). Learn individually	 Here students are **actively** participating in on **constructing and reconstructing** in a meaning-making process.

	Learn progressively on his/her own under the proper guidance of the teacher and interaction with peers.
E. Classroom environment It is authoritative and students work competitively.	Classroom environment is democratic, and students primarily work in groups.
F. Knowledge It is considered objective, comprising inert facts or information.	In this classroom knowledge is seen as dynamic, ever changing with individual experiences. Here, knowledge is viewed according to the perception of learner i.e. unique for the individual.

Adapted from Yaduvanshi & Singh (2015, p.168)

2.8.2 ADVANTAGES OF CONSTRUCTIVISM

Constructivism brings a number of advantages into learning.

Bada & Olusegun (2015) noted the following important six benefits of constructivism.

- Learners enjoy learning and learn more as they are actively involved in the lessons.
- Constructivism focuses on learning how to think and understand. Hence, education becomes fruitful as it concentrates on thinking and understanding.
- Learners can easily transfer what they take with them from a constructivist classroom to other learning settings.
- "Constructivism gives students ownership of what they learn, since learning is based on students' questions and explorations, and often the students have a hand in designing the assessments as well. The students are also more likely to retain and transfer the new knowledge to real life". (p.68)
- Self-exploration in constructivist classrooms help learners to question things and they apply their natural curiosity to the world.
- "Constructivism promotes social and communication skills by creating a classroom environment that emphasises collaboration and exchange of ideas. Students must learn how to articulate their ideas clearly as well as collaborate on tasks effectively, by sharing in group projects. Students must therefore exchange ideas and so must learn to "negotiate" with others and evaluate their contributions in a socially acceptable manner.

This is essential to success in the real world, since they will always be exposed to a variety of experiences in which they will have to cooperate and navigate among the ideas of others"(p.68).

2.8.3 CONSTRUCTIVIST TEACHER

Singh and Yaduvanshi (2015) noted that most research in science teaching provides evidence for the constructivist learning model being one of the successful strategies for providing meaningful learning experiences to children in the science classroom. They also noted that learners who are taught in a constructivist way show better retention of knowledge than those who learned through traditional methods. "The constructivist approach in teaching at all levels of school is needed because the conventional pedagogical practices of teaching emphasise the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understanding the context, reading in lieu of doing i.e, not efficient to achieve the objectives of teaching science" (Singh & Yaduvanshi, 2015, p.1).

Constructivist teaching is very challenging. Gilakjani *et al.* (2013) noted that many teachers favour the adoption of constructivist instructional approaches but struggle to find the starting point. In the constructivist classroom, the curriculum is presented whole or in part. Whole to part learning provides students with a synopsis of the subject before going into exact details. This help the students to vigorously participate in their own method of education. This way of teaching and learning impacts and augments how students think, act, exhibit, and demonstrate their knowledge. In a constructivist classroom, curricular activities serve to bolster relevance in students, and teachers generally behave in an interactive manner, negotiating an environment for students learning. Constructivist approaches focus on real-life applications that might be used to refocus the process of educational reform (Akpan & Beard, 2016). Thakur (2014) highlighted the role of a teacher in a constructivist classroom as that of the facilitator or a guide but not of a director. The teacher must stimulate learners' exploration of various ideas. Students should rather be an active thinker, active partner in the construction of knowledge with others than a passive listener. Singh and Yaduvanshi (2015) echoed the same sentiment by noting "While in constructivist classroom, the role of teacher is shifts from *transmitter* of knowledge to *facilitator* of knowledge construction and the role of students changes from *knowledge gainer* to *knowledge constructor"* (p.2). Therefore, the role of the constructivist teacher is to create a learning environment that is fascinating, interactive, mesmeric, and informative (Gilakjani *et al.* 2013). Such a learning environment supports students to take responsibility for their own learning. (Cirik et. al, 2015)

According to Singh & Yaduvanshi (2015) there are ten basic guiding principles of constructivist thinking that educators must keep in mind.

1. "Learning is an active process in which the student constructs meaning.
2. People learn to learn.
3. Learning involves language.
4. Learning is a social activity.
5. Learning is contextual.
6. The act of constructing meaning is mental.
7. Everyone needs knowledge to learn.
8. Learning is not the passive acceptance of knowledge, it takes work.
9. Motivation is a major aspect of learning.
10. It takes time to learn". (p.2)

The researcher believes that constructivism is the proper learning model for science as it "provides ample opportunities for the students to learn science according to nature of science" (Singh & Yaduvanshi, p1). It could help to address the misconceptions among learners. Singh & Yaduvanshi (2015) reported that misconception among students could be better resolved using the constructivist approach.

2.9 THEORETICAL FRAMEWORK

Constructivism is a theory that claims that meaningful learning only depends on the construction of knowledge by the learner (Gilakjani *et al*., 2013). Duffy and Jonassen (1992) explains the idea of learning, according to constructivism, as "a self-regulated process of solving inner cognitive conflicts that often become apparent through concrete experience, collaborative discourse, and reflection" (p. 40). They claim that simulations can allow a learner to function at a level that surpasses the limitations of his or her cognitive system and are compatible with constructive theory about knowledge. Simulations can provide an environment that best suits the learners to construct the knowledge.

The research findings of Wieman *et al*. (2008), who are the developers of PhET simulations, pointed out that to construct meaningful knowledge learners must be motivated to engage actively with the content and they must be able to learn from that engagement. The advantages of constructivism, discussed in section 2.8.2, and the advantages of simulations, discussed in section 2.4.2, strengthened the researcher's choice of constructivism as the theoretical framework for this study on the use of simulations as a teaching tool on the performance of Grade 12 learners in the topic of the photoelectric effect.

One of the components of various theories of constructivism is the concept of Zone of Proximal Development (ZPD) put forwarded by Vygotsky (1978). Siyepu, (2013) observes that "teachers may use the zone of proximal development (ZPD) to bridge the gap between what a learner can do without help and what a learner can do with assistance" (p. 3). This help or assistance could be of the form of providing necessary learning environment such as using computer simulation. The researcher firmly believes that the computer simulations can help teachers and learners in achieving the ZPD.

To achieve the ZPD the role of More Knowledgeable Other (MKO) is very important. Hence Bunyakarte (2010) commented that "combined, the ZPD and the MKO are the basis of the scaffolding model of instruction" (p.11). Sundararajan (2010) identified the teacher as the natural MKO and who was expected to help the learners to cover the ZPD. When learners are at the ZPD for a particular task, using suitable scaffolding or assistance, the learners achieve the mastery of the task. This means that the scaffolding can now be taken away so that the learners will now be able to execute the task on their own. Hence, it is vital that the individuals that are taking the role of MKOs must be familiar with their ZPD.

Teaching using simulations employs the constructivist principles (Brown, 2005). Constructivism envisages the learner as the centre of learning. Hence, the teaching of the photoelectric effect using PhET simulations could done be in two ways. The learners should be allowed to manipulate the simulations, or the teacher manipulates the simulation. The researcher is interested to establish which way of the use of simulations is more beneficial to learners. Hence the teacher-centred versus learner-centred use of simulations is reviewed.

2.9.1 USE OF SIMULATION: TEACHER-CENTRED VERSUS LEARNER-CENTRED

Tüysüz (2010) recommended that since "most of the contents of science lessons are abstract topics, to make students to understand such topics it is necessary to use constructivist based student-centered instructional methods" (p.38). This is why the concept of learning by doing is encouraged in constructivist science classrooms. Therefore, the role of learners in the use of interactive simulations is important. Should the teacher-centered or learner-centred approach be used? That is, should the teacher allow the learners to manipulate the simulations to facilitate learning or should the teacher manipulate the simulations for better understanding? The researcher is very keen to find an answer to this question using the PhET simulation in the photoelectric effect.

Most of the research explains how the use of simulations help learners in improving their performance and attitude towards science learning compared to the traditional teaching strategies (Richards *et al.*, 1992; Zacharias, 2001; Wieman et al, 2008; Akkagit, & Tekin, 2012; Smetana & Bell, 2012; Anderson & Barnett, 2013; Eckhardt *et al.* 2013; Darrah *et al.* 2014; Sarabando *et al.* 2014; Peffer et al, 2015; Taub *et al.* 2015; Krobthonga, T., 2015; Stephens & Clement, 2015; Hursen & Asiksoy, 2015; Rutten *et al.* 2015; Ceberio *et al.* 2016; Anderson & Wall 2016; Chao *et al.*, 2016; Ulukök, & Sari, 2016). Only very few studies were available exploring how various teaching methods of using simulations (namely teacher-centered and learner-centred) influences the learning outcomes, especially at the secondary school level.

Chang (2002) conducted a study to find the effects of teacher-centred against learner-centred use of multimedia on the science achievement of grade 10 students in Taiwan in the topic of earth science. He reported that the teacher-centered approach was more effective in promoting the students' science achievement. A similar study conducted by Chang in 2003 confirmed the results of his previous study. Chang and Tsai (2004) conducted another study with 347 grade10 learners in the earth sciences. The study was over a week. One group of learners (n = 216) were taught by a teacher-centered method whereas the other group of learners (n = 131) were subject to a student-centered method. This time, the results were quite different. They found no statistically significant difference between the students' earth science achievement for the two groups. Another interesting finding was that the teacher-centred group had significantly better attitudes toward earth science than the learner- centered group. Also the teacher-centered instructional approach seemed to be beneficial to less constructivist-oriented learners, whereas the learner-centered method was more beneficial to only more constructivist oriented learners.

Wu and Huang (2007) carried out a study in science with 54 learners in Taiwan. One class (n = 25) was assigned to a student-centered approach and the other class (n = 29) was assigned to learner- centered approach in the teaching of force and motion. Statistical analysis of pre-test, post-test and delayed post-test data suggested four findings. (1) None of the instructional approaches was better than another in terms of helping learners to learn the concepts. (2) Low achieving learners benefited less from the student-centered approach. (3) Medium achieving learners seemed to improve more in the student-centered learning approach. (4) The effect of instructional approach did not last long in both groups.

Sidddiqui and Khatoon (2013) investigated the effects of traditional teaching, teacher-centred computer assisted instruction and learner-centred computer assisted instruction on secondary school students' achievement in physical science using 120 tenth grade secondary students in India. The traditional teaching group was the control and the other group was the experimental one. They found that in the post-test, the teacher-centered group had the largest adjusted mean while the control group had the lowest adjusted mean. That is the teacher-centred group had significantly better performance compared to the other groups.

It is very interesting to note that many of these studies were carried out in Asia. All these studies did not agree that the teacher-centred group always benefits more than the learner-centred group. Also, none of these studies involves the photoelectric effect using PhET simulation. The researcher wanted to carry out a study using the PhET simulation in the photoelectric effect in different situations in a South African context. Should we follow a learner-centred model or a teacher-centred model? This is to find which model is more beneficial to the learners and the broad science teaching fraternity in general.

2.10 SUMMARY

This chapter presented a review of the relevant literature pertaining to the study. Literature review includes; the issues relating to the learning and teaching of quantum mechanics, different models for teaching quantum mechanics, photoelectric effect and its role in understanding quantum mechanics, simulations, constructivism etc. PhET simulation for the photoelectric effect and its advantages are also detailed. The theoretical framework that guides the study is also presented in this chapter.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

To verify the effect of computer simulations on Grade 12 learners' understanding of concepts in the photoelectric effect, a case study was carried out in one school in the Frances Baard District of the Northern Cape province. A case study design encourages the use of both qualitative and quantitative methods (Merriam, 1998; Stake, 1995; Stewart, 2014). Quantitative research was used to answer the research questions and qualitative research is used to assert the findings.

3.2 RESEARCH DESIGN

A research design is the arrangement of conditions for data collection and its analysis in a manner that aims to combine relevance to the purpose of the research with economy in procedure (Saleem *et al*. 2014).

The case study research design was used. Zainal (2007) observes that case studies can be a practical solution when a big sample population is difficult to obtain. A big sample population could not be found since the research was carried out in a sparsely populated province namely the Northern Cape. Another reason for the use of a case study is it allows for both quantitative and qualitative analyses of the data (Zainal, 2007). Yin (1984) defines the case study research method "as an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (p.23).

The multiple sources of data were pre- and post-tests, observation schedules and learner interviews. Qualitative data were collected through observation of the lessons and learner interviews while quantitative data was collected using a randomised pre-test - post-test control group design (Campbell & Stanley, 1996).

The research design can be represented as:

	Pre-test	Treatment	post-test
CG	T	X_a	T
TCEG	T	X_b	T
LCEG	T	X_c	T

Here the CG represents the control group, for which the traditional teaching approach (X_a) was used. TCEG represents the Teacher--centred Experimental Group (experimental group 1) where the teacher manipulated the computer simulation (X_b). LCEG represents the Learner-Centred Experimental Group (experimental group 2), allowing the learners to manipulate the computer simulation (X_c). The LCEG group were offered very short lectures to introduce the key concepts about the photoelectric effect, after which they were allowed to work alone under the supervision of the teacher. This group was also given an instruction sheet to guide their learning (see APPENDIX M). T represents the Photoelectric Effect Achievement Test (PEAT) that was given as pre- and post -tests to the students in all the three groups at the beginning and end of the treatment to measure learners' achievement in the photoelectric effect.

3.3 PARTICIPANTS

Population is the group of interest to the researcher, the group to which the researcher would like the results of the study to be generelisable (Gay & Airasian, 2000). Generalisability is regarded as the extent to which the findings of one study can be applied to other situations or a large population. In this study, the participants of the study were two physical sciences classes and their regular teacher in a rural high school in circuit 5 of the Frances Baard district of Northern Cape province of the Republic of South Africa. One Grade 12 class, 12 C consists of 20 learners and the other class, 12 D consists of 10 learners. These 30 learners were sorted randomly into 3 groups of 10 each. Random sampling is a process of selecting a sample in such a way that all individuals in the sample have an equal probability of being selected in the group and the selection of one individual will not affect in any way the selection of another individual (Gay & Airasian, 2000). The age of the group ranges from 16 to 21 years.

One group of 10 learners formed the control group (CG) where the teacher taught the photoelectric effect in the traditional way. Another group of 10 learners formed the Teacher-

Centred Experimental group (TCEG), where the teacher used simulations and only the teacher manipulated the simulation. The last group of 10 learners formed the Learner-Centred Experimental group (LCEG) where the teacher had limited interaction with the learners compared to the other groups. The teacher supported this group only when the learners asked for help. This group was offered 1hour computer training in which the different options in the PhET simulations were introduced.

The participating teacher is a BSc graduate in maths and physics and who also has a diploma in physical sciences teaching. He is one of the lead teachers in the district and has 11 years teaching experience in the subject. He was observed in two participating classes prior to the research to observe his teaching style. The teacher was observed while teaching the groups using a teacher-centred approach and when using the simulations. In the LCEG group, the learners were observed.

3.4 SELECTION OF THE SCHOOL

The Northern Cape is sparsely populated even though it is the largest province in the country in terms of land area. Getting a school with a sizable number of learners is a challenging task. Some of the schools that had the required number of learners, did not have a computer lab which is necessary for the participants in the LCEG. The attitude of the principals and teachers in some schools was not encouraging. The school mentioned above was ultimately selected, even though it was far from the district office, with the cooperation of the School Governing Body (SGB), principal, teachers and the learners. This school had an academic performance above 70% consistently in the NSC over the past 5 years. The school has a separate classroom for physical sciences fitted with a data projector and has a computer lab.

3.5 INSTRUMENTATION

3.5.1 CLASSROOM OBSERVATION SCHEDULE

An observation schedule adapted from The Reformed Teaching Observation Protocol (RTOP) was used (See Appendix A). RTOP was designed by the Evaluation Facilitation Group (EFG) of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) (Maclsaac *et al*., 2002). It is an instrument for observation, specifically designed to measure "reformed" teaching. The Evaluation Facilitation Group (EFG) of Arizona started the reform movement because mathematics and science educators are involved in a massive effort of reform currently in the United States of America. Reformed teaching advocates that instruction should be *through the different approaches advocated by professional organizations and researchers based on constructivist, inquiry-based methods (*Maclsaac & Falconer, 2002). The RTOP was designed to measure those characteristics and qualities that define "reformed teaching". The use of the observation schedule was to enable the researcher to collect data on the teaching style of the teacher in the various groups and to ensure that the teacher covered all the concepts related to the photoelectric effect, as explained in CAPS and examination guidelines.

All aspects of the observation schedule were discussed with the teacher prior to the intervention. This was to ensure that the teacher also gave his consent and that he should not feel uncomfortable when being observed.

3.5.2 PRE- TESTS AND POST-TESTS

The Photoelectric Effect Achievement Test (PEAT) (see APPENDIX B) consists of two structured questions. This test was used as pre- and post-tests. From the researcher's experience as a teacher and subject specialist, learners always have a tendency to guess when it comes to the multiple-choice questions. So, the multiple-choice questions (MCQ) were omitted in the test for higher reliability. The questions in the test were adapted and modified from the following sources on the specific topic.

- Previous NSC Physical science P1 question papers.
- Previous Northern Cape Department of Education's (NCDoE) physical science P1 question papers.

- DBE approved text-books.

3.5.3 INTERVIEW

Structured interviews are pre-planned interviews where the researcher prepares the interview questions before conducting the interview. Even though it makes the interview comparable among interviewees, this type of interview lacks richness and limits the availability of in-depth data. (Alsaawi, 2014). *Unstructured interview*s are a type of interview, that is opposite to the structured interview in which flexibility is greater. Interviewees can elaborate, leading in unpredictable directions and hence result in more data being collected. *Semi-structured interviews* are a mix of structured and unstructured interviews. Here the interviewer pre-plans questions (see APPENDIX E) prior to the interview but gives the interviewee a chance to elaborate and explain particular issues through the use of open-ended questions (Alsaawi, 2014).

In this research, a semi-structured interview method is employed. Three learners (one high achiever, medium achiever and a low achiever) from each of the groups were interviewed. They were identified using the pre-test scores. Interviews were used to verify the findings of the quantitative analysis of the pre- and post-test data.

3.6 RELIABILITY AND VALIDITY OF THE INSTRUMENTS

Reliability refers to the consistency, stability and repeatability of the results from the research. Therefore, the result of a researcher is considered reliable only if consistent results have been obtained in identical situations but in different circumstances (Twycross & Shields, 2004). Validity "is the extent to which any measuring instrument measures what it is intended to measure" (Thatcher, 2010, p.125). Reliability and validity are ways of manifesting and transmitting the rigour of research processes and the trustworthiness of the findings of the research. (Roberts & Priest, 2006; Alshenqeeti, 2014).

3.6.1 VALIDITY OF THE INSTRUMENTS

Masuwai *et al.* (2016) argues that validity is a very important aspect of a research. "Validity ensures that the questions being asked allow valid inferences to be made" (p.12). Face and content validity were considered for this study.

Face validity refers to the subjective assessments of the relevance and presentation of the instrument as to whether the items in the instrument appear to be relevant, appropriate, reasonable and clear (Masuwai *et al.* 2016). Content validity is the extent to which a descriptive system of a measure "represents the most relevant and important aspects of a concept in the context of a given measurement application" (Hays *et al.*, 2012). Content validity depends on the judgement of a panel of experts in the field (Kimberlin & Winterstein, 2008 & Kothari, 2004).

PHOTOELECTRIC EFFECT ACHIEVEMENT TEST (PEAT)

The Photoelectric Effect Achievement Test (PEAT), the observation schedule and the interview questions were given to three experts in physical sciences for validation. They were requested to moderate the questions and make necessary corrections and changes. One of them was a national examiner and the other one was the national internal moderator. They both hold a BSc degree in physics and chemistry and have an experience of more than 30 years in teaching and assessing the subject. The third person was a lecturer of physical sciences in the School of Education in the Sol Plaatje University, Kimberley, Northern Cape. She also has an experience of more than 10 years teaching physical science in Gr 12. Their most valuable suggestions are as follows.

