The Effect of Guided Enquiry-Based Learning Approach on Electrical Engineering Students' Recall Ability, Conceptual Understanding, Problem Solving Skills and Critical Thinking Ability in Power Electronics Course at a Selected University in South Africa

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The Effect of Guided Enquiry-Based Learning Approach on Electrical Engineering Students' Recall Ability, Conceptual Understanding, Problem Solving Skills and Critical Thinking Ability in Power Electronics Course at a Selected University in South Africa

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PLAGIARISM DECLARATION

I, Vinod Kumar, student number 201415921, hereby declare that I fully understand the University of Fort Hare's policy on plagiarism and I have acknowledged all references and taken every measure to comply with the policy.

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ABSTRACT

Power Electronics (PE) forms the major part of the syllabus for the Industrial Electronics (INDE) course of the National Diploma (ND) programme in Electrical Engineering. This study investigated the effect of Guided Enquiry-Based Learning (GEBL), an Active Learning (AL) approach on Electrical Engineering students' recall ability, conceptual understanding of PE, problem solving skills and critical thinking ability. The study was carried out at one of the campuses of a selected university in South Africa's Eastern Cape Province in an attempt to check if GEBL would improve student performances in the above focused areas. The expected population for this research in 2017 was 21, similar to the numbers enrolled in 2016. However, in 2017 the enrollment dropped to 14 and this posed a limitation. Since cancelling the study due to the drop in enrollment would have caused the loss of a research report on PE students, it was decided to continue with it. This was especially so, since no other report on PE within South Africa could be located. The instruments were developed using inputs from subject experts to ensure content validity. Cronbach's Alpha was used to test the reliability of the instrument. A pilot study was conducted during the previous year with the 2016 PE students and deficiencies in the instruments were rectified. Out of the 14 students in 2017, seven volunteered to be taught using the GEBL approach. All ethical considerations applicable to the study were adhered to. All students from the GEBL group signed the informed consent forms prior to the study. The study adopted a pragmatist paradigm and a mixed method approach. A quasi experimental non-equivalent group post-test only research design was used where both the experimental group and the control group were selected (without random assignment). The post-test only design was selected because of the time constraints with the semester courses. A student-centred GEBL approach was used as an intervention for the experimental group and a teacher-centred traditional approach was used for the control group. Students from both the GEBL and Traditionally Taught Groups (TTGs) were subjected to the same assessments. Quantitative data were collected from two formative assessments and one summative assessment and the qualitative data were collected by interviewing all students from the GEBL group. The collected data were statistically and thematically analysed to determine the extent to which the intervention affected the students' recall ability, conceptual understanding of PE, problem solving skills and their critical thinking ability. The main conclusions were that when compared to the traditional approach, GEBL was significantly more effective in enhancing recall as well as understanding of PE concepts. However, significant differences were not evident in problem solving and critical thinking. The recommendations are that: students must be encouraged to be more active in the learning process; the shift of strategy from traditional to AL methods such as GEBL must be introduced gradually; and the benefits of GEBL and exposure to it must be popularised in order to develop positive attitudes to GEBL not only among students, but also teaching staff.

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LIST OF ACRONYMS

ABET	-	Accreditation Board for Engineering and Technology
AL	-	Active Learning
ANOVA	-	Analysis of Variance
CHE	-	Council of Higher Education
CLA	-	Collegiate Learning Assessment
CT	-	Critical Thinking
DC	-	Direct Current
DUT	-	Durban University of Technology
EBL	-	Enquiry-Based Learning
ECSA	-	Engineering Council of South Africa
EHEA	-	European Higher Education Area
ELO	-	Exit Level Outcomes
ETS	-	Educational Testing Service
GEBL	-	Guided Enquiry-Based Learning
HE	-	Higher Education
HEI	-	Higher Education Institutions
HEQC	-	Higher Education Quality Committee
INDE	-	Industrial Electronics
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
ND	-	National Diploma
NDELEC	-	National Diploma in Electrical Engineering

NGSS	-	Next Generation Science Standard
PBL	-	Problem-Based learning
PE	-	Power Electronics
PIV	-	Peak Inverse Voltage
PLD	-	Programmable Logic Design
PR	-	Peer Reflection
SA	-	South Africa
SAQA	-	South African Qualifications Authority
SCR	-	Silicon Controlled Rectifier
SL	-	Scientific Literacy
STEM	-	Science, Technology, Engineering and Mathematics
STSE	-	Science, Technology, Society and Environment
TBL	-	Team-Based Learning
TTG	-	Traditionally Taught Group
US	-	United States