- In the preamble of QUESTION 1 the work function of sodium metal was given as 2,28 X 10^{-19} J. This value was wrong, and they suggested it as 3,65 X 10^{-19} J.
- In QUESTION 1.3, "explain the term work function" was changed to "define work function" as mentioned in the examination guidelines issued by DBE.
- In QUESTION 1.4 the part of the sentence "ejected electrons have a velocity of 5,14 X 10^5 m.s^{-1}" was changed to "ejected electrons have a maximum velocity of 5,14 X 10^5 m.s^{-1}". This is in accordance with Einstein's photoelectric equation.

- In QUESTION 2, the maximum kinetic energies were given in electron Volt (eV). These were converted to Joules. This was because eV was not mentioned in the CAPS document or the examination guidelines.

The three experts agreed that the test measures all the aspects of the photoelectric effect adequately, as mentioned in the examination guidelines which is given below.

Photo-electric effect
• Describe the *photoelectric effect* as the process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on that surface.
• State the significance of the photoelectric effect.
• Define *threshold frequency*, f_o, as the minimum frequency of light needed to emit electrons from a certain metal surface.
• Define *work function*, W_o, as the minimum energy that an electron in the metal needs to be emitted from the metal surface.
• Perform calculations using the photoelectric equation: $E = W_o + K_{max}$, where $E = hf$ and $W_o = hf_o$ and $K_{max} = \frac{1}{2}mv^{2}{}_{max}$
• Explain the effect of intensity and frequency on the photoelectric effect.

Table 3.1 An extract from Examination guidelines, Grade 12, 2014, DBE, p. 13.

In addition to the inputs made by these experts the test was used in a teachers' training program as a pre-test. Teachers were requested to make suggestions to improve the quality of the questions. This was to strengthen the face and content validity of the pre- and post-tests. However, there were no suggestions from the teachers.

OBSERVATION SCHEDULE

Two of the three experts completely agree with the observation schedule. They commented that the observation schedule covers all the essential aspects of a lesson. The third expert suggested to provide numerical value for various responses. So "not done" is assigned 0, "done" assigned 1 and the "well done" assigned a value of 2. The observation schedule can be found in Appendix A. This recommendation was very helpful in measuring the agreement between the researcher and the expert when the teacher was observed together but independently.

INTERVIEW QUESTIONS

All three experts agreed that the interview questions were suitable for the evaluation the effectiveness of the three methods of teaching used in this case study.

3.6.2 RELIABILITY OF THE INSTRUMENTS

PEAT TEST

According to Wells and Wollack (2003) it is important for a researcher to be concerned with a test's reliability. They pointed out two important reasons. Firstly, reliability provides a measure of the extent to which a participant's score reflects random measurement error. The second reason is that reliability is a precursor to testing validity. That is, it is impossible to conclude that the scores accurately measure the domain of interest, if test scores cannot be assigned consistently. Cronbach's alpha is a popular index to measure the reliability. It "provides a measure of the extent to which the items in a test, each of which could be thought of as a mini-test, provide consistent information with regard to students' mastery of the domain" (Wells & Wollack, 2003 p.4). For this reason, the reliability of the test was established after the validity considerations, using the Cronbach's alpha.

Cronbach's alpha is defined as $\alpha = \frac{p}{p-1}\left(1 - \frac{\sum_{i=1}^{p} \sigma_{xi}^2}{\sigma_u^2}\right)$

where p is the number of items x_i, and $u = x_1 + x_2 + \text{-----} + x_p$ Cronbach, 1951 (p.299)

Cronbach's alpha is usually expressed numerically ranging from 0.0 to 1.0. A low value of α, indicates low reliability and a high α indicates high reliability. Various authors recommend that a minimum Cronbach's alpha of 0.70 is needed to demonstrate an acceptable level of internal consistency (Wells & Wollack, 2003; Beech, 2007).

Cronbach's alpha was calculated using the reliability calculator designed by D. Siegle of Connecticut University which is available online free in the following address:

researchbasics.education.uconn.edu/wp-content/.../06/Siegle-Reliability-Calculator.xls. Cronbach's alpha was calculated as 0,73 which is of in the acceptable range.

OBSERVATION SCHEDULE

Most of the time, observations tend to be subjective. This is because, the observers bring their own interests and biases to the observations. In a research this has to be limited, it is very important that observations should be as objective as possible. To measure the reliability of the observation schedule, three observation sessions were conducted in each group along with the lecturer from the Sol Plaatje University, who is also currently doing her PhD. These observations were conducted together but independently. At the end of each observation session, the results were compared and checked for consistency. An agreement of about 90% was recorded in the observations. Thus, the reliability of the observation schedule (RTOP) in this context is established.

INTERVIEW

Conway *et al.* (1995) found that achieving reliability is a difficult task in interviews. This is because each interview is unique in some way. Conway *et al.* (1995) commented that conducting one-to-one interviews with standard questions appeared to have the highest reliability. Hence, in this study, the learners were interviewed one-to-one with the same set of standard questions. (See Appendix E)

3.7 METHODOLOGY

INTERVENTION: CONTROL GROUP

The Photoelectric Effect Achievement Test (PEAT) was used to determine if there were no significant differences between the groups. The pre-test was also used to determine if there was a difference in performance of the learners after the intervention by comparing the pre-test with the post-test scores in each of the different groups.

INTERVENTION: TEACHER CENTRED EXPERIMENTAL GROUP

During the intervention, the Control Group (CG) was taught the photoelectric effect in the traditional way. The traditional way is where the teacher lectured, and the learners listened. The problems that needed to be solved in the class were from the approved text-books (Study and Master and Oxford) and the questions from previous NSC Paper 1 question papers. In this group, learners expressed doubts about some concepts such as the work function, gradient of the frequency *vs* kinetic energy graph etc. and the teacher explained their doubts using pictures from the text-books, drawings on the board and verbal explanations.

In the Teacher-Centred Experimental Group (TCEG) the teacher augmented the teaching using PhET simulations. Here, the simulations were projected onto a screen using a data projector and the teacher manipulated the simulations. The teacher selectively used some of the features of the simulation and blended them with the concepts such as *photoelectric effect*, *threshold frequency, work function* and the *effect of intensity and frequency on the photoelectric effect.* Here the teacher was very careful, as there are some features available in the PhET simulation that are not mentioned in the CAPS curriculum. For example: voltage of the battery, stopping voltage, graphs of current versus battery voltage and current versus light intensity.

INTERVENTION: LEARNER CENTRED EXPERIMENTAL GROUP

In the Learner-Centred Experimental Group (LCEG), the teacher explained only the basic concepts. In this group, learners were encouraged to learn by themselves using the simulations. They were given instruction sheets to guide the learning. Samples of the instruction sheet can be found in Appendix M. The teacher was always available if they needed any help.

All the groups were offered 6 hours intervention in total. This time excluded the pre- and post-tests. The intervention spanned over three weeks. This is because only one group could be treated in one day because the intervention was after the school day. All the groups followed the same instruction sequence and had the same learning objectives. This was to ensure that an appropriate comparison could be made among the three instruction methods. The classes had a duration of 1hour and 30 minutes and were from 14.00 to 15.30, after school. All the groups were given the same text-book problems and past NSC Paper 1 question papers. Because each group had the same time, CG had extra time to do more problems from previous years NSC questions. They did 7 problems compared to the 5 problems done by TCEG and LCEG. A detailed explanation of the different groups can be found in chapter 4 (see section 4.3). All the classes were observed by the researcher and observation notes were taken. A consolidation of the observations is presented (see section 4.3).

Before the intervention, all three groups wrote the same pre-test namely Photoelectric Effect Achievement Test (PEAT). The same test was also written after the intervention. At the end of the treatment three learners from each group were interviewed. The top learner, an average learner and one of the weak learners were selected from each group. Pre-test scores were used to identify the learners. The interview is presented in detailed in section 4.5.6

Figure 3.1 given below, diagrammatically illustrates the research procedure followed in this study.

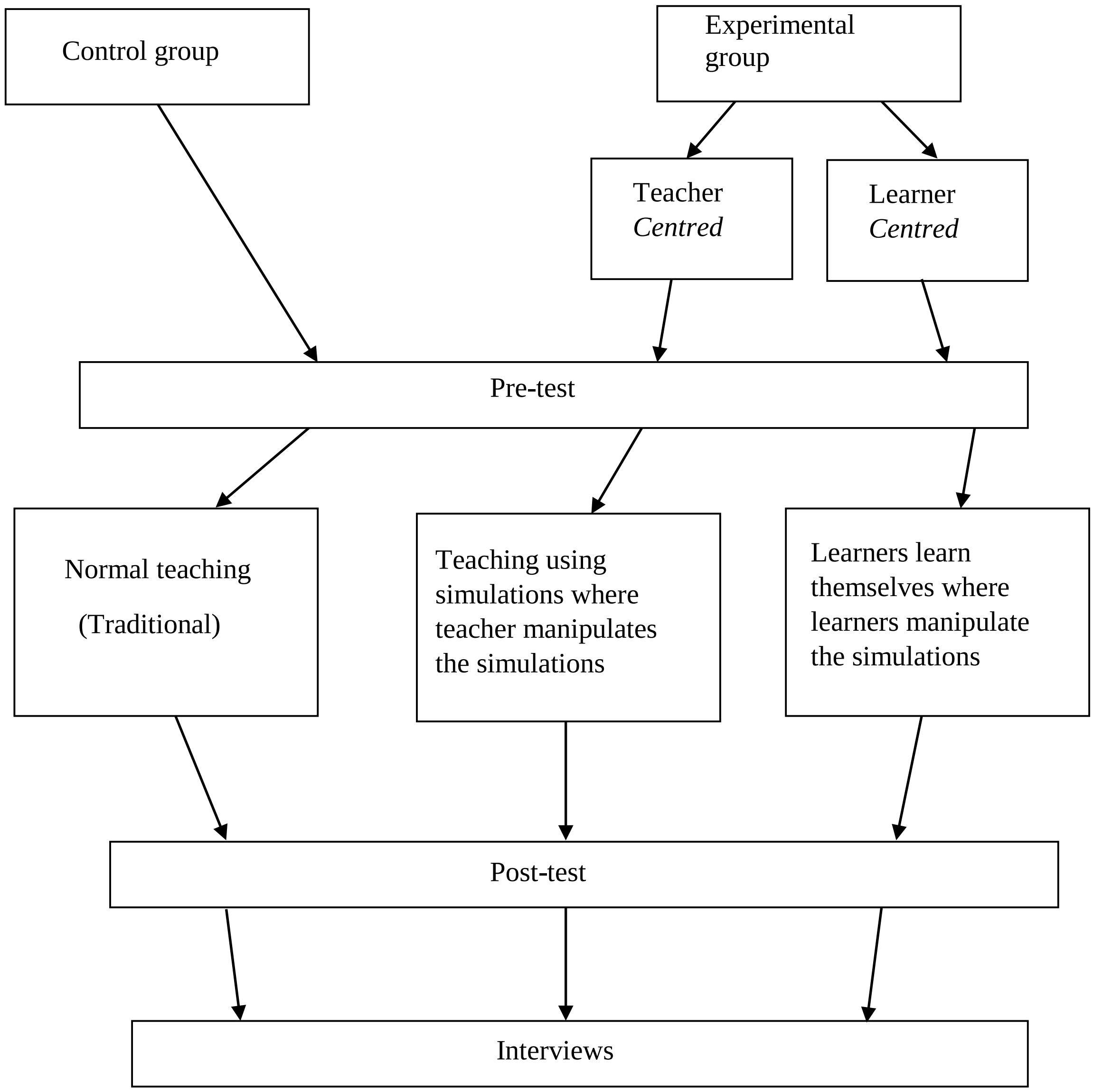


Figure 3.1: Research procedure

3.8 DATA COLLECTION

The scripts of the pre- and post-tests were marked, and the different scores were recorded per group. Classroom observations were conducted using the observation schedules when the different groups were taught by the teacher. After the intervention, all the groups wrote the PEAT as the post-test at the same time. These scripts were also marked, and the scores were captured per group. The interviews were conducted just after the post-test.

3.9 DATA ANALYSIS

QUANTITATIVE DATA ANALYSIS

The data from the PEAT were analysed using the SPSS 24.0. Means (M) and standard deviations (SD) were calculated. One-way Analysis of Variance (ANOVA) is used to determine whether there was any statistically significant differences between the three groups before the intervention. A paired t-test was done to determine whether there was any statistically significant difference between the pre- and post-test scores in PEAT for each of the three groups. Analysis of Covariance (ANCOVA) was used to determine whether a significant difference existed between group means of PEAT for the control and experimental groups when differences in pre-test scores were controlled.

To evaluate the effectiveness of the intervention, Hake's normalised gain was calculated. Hake (1998) introduced the normalised gain (<g>) to measure the effectiveness of a course in promoting conceptual understanding. He defined the "average normalised gain <g> for a course as the ration of the actual average gain <G> to the maximum possible average gain.

$$<g> = \frac{\% < G >}{\% < G >_{max}} = \frac{(\% < S_f > - \ \% < S_I >)}{(100 - \% < S_i >)}$$

where $<S_f>$ and $<S_i>$ are the final (post) and initial (pre) class averages". (p. 65).

According to him if (<g>) $\geq$ 0.7, it is considered as a high -g, and means that the course is highly effective. If (<g>) $\geq$ 0.3, it is considered as a medium-g, and means that the course was average and if (<g>) < 0.3, it is considered as a low-g, which means that the course was less effective.

QUALITATIVE DATA ANALYSIS

The data from the observation schedule was used to ascertain how the teacher introduces the lessons, the involvement of learners in the lessons and the teacher's ability to teach the content of photoelectric effect. It also helped the researcher to collect data on the teaching style of the teacher in various groups.

The interview data was analysed to verify the findings of the quantitative analysis of the data collected by the PEAT.

3.10 ETHICAL CONSIDERATIONS

3.10.1 OFFICIAL PERMISSIONS

All the research projects should follow ethical considerations when the research involves human participants (Alshenqeeti, 2014). Therefore, the researcher applied for ethical clearance to the Ethics Review Committee of the University of South Africa. The committee granted permission in writing and this can be found in Appendix F. Permission was granted to conduct the research from the Northern Cape Department of Education who is the employer of the researcher as well as from the Frances Baard District Director of Education where the school was located. The district director gave permission in writing and this can be found in Appendix G. These are the requirements before conducting any research in the University of South Africa and the Northern Cape Department of Education. The following paragraph describes how the stakeholders were contacted regarding the ethical clearance.

3.10.2 TEACHERS, LEARNERS AND PARENTS

The principal of the school was contacted and the process was explained by indicating that this research could be beneficial not only to the learners of the school but also to the learners and teachers in the province. The participating teacher was very positive and willing to participate in the study from the outset. A brief account on the research was given to him. His role in the research and the different activities were discussed. The School Governing Body (SGB) was also briefed about the research and permission was granted. The principal invited the researcher to a staff meeting where the aim and the modus operandi of the research was explained. Teachers were sceptical initially due to the involvement of Grade 12 learners. After explaining the finer details, for example the intervention times and duration of the research, they were on board. This meeting was helpful because the participating teacher and the researcher needed the cooperation of the other teachers who were teaching the Grade 12 physical science learners. An agreement was made with the other teachers that when the learners are undergoing the treatment they will not have any other classes for any other subjects. In addition, the research was explained to the parents in a Grade 12 parents' meeting.

A session with the learners were organised to explain the rationale behind the research. This was scheduled as participants in research have the right to be informed about the aims, purposes and the consequences and the likely publication of the findings.

Participants were informed that their participation is voluntary, and nobody will be victimised in anyway by anyone in participating in this research. They were notified that they could withdraw at any time from the research as stated in the different consent forms (See Appendix I,J,K). Letters of informed consent for the teacher, minors' and their parents, and for learners above 18 years can be found in the Appendices I, J and K. These forms were completed, signed by the relevant parties and collected. Some learners who signed the consent form later withdrew from the research, citing various reasons.

3.11 SUMMARY

In this chapter, the research design, the methodology used in the research and the participants in this study were explained. The instruments used and its validity and reliability as well as how the data was collected and analysed was discussed. This chapter also outlined the ethical procedures followed in this research.

CHAPTER 4

PRESENTATION AND DATA ANALYSIS

4.1 INTRODUCTION

The data and the analysis of the data from the study are presented in this chapter. The analysis of the data seeks answers to the research questions, which guided this work. The research questions are:

1. What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive demonstration tool, manipulated by the teacher in the classroom?
2. What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive tool, manipulated by the learners in the classroom?

4.2 RESEARCH HYPOTHESIS

In order to suitably address the above-mentioned research questions, the following null hypotheses were formulated:

H_0 1 There is no significant difference between the mean pre-test and post-test scores for learners in the control group.

H_0 2 There is no significant difference between the mean pre-test and post-test scores for learners in the teacher-centred experimental group.

H_0 3 There is no significant difference between the mean the mean pre-test and post-test scores for learners in the learner-centred experimental group.

H_0 4 There is no significant difference between the mean post-test scores for learners in the control group, teacher-centred experimental group, and learner-centred experimental group after controlling the effect of pre-test scores.

To provide context to the data, the different groups were described by indicating how each of the lessons were taught. An interpretation of possible reasons of what was happening is then presented.

To find the answers to the research questions a pre-test and a post-test (Photoelectric Effect Achievement Test) were conducted. The data from the Photoelectric Effect Achievement Test (PEAT) were analysed by SPSS 24.0. A one-way Analysis of Variance (ANOVA) was performed to determine whether there is any statistically significant difference between the groups before the intervention. A paired t-test was used to determine if there was a statically significant difference between the pre-test and post-test scores for each of the three groups. An Analysis of Covariance (ANCOVA) was performed to determine whether a significant difference between group means of the scores of post-test for the control and experimental groups when the differences in pre-test scores were controlled. This analysis was used to determine whether the null hypothesis should be accepted or rejected.

To substantiate the findings of the analysed data, interviews were conducted and analysed. This was followed by calculating Hake's normalised gain to roughly calculate the effectiveness of a course in promoting conceptual understanding (Hake, 1998).

4.3 PRESENTATIONS OF THE LESSONS

4.3.1 TEACHER-CENTRED EXPERIMENT GROUP

Lesson 1

In this group, the teacher introduced the phenomenon of the photoelectric effect using PhET simulations through a series of manipulations. The teacher manipulated the simulations during the lessons.

The teacher explained the set up shown in figure 4.1, starting with the electrodes. He mentioned that there are provisions to change the intensity and frequency by sliding the corresponding bars. Intensity is a vague term for learners as they have not studied the concept in any of the previous grades or even in grade 12 in CAPS. However, the effect of what is happening by sliding the bar representing intensity in PhET is presented in a way that it can be easily grasped by the learners. For example, for zero intensity it is dark and as the intensity increases, the brightness also increases. The electromagnetic spectrum is shown in the frequency bar. This enables the learners to understand what is meant by increasing and decreasing of frequency.

The teacher did not mention or explain the voltage bar as this is not required in the CAPS as there is no mention of the term "stopping potential" (Curriculum Assessment Policy Statement, physical sciences, DBE, 2011, p.132-133)

The teacher showed the learners that when no light is shining (intensity is 0%) onto the cathode, no electrons are ejected, or the photocurrent is zero (figure 4.1).