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CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 Introduction

This chapter provides an introduction and background to the study beginning with an overview of engineering education in international and African contexts. The significance of conceptual understanding, problem solving and critical thinking skills in engineering education, and the effect of Active Learning (AL), Innovative Learning, Enquiry-Based Learning (EBL) and Guided Enquiry Based Learning (GEBL) approaches in engineering education are elaborated on. The learning difficulties in Science, Mathematics and Engineering Education and the elements of teaching quality are explicated. The rationale and problem statement are elaborated on. The research questions, objectives and purpose of the study with its perceived significance are outlined and the theoretical framework used in this study is elaborated on. A brief overview of the research methodology and the delimitations of the study follow. Definitions of operational terms used in the study and the structure of the document are outlined. This study investigated the effect of GEBL on National Diploma (ND) engineering students' enhancement of conceptual understanding, problem solving skills and critical thinking ability in Power Electronics (PE).

1.2 Background

Among researchers, educators and education leaders there is growing consensus that the method of teaching and learning must change to help students develop the skills they need to succeed in today's world (Ananiadou & Claro, 2009; Scheuermann & Pedro, 2009). Research on learners' difficulties in understanding scientific and engineering related concepts and principles has been ongoing for the past few decades. There have also been studies focused on enhancing understanding through diagnosis and action on learning difficulties. Students' difficulties associated with scientific and technological concepts and principles have been a prime factor for investigation in this area (for example, see Fischer & Breuer, 1994; Bryce & McMillan, 2005). These studies focused on both secondary and post-secondary levels. Some of these studies focused on conceptual understanding and misconceptions (Fischer & Breuer, 1994; Bryce & McMillan, 2005; Baser & Geban, 2007). Others focused on the teacher's role in enhancing student learning

(Rodriguez-Andina, 2010; Shamsudin, Nabilah & Nurlatifah, 2013; Warner & Myers, 2014). In order to improve the students' performance and learner outcomes, Higher Education (HE) institutions all over the world have been investigating alternative methods of teaching. For example, recently there has been an increasing awareness of the effectiveness of various active learning (AL) approaches (Douglas & Chiu, 2012) such as problem and case-based learning (Duch, Groh & Allen, 2001; Kilroy, 2004; Savery, 2006; Srinivasan, Wilkes, Stevenson, Nguyen & Slavin, 2007; Hsieh & Knight, 2008), team-based learning (Nieder, Parmelee & Stolfi, 2005; Michaelsen & Sweet, 2011), peer instruction/discussion (Crouch & Mazur, 2001; Nicol & Boyle, 2003; Lasry, Mazur & Watkins, 2008), peer teaching (Whitman & Fife, 1988; Cate & Durning, 2007; Boud, Cohen & Sampson, 2014) and inquiry-based learning (Crouch & Mazur, 2001; Tien, Roth, & Kampmeier, 2002; Knight & Wood, 2005; Smith, 2012). Empirical research has shown improvement in learning outcomes by the use of various AL techniques (Knight & Wood, 2005; Prince & Felder, 2006; Lasry, Mazur & Watkins, 2008; Markant, Ruggeri, Gureckis & Xu, 2016). Prince and Felder (2006) have also provided a comprehensive review of the effectiveness of various types of AL methods, both within education in general and engineering education in particular. GEBL as an AL was also reported by (Prince, 2004; Klentschy & Thomson, 2008; Louw, 2012). This study was carried out at a South African University.

1.2.1 An Overview of Engineering Education

Engineering education has evolved over time and efforts are made to improve the readiness of the graduates to meet the challenges of the twenty-first century (Litzinger, Lattuca, Hadgraft & Newstetter, 2011). Engineering education should incorporate learning experiences that promote conceptual understanding, problem solving skills and critical thinking skills. There are considerable changes in engineering education to enhance the learning of students through team-based, project-driven activities. However, additional enhancements are needed to prepare the engineering graduates to meet the challenges of the twenty-first century (Jamieson & Lohmann, 2009). Studies have indicated that students are graduating with good engineering knowledge but lack the ability to apply that in practice. The national accreditation criteria of the engineering programs in some countries place emphasis on what is being learned by the students rather than what is being taught in the program (Besterfield-Sacre, Cox, Borrego, Beddoes & Zhu, 2014; Duse & Duse, 2017).

1.2.2 Engineering Education - Global

With the intention of promoting the mobility and the free movement of students and teachers in European tertiary education, the European Commission has started building a European Higher Education Area (EHEA). US universities are introducing systems to strengthen students' systems thinking and problem solving competencies (Alves, Kahlen, Flumerfelt & Manalang, 2013). Philippines is trying to align itself with Accreditation Board for Engineering and Technology (ABET) system from the US. In Australia the outcome of the reviews carried out in Engineering education was an emphasis on some generic attributes of engineering graduates including the ability to apply knowledge of basic science and engineering fundamentals, ability to communicate effectively and ability to undertake problem identification, formulation and solution (Oyekan, 2004).

The scoping and pace of higher education programmes for engineers is varying and of mixed pedagogical methods. These are not necessarily meeting the expectations for engineering practice. That is, resources and teaching methods in Higher Education Institutions (HEIs) often do not match the widely dispersed expectations and outcomes of engineering education, as expected by the industry. This gap brings challenges for all stakeholders including potential employers, higher education sector and the engineering graduates (Alves et al., 2013).

Rugarcia, Felder, Woods and Stice (2000) state that the skills required, for future engineers, to address the challenges can be divided into the following categories: (a) interdependent and lifetime learning skills; (b) problem solving, critical thinking, and creative thinking skills; (c) interpersonal and team work skills; (d) communication skills; (e) self-assessment skills; (f) integrative and global thinking skills, and (g) change management skills. Engineering education is going through a major change. Several studies have shown serious deficiencies in traditional teaching methods and have provoked calls for changes in how engineering curricula are structured, delivered and assessed (Felder, 2012; Garcia, Garcia, Arboleya & Guerrero, 2013; Bastami, Avestruz & Leeb, 2014). Prince and Felder (2006) argued that engineers require to be equipped with skills that have previously not been emphasized in engineering curricula to make them competitive. To do so, he posited that critical and creative thinking are important. It was stated in the outcome of the 1998 Global Congress of Engineering Education at Cracow (Poland) that the integration of lectures with laboratory experiences and project work is an ideal scenario (Jones, 1998; Louw, 2012). About two decades back in 1998, Jones observed that the one basic set of skills that must be developed in engineering students is critical thinking and problem solving (Jones, 1998).

A report from National Academies press (2005) indicates that the United States (U.S.) is in danger of losing its historic pre-eminence in creating and manufacturing advanced products specifically due to problems with engineering education. The report suggests that the problems facing engineering education go beyond a need to simply educate more students or raise performance in examinations. However, Gordon and Silevitch (2009) argues that when it comes to engineering and engineering education, quality is more critical than quantity.

Today's engineering professionals constantly deal with technological change in the work place which demands technical competence. Industries are using technologically advanced instruments and techniques and as such, there is also a gap in the experience of HEI engineering graduates in this regard. Despite these challenges, the teaching strategies of engineering education remain to be – "chalk and talk" (Mills & Treagust, 2003).

1.2.3 Engineering Education – Africa

Mohamedbhai (2016) in a study on improving the quality of engineering eduction in Sub-Saharan Africa (SSA) concluded that there is a lack of capacity and shortage of skilled and experienced engineers in this region. The above impacts on achieving of developmental goals. Mohamedbhai (2016) further states that many engineering graduates are unemployed because of their lack of necessary skills and experience to be employable. Some causes include "the deficiency in resources of the engineering institutions to support engineering activities; the poor quality of engineering eductation based on outdated teaching methods and curricula" Mohamedbhai (2016, p 4).

The above paper also reports on findings of the UNESCO Report on Engineering (2010) which outlines issues to be addressed in promoting engineering for development. In relation to engineering education, the suggestion is to transform engineering curricula and teaching methods to emphasise relevance and a problem-solving approach. It is noted that the curricula of engineering courses have been copied from universities in Europe or the USA and hence not necessarily relevant to the African context and hence requires revision to suit local needs. A Problem-Based Learning (PBL) approach is recommended to improve students' ability to solve problems, improve creativity and acquire communication skills. A further issue to be addressed is the poor quality of teaching due to lack of pedagogical training of engineering lecturers. Many universities insist on lecturers having a PhD in their technical discipline, whereas an emphasis on a Masters degree, with industrial experience and pedagogical training of academic staff would better equip them for their teaching.