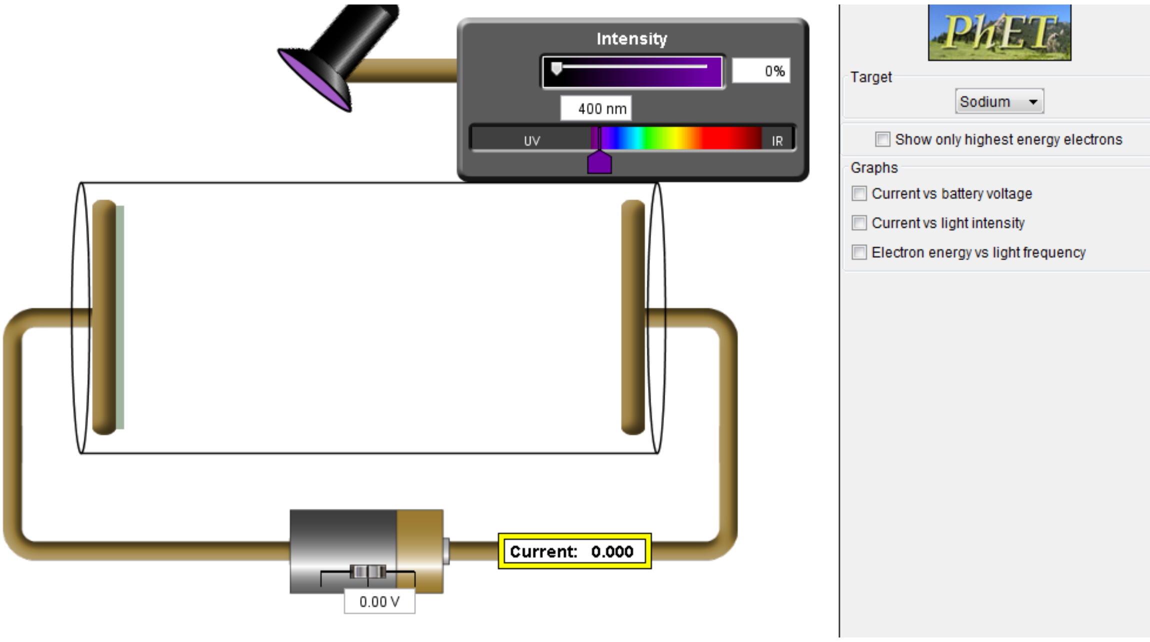


Figure 4.1: Screenshot from PhET interactive simulation showing there are no photoelectrons when there is no intensity of light.

Then the teacher increased the intensity to 20% and then showed that the electrons are ejected resulting in a current of 0.028 A, as shown in figure 4.2. Thus, the learners saw the photoelectric effect as a phenomenon in which electrons are ejected from a metal surface when it is irradiated by light.

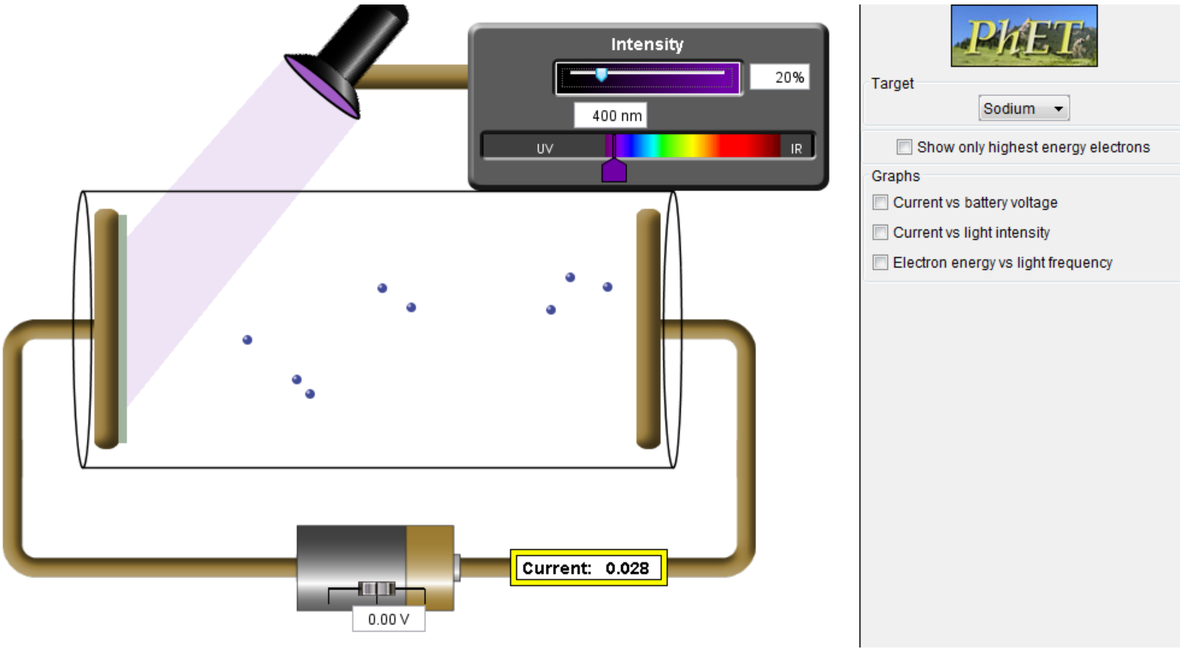


Figure 4.2: Screenshot from PhET interactive simulation showing photoelectrons when the intensity of light is 20%.

To highlight the particle nature of light, the teacher switched to the "show photons" option in the menu as shown in figure 4.3.

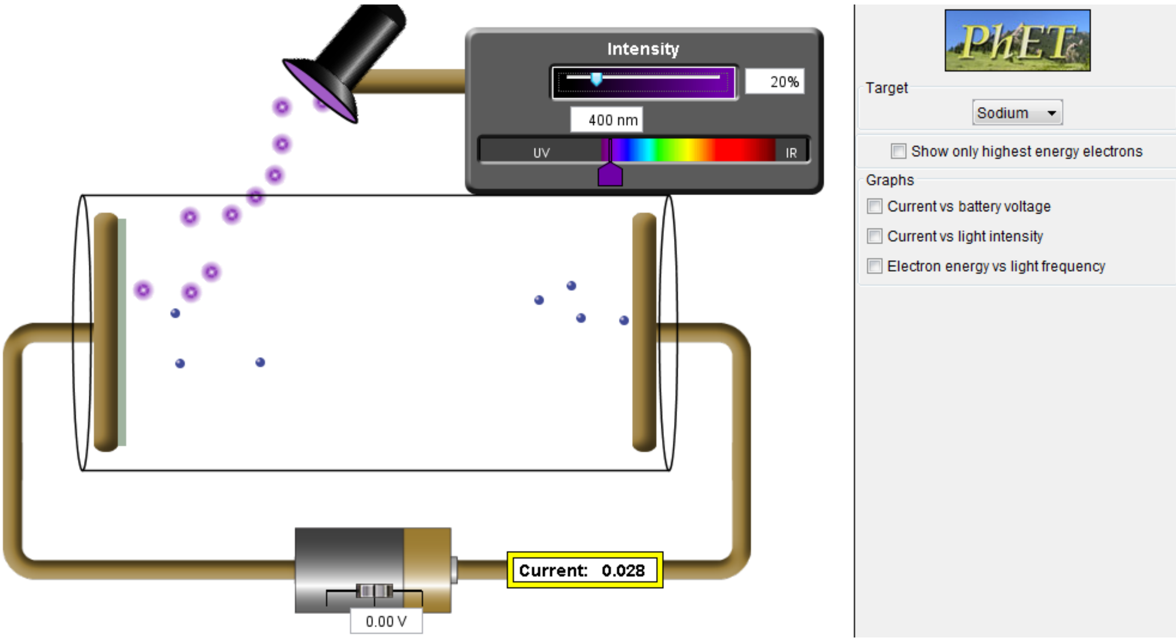


Figure 4.3: Screenshot from PhET interactive simulation showing incident light in terms of photons.

During this lesson, the concept of work function is introduced with a series of simulations. Initially, the teacher selected sodium which is the default target in the simulation. He then selected a particular intensity and frequency so that there was ejection of photoelectrons, as shown in figure 4.4

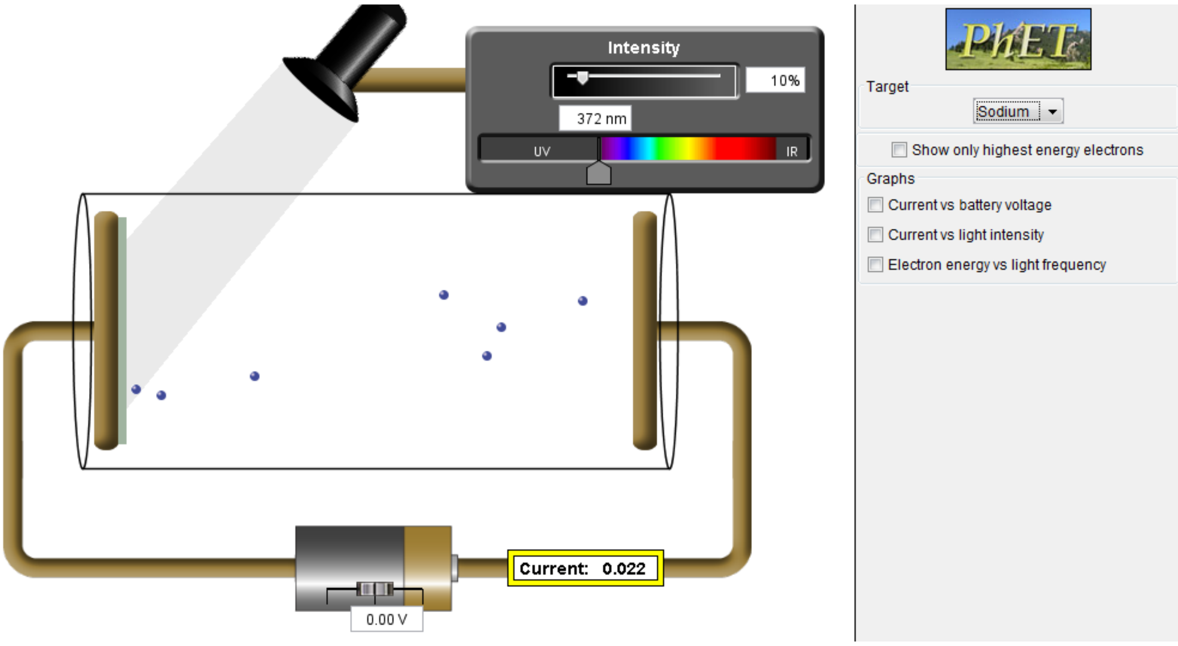


Figure 4.4: Screenshot from PhET interactive simulation showing photoelectrons when the cathode is sodium.

He then replaced sodium with copper keeping the same intensity and frequency and there were no electrons emitted, as shown in figure 4.5

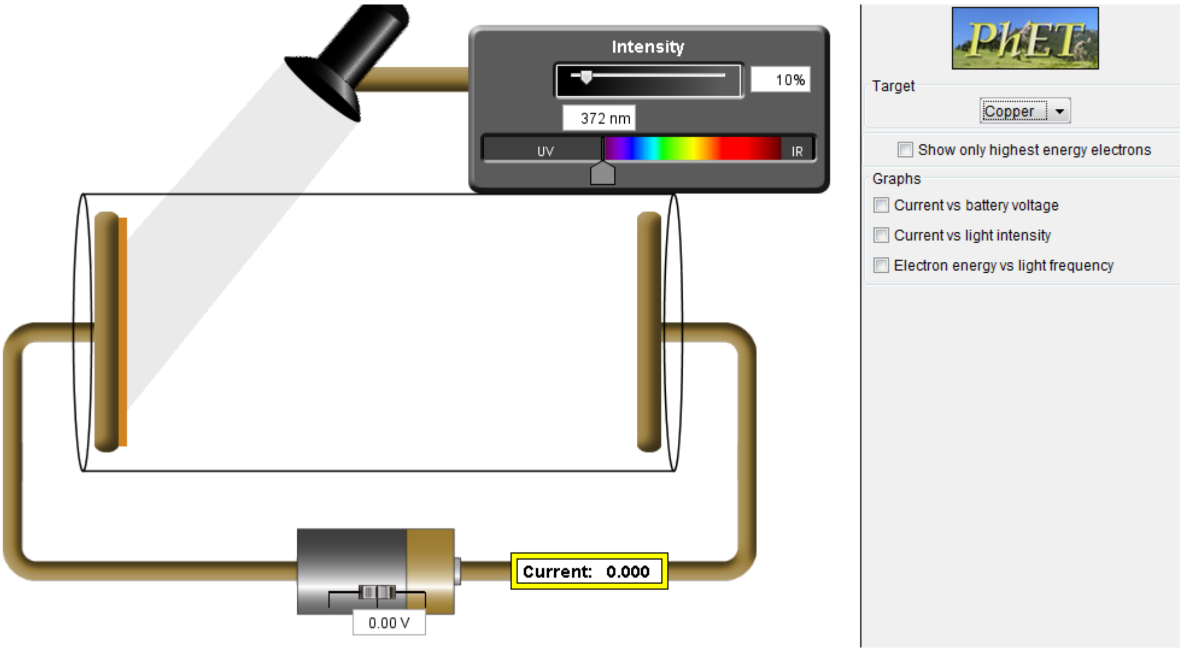


Figure 4.5: Screenshot from PhET interactive simulation showing no photoelectrons emitted when the cathode is copper.

He repeated it for other metals such as zinc, platinum and calcium which are the available targets in the simulation and showed that electrons will not eject automatically from all metals when irradiated. The teacher stressed the fact that the photoelectric effect depends on the metal. Thus, the teacher could develop the concept of work function.

Lesson 2

The concept of threshold frequency was introduced. The teacher used the simulation as shown in figure 4.6. He randomly kept the intensity as 20% and selected the 372 nm light source with sodium as the cathode. Learners observed that photoelectrons are ejected so that a photocurrent of 0.004 A is registered.

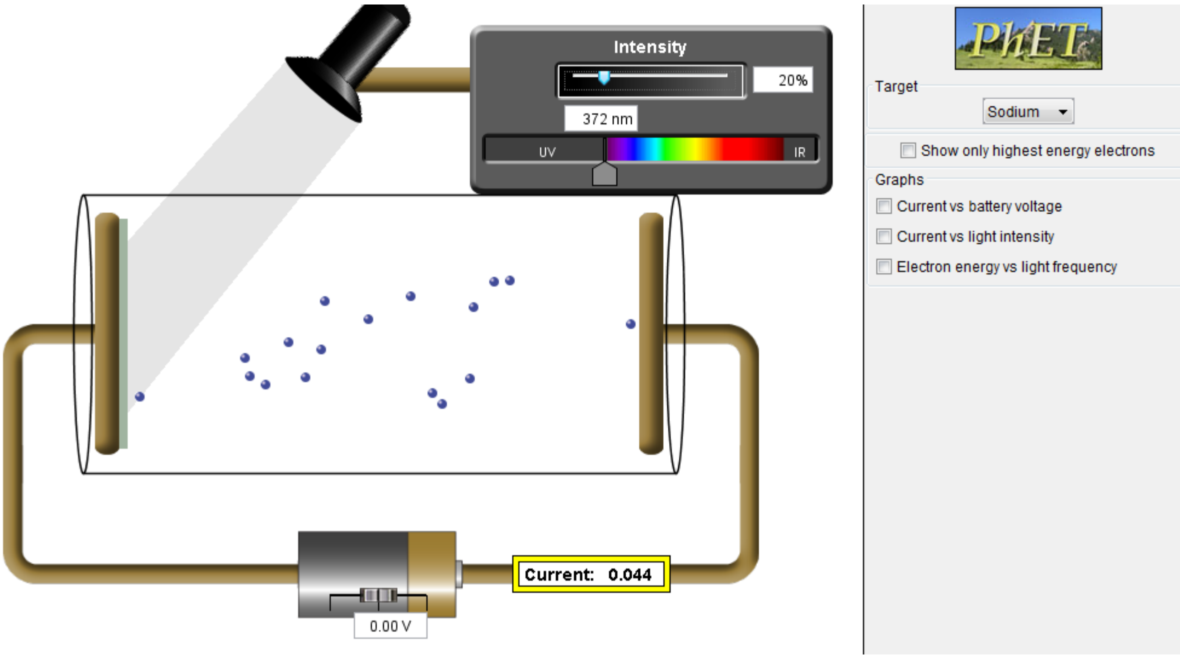


Figure 4.6: Screenshot from PhET interactive simulation showing photocurrent when light of 372 nm is shown to the sodium cathode.

Then the teacher asked learners to observe as he lowered the frequency, by increasing the wavelength to 579 nm. He referred the equation $v = f\lambda$ to explain the relation between wavelength and frequency. Learners observed that at 579 nm no photoelectrons are ejected (figure 4.7). The teacher increased the frequency step by step and learners observed that the photoelectrons are emitted only when the incident frequency is above a certain frequency. Teacher then asked the learners to explain their observation in terms of the energy of radiation using the equation, $E = hf$. Learners could explain that as the frequency increases, the light has more energy and caused the ejection of electrons. He then asked whether it is possible to have photoelectrons for any frequency and learners answered that it is possible only if the frequency is sufficiently high. Thus, the concepts of threshold frequency and threshold wavelength are established.

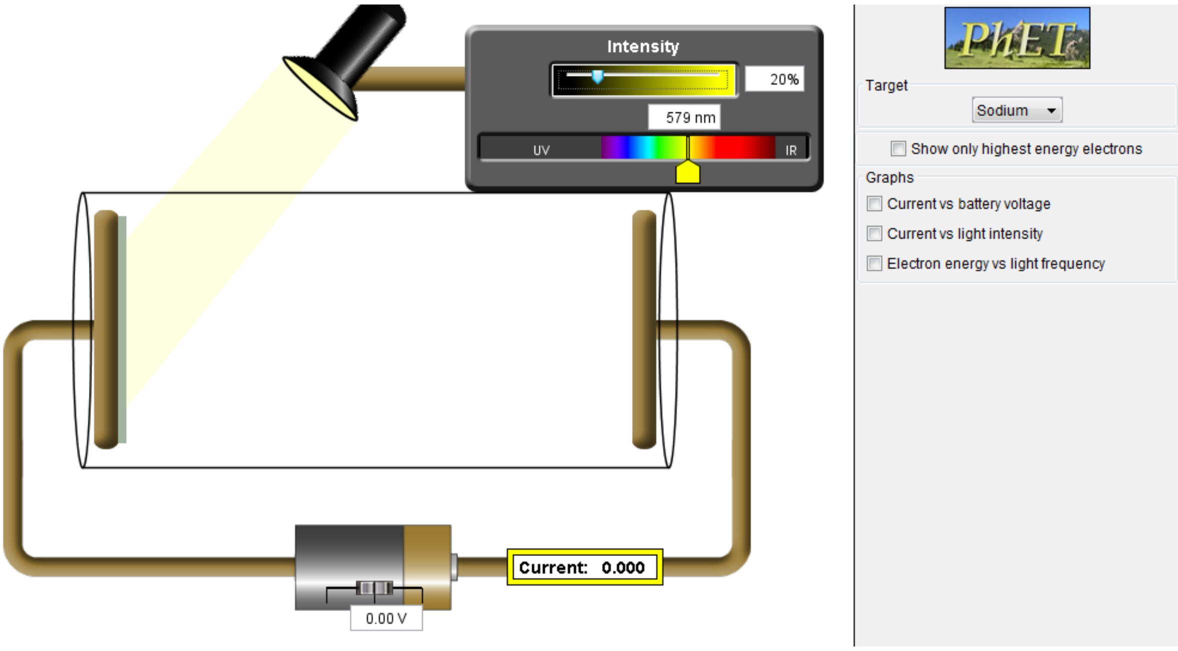


Figure 4.7: Screenshot from PhET interactive simulation showing no photoelectric effect when the wavelength is 579 nm.

In teaching the experimental laws of the photoelectric effect, especially the relation between intensity of light and the photocurrent the simulations were very helpful. The teacher selected the following simulation (figure 4.8) and asked the learners to note the intensity of the light, the number of photoelectrons and the photocurrent.