In a study on enhancing Teaching and Learning of Electrical Power Engineering in Nigerian Tertiary Institutions (Barau, 2015), it was concluded that engineering education can be enhanced by modifying the curriculum to include a combination of both traditional teaching methods as well as enquiry based methods of teaching.

1.2.4 Engineering Education – South Africa

The engineering curriculum is often structured into distinctly theoretical and practical components (Wolff & Hoffman, 2014). South African Univeristies offer engineering degrees and diplomas in various engineering disciplines. Engineering education is regulated by the Engineering Council of South Africa (ECSA) and the Higher Education Quality Committee (HEQC) under the Council for Higher Education (CHE). The Exit Level Outcomes (ELO), endorsed by the ECSA, intend to provide a holistic achievement in engineering qualification (Wolff & Hoffman, 2014).

The institution where the research was carried out offers the ND programme in Civil, Mechanical and Electrical Engineering disciplines. The purpose of the engineering diploma educational programme is to build the necessary knowledge, understanding, abilities and skills in order to qualify as an engineering technician who has a working understanding of engineering sciences underlying the techniques used (ECSA, 2012; Wolff & Hoffman, 2014). According to South African Qualifications Authority (n.d.), the purpose and rationale of the ND qualification in Electrical Engineering is "…a qualifying learner will be competent to apply technical knowledge, engineering principles and problem-solving techniques in the field of Electrical Engineering by operating within the relevant standards and codes in collaboration with other members of the engineering team".

As a lecturer teaching at ND level, the researcher's experience shows that most students exhibit inadequate, or in some cases a lack of understanding of the concepts covered in the theory. As such, they may not be able to apply their knowledge practically in their future work. The present teaching strategies using mostly traditional learning and teaching strategies appear not to enable students to deal with technical aspects correctly. This becomes evident during question and answer sessions in the classroom as well as written assessments.

In the annual report of the CHE it was stated that only 5% of first time engineering students at 'Comprehensive Universities' complete their engineering Diploma in three years (CHE, 2007). Various factors might be contributing to this such as student's background knowledge in the particular course as well as the clashes between lecturer's teaching style and student's learning style (Louw, 2012). Studies with students' difficulties in universities in the Eastern Cape Province are not new. For example, Muthiraparampil (2012) dealt with misconceptions in electrostatics and Louw (2012) researched on the learning and teaching of thermodynamics. Both the above studies were carried out at comprehensive universities similar to the one in this study.

South African universities are evolving to an undergraduate engineering curriculum with learning options such as project-based learning. This is intended to address the education-workplace gap (Alves et al., 2013) alluded to earlier in the global context.

Louw (2012) refers to a study which was conducted at the Durban University of Technology (DUT) on an alternative presentation of a module in chemical engineering. He cites Ramsuroop (2011) who states that the chemical engineering design module in the ND programme has focused on developmental projects associated with sustainability emphasising hands-on learning. At DUT the primary objective was to adopt AL method that would improve students' physical interpretation and understanding of real engineering systems.

1.2.5 Electrical Engineering and PE in the context of Engineering Education

Electrical engineering as a discipline deals with increasingly complex systems and abstract notions such as current, voltage, resistance, inductance, capacitance etc. As stated by Bauer, Davat, Fedak & Hajek (2005, p. 46), "these electrical quantities and phenomena are not directly observable and can only be made observable by means of measurements. This is all the more so in the area of power electronics".

PE is a multidisciplinary area in the electrical engineering domain. It has a wide variety, scale and range of applications from energy production and conversion, power supplies, automation and process controls, robotics, heat, light and motor controls down to applications in home appliances (Bauer et al., 2005; Rashid, 2008). PE therefore requires knowledge of diverse fields like electric circuits, magnetic elements, power systems, signal processing and control systems (Petry et al., 2014).

Bauer et al. (2005), found that because of the dynamics and dimensionality of these systems, students have problems in understanding and dealing with these complexities. The large number of simultaneously occurring variables i.e. voltages and currents make these systems complex. Engineers have to design, operate and maintain these highly complex systems. This is complexity is required to be reflected in engineering education, "where teachers try to communicate the many aspects of complex systems and where students try to learn and deal with this complexity" (Bauer et al., 2005, p.45). Petry et al. (2014) in their study on streamlining power electronics teaching, advocate for alternative teaching approaches like PBL to allow for the integration of interdisciplinary knowledge and learning of different skills required for mastering of PE.