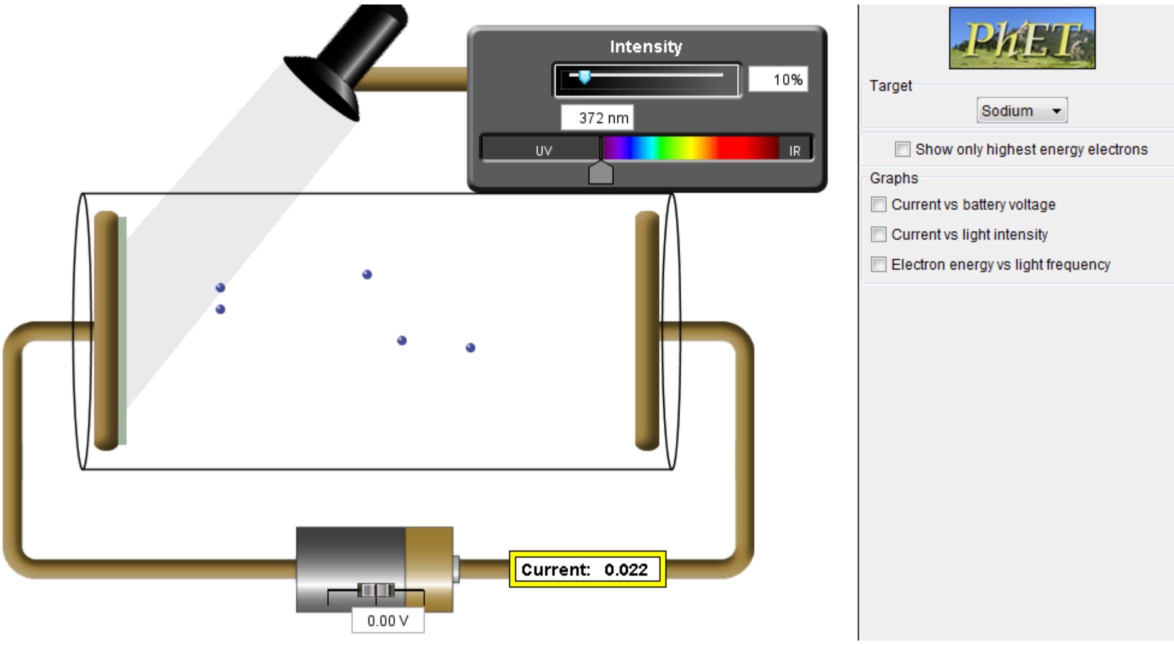


Figure 4.8: Screenshot from PhET interactive simulation showing the photocurrent of 0.022 A for 10% of intensity of incident light.

He then increased the intensity gradually while the learners checked what is happening to the number of phototoelectrons and hence the photocurrent. Figure 4.9 shows the screen,shot when the intensity is 60%.

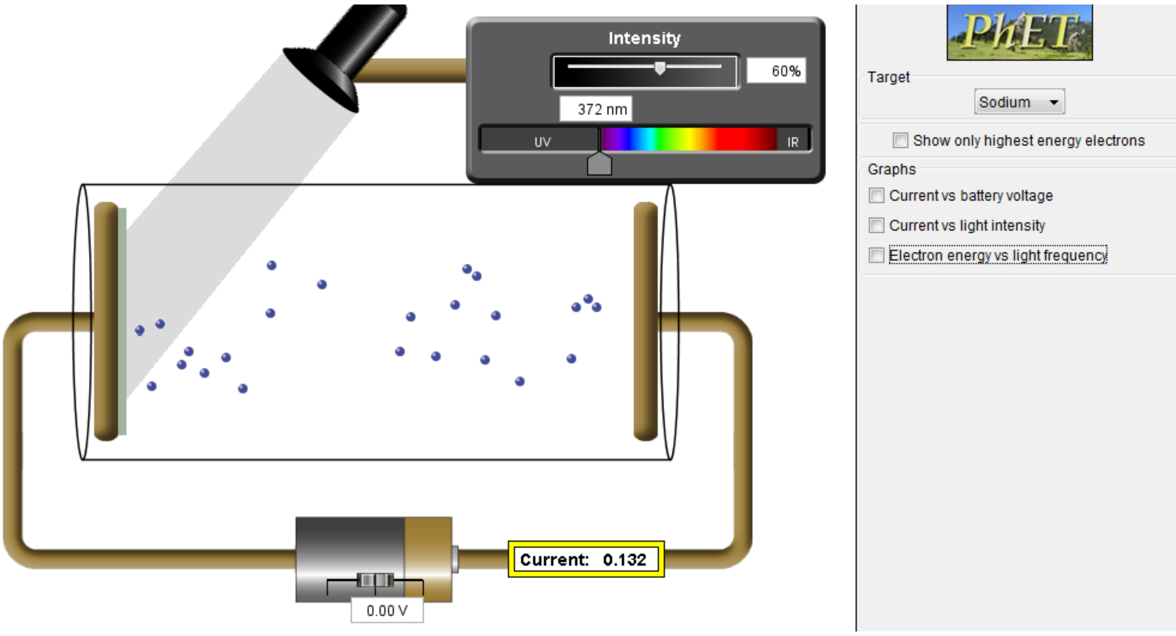


Figure 4.9: Screenshot from PhET interactive simulation showing the photocurrent of 0.132 A for 60 % of intensity of incident light.

From the simulations learners observed that as the intensity increases, the number of ejected electrons increases and hence the photocurrent increases.

Lesson 3

The teacher introduced Einstein's photoelectric equation ($E = W_o + E_k$) through an historical perspective after revisiting the Plank's equation E = hf that they have learned in grade 10. He then explained what happens to the kinetic energy of the ejected electrons as the frequency of the incident light is increasing. The teacher showed the relation between the frequency and kinetic energy graphically while manipulating the frequency. The feature of plotting of graphs in the PhET made it easy for the teacher. A typical kinetic energy vs frequency graph for sodium electrode is shown in figure 4.10

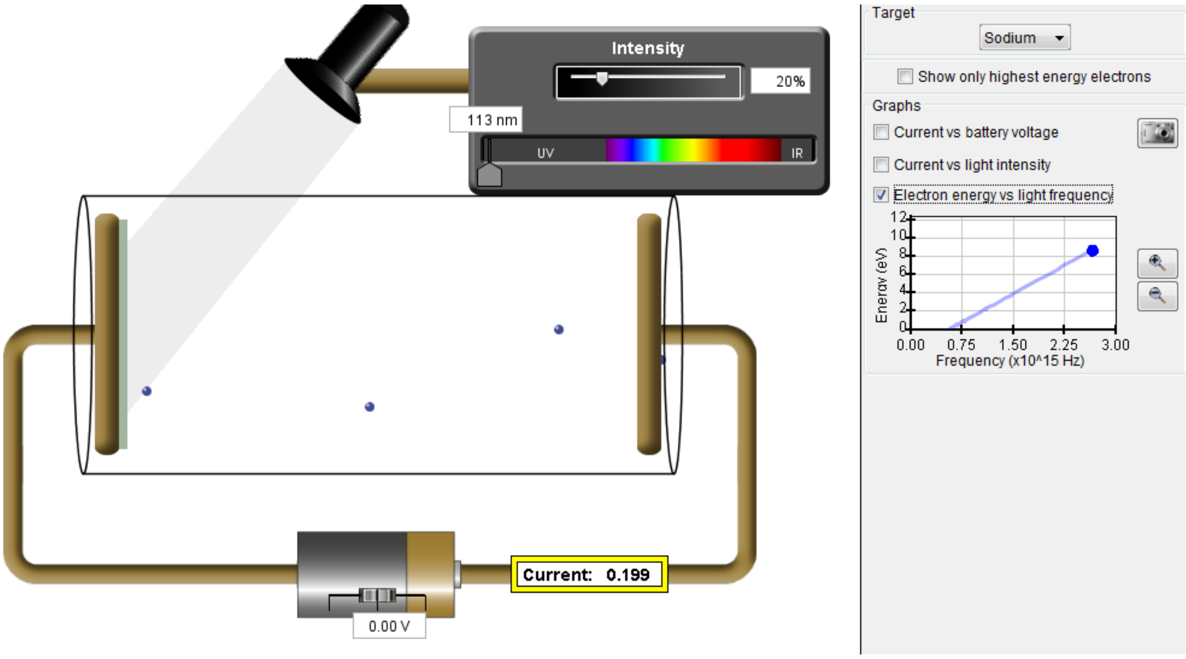


Figure 4.10: Screenshot from PhET interactive simulation showing the graph connecting frequency and kinetic energy.

In all the simulations, the teacher was cautious not to manipulate the voltage as it is beyond the scope for grade 12 learners in CAPS. Also, he did not emphasis the change of current when the frequency of incident radiation is varied. This was because the teacher was not confident enough to explain the relationship between the photocurrent and frequency of the incident radiation. This purposeful and selective manipulations and explanations were presented to give an indication of what happened during the lessons when the teacher manipulated the simulations.

4.3.2 LEARNER-CENTRED EXPERIMENT GROUP

Lesson 1

The teacher briefly explained the photoelectric effect using a simulation and gave a summary of its historical importance. The learners were given the notes and there were instruction sheets to help the learners to proceed with their learning when using the simulations. A sample of the instruction sheet is shown in Appendix M. Learners manipulated the simulations to understand the phenomena better and they enjoyed it in lesson 1.

Lesson 2

From lesson 2, when they were learning threshold frequency and threshold wavelength, they started to manipulate the voltage bar. This created lot of confusion among the learners.

An example of the problems faced by the learners is explained using some of the screenshots. In figure 4.11 photoelectrons are emitted when 400 nm light falls on the sodium electrode, registering a current of 0.071 A.

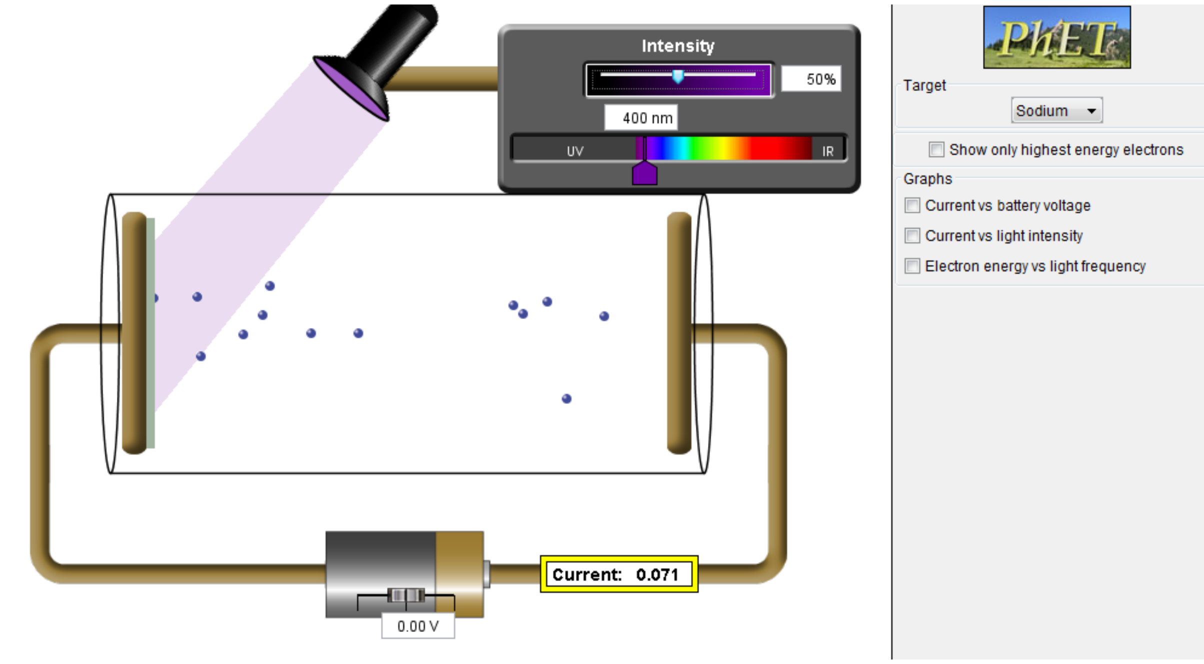


Figure 4.11: Screenshot from PhET interactive simulation showing the photocurrent of 0.071 A for 400 nm light with 50% of intensity of incident light.

Then the learners tried different combinations by manipulating the voltage bar of the simulation. They have found that when the voltage is negative, the flow of photoelectrons ceased, and the photocurrent is 0, as shown in the figure below.

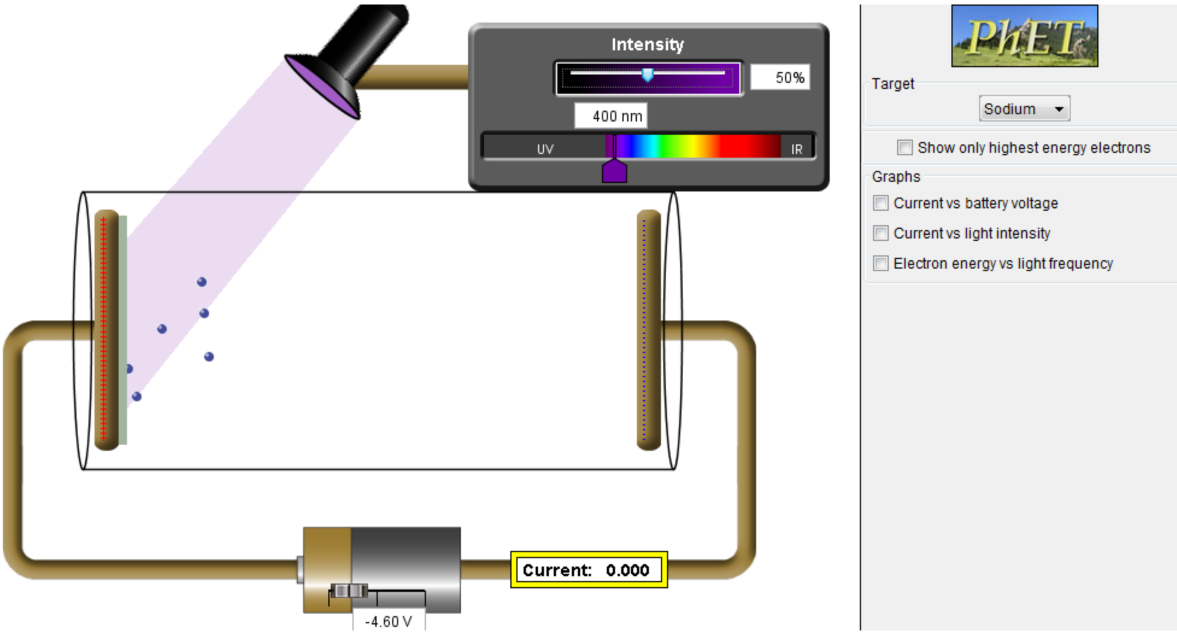


Figure 4.12: Screenshot from PhET interactive simulation showing no photocurrent when the voltage is -4.60 V.

They called the teacher several times and the learners were not able to understand the explanation of the teacher. The teacher tried his level best to explain but the learners did not understand and were not satisfied with the teacher's explanation. The teacher concluded the discussion by making a statement that the photocurrent is dependent on the voltage and that is not part of the curriculum. They again tried to manipulate the simulation with other voltages, but the teacher intervened and forced them to move on as they could not follow the pace of the teaching plan.

One of the learners had the program on his laptop and tried several combinations after the school at his home. He came with two scenarios as shown in the figures 4.13 and 4.14 below.

In figure 4.13, the learner selected sodium as the electrode and irradiated it with light of wavelength 293 nm, while keeping the voltage as 0. He also selected all the graphs.

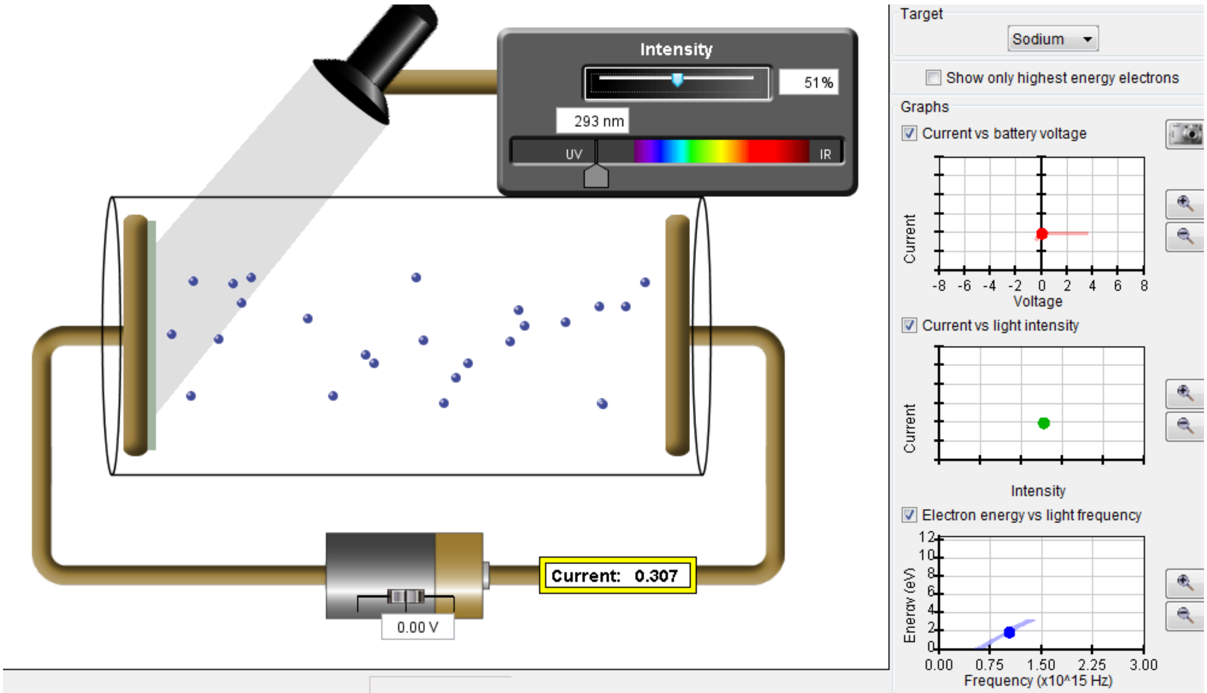


Figure 4.13: Screenshot from PhET interactive simulation showing photocurrent when the voltage is 0 V.

He then changed the voltage to 1.40 V while keeping all other parameters unchanged. He observed that the current registered was the same without the voltage. He also found that the graphs are the same, except for the current versus voltage graph.

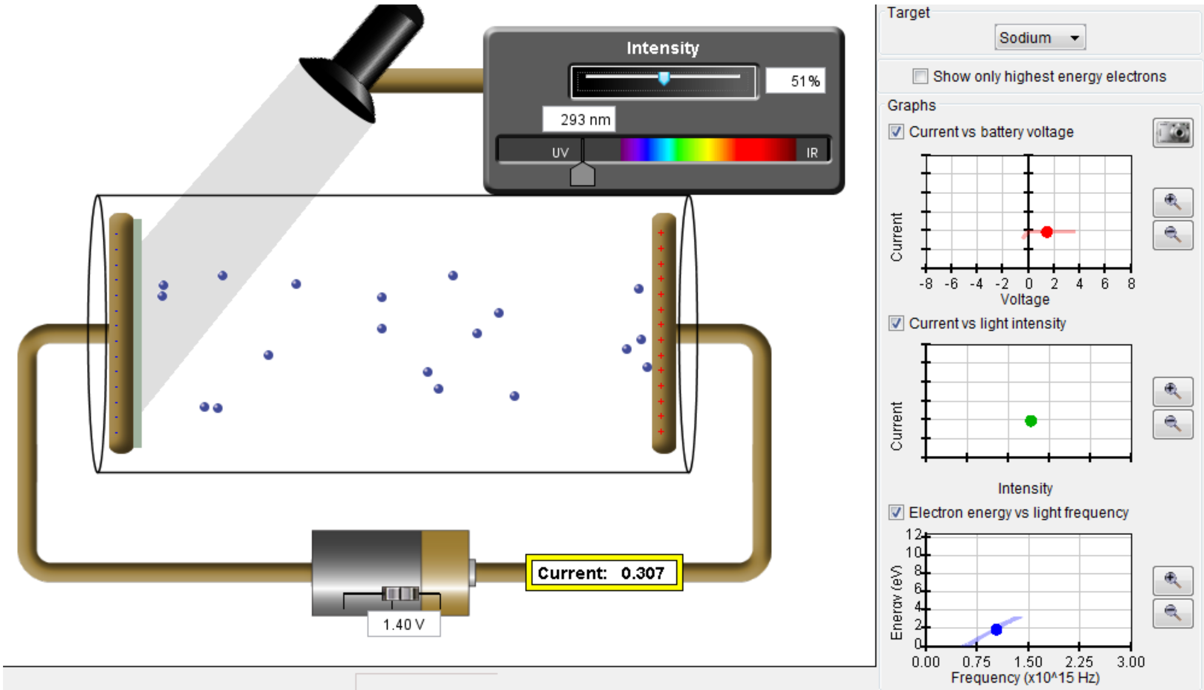


Figure 4.14: Screenshot from PhET interactive simulation showing photocurrent when the voltage is 1.40 V.

The teacher could not explain the situation correctly. He made a statement that once the electrons start being emitted, the voltage plays no role in the phenomenon. The whole group was arguing that the simulation has serious flaws or the teacher's explanation was wrong. The researcher later intervened and explained the observation.

Lesson 3

The learners came across the following situation.
They wanted to check the second experimental law of the photoelectric effect using the simulation. They selected sodium as the electrode and 400 nm as the wavelength of the incident light. The photocurrent registered as 0.028 A. This is shown in figure 4.15.

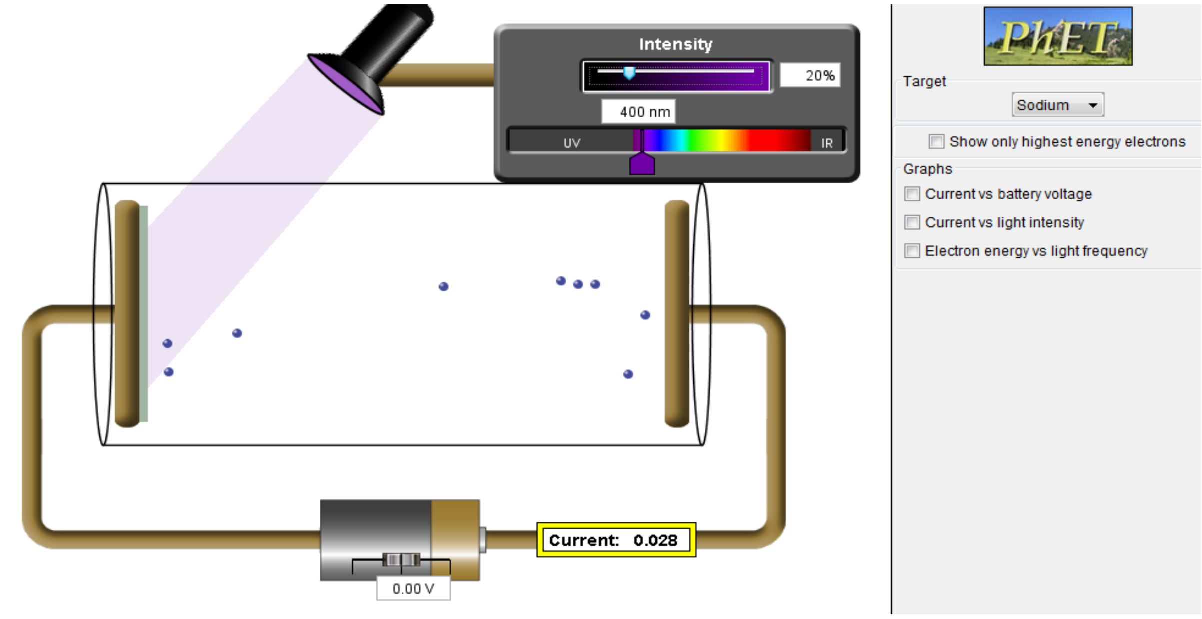


Figure 4.15: Screenshot from PhET interactive simulation showing photocurrent of 0,028 A when the wavelength is 400 nm.

Now they changed the wavelength to 370 nm. They expected that the current to be constant at 0,028 A, as the current depends only on the intensity according to the experimental law of photoelectric effect. But the recorded current was 0.045 A as shown in figure 4.16.

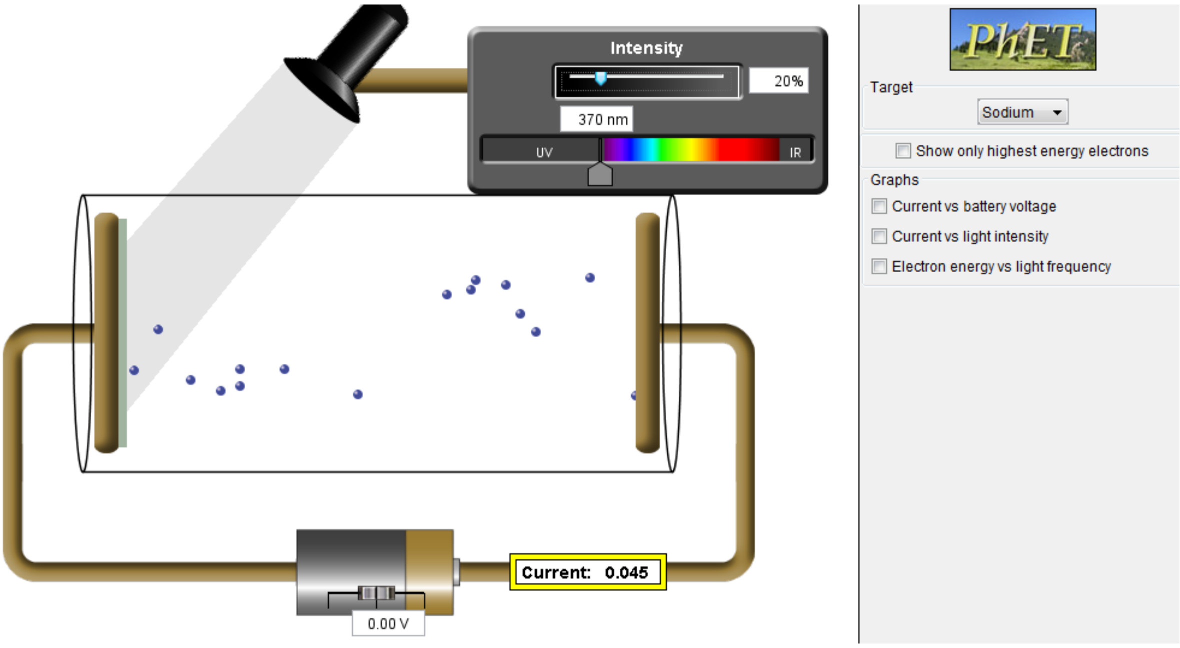


Figure 4.16: Screenshot from PhET interactive simulation showing photocurrent of 0,045 A when the wavelength is 370 nm.

This again puzzled the learners. They asked the teacher why the variation in wavelength affect the photocurrent and the teacher was unable to explain this correctly. The teacher was arguing that when the frequency increases the number of photons could also increase. According to him, each photon possesses an energy and when the frequency increases the energy also increases and leads to more photons being emitted. This also had some negative impact on the use of simulations by the learners.

4.3.3 CONTROL (TRADITIONAL) GROUP

Lesson 1

The teacher presented the phenomenon with all the historical perspectives. He stated that this phenomenon posed a serious challenge to the physicists at that time regarding the nature of the light, when the scientific world had fully absorbed the wave theory. Not only that, the accepted theory could not explain the phenomenon correctly.

The teacher used the pictorial representation of an experimental setup for the photoelectric effect, which is shown below to explain the phenomenon.

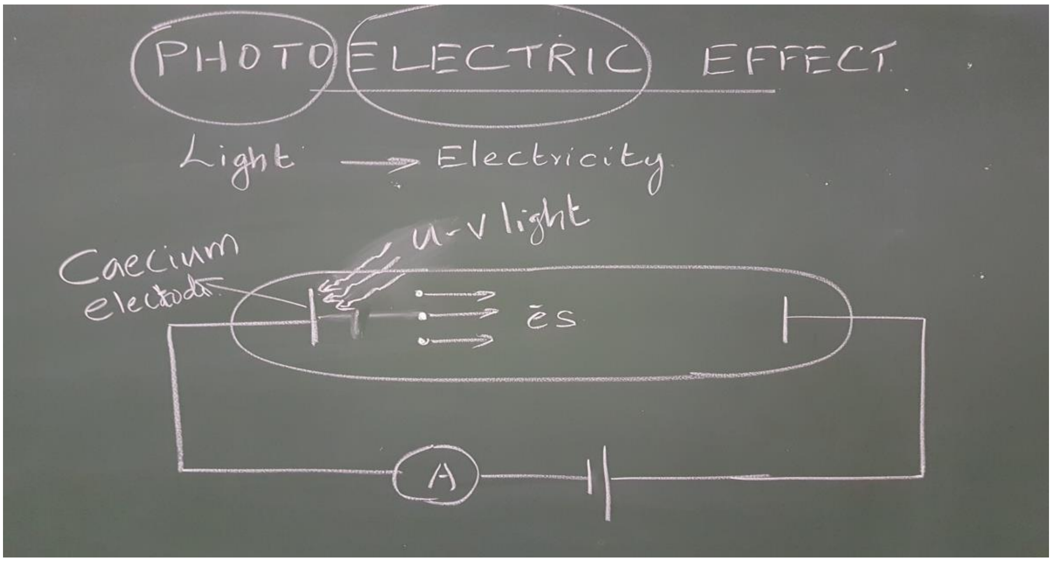


Figure 4.17: Pictorial representation of the experimental setup of photoelectric effect

The teacher said when "sufficient" light from the source falls on a caesium cathode, electrons will emit from it. An ammeter connected in the circuit reads a current called the photocurrent. He later tried to explain the "sufficient" light with real values. He said "for caesium metal, if the energy of the incident light is less than say 4 J,, no electrons will be emitted. Maybe for sodium that energy will be 3 J and for another metal it will be another value". In this way he introduced the concept of work function.

Lesson 2

The teacher started with the concept of work function and connected that with the frequency (f) using the equation E = hf, which was familiar to the learners. He stated the frequency corresponding to the "sufficient" energy is the threshold frequency. And then the concept of threshold frequency was also introduced.

To explain the experimental laws of the photoelectric effect, the teacher used the same diagram showed in figure 4.17. It was difficult for the teacher to explain the concept of the intensity of light. The teacher closed the doors and windows and made a statement that "the room is darkened a little bit as the intensity of light is less". He slowly opened the doors and windows (with the help of the learners) and told the learners "now the intensity is increasing". Thus, the various experimental laws of photoelectric effect were introduced.

Lesson 3

The teacher introduced Einstein's photoelectric equation in this lesson. He used different values to explain the equation based on the conservation of energy. The teacher, referring to the previous lessons, reminded the learners that the incident energy is used for two "things". First "thing" is to rip the electrons out of the metal and the second one is to give kinetic energy to the ejected electrons. Teacher thus introduced Einstein's photoelectric equation.

In all the lessons in the three groups observation notes were made and a summary is presented in Table 4.1 below

Table 4.1: Summary of observation notes of lessons for the three groups

LESSON/TOPIC	ACTIVITY		
	TRADITIONAL TEACHING GROUP (CG)	TEACHER-CENTRED GROUP USING SIMULATIONS (TCEG)	LEARNER-CENTRED GROUP USING SIMULATIONS (LCEG)
Lesson 1 Photoelectric effect Significance Work function	Teacher explained the phenomenon using a drawing on the chalk-board. Struggled to explain the work function. Learners were losing attention and the teacher kept reminding the learners that this topic is very important and carries 10% of the final examination to motivate them.	Teacher could explain the phenomenon very quickly with the simulation. Learners understood the concept of work function a little quicker as PhET allows them to select different metals. They saw that changing the metal electrode affects the phenomenon of the photoelectric effect.	Learners seemed to be very excited. Several times, the teacher intervened as the learners wanted to manipulate the simulation continuously without reading the notes. They did not try the simulation the correct way. They were interested in playing the simulation the whole time.
Lesson 2 Threshold frequency Threshold wavelength Experimental laws	Teacher again drew the experimental setup and different graphs and explained the laws. He also explained	Teacher showed the simulation with low frequency and gradually increased the frequency of the incident light.	Learners were again reminded many times to go back to their notes before manipulating the

	the threshold frequency and showed what happens when the frequency of the light is less than the threshold frequency. Explained a few questions that test the concept.	Learners understood that it is not possible to have photoelectrons below a particular frequency. Teacher selected 0 V as the potential difference between the electrodes as learners are not studying stopping potential.	simulation. They sometimes selected high voltage between the electrodes and required many interventions by the teacher. Many of them were confused and were not happy with the advice that they should not work with voltage as it is not part of the curriculum.
Lesson 3 Photoelectric equation Exercises	Explained the equation with some values and with diagrams. Showed how the experimental laws could be explained by Einstein's photoelectric equation. Did a few problems from previous papers and struggled to explain the question relating kinetic energy, photocurrent, intensity of light and frequency of light.	Used the inbuilt graphs to explain the experimental laws and showed that how Einstein's photoelectric equation explains the different graphs. When doing the exercises, it was easy to check what happens when the intensity and frequency changes.	Again, the teacher intervened many times to force them to read their notes. When doing the exercises, they wanted to work with simulations to check their answer. But the simulation did not have any feature of calculating the kinetic energy of the ejected electrons.
Lesson 4 Dual Nature Applications	This lesson was almost same for all groups as there was no feature in the simulation that deals with this topic.		
Lessons 5 Consolidation exercises	Teacher was revising the main concepts using some selected	Teacher used the simulation to consolidate the main concepts.	Learners were asked to go through the notes and then check the

	exercises. Used diagrams.	Also used the simulation to explain the conceptual questions.	simulations. Teacher intervened different times as they were not doing the exercises at the pace that was expected from them.

4.4 INTERPRETATION OF DIFFERENT LESSONS

In the Teacher Centred Experimental Group, it was easy for the teacher to explain the phenomenon of the photoelectric effect using the simulation. The feature of the PhET having different metals as the target helped the teacher to explain the concept of work function in lesson 1. The dependence of photoelectric current on intensity of light and the dependence of maximum kinetic energy of the ejected electrons on the frequency of light were the highlight in the whole lesson. The teacher managed well in this area and the learners seems to enjoy the lessons. The participation of the learners in this group was also exemplary.

Lesson 1 went very well in the Learner Centred Experimental group. Things started to change when the learners started to manipulate the voltage bar. It was not easy for the teacher to explain the dependence of voltage on photoelectric effect. One of the reason was the necessary electrostatic relations to explain this dependence ($W = qV$ and $V = Ed$) are not part of the CAPS curriculum. Another reason was the level of knowledge of the teacher in the photoelectric effect. This group of learners were very active and wanted to verify most of the teacher's claims using the simulations. Teacher struggled to keep the learners following the pace of the lessons in this group.

In the control group, the teacher primarily used the lecturing method. Learners were very interested when the teacher was presenting the historical perspectives of the phenomenon in lesson 1. In other lessons, the learners did not seem to have that interest.

4.5 DATA PRESENTATION AND ANALYSIS OF THE PRE- AND POST TEST

4.5.1 Analysis of Variance (ANOVA)

The means (M) and standard deviations (SD) of the Photoelectric Effect Achievement Test scores were calculated using SPSS 24.0. An Analysis of Variance was used to determine whether all the three groups were initially comparable before the intervention. It was found that there was no significant difference on pre-test scores at the $p<0.05$ level for the three groups [$F(2,27) = 0.047$, $p = 0.954$] as described in Table 4.2.

ANOVA					
Pre_test					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.467	2	0.233	0.047	0.954
Within Groups	132.900	27	4.922		
Total	133.367	29			

Table 4.2: ANOVA result on pre-test

4.5.2 Observation Schedule

The scores from the observation schedules were calculated for the different groups. For the control group (CG) the total score was 50 and for the teacher centred group (TCEG) the total score was 65. Surprisingly the total score for the learner centred group (LCEG) was 37, far below than that of the other groups. This was the first indication that the learner centred manipulation of simulation is less effective.

4.5.3 Paired t-test

Control Group

To evaluate the impact of the intervention on the control group's (CG) achievement in the photoelectric effect, descriptive statistics were calculated for their pre- and post-test scores on the Photoelectric Effect Achievement Test (PEAT). Table 4.3 below describes the pre-test and post-test means and standard deviation for the control group.

Achievement in photoelectric effect	Mean	N	Std. Deviation
Pre- Test	10.20	10	2.300
Post Test	16.20	10	2.616

Table 4.3: Descriptive statistics for Control Group (CG)

A paired-sample t- test was conducted to check whether there was a significant difference between the mean pre-test and post-test scores for the control group (CG). Table 3 gives the paired-sample t- test results from the SPSS. The control group performed well in the post- test (M = 16.20, SD = 2.616) compared to the pre-test (M = 10.20, SD = 2.300). Table 4.4 shows that there is a significant difference between the pre-test and post-test scores in the control group, which can be reported as, $t(9) = -8.393$, $p < 0.05$.

	Paired Differences				t	df	Sig. (2-tailed)
	Mean	Std. Deviation	95% Confidence Interval of the Difference				
			Lower	Upper			
Pre-test -Post-test	-6.000	2.261	-7.617	-4.383	-8.393	9	.000

Table 4.4: Paired-sample t- test for Control Group (CG)

The above results validate the rejection of the null hypothesis (H_01) that there is no significant difference between the mean pre-test and post-test scores for learners in the control group.

Teacher-Centred Experimental Group

To evaluate the impact of the intervention on the Teacher Centred Experimental Group's (TCEG) achievement in the photoelectric effect, descriptive statistics were calculated for their pre- and post-test scores on the Photoelectric Effect Achievement Test (PEAT). Table 4.5 below describes the pre-test and post-test means and standard deviation for the Teacher Centred Experimental Group's (TCEG)

Achievement in photoelectric effect	Mean	N	Std. Deviation
Pre- test	13.90	10	4.383
Post- test	22.00	10	1.054

Table 4.5: Descriptive statistics for Teacher-Centred Experimental Group (TCEG)

A paired-sample t- test was conducted to check whether there was a significant difference between the mean pre-test and post-test scores for the Teacher- Centred Experimental Group (TCEG). Table 5 gives the paired-sample t- test results from the SPSS. The Teacher- Centred Experimental Group outperformed the pre-test ($M = 13.90$, $SD = 4.383$) in the post-test ($M = 22.00$, $SD = 1.054$). Table 4.6 shows that there is a significant difference between the pre-test and post-test scores in the Teacher-Centred Experimental Group, which can be reported as, $t(9) = -6.135$, $p < 0.05$.

	Paired Differences				t	df	Sig. (2-tailed)
	Mean	Std. Deviation	95% Confidence Interval of the Difference				
			Lower	Upper			
Pre-test -Post-test	-8.100	4.175	-11.087	-5.113	-6.135	9	.000

Table 4.6: Paired-sample t- test for Teacher-Centred Experimental Group (TCEG)

The above results validate the rejection of the null hypothesis ($H_0 2$). Thus, the null hypothesis, that there is no significant difference between the mean pre-test and post-test scores for learners in the Teacher-Centred Experimental Group (TCEG) was rejected.