1.3 Significance of Conceptual understanding in Engineering Education

According to Hiebert and Carpenter (1992) conceptual understanding involves a network connection of knowledge structures. Conceptual understanding is thus a student's ability to apply and connect what he or she is currently learning to prior learning and other related fields. Mastery of relevant concepts provides a foundation for gaining knowledge and understanding in engineering subjects.

Louw (2012) in his study indicates that a research done by Klentschy and Thomson (2008) in a science class based on GEBL found that students understood concepts explained to them better. He elaborates further that there was sufficient evidence that the classroom discussions and resources used as part of a GEBL approach assisted students in achieving a deeper understanding of course content.

Kolloffel and Jong (2013) conducted a study to find out how the attainment of conceptual understanding of electrical circuits can be facilitated. The study compared two experimental conditions, where in one the students followed traditional instruction only and the other where the students followed traditional instruction supplemented with enquiry learning within a virtual lab. In both conditions the students followed the same traditional electricity curriculum. Post-test results indicated that students in the virtual lab condition outperformed students in the traditional condition on conceptual understanding.

Conceptual understanding can be hampered by misconceptions. Research on learners' ideas concerning learning concepts in various scientific disciplines has long been of interest to many researchers all over the world. Children come to classrooms holding a variety of pre-conceptions on many scientific phenomena. They had ideas that quite effectively competed with the concepts presented in the classroom (Smith, diSessa & Roschelle, 1994). They hold resilient conceptions with explanatory power, but are inconsistent with the accepted scientific concepts presented in the classrooms. Learners' responses which differ from the currently-accepted scientific point of view are frequently termed "misconceptions"; however, constructivists argue that from the learner's point of view, the conceptions held by them make more sense than the scientifically-acceptable one. Hence it is important to take students' conceptions seriously (Hewson & Hewson, 1988; John, Molepo & Chirwa, 2016).

Although some misconceptions may be addressed through standard instructional procedures and gradually disappear as the course progresses, learners may also hold other conceptions which are highly resistant to instruction. Misconceptions originate from prior learning which had generated either in the classroom or from the interaction with the physical and social world (Smith et al., 1994). According Baweneh, Zain and Salmiza (2010), knowledge that is inaccurately acquired will make subsequent learning also inaccurate, which may then eventually lead them to make incorrect conclusions and judgmental opinions regarding various other related phenomena. It is, therefore, necessary that educators and researchers assess what explanations and intuitions the abundant experience of prior knowledge has generated in learners' minds (Durkin & Rittle-Johnson, 2015).

Educators can measure the strength of the existing alternative conceptions while assessing their learners' prior knowledge. A study was conducted by Potgieter, Malatje, Gaigher and Vender (2010) to explore South African learners' baseline knowledge and understanding in mechanics upon their entry to tertiary education. The findings revealed that many of the incorrect explanations held by the participants were not due to strong alternative conceptions. Instead, the respondents in their analysis made critical error by overlooking or misinterpreting the facts and information provided or lacked problem-solving skills. This suggests that not all the incorrect conceptions are strong enough to be considered as misconceptions or alternative conceptions. Misconceptions are deeply rooted and resistant to change (Steinberg, Brown & Clement, 1990; Cheng, Lin, Chen & Heh, 2005; Badenhorst, Hartman & Mamede, 2016), while errors resulting from ignorance can be reduced by training (Gray, 2000).

Misconceptions are not temporary assumptions that are quickly discarded; instead they consistently appear before and after instructions in many students and even adults (Smith et al., 1994). For example, Cohen, Eylon and Ganiel (1983) reported that many of their high school students and physics teachers held onto their misconceptions about simple electric circuits. Moreover, students may keep their misconceptions even after they receive instructions specifically designed to correct them. Misconceptions, in many cases, were reported to be "deep seated" and "resistant to change" (Steinberg & Clement, 1997; Ojose, 2015) and "consistent across individuals", "very strongly held" and "not easily changed by classroom instruction" (McCloskey, 1983). Since classroom instructions may not always be successful in replacing learners' misconceptions with scientifically- or mathematically-accepted ideas, instructional strategies need to be carefully planned and implemented with a focus to the attainment of conceptual change amongst learners.