Learner-Centred Experimental Group

To evaluate the impact of the intervention on the Learner-Centred Experimental Group's (LCEG) achievement in the photoelectric effect, descriptive statistics were calculated for their pre- and post-test scores on the Photoelectric Effect Achievement Test (PEAT). Table 4.7 below describes the pre-test and post-test means and standard deviation for the Learner-Centred Experimental Group's (LCEG)

Achievement in photoelectric effect	Mean	N	Std. Deviation
Pre-test	10.10	10	1.969
Post-test	12.10	10	3.635

Table 4.7: Descriptive statistics for Learner-Centred Experimental Group (LCEG)

A paired-sample t- test was conducted to determine whether there was a significant difference between the mean pre-test and post-test scores for the Learner-Centred Experimental Group (LCEG). Table 4.8 shows that there is a significant difference between the pre-test and post-test scores in the Learner-Centred Experimental Group's (LCEG), which can be reported as $t(9) = -3.078$, $p < 0.05$.

	Paired Differences				t	df	Sig. (2-tailed)
	Mean	Std. Deviation	95% Confidence Interval of the Difference				
			Lower	Upper			
Pre-test -Post-test	-2.000	2.055	-3.470	-.530	-3.078	9	.013

Table 4.8: Paired-sample t- test for Learner-Centred Experimental Group (LCEG)

The above results validate the rejection of the null hypothesis (H_03). Thus, the null hypothesis, that there is no significant difference between the mean pre-test and post-test scores for learners in the Learner-Centred Experimental Group (LCEG) was rejected.

The graphical comparison of the control group and the two experimental groups is shown below in figure 4.18.

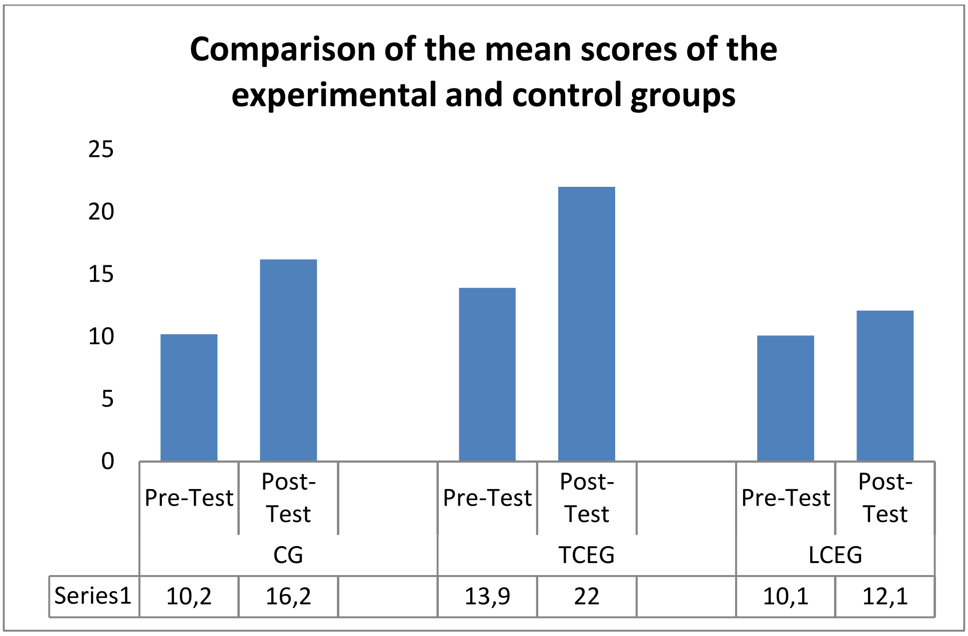


Figure 4.18: Graphical comparison of the mean scores of the experimental and control groups

4.5.4 Analysis of Covariance (ANCOVA)

Analysis of Covariance (ANCOVA) was used to determine whether a significant difference between group means of the post-test for the three groups when differences in the pre-test scores were controlled. In all statistical tests an alpha level of 0.05 was used.

Therefore, a one-way analysis of covariance was conducted to test hypothesis 4 and to evaluate the different instructional strategies. The different teaching strategies, such as traditional, learner-centred and teacher-centred, was taken as the independent variable. The post-test scores were taken as the dependent variable, where the pre-test scores were used as the covariate to control for individual differences. The means and standard deviations for the pre-tests and post-tests are given in Table 4.9.

		Pre-test		**Post-test**	
Group	**N**	**Mean**	**std deviation**	**Mean**	**std deviation**
CG	10	10.20	2.300	16.20	2.616

TCEG	10	13.90	4.383	22.00	1.054
LCEG	10	10.10	1.969	12.10	3.635

Table 4.9: Descriptive statistics of achievement scores by instruction group

Table 4.10 below shows the summary of the ANCOVA results.

Tests of Between-Subjects Effects						
Dependent Variable: Post-test						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	569.361[a]	3	189.787	42.536	.000	.831
Intercept	100.942	1	100.942	22.624	.000	.465
Pre-test	74.494	1	74.494	16.696	.000	.391
Group	470.829	2	235.415	52.763	.000	.802
Error	116.006	26	4.462			
Total	9119.000	30				
Corrected Total	685.367	29				
a. R Squared = .831 (Adjusted R Squared = .811)						

Table 4.10: ANCOVA summary for achievement by instruction group

The result of the ANCOVA showed a significant effect of the covariate, which is the pre-test as F (1, 29) = 16,696, p < 0,05. It also yielded a significant effect on the instructional method (Group) as, F (2, 29) = 52.763, p < 0,05. Since the ANCOVA results shows that there are statistically significant post-test scores between the groups, the null hypothesis ($H_0$4), stating that there is no significant difference between the mean post-test scores for learners in the control group, teacher-centred experimental group, and learner-centred experimental group after controlling the effect of pre-test scores, was rejected.

4.5.5 HAKE's NORMALISED GAIN

Hake's normalised scores were calculated for the different groups and are presented below in Table 4.11.

GROUP	Value of <g>	Classification
CG	0.405	Medium-g
TCEG	0.794	High-g
LCEG	0.134	Low-g

Table 4.11: Hake's normalised scores for the different instruction groups.

This analysis also proved that the instruction in the Teacher-Centred Experimental Group was very effective and that used in the Learner-Centred Experimental group was less effective. The Control group had a medium -g which indicated that the course was average. This is very interesting as the Learner-Centred Experimental group scored a low-g. This indicates that the traditional method of teaching is more effective than a learner-centred method when using the simulations.

4.5.6 INTERVIEWS

At the end of the research, three learners from each group were interviewed to verify the results of the quantitative analysis of the pre- and post-tests. A semi-structured interview method was employed in the research. The transcripts of the interview are presented below.

The Control Group Learner is presented as CG before the name, while the Teacher-Centred Experimental Group Learner is presented as TCEG before the name and the Learner-Centred Experimental Group Learner is presented as LCEG before the name.

In the interview, four questions were asked to the control group learners and an additional two questions were asked to the experimental group learners. The different questions and the various responses are outlined below.

QUESTION 1. How does the increase of intensity of light affect the number of ejected electrons in the photoelectric effect?

CG Kanyisa- "I think it will increase".
Interviewer- Could you please explain what could be the reason.
CG Kanyisa- As intensity increases metal receive more light. More electrons are covered.
CG Kgathlane - "Number will decrease".
CG Botsheng- "I am not sure".

TCEG Kgomotso- "Definitely increase".
Interviewer- Why do you say so?
TCEG Kgomotso- "More photons reach the plate and each photon emits each electron".
Remark*:* The other two learners in this group also answered the same.

LCEG Lebogang- "It increases".
Interviewer- Could you please explain what could be the reason.
LCEG Lebogang - "More intensity means more photons and emits more electrons".
Remark: Other two LCEG learners gave the correct answer but could not explain it fully in the follow up question.

Comments on Question 1

Kanyisa from the Control Group thinks that increasing intensity means the light beam becomes wide. This is a misconception that the researcher has come across in his teaching years. It should be noted that all the learners from the experimental groups answered the question correctly. But only the learners from the Teacher-Centred Experimental group could give the correct explanation in the follow up questions.

QUESTION 2. The increase in the frequency of light, results in the increase of kinetic energy of the ejected electrons. How can you explain this?

CG Kanyisa- "If we increase the frequency, we are increasing the energy. More energy is given to the electrons and eject out with higher kinetic energy".
Interviewer- Is there any role for the work function here?
CG Kanyisa- "No".
Remarks: Other CG learners could not explain the statement.

TCEG Tumelo- "You see the energy needed to take the electrons out from the metal surface is a constant. By the way that is called work function. Rest is giving as the kinetic energy. If the incident light has more energy, since work function is constant, the kinetic energy increases".

Remark*:* All the three learners in the group explained the statement in an almost similar manner.

LCEG Tshegofatso- "When the frequency increases, we are in the UV region where the energy is high. So the electrons are getting more energy".

LCEG Lebogang- "As the frequency increases the photons move faster and give more energy to the electrons"

LCEG Gobonemang- "Increasing frequency means lambda decrease. So the light is more energetic and gives more energy to the electrons"

Comments on Question 2

Only the TCEG learners could give a complete explanation for this question. Even though the LCEG group remember the minute feature of the PhET simulation, they could not explain the statement fully.

QUESTION 3. Could you please comment on the graph the shown below (Fig. 4.19).

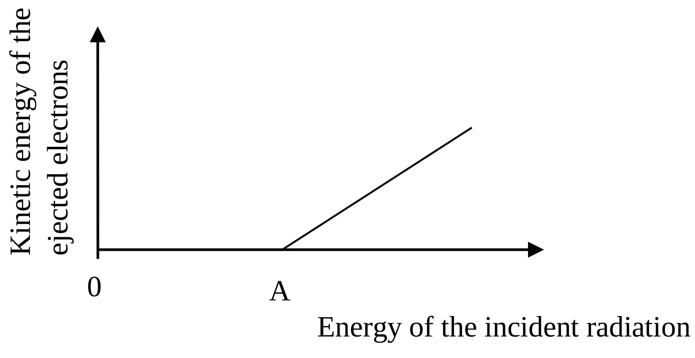


Fig.4.19 Graph of energy of incident radiation versus kinetic energy of ejected electrons

CG Kanyisa- "This graph is wrong. The X-axis should be frequency".

CG Kgathlane- "This graph is not familiar"

CG Botsheng- "Can be correct. Wait the X-axis is not right"

TCEG Tumisang- "Well this is not an experimental graph that was introduced. But the graph makes some sense. You can see that beyond A, no electrons are ejected and then A should be the Work function. But I am not sure about the straight-line nature of the graph".

Remark: Tumelo also gave some explanation of this graph similar to the one explained above. But Tumisang could not explained it.

LCEG Gobonemang- "This graph is not there in the simulation".

LCEG Lebogang- "This is not a correct graph"

LCEG Tumisang- "You labelled it wrongly"

Comments on Question 3

This question helped in detailing the critical thinking abilities of the learners in different groups. Only the TCEG learners could give some explanation regarding the graph, even though it was not a prescribed graph.

QUESTION 4. What nature of light is evident from photoelectric effect?

CG Kgathlane: "Particle nature".

Interviewer- Can you explain further.

CG Kgathlane- "Teacher told us that"

Remarks: Others in this group gave almost the same answer.

TCEG Kgomotso- "Surely particle nature. In this phenomenon the photon model of light was successful. The incoming light consists of photons and photons collide with the electrons and eject them".

TCEG Tumelo- "The particle photon eject the electrons. If the light is a wave, we cannot have it as a sudden process".

Remark: Tumisang could not explain the follow up question correctly.

LCEG Lebogang- It is particle nature. It is clear in the simulation.

Remark: Others also give the same answer.

Comments on Question 4

The CG learners answered from memory. All the LCEG learners gave the answer by recalling their experience with the simulations. But they could not provide a satisfactory explanation for the follow-up question. At the same time, 2 out of 3 TCEG learners explained this in detail. The teacher's use of simulation with the explanation helped them to explain this.

The following questions were asked only of the LCEG and TCEG learners.

QUESTION 5. How do the simulations help in answering the above questions?

TCEG Kgomotso- "Simulations helped a lot. When you asked the questions, I got the image from the simulation. We understood photoelectric effect well".

TCEG Tumelo- "Very much. It helped in understanding photoelectric effect"

TCEG Tumisang- "Helped me a lot".

LCEG Tshegofatso- "We did this experiments several times. So, we can easily remember what happens when something is changing".

Remark: Other LCEG learners also gave a similar response.

Comments on Question 5

Both TCEG and LCEG learners agreed that the simulation helped them to understand the phenomenon well.

QUESTION 6. What is your comment about PhET simulation for the photoelectric effect?

TCEG Tumelo- "Our teacher told us that photoelectric effect is a difficult topic. Now I don't agree. It is very simple. Simulation helped in understanding the different changes, I mean in frequency and intensity and what happens to the number of electrons and kinetic energy of electrons. Very good".

TCEG Kgomotso- "It is super. It makes us to understand it easily. I wish if our teacher was using this for all the topics. I could easily get a level 7".

TCEG Tumisnag- "This is very nice. I like to study with that"

LCEG Gobonemang- "This is good. But our teacher did not explain some of the observations. He told us when the frequency change there will be no change in the photoelectric current. But it is not like that. I can show you that. So now I am confused. Teacher said one thing and we see another thing".

LCEG Lebogang- "It was good to work with the simulations. We also learned to handle computers also. But I don't know why the simulation and the text-book are not saying the same thing. Especially with the intensity. We also did not get enough time to check many things".

LCEG Tshegofatso- "It was good, but we had some problems. Think it is more suitable for the varsity students"

Comments on Question 6

The confusion over the dependence of frequency over photocurrent is very common, even among the experts. This is evident from the NSC question papers from the Department of Basic Education. In February - March 2013 the memo for QUESTION 11.3.2 says that the increase in frequency increases the photocurrent but in November 2014 the memo for QUESTION 1.10 says that the kinetic energy is independent of the frequency of the incident light.

PhET simulation shows that on fixing the intensity, changing frequency results in the change of the photocurrent. This finding is inconsistent with the common text-books available in South Africa. Text-books teaches that the photocurrent depends only on the intensity and is independent of the frequency of light (Siyavula, p.429)

The teacher was well aware of this problem and in the use of simulation in the TCEG, he did not highlight the change in current when the frequency is varied on fixing the intensity. This was to avoid creating confusion among the learners. It should be noted from the interview data, that the TCEG learners are more satisfied than the LCEG learners. One of the reason could be the selective manipulation of the features of the PhET simulation by the teacher. Thus, the vital role of the teacher in manipulating the simulation is again established to eliminate misconception and dissatisfaction among learners.

4.6 RESEARCH QUESTION 1: What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive demonstration tool, manipulated by the teacher in the classroom?

In answering the research question 1, the data analysis in 4.5.2 shows a significant impact of using the simulations, manipulated by the teacher in the classroom. The pre- and post-test data presented in Table 3 shows that there is a significant improvement in the performance of the learners in the Teacher-Centred Experimental Group compared to the other two groups. The mean score improved by 8.10 points in TCEG which is the highest in the three groups. The paired-sample t-test presented in Table 7 shows that there is a significant difference between the pre- and post-test scores in the Teacher-Centred Experimental Group. It should also be noted that in the pre-test, the standard deviation was 4.383 and for the post-test it reduced to 1.054. This indicates that the method catered well for the slow learners in the group.

The Hake's normalised gain which is presented in section 4.5.4 underlines the findings from the data analysis of the Teacher-Centred Experimental Group. The gain is maximum for the Teacher-Centred Experimental Group at 0.794 which is presented in Table 9. This gain is classified as a high-g which means that the use of simulations by the teacher in promoting the conceptual understanding of the photoelectric effect in the Teacher-Centred Experimental Group was highly effective.

The interview data which was presented in section 4.5.6 suggests that the learners in the TCEG gained a high conceptual understanding of the photoelectric effect compared to the other groups. The selective presentation of the simulations using only the relevant features of the simulation helps in transferring the knowledge to learners. The data confirms that the learners in the Teacher-Centred Experimental Group were less confused and more confident in the topic.

The above analysis reveals that the use of computer simulation as an interactive demonstration tool, manipulated by the teacher in the classroom for the teaching of the photoelectric effect, was effective.

4.7 RESEARCH QUESTION 2: What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive tool, manipulated by the learners in the classroom?

The analysis of pre- and post-test data presented in 4.5.2 shows there is some impact on the performance of the learners when they were given the opportunity to manipulate the simulation in the classroom. The descriptive statistics presented in Table 5 shows that the mean post-test score was improved by 2 scores among the learners in this group. The paired sample t-test conducted, which is presented in Table 6, confirms that there is a significant difference between the mean pre- and post-test scores for LCEG learners. But the improvement in the mean post-test scores is the lowest in this group. The LCEG learners' mean post-test scores showed an improvement of only 2, while that of the TCEG is 8.1 and that of the control group was 6. The control group learners who was subjected to traditional learning performed better than the LCEG learners. It should also be noted that the standard deviation increased from 1.969 in the pre-test to 3.635 in the post-test. This shows that the slow learners struggle with this method of learning.

The Hake's normalised gain presented in section 4.5.5 gives a low score of 0.134 for the Learner-Centred Experimental Group. This low-g value shows that the method employed in the learning of this group promoted a little conceptual understanding in photoelectric effect. In other words, the learning was less effective. The interview data presented in section 4.5.6 underline this finding. LCEG learners were more confused and they were less confident in photoelectric effect among the three groups.

The above analysis proved that the use of computer simulation when the learners are given the opportunity to manipulate the above simulation is less effective. This method is not recommended compared to the use of simulation in the classroom manipulated by the teacher.

4.8 SUMMARY

This chapter presented context to the data, by describing how the different groups were taught. Statistical analysis of the pre- and post-test scores were provided as well as the interviews with learners from all the three groups. The two research questions that guided this research were also answered in this chapter.

CHAPTER 5

CONCLUSIONS AND RECOMENDATIONS

5.1 OVERVIEW

The photoelectric effect is a very important quantum mechanical phenomenon that helps learners to build an understanding of the photon model of light (see section 2.3.1). It is one of the historically important experiments that the students must learn for the successful understanding of the basics of quantum mechanics. (see section 2.3.1). But the topic of the photoelectric effect is very poorly understood by most learners and therefore they are not able to answer the questions on it in the National Senior Certificate physics examination (see section 1.3). Research suggests that teaching using computer simulations can have benefits on the teaching and learning of the photoelectric effect (see section 2.6). Therefore, the aim of this study was to determine the effect of computer simulations on Grade 12 learners' understanding of concepts in the photoelectric effect in one of the rural school in the Northern Cape province. Hence, the following research questions guided the study:

1. What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive demonstration tool, manipulated by the teacher in the classroom?
2. What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive demonstration tool, manipulated by the learners in the classroom?

To answer these questions, three groups were compared. One, where the teacher was using the traditional method of teaching as the control group. In the second group, computer simulations were used, and the teacher manipulated the simulations. In the third group, learners were given the opportunity to manipulate the simulations. The last two groups were the experimental groups.

5.2 SUMMARY OF FINDINGS

The first research question of this research was " What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive demonstration tool, manipulated by the teacher in the classroom?"

In answering this question, the analysis of post-test data shows a significant impact of using simulations, manipulated by the teacher in the classroom. The paired--sample t-test and ANCOVA shows that there is significant difference between the pre- and post-test scores in the Teacher Centred Experimental Group. The Hake's normalised gain which is presented in section 4.4.5 also reveals the success of the teacher manipulating the simulations in the teaching and learning of the photoelectric effect. The interview data also confirms that the learners in the Teacher-Centred Experimental Group were less confused and more confident in the topic of the photoelectric effect. All the above analysis reveals that the use of computer simulation as an interactive demonstration tool, manipulated by the teacher in the classroom for the teaching and learning of the photoelectric effect was effective.