1.4 Significance of Problem Solving skills in Engineering Education

Engineers of the 21st century are expected to have the skills to solve novel, complex and multidisciplinary problems in a fast changing world. Many studies have highlighted the importance of problem solving skills among engineering graduates (Mohd-Yusof, Phang & Helmi, 2014). The purpose of engineering education is to produce engineering graduates who are capable of identifying, structuring and solving complex problems. Savander-Ranne and Kolari (2003), state that an important role of engineering education is the attainment of problem solving skills. Greater knowledge and understanding in turn provide the necessary skills for problem solving. Savander-Ranne and Kolari argue that mastering of concepts and understanding of phenomena results in good problem solving skills. It is also claimed that in the physical sciences and engineering subjects, lack of conceptual understanding and deeper insight into the consequences of phenomena is a common cause of failure in problem solving. However, studies show that traditional curricula propagate linear thinking which does not develop the kind of skills required to solve problems in today's work environment (Haupt & Webber-Youngman, 2018). Engineering students are generally taught to solve well-structured problems but those are not the kind of problems they face in the real world. Therefore a good engineering education must train students methods to identify and solve problems so that when they are faced with real world challenges, they will have the necessary skills to solve the problems (Mohd-Yusof et al., 2014; Adams, Kaczmarczyk, Picton & Demian, 2015; Haupt & Webber-Youngman, 2018).

1.5 Significance of Critical Thinking skills in Engineering Education

A university education implies more than the acquisition of a wide range of information. Students are also expected to develop the ability to conduct analysis based on data and evidence, develop new ideas, and articulate positions reflecting critical thinking. This critical thinking process is expected to be a lifelong skill useful in today's workplace. Critical thinking is learned skill that requires both training and practice and it is a process of conceptualizing, applying, analysing, synthesizing, evaluating, and communicating information (Kim, Sharma, Land & Furlong, 2013).

In South Africa the main curriculum content and implementation are nationally determined. HEQC under the CHE monitors and Engineering Council of South Africa (ECSA) as a professional body have an important control over these. Both these regulatory bodies consider critical thinking as a fundamental under-graduate attribute for engineering qualifications. This is a quote by McRuairc, McNamara and O'Donnell (2012) through the statement that critical thinking indeed is a defining characteristics of university education. Felder (2012) corroborates the above with the observation that employers complain of lack of critical thinking skills amongst recent outputs of engineering under-graduates.

1.6 Active Learning

Active Learning (AL) is generally defined as any instructional method that engages students in the learning process in the classroom (Prince, 2004). It is often contrasted with traditional lectures where students passively receive information from the instructor. Research has revealed a number of positive outcomes of AL, such as improved short and long-term recall of information, increased conceptual understanding, improved attendance of lectures, higher retention in academic programs, enhanced critical thinking skills, interpersonal relationships and self-esteem, fewer misconceptions and improved teamwork skills (Drake & Battaglia, 2014).

Studies on AL have been conducted in various countries such as the USA (Hoekstra & Mollborn, 2012; Lumpkin, Achen & Dodd, 2015), India (Rajcoomar, 2013), Spain and Mexico (Mendez & Delgado, 2013) and also South Africa (Sekwena, 2014). Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt and Wenderoth (2014) conducted a meta-analysis of 225 studies on AL in undergraduate science, technology, engineering, and mathematics (STEM) courses. They stated that on average, student performance on examinations and concept inventories increased by 0.47 Standard Deviations (SDs) under AL, and the average examination scores improved by about 6%. They further reported that students in classes with traditional lecturing were 1.5 times more likely to fail than those in classes where AL was used. Their analyses showed that failure rates in mathematics dropped by 15% on average when AL was used. AL was found to be effective across all class sizes and across the STEM disciplines and had a strong positive impact on female students. The researchers quite rightly raised questions about the continued use of traditional lecturing and expressed support for AL as the preferred, empirically validated teaching practice.

1.7 Innovative Teaching and Learning

The word ‘innovative’ encompasses something ‘novel’ and in the learning and teaching context innovative methods refer to novel and productive ways of achieving successful student learning. Despite extensive literature search and going through several research articles dealing with innovative learning and teaching either briefly or elaborately, the present researcher could not find a concise definition for the principal critical attribute of innovative learning and teaching other than that suggested by Lunde and Wilhite (1996). As such as a starting point, their definition is quoted here. “The term innovative teaching represents a construct, comprised of a cluster of qualities including effective interaction with learners, openness to change, persistence, reflective practice, specificity of approach, and discipline-embedded pedagogy” (Lunde & Wilhite, 1996, p.156). Innovative learning and teaching has many attributes as Lunde and Wilhite (1996) allude to. Lunde and Wilhite (1996) recognised that it is not a simple task to set forth critical attributes of innovative learning and teaching. According to Lunde and Wilhite (1996, p.156), innovative learning and teaching refers “… either to programmatic changes or to single innovations in specific courses”. Biggs (1998) highlights deep learning (Asikainen & Gijbels, 2017) as opposed to surface learning (Islam & Shafiq, 2016) as outcome of innovative learning and teaching. All the above authors either implicitly or explicitly argue for innovative teaching activity to bring about critical attributes such as learner centeredness and scaffolding the learning to result in the necessary understanding which Biggs (1998) referred to as ‘deep learning’ and this has been considered in this research.