The improvement in the performance of the TCEG learners may be directly attributed to the role played by the teacher in this group. The success of this group is due to the constructivist principle employed by the teacher. In this group, the teacher was an analyser or coach and was not an instructor. Chang (2014) observed that the TCEG provided learners with a systematic and organised teaching sequence and helped students to grasp the concepts more easily (see section 2.9.1). The teacher provided an environment and tools that helped learners interpret the different relations in the photoelectric effect and which helped the learners to achieve their ZPD. In this group, the learners were provided and guided with more authentic tasks. From that, the teacher allowed more reflective practices in different lessons as illustrated in section 4.3. These steps followed by the teacher are the principles put forward by the different constructivists such as Jonassen (1991). Moreover, the teacher took a scaffolding approach to solve the different problems faced by the learners in studying the photoelectric effect, as explained in section 2.7.2.3. The success of the role of teacher in using the simulation in this case study confirms the findings of Chang (2002, 2010 & 2014), Wu and Huang (2007), Tüysüz (2010) and Siddiqui and Khatoon (2013) in South African situation. The finding also confirms Sunderarajan's (2010) claim of using suitable scaffolding tasks by an MKO, such as a teacher in helping to achieve the ZPD. This affirms that the role of the teacher is central in using the various simulations in the classroom, especially at the secondary level.

The second research question that guided this research was " What is the effect on grade 12 learners of the use of the photoelectric effect computer simulation as an interactive demonstration tool, manipulated by the learners in the classroom?"

The analysis of the pre-and post-test data shows that there is some impact on the performance of the learners when they were given the opportunity to manipulate the simulation in the classroom (see section 4.4). The paired-sample t-test conducted, confirms that there is a significant difference between the mean pre- and post-test scores for the learners in the Learner-Centred Experimental Group. When comparing the improvement in the mean post-test scores, the LCEG group registers the lowest improvement. The Control Group learners who were subjected to traditional teaching and learning, performed better than the LCEG learners. The Hake's normalised score of 0.134 for the LCEG suggests that the method employed in this group promoted a very little conceptual understanding in photoelectric effect or the learning was less effective. The interview data presented in section 4.4.5 shows that the LCEG learners were confused and were less confident in the photoelectric effect among the three groups.

It is interesting to note that the CG learners performed better than the LCEG learners, even though most of the constructivist principles were followed in the LCEG group (see section 2.8.1). The LCEG group was allowed to learn independently, according to their own pace. It is very important to consider the factors that might strongly affect learners' learning in this group. The most important factor that might affected their learning was the self-learning. The participating learners had never learned independently using a computer before the current intervention. The LCEG left students on their own to handle large amounts of information that might have hindered their ability to develop meaningful knowledge. Chang (2010) commented that the participating learners' age is also a factor. In a much-developed country like Taiwan, if the learners around the age of 17 do not possess the learning skills to work independently using computers, then in a rural area of South Africa, it would be worse. It should also be noted that in this group, there was not a suitable MKO to provide suitable scaffolding. An important principle of constructivism identified by Jonassen (1991) is the provision of "foster reflective practice" (p. 35). This reflection could be carried out effectively by the teacher in the TCEG, who is assumed to be familiar with their ZPD. But in the LCEG, the learners were their own

MKOs who were not known to their ZPD. Also, LCEG learners did not have the skills for necessary reflection of the results that they obtained from the PhET simulation. This is why it is important that in all the science classrooms, teachers should encourage this reflection by the learners to develop their ZPD. The other contributing factor for the poor performance of this group is the PhET photoelectric simulation itself. This simulation was not designed for the NSC curriculum and has many extra features. The LCEG learners wanted to explore those features and thereby became lost many times as explained in section 4.3.2.

5.3 IMPLICATIONS AND RECOMMENDATIONS

There is no attempt made by the researcher to generalise the findings of this research. The intention of this research was to perform a case study to verify the effect of computer simulations on the performance of Grade 12 learners' understanding of concepts in the photoelectric effect. But the research findings have implications for teachers, subject advisors, researchers, learners and the Department of Basic Education.

Tüysüz (2010) suggested that to achieve the goals of science education, simulations must be supported with appropriate instructional methods. These observations are found to be true in this case study. The current case study has two major implications. Firstly, PhET simulation must be used in the teaching of the photoelectric effect to help the learners better understand the phenomenon and to conceptualise the experimental laws. Secondly, teachers should be trained properly in the content and also using the simulations in the respective topics.

Chang (2014) observed that there are numerous studies focused on the efficacy of simulation-assisted instruction versus traditional instruction but there are fewer studies exploring how different forms of computer simulations influence students' science learning outcomes in secondary-school classrooms. In relation to this, the findings of the study warrant recommendation that the study be repeated with a more representative and larger sample. In such a replication, all efforts should be made to identify the specific needs of the teachers and learners for the purposes of teacher training.

5.4 CONCLUSION

The paired- sample t-test shows that there is a significant difference in the pre and post test scores in all the three groups. However, the ANCOVA result, Hake's scores and the interview data suggest that the teacher-centred use of simulation was most effective in the three groups. The findings are of great value as it suggests that a teacher-centred experimental approach (TCEG) produces better understanding of photoelectric effect than the learner-centred experimental approach (LCEG). Also the traditional approach used in the control group even performed better than LCGE. This study goes further and challenges, as educators, our traditional notions of constructivism and learner-centred activities.

The finding of the research is extremely relevant, nationally and internationally. There are huge costs and time involved when we give the learners the opportunity to use the simulations by themselves. Instead of one computer and projector in a classroom we have to set up and buy equipment for every learner which would be a huge burden for South African schools that have large classes and already struggling with resource limitation.

The use of computer simulations in the teaching of the photoelectric effect contributed positively towards the performance of learners, especially in the TCEG group. This is because the simulations gave them a more conceptual understanding of the phenomenon with the help of the teacher and was seen during the interviews. It would be evident that the teacher who was a better MKO, was in a good position to shift the barrier to promote the ZPD. The teacher could make it clear to students what their objectives were in each lesson. This helped the TCEG learners to focus on the most important information that is needed for them to master the concepts of photoelectric effect. The role of the teacher in manipulating the simulations is reconfirmed in this case study, especially at secondary school level. This is because the learners at this age might not be trained or ready to learn independently and are more used to being taught in the traditional way, especially in the rural areas. So, it is vital that in teaching the photoelectric effect using simulations, the teacher should manipulate the simulations and follow constructivist principles to secure higher achievement. The ZPD that was put into practice by the teacher in the TCEG group is a practice that the teachers can use effectively in the teaching of the photoelectric effect using PhET simulations. The researcher believes that this should not be limited in teaching the photoelectric effect only but could be applied to other complex concepts in physics.

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APPENDICES

APPENDIX A

CLASS ROOM OBSERVATION SCHEDULE

Group: **Lesson:**

Observer:

Topic:

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners			
2	Learners were encouraged to take part in discussions and make predictions (learner centred)			
3	Teacher presented suitable examples on concepts that relate to their everyday life			
4	Teacher shows commanding subject knowledge			
5	Teacher was listening and was very patient with learners			
6	Teacher posed questions very often that encouraged critical thinking by learners			
7	There was often discussion between the learners and the teacher			
8	There was order in the class			
9	The lesson is well planned and presented			
10	The fundamental concepts are discussed			

APPENDIX A_1

CLASS ROOM OBSERVATION SCHEDULE

Group: CG **Lesson:** 1

Observer: Researcher

Topic: Photoelectric effect, Significance and Work function.

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)		X	
3	Teacher presented suitable examples on concepts that relate to their everyday life		X	
4	Teacher shows commanding subject knowledge	X		
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher			X
8	There was order in the class	X		
9	The lesson is well planned and presented	X		
10	The fundamental concepts are discussed	X		

APPENDIX A_2

CLASS ROOM OBSERVATION SCHEDULE

Group: LCEG **Lesson:** 1

Observer: Researcher

Topic: Photoelectric effect, Significance and Work function.

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)		X	
3	Teacher presented suitable examples on concepts that relate to their everyday life		X	
4	Teacher shows commanding subject knowledge	X		
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged the critical thinking by learners			X
7	There was often discussion between the learners and the teacher			X
8	There was order in the class	X		
9	The lesson is well planned and presented	X		
10	The fundamental concepts are discussed	X		

APPENDIX A3

CLASS ROOM OBSERVATION SCHEDULE

Group: TCEG **Lesson:** 1

Observer: Researcher

Topic: Photoelectric effect, Significance and Work function.

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)	X		
3	Teacher presented suitable examples on concepts that relate to their everyday life		X	
4	Teacher shows commanding subject knowledge	X		
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher	X		
8	There was order in the class	X		
9	The lesson is well planned and presented	X		
10	The fundamental concepts are discussed	X		

APPENDIX A4

CLASS ROOM OBSERVATION SCHEDULE

Group: CG **Lesson:** 2

Observer: Researcher

Topic: Threshold frequency, Threshold wavelength and Experimental laws

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)		X	
3	Teacher presented suitable examples on concepts that relate to their everyday life		X	
4	Teacher shows commanding subject knowledge		X	
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher			X
8	There was order in the class	X		
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed		X	

APPENDIX A_5

CLASS ROOM OBSERVATION SCHEDULE

Group: LCEG **Lesson:** 2

Observer: Researcher

Topic: Threshold frequency, Threshold wavelength and experimental laws

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners			X
2	Learners were encouraged to take part in discussions and make predictions (learner centred)	X		
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge			X
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher	X		
8	There was order in the class			X
9	The lesson is well planned and presented			X
10	The fundamental concepts are discussed		X	

APPENDIX A_6

CLASS ROOM OBSERVATION SCHEDULE

Group: TCEG **Lesson:** 2

Observer: Researcher

Topic: Threshold frequency, Threshold wavelength and Experimental laws

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)	X		
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge		X	
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners	X		
7	There was often discussion between the learners and the teacher	X		
8	There was order in the class		X	
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed	X		

APPENDIX A7

CLASS ROOM OBSERVATION SCHEDULE

Group: CG **Lesson:** 3

Observer: Researcher

Topic: Photoelectric equation and exercises.

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)			X
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge	X		
5	Teacher was listening and was very patient with learners			X
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher		X	
8	There was order in the class	X		
9	The lesson is well planned and presented	X		
10	The fundamental concepts are discussed	X		

APPENDIX A_8

CLASS ROOM OBSERVATION SCHEDULE

Group: LCEG **Lesson:** 3

Observer: Researcher

Topic: Photoelectric equation and exercises

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners			X
2	Learners were encouraged to take part in discussions and make predictions (learner centred)	X		
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge			X
5	Teacher was listening and was very patient with learners			X
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher			X
8	There was order in the class			X
9	The lesson is well planned and presented			X
10	The fundamental concepts are discussed		X	

APPENDIX A9

CLASS ROOM OBSERVATION SCHEDULE

Group: TCEG **Lesson:** 3

Observer: Researcher

Topic: Photoelectric equation and exercises

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)	X		
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge		X	
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners	X		
7	There was often discussion between the learners and the teacher	X		
8	There was order in the class	X		
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed	X		

APPENDIX A_{10}

CLASS ROOM OBSERVATION SCHEDULE

Group: CG **Lesson:** 4

Observer: Researcher

Topic: Dual nature and applications of photoelectric effect

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners	X		
2	Learners were encouraged to take part in discussions and make predictions (learner centred)		X	
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge			X
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners		X	
7	There was often discussion between the learners and the teacher			X
8	There was order in the class	X		
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed	X		

APPENDIX A11

CLASS ROOM OBSERVATION SCHEDULE

Group: LCEG **Lesson:** 4

Observer: Researcher

Topic: Dual nature and applications of photoelectric effect

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners			X
2	Learners were encouraged to take part in discussions and make predictions (learner centred)	X		
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge			X
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher		X	
8	There was order in the class		X	
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed		X	

APPENDIX A12

CLASS ROOM OBSERVATION SCHEDULE

Group: TCEG **Lesson:** 4

Observer: Researcher

Topic: Dual nature and applications

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners		X	
2	Learners were encouraged to take part in discussions and make predictions (learner centred)	X		
3	Teacher presented suitable examples on concepts that relate to their everyday life	X		
4	Teacher shows commanding subject knowledge		X	
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners	X		
7	There was often discussion between the learners and the teacher	X		
8	There was order in the class	X		
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed	X		

APPENDIX A13

CLASS ROOM OBSERVATION SCHEDULE

Group: CG **Lesson:** 5

Observer: Researcher

Topic: Consolidation exercises

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners	X		
2	Learners were encouraged to take part in discussions and make predictions (learner centred)		X	
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge			X
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher		X	
8	There was order in the class	X		
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed		X	

APPENDIX A14

CLASS ROOM OBSERVATION SCHEDULE

Group: LCEG **Lesson:** 5

Observer: Researcher

Topic: Consolidation exercises

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners	X		
2	Learners were encouraged to take part in discussions and make predictions (learner centred)		X	
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge			X
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher		X	
8	There was order in the class	X		
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed		X	

APPENDIX A15

CLASS ROOM OBSERVATION SCHEDULE

Group: TCEG **Lesson:** 5

Observer: Researcher

Topic: Consolidation exercises

Instructions: Mark X for each of the criteria in the appropriate box.

No	Criteria	Well done (2)	Done (1)	Not done (0)
1	Teacher builds the lesson based on the prior knowledge of the learners	X		
2	Learners were encouraged to take part in discussions and make predictions (learner centred)		X	
3	Teacher presented suitable examples on concepts that relate to their everyday life			X
4	Teacher shows commanding subject knowledge			X
5	Teacher was listening and was very patient with learners		X	
6	Teacher posed questions very often that encouraged critical thinking by learners			X
7	There was often discussion between the learners and the teacher		X	
8	There was order in the class	X		
9	The lesson is well planned and presented		X	
10	The fundamental concepts are discussed		X	

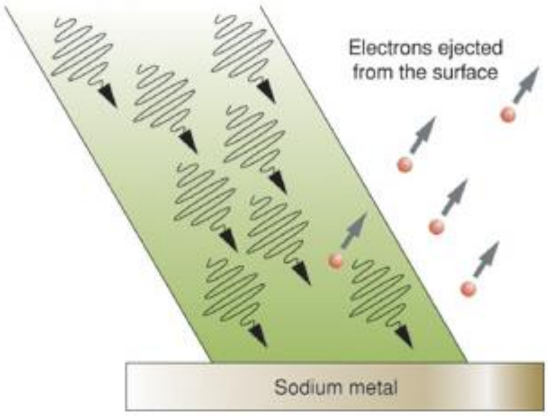
APPENDIX B

PRE-TEST

MAX. MARKS -25
TIME :40 minutes

QUESTION 1

A beam of violet light is falling on a sodium metal plate of work function 3,65 X 10^{-19} J. It is found that electrons are ejected from the metal surface.



1.1 Identify the optical phenomenon explained above. (1)

1.2 What nature of light is deduced from this optical phenomenon? (1)

1.3 Define work function. (2)

1.4 If the ejected electrons have a maximum velocity of 5,14 X 10^5 m.s^{-1}, calculate the wavelength of the violet light used. (5)

1.5 The intensity of the violet light is increased while using the same sodium metal plate.

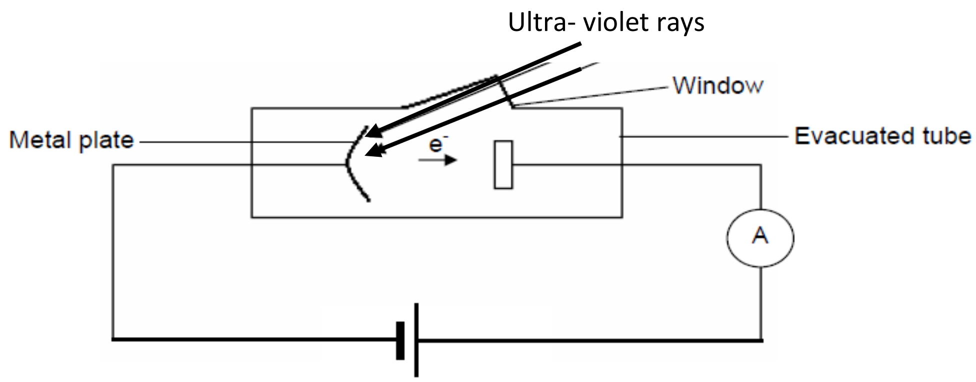
1.5.1 What effect does this have on the number of electrons ejected? Write only INCREASES, DECREASES and REMAINS THE SAME (1)

1.5.2 Explain your answer to QUESTION 1.5.1 (2)

[12]

QUESTION 2

A group of learners were investigating the dependence of work function of different metals on the kinetic energy of the ejected electrons. They used an apparatus as shown below.



Ultra- violet rays of wavelength 2 x 10^{-8} m is passed through a window and allowed to fall on different metal plates and the corresponding maximum kinetic energy is measured. The learners summarised their observations in the following table.

Name of the metal plate used	maximum kinetic energy (10^{-18} J)
Caesium	9.61
Lead	9.28
Potassium	9.58
Silver	9.19
Zinc	9.56

2.1 Write an investigative question for the learners' investigation. (2)

2.2 Identify the dependent variable in the learners' investigation (1)

2.3 Without using a calculation identify the metal having the highest work function in the learners' investigation. (2)

2.4 Explain your answer to QUESTION 2.3 using the relevant laws of photoelectric effect. (3)

2.5 Use the observation table of the learners to find the work function of lead. (5)

[13]

APPENDIX C

PRE-TEST SCORES

Group	LCGE	TCGE	CG
Leaner 1	10	7	12
Leaner 2	9	12	7
Leaner 3	10	13	13
Leaner 4	8	8	9
Leaner 5	9	14	13
Leaner 6	8	8	11
Leaner 7	12	12	12
Leaner 8	14	9	9
Leaner 9	12	11	7
Leaner 10	9	10	9
Average	10.1	10.4	10.2
Mode	9	12	9
Standard Deviation	1.9692	2.366432	2.299758

APPENDIX D

POST-TEST SCORES

Group	LCGE	TCGE	CG
Leaner 1	12	21	16
Leaner 2	9	23	11
Leaner 3	14	22	18
Leaner 4	8	23	18
Leaner 5	12	23	18
Leaner 6	10	21	17
Leaner 7	15	22	18
Leaner 8	18	22	18
Leaner 9	16	23	16
Leaner 10	7	20	12
Average	12.1	22	16.2
Mode	12	23	18
Standard Deviation	3.634709	1.054093	2.616189

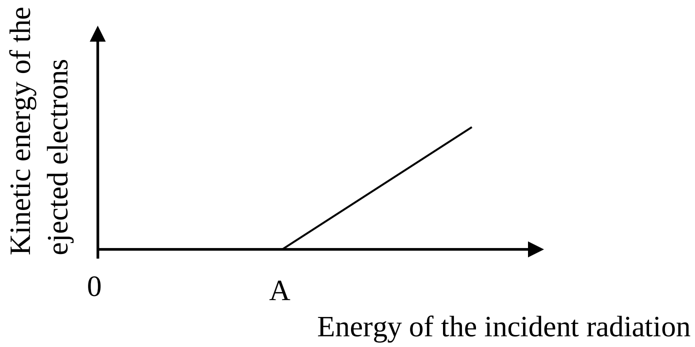
APPENDIX E

INTERVIEW QUESTIONS

QUESTION 1. How does the increase of intensity of light affect the number of ejected electrons in the photoelectric effect?

QUESTION 2. The increase in the frequency of light, results in the increase of kinetic energy of the ejected electrons. How can you explain this?

QUESTION 3. Could you please comment on the graph shown below?



QUESTION 4. What nature of light is evident from photoelectric effect?

Following questions will be asked only to the LCEG and TCEG learners.

QUESTION 5. How the simulations help in answering the above questions?

QUESTION 6. What is your comment about PhET simulation for photoelectric effect?