Innovative teaching and learning methods are used to teach students to make informed and balanced decisions and to use scientific knowledge to solve problems. (American Association for the Advancement of Science, 1993; Council of Ministers of Education, 1997; Millar, Osborne & Nott, 1998). Innovative learning is best accomplished by using more student-centred AL strategies. Other researchers focused on enabling environments in learning institutions to enhance understanding of scientific and technological concepts and principles such as facilities for virtual realities, virtual laboratories and e- and m-learning enablers. Ott, Cohen and Ott (2015) recently presented their experiences with the effectiveness of virtual reality and simulations to enhance learning.

1.8 Enquiry Based Learning (EBL)

Hutchings (2007) refers to enquiry as a process of learning through the posing of questions which may be of an open-ended nature or otherwise. Much along the lines of AL approaches to gaining knowledge, students acquire knowledge by means of active enquiry (Ernst, Hodge & Yoshinobu, 2017), the learning outcomes of which Hutchings describes as more ‘intellectually embedded’ i.e. ‘what we discover, we retain’. The method therefore resonates with that of deep learning approaches, linking outcomes to the long-term retention of ideas formed.

The combination of the educator’s responsibility to enlighten, together with the learner’s role to take possession of the process of discovery is likened to that of the production of a scenario on the one hand, and the addressing of the scenario on the other. The former being the responsibility of the educator and the latter that of the learner. Hutchings states,

> The scenario acts as the stimulus, the motivation to learning; learning takes place as the students work on the scenario. Devising the scenarios is the creative task for the tutor. The nature of the scenario, the extent to which it is defined or the time allowed for work on it, and the amount and level of knowledge required will determine the kind of learning that the students will undertake (Hutchings, 2007, p. 12).

Learning itself is self-directed and driven by the students who bring prior knowledge and relevant issues, which are discussed and ideas pooled and reflected upon. Students then carry out research and investigation to address these issues, and in this process take ownership of the process of enquiry which initiates EBL.

1.9 Guided Enquiry Based Learning (GEBL)

Kuhlthau, Maniotes and Caspari (2015) describe Guided Enquiry as an innovative team approach to teaching and learning where, educators, together with experts and specialists design and implement enquiry learning. Vlassi and Karaliota (2013) state that EBL has been officially promoted as a pedagogy for improving science learning in many countires (NRC, 2000; Bybee, 2006). Vlassi and Karaliota (2013) continue to say that in this method, students explore and the teacher becomes the guide in a research. Quoting Bybee (2006), Vlassi and Karaliota (2013) state that the strategy of directed investigation includes the following seven steps:

- Elicitation (psychological and cognitive preparation, verification of previous knowledge, elicitation of the students' misconceptions).
- Engagement (specification of the problem).
- Exploration (encouragement of the hypotheses, planning of the investigation, experimentation, collection and organization of data).
- Explanation (analysis and regularization of the data, explanations).
- Elaboration (overshooting of the data, explanation of the phenomena, finding of analogies, evaluation of the ascertainment.
- Evaluation (evaluation of the learning objectives by the teacher).
- Extending (application of new learning objects to similar cases, generalization and transport of new learning objects to different situations).

Vlassi and Karaliota (2013) continue to say that the guided enquiry method moves away from the traditional ways of teaching, where the teacher's opinion dominates and the students are only required to memorize and reproduce knowledge. Vlassi and Karaliota (2013) quote Wang and Posey (2011), saying that the above is in direct contrast with the EBL model where students learn contents on their own, providing opportunities to develop critical thinking and gain a deeper understanding of concepts. Vlassi and Karaliota (2013) conclude by saying that the guided enquiry method is based on constructivism where student centred activities engage students in learning processes, where teaching is done based on what students already know - thereby encouraging students to construct their own understanding of knowledge gained. As such, GEBL has all the essential ingredients of AL and EBL.