APPENDIX F

UNISA college of science, engineering and technology

Dear Mr Kunneth, B. J. (45997578)

Date: 2014-09-10

Application number:

2014_CGS/ISTE_016

REQUEST FOR ETHICAL CLEARANCE: (A Study on the Use of Simulations as a Teaching Tool on the Performance of Grade 12 Learners in the topic Photoelectric Effect.)

The College of Science, Engineering and Technology's (CSET) Research and Ethics Committee has considered the relevant parts of the studies relating to the abovementioned research project and research methodology and is pleased to inform you that ethical clearance is granted for your research study as set out in your proposal and application for ethical clearance.

Therefore, involved parties may also consider ethics approval as granted. However, the permission granted must not be misconstrued as constituting an instruction from the CSET Executive or the CSET CRIC that sampled interviewees (if applicable) are compelled to take part in the research project. All interviewees retain their individual right to decide whether to participate or not.

We trust that the research will be undertaken in a manner that is respectful of the rights and integrity of those who volunteer to participate, as stipulated in the UNISA Research Ethics policy. The policy can be found at the following URL:
http://cm.unisa.ac.za/contents/departments/res_policies/docs/ResearchEthicsPolicy_apprvCounc_21Sept07.pdf

Please note that the ethical clearance is granted for the duration of this project and if you subsequently do a follow-up study that requires the use of a different research instrument, you will have to submit an addendum to this application, explaining the purpose of the follow-up study and attach the new instrument along with a comprehensive information document and consent form.

Yours sincerely

Prof Ernest Mnkandla
Chair: College of Science, Engineering and Technology Ethics Sub-Committee

Prof IOG Moche
Executive Dean: College of Science, Engineering and Technology

RECEIVED
2015 -02- 1 8
OFFICE OF THE EXECUTIVE
College of Science, Engineering and Technology

University of South Africa
College of Science, Engineering and Technology
The Science Campus
C/o Christiaan de Wet Road and Pioneer Avenue,
Florida Park, Roodepoort
Private Bag X6, Florida, 1710
www.unisa.ac.za/cset

UNISA college of science, engineering and technology

APPENDIX G

Frances Baard District

9 Hasston Road
Hadison Park
Kimberley 8301

Private Bag X5[illegible]
Kimberley 8300
Republic of South Africa

Tel 053 830 1[illegible]
Fax 053 830 1625
Web [illegible]

DEPARTMENT OF EDUCATION

Enquiries: E.S. Kistoo
Reference: L4.3.4
Date: 25 July 2016

B.J. Kunnath
Department of Education
I.K. Nkoane Education House
Private Bag X5023
KIMBERLEY
8300

SUBJECT: REQUESTING PERMISSION TO CONDUCT RESEARCH AT MOGOMOTSI HIGH SCHOOL

The Northern Cape Department of Education encourages research, which is in the best interest of education and will consider any meaningful research project in this regard. The Department therefore supports the conducting of high quality research that enables the Department to make evidence based policy decisions, and to enhance delivery of quality education to our learners.

When preparing your questionnaires, you must take the sensitivity of the contents, learners, since respondents such as the Northern Cape Department of Education, educators, learners, governing bodies and parents may not be offended or embarrassed by them.

You must obtain consent from participant categories, such as Principals, parents, teachers and learners. After approval has been granted by the Northern Cape Department of Education, the following conditions would be applicable.

1. There must not be any financial implications for the Northern Cape Department of Education.
2. Institutions and respondents must not be identifiable in any way from the result of the investigation.
3. The researcher must make all the arrangements concerning his/her investigation.
4. Prospective researchers must present a copy of the written approval of the Northern Cape Department of Education to the head of the institution concerned before any research may be undertaken.
5. In case of some research projects it will be necessary for the applicant to obtain the written permission of the parents or legal guardians concerned personally before learners/ learners are involved.
6. Research may not be conducted during official contact time, as educator programmes should not be interrupted.
7. The research may not be conducted during the fourth term.

8. The research will be limited to those schools or institutions for which approval has been granted.
9. A copy of the completed report, dissertation or thesis, accompanied by a separate synopsis (maximum 2-3 typed pages) of the most important findings and recommendations if it does not already contain a synopsis, must be provided to the Frances Baard District Director.

This letter herewith provides you with permission for the research project to be conducted at Mogomotsi High School within the Frances Baard District in the Northern Cape Province on condition the above are adhered to.

Yours sincerely

E.S. KISTOO
DISTRICT DIRECTOR: FRANCES BAARD DISTRICT

ensuring quality learning and teaching for all

HIV/AIDS is everyone's concern

APPENDIX H

UNISA

TO

PRINCIPAL,
SCHOOL GOVERNING BODY,
MOGOMOTSI HIGH SCHOOL,
FRANCES BAARD DISTRICT,
DEAPRTMENT OF EDUCATION.

Dear Sir

I am a student studying through University of South Africa (UNISA) enrolled for my MSTE degree in the Institute for Science and Technology Education. One of the requirements of my degree is that I conduct research and write a research report. The research is titled: **A Study on the Use of Computer Simulations as a Teaching Tool on the Performance of Grade 12 Learners in Photoelectric Effect.**

Understanding the photoelectric effect is an important milestone in understanding the particle nature of light, one of the corner stone of quantum mechanics. But the Diagnostic reports on NSC examination from the Department of Basic education repeatedly pointing to the factor that the learners do not understand the concept well. Recent studies shows that the use of computer simulations can improve the understanding of learners.

The purpose of my research is to investigate how the use of computer simulations in a class improve the performance of the learners.

if you give permission, learners will be asked to agree to take part in this research. No learner will be forced to take part if they do not want to and they will not be penalised if they choose not to do so. Learners can also withdraw at any time.

The following research activities will be required from the learners.

1. Participation in a pretest in photoelectric effect.
2. Participation in a 3-4 hour contact lessons by your teacher over 1 week.
3. Participation in a postest in photoelectric effect after the contact lessons.

Information obtained from the research will only be used for academic purposes. Information given by participants will be treated with confidentiality and will not be disclosed to anyone as all ethical procedures will be followed. Finally, I have to produce a research report and a scholarly article will be written about the findings, but no one will be able to trace any information back to any learners or to the school. I would like to ask your permission for do the research in your School with the help of the Physical Science teacher based at the school.

Yours faithfully

MSTE Candidate and Researcher- Mr. Bobby Joseph Kunnath
(Cell: 079 597 9858
Email. bjkunnath@gmail.com)

APPENDIX I

Letter to the participating educator

Dear educator,

I am Bobby Joseph Kunnath, who is working in the provincial office of the Northern Cape Department of Education. I am also a Master's student at UNISA at the Institute of Science and Technology Education. As a requirement for the award of a Master of Science degree in Science, Mathematics and Technology Education, I am investigating the impact of Computer Simulations as a Teaching Tool on the Performance of Grade 12 Learners in the topic Photoelectric Effect. The study will involve the use of PhET simulation to teach photoelectric effect to Gr 12 Physical sciences learners.

Learners will attend the intervention in the afternoons and you need to use PhET simulations to teach photoelectric effect in two experimental groups while the control group will be taught using the traditional teaching methods. Before the intervention starts the learners are supposed to write pre-test and after the intervention they are expected to write a Post-test. Some selected learners are expected to be interviewed also.

Participation in this research is voluntary and there will be no victimisation whatsoever for refusal to participate. There would be no interruption of your normal school programme. The data collected will be treated with confidentiality and the participants' name or school name would not be divulged. I am sure that you will be benefited from this research since you would be trained in the use of the simulations. The learners would also benefit as the use of simulations would enhance their understanding of the concepts.

Please do not hesitate to contact me if you have any further queries or clarifications. My contact details are as follows.

Email: bjkunnath@gmail.com Cell: 079 597 9858 Office: 053 839 6462

I am looking forward to your positive response.

Thanking you.

Yours faithfully

Bobby Joseph Kunnath

APPENDIX J

Letters of informed consent: (Learners above 18)

UNISA

Institute for Science and Technology Education

Date:

Letter of informed consent for participation in a study

Dear Participant,

We are inviting you to participate in a research investigating 'The effect of computer simulations as a teaching tool on the performance of grade 12 learners on the topic Photoelectric Effect.

The researcher guarantees that in this study, non-disclosure , no betrayal, informed consent and confidentiality agreements will be prioritised. No real names of the school or the respondents will be used.

The researcher assures the participants as adults that they will be allowed to exercise their rights and freedoms during the course of the interview.

Should you choose to participate in this research; the following research activities will be required of you.

1. Participation in a pretest on photoelectric effect.
2. Participation in a 6 hour contact lessons by your teacher over 3 weeks in which you may handle a computer .
3. Participation in a postest on photoelectric effect after the contact lessons.

The research results, in the form of a dissertation will be used to meet the requirements for a Masters in Science and Technology Education in Physics Education, Institute of Science and Technology Education, University of South Africa (UNISA). The dissertation will therefore become public domain for the scrutiny of examiners and the academic community.

I assure you again that I will abide by the UNISA policy on research ethics regulations and will use the information for the purposes of this study only.

Your participation is voluntary and you may withdraw your participation at any stage during the research process, prior to the reporting of the findings for the research project. You will also have the opportunity to review the findings prior to publication and will be able to provide advice on the accuracy of this information.

It is important to note that your name and identities of institutions will be withheld in the reporting of the data. Your behaviour or any other personal details will not be disclosed to other individuals in a way that will allow them to identify contributions that you may make to the research.

As such, confidentiality and anonymity will be guaranteed. If you are willing to participate in this research, please sign below in the space provided by this letter as a declaration of your consent i.e. you participate willingly that you understand that you may withdraw from the study at any time prior to publication of findings.

Participant's Signature: Researcher's Signature:

Date:

Should you have any queries about the research and/ or the contents of this letter, please do not hesitate to contact my supervisor or myself for further information.

Yours faithfully

MSTE Candidate and Researcher
Mr. Bobby Joseph Kunnath
email:bjkunnath@gmail.com
Cell: 079 597 9858)

Research Supervisor
Prof.Jeane Kriek
Institute for Science and Technology Education (ISTE)
Office: Theo Van Wijk Building 6-44
Unisa Main Campus
Work: +27(012) 429 8405
Fax: +27 (012) 429 8690
Cell: 082 878 1563
email: kriekj@unisa.ac.za

APPENDIX K

UNISA

Institute for Science and Technology Education

Date:

Youth assent form

Dear parent/guardian,

I am a student studying through University of South Africa (UNISA) enrolled for my MSTE degree in the Institute for Science and Technology Education. One of the requirements of my degree is that I conduct a research and write a research report.
I hereby ask your permission for the participation of your child in this research.

The research is titled: **A Study on the Use of Computer Simulations as a Teaching Tool on the Performance of Grade 12 Learners in the topic Photoelectric Effect.**

Understanding the photoelectric effect is an important milestone understanding the particle nature of light, one of the corner stone of quantum mechanics.
The Diagnostic reports on NSC examination from the Department of Basic education are repeatedly pointing to the fact that the learners do not understand the concept well. Recent studies show that the use of computer simulations can improve the understanding of learners.

The purpose of my research is to investigate how the use of computer simulations in a class can improve the performance of the learners.

With your permission, your child will also be asked to agree to take part in this research. No learner will be forced to take part if they do not want to and they will not be penalised if they choose not to do so. Your child can also withdraw at any time.

If your child is participating the following research activities will be required from your child.

1. Participation in a pretest in photoelectric effect.
2. Participation in a 12 hour contact lessons by your teacher over 3 weeks in which your child may handle a computer .
3. Participation in a postest in photoelectric effect after the contact lessons.

Information obtained from the research will only be used for academic purposes. Information given by participants will be treated with confidentiality and will not be disclosed to anyone as all ethical procedures will be followed. Finally, I have to produce a research report and a scholarly article will be written about the findings, but no one will be able to trace any information back to your child or to the school.

If you agree to allow your child to take part in this research, please fill in the consent form provided below.

Consent form

I parent/guardian of -- (name of child), give permission/ do not give permission (delete what is not applicable) for my child to take part in the research project titled: **A Study on the Use of Computer Simulations as a Teaching Tool on the Performance of Grade 12 Learners in the topic Photoelectric Effect.**

I understand that my child will be asked to agree before he/she will take part. My child will be asked to write the pretest and attend lessons for 3 weeks and after that to write a post test.

I understand that the researcher subscribe to the general ethics principles guided by UNISA in which the importance of

- *Respect for and protection of participants' rights*, meaning that the participants might withdraw from the research at any time and their decision will always be respected.. means that the *confidentiality* and *anonymity* of human respondents should be protected at all times.
- *Informed consent*, meaning that research participants must at times be fully informed about the research processes and purposes and must give consent to their participation in the research.
- *Risk minimisation*, which implies that the participants should not be placed at risk or harm of any kind.
- *Integrity, transparency and accountability*, which implies that researcher should be honest about his own limitations, competence, belief systems, values and needs

Signature:-------------------------- Date: ------------------

If you have any questions about the research and/or the contents of this letter, please do not hesitate to contact my supervisor or me at the numbers given below or via email.

Yours faithfully

MSTE Candidate and Researcher
Mr. Bobby Joseph Kunnath
Cell: 079 597 9858
Email. bjkunnath@gmail.com

Research Supervisor
Prof.Jeane Kriek
Institute for Science and Technology Education (ISTE)
Office: Theo Van Wijk Building 6-44
Unisa Main Campus
Work: +27(012) 429 8405
Fax: +27 (012) 429 8690
Cell: 082 878 1563
email: kriekj@unisa.ac.za

APPENDIX L

UNISA

Date:

Youth assent form (Minors)

Dear Learner,

We are inviting you to participate in a research investigating the effect of computer simulations in teaching the topic Photoelectric effect. Your school was selected for the research because of the consistent performance in NSC examinations in Physical Science.

Understanding the photoelectric effect is an important milestone in understanding the particle nature of light, one of the corner stone of quantum mechanics. But the Diagnostic reports on NSC examination from the Department of Basic Education are repeatedly pointing to the fact that the learners do not understand the concept well. Recent studies shows that the use of computer simulations can improve the understanding of learners.

The purpose of my research is to investigate how the use of computer simulations in a class improve the performance of the learners.

The researcher guarantees that the names of the participants and school will not be identified or revealed.

Should you choose to participate in this research; the following research activities will be required of you.

1. Participation in a pretest in photoelectric effect.

2. Participation in a 12 hour contact lessons by your teacher over 3 weeks in which you may handle a computer .

3. Participation in a postest in photoelectric effect after the contact lessons.

The research results, in the form of a dissertation will be used to meet the requirement for a Masters in Science and technology Education in Physics Education, Institute of Science and Technology Education, University of South Africa (UNISA).

Your participation is voluntary and you may withdraw your participation at any stage during the research process, prior to the reporting of the findings for the research project. However please remember that Photoelectric effect is a very important topic in Physical Sciences for your NSC examination. Your participation will also be beneficial to you in this regard.

It is important to note that your name and identities of institutions will be withheld in the reporting of the data. Your behaviour or any other personal details will not be disclosed to other individuals in a way that will allow them to identify contributions that you may make to the research.

If you tick "yes", it means that you have decided to participate and have read everything on this form. You and your parents will be a given a copy of this form to keep.

------- Yes, I would like to participate in the study.

Participant's Signature: Researcher's Signature:

Date:

Should you have any queries about the research and/ or the contents of this letter, please do not hesitate to contact my supervisor or myself for further information.

Yours faithfully

MSTE Candidate and Researcher-

Mr. Bobby Joseph Kunnath

email: bjkunnath@gmail.com

Cell: 079 597 9858

Research Supervisor

Prof.Jeane Kriek

Institute for Science and Technology Education (ISTE)

Office: Theo Van Wijk Building 6-44

Unisa Main Campus

Work: +27(012) 429 8405

Fax: +27 (012) 429 8690

Cell: 082 878 1563

email: kriekj@unisa.ac.za

(Cell: 079 597 9858)

APPENDIX M

GR 12 PHYSICAL SCIENCES

Content: Photoelectric effect

Lesson 2 (60 Minutes)

Concepts: Threshold frequency, Threshold wavelength & Experimental laws.

Reminder: You saw in the last session that the *work function* (W_0) of different metals differ.
Photoelectric effect depends on the metal plate used, intensity of light, frequency of light.

Activity 1

1. Open the PhET simulation.
   - Select the Target as sodium.
   - Keep the intensity at 30%.
   - Move the wavelength slider to the extreme right of the IR region.
   - Keep the default voltage (0 V). (**You are not supposed to alter the voltage throughout the lesson**)
2. Observe whether any electrons are ejected from the sodium plate.
3. Move the wavelength slider to the left slowly. Check at what wavelength the electrons just started to emit. Enter the value in the table 1 below. (Will be around 538 nm)
4. Repeat the experiment for Zinc and Platinum.

Target	**Value of wavelength when electrons start to eject. (nm)**	**Value of frequency when electrons start to eject. ($f = c/\lambda$)**
Sodium		
Zinc		
Platinum		

5. Is the corresponding frequencies same for the different metals?
6. Will the electrons eject below that frequency?

Threshold frequency: Minimum frequency of light needed to emit electrons from a certain metal surface.

Activity 2

1. What happens to the wavelength when the frequency increases?

2. What is the proportionality relation between them?
3. Suggest a definition for threshold wavelength.

Activity 3

1. Open the PhET simulation.
    - Select the Target as sodium.
    - Select the wavelength at around 300 nm. (Keep this CONSTANT in this activity)
    - Keep the intensity at 0%.
    - Increase the intensity and observe what happens to the current.

Activity 4

Open the PhET simulation.
- Select the Target as sodium.
- Select the intensity at around 30%. (Keep this CONSTANT in this activity)
- Move the wavelength slider to the extreme right of the IR region.
- Move the wavelength slider to the left slowly. Check what happens to the kinetic energy (speed) of ejected electrons.

All your observation from the different activities are consolidated below.

1. For a given metal, photoelectrons stop completely below a minimum frequency called the threshold frequency, however great the intensity may be. **(Activity 1)**

2. For a given metal, the number of electrons ejected per second (photoelectric current) is directly proportional to the intensity of the incident radiation, provided the frequency is greater than the threshold frequency. **(Activity 3)**

3. The photoelectric emission is an instantaneous process. (there is no time lag between the incidence of radiation and the emission of photoelectrons.)

4. The maximum kinetic energy of the photo electrons is directly proportional to the frequency of incident radiation, but is independent of its intensity. **(Activity 4)**

They are called the experimental laws of the photoelectric effect.

You are free to verify these laws using the PhET simulation

APPENDIX N

DEFINITIONS OF SOME CONCEPTS IN PHOTOELECTRIC EFFECT

1. Dual nature

The nature of light that it can behave as a wave and a particle at the same time.

2. Frequency

Frequency of a wave is the number of waves passing a point in one second.

3. Intensity of light

Intensity is the power transferred per unit area.

4. Threshold frequency

The minimum frequency of an incident light that can cause the ejection of a photoelectron.

5. Threshold wavelength

The maximum wavelength of an incident light that can cause the ejection of a photoelectron.

6. Wavelength

Wavelength is the distance between two consecutive crest or troughs.

APPENDIX O

EDITING CERTIFICATE

Cheme-E Editing Services

P O Box 38073
Garsfontein East
Pretoria
South Africa
0600

mike.scurrell2011@gmail.com **+2782 4692260**

5 Dec 2017

This letter serves to confirm that I have conducted copy editing using the file provided by Mr Bobby J Kunnath of a work entitled:

The effect of Computer Simulations on Grade 12 Learners' understanding of concepts in the Photoelectric Effect

A total of 2245 revisions were suggested, covering the main text, references and appendices.

Yours faithfully

M S Scurrell, PhD, DSc, FRSC, CChem, FRSSAf

APPENDIX P

SIMILARITY INDEX

DISSERTATION FINAL

ORIGINALITY REPORT

25%	20%	11%	10%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	uir.unisa.ac.za Internet Source	5%
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