1.10 Learning difficulties in Science, Mathematics and Engineering Education

Pundak and Rozner (2008) state that during the past decades there is a consensus that traditional teaching of basic science courses (e.g. physics, maths and chemistry) does not result in expected outcomes. Students completing these courses have a shallow understanding of basic concepts and scientific processes and a negative approach to learning related concepts in these branches of knowledge. For example, students learning physics at the university level often have great difficulty with mathematical problem solving which is an integral part of most physics classes (Tuminaro & Redish, 2005) and since physics is integrally related to engineering concepts, these have an impact on engineering concepts and principles too.

A learning difficulty may be said to exist in any situation where a student fails to grasp a concept or idea as a result of ideas/knowledge system already possessed by the student, demand and complexity of a learning task, communication problems arising from language use, e.g., in relation to technical terms or mismatch between instructional approaches used by the teacher and the student's preferred learning mode (Kemp, 1991). A proper understanding of the concepts for science and engineering related subjects is necessary to solve problems related to the subject (Walsh, Howard & Bowe, 2007). Studies have shown that although students can solve quantitative problems by simply plugging in values into formulae and obtaining an answer, they may not be developing the skills necessary to solve more complex problems with understanding; the so-called deep learning.

1.11 Elements of Teaching Quality

Some institutions also research the quality of teaching focused on whether teaching indeed brings about learning, for example, Penn State University carried out a survey and published a report in 2014 which focused on the various elements of teaching quality through gathering 644 students' and 125 instructors' views at the institution. It was interesting to note that there was consensus in many variables, among others, associated with the learning and teaching process such as instructors' thorough knowledge of the content, availability of well-developed course content, instructors to be well-prepared for the lesson, instructors' preparedness to present well-organised lessons, effective use of instructional time, student interactions and collaborative learning (Pennsylvania State University, 2014; Willits & Brennan, 2015).

1.12 Problem Statement

Traditionally, teaching methods in engineering education include the use of text books, class notes and practicals. In the textbooks, the subject matter is often approached from a factual and calculus-based angle (Kolloffel & Jong, 2013). Students often work individually on lecture notes and text books to focus on the basic requirements to pass the examination. As such there may not be optimum understanding of the PE concepts and principles. Students then take the surface learning approach. Surface learning does not link new knowledge to the prior knowledge. It replaces one set of knowledge with another without actually understanding it (Hay, 2007). As per scaffolding principles in educational contexts, practicals and demonstrations promote conceptual understanding of PE concepts and principles. Nonetheless, inadequacy or sometimes non-availability of the necessary equipment and accessories tends to hamper full understanding of PE concepts and principles. This problem was identified way back in the 90's by Schauble, Klopfer and Raghavan (1991). According to them, students, in practical lessons, tend to focus on making their circuit work rather than on trying to understand the relations between variables and outcomes. Based on the guidelines of the South African (SA) regulatory authorities in engineering education referred to earlier, this ought not to be the case. Furthermore, due to the time constraints of completing the course in one semester, students get limited exposure to practical experiments.

Since South Africa is facing a shortage of engineers, enhancing the understanding of the concepts and principles in PE and their applications is significant as is well known (Rasool & Botha, 2011). At work, engineers are required to analyse problems and communicate fluently and effectively to find the solution to a problem as alluded to by CHE and ECSA. This makes it necessary that they have an in-depth understanding of technical concepts and principles and be able to effectively discuss and work with others. Different styles of teaching and learning other than the chalk and talk which is currently practised commonly might enhance students' understanding.

1.13 Rationale for the Study

PE is a rapidly developing area of electrical engineering. It is multidisciplinary, requiring knowledge in electrical engineering areas such as electronics, automatic control systems and power systems (Oliveira, Nascimento, Goedtel, Monteiro, Manoel & Aguiar, 2009). Since industries are keeping pace with the fast developments in technology as alluded to earlier and as emphasised by (Rodriguez-Andina, 2010), the students are required to have a grasp of the basic electrical engineering concepts to understand the working of PE equipment.

This study focused on PE course in Electrical Engineering ND programme at one of the comprehensive universities in South Africa’s Eastern Cape Province. Students at this university come from disadvantaged background socially, financially and academically in particular (Spaull, 2012). It is also observed that they struggle to correctly deal with technical subjects. Different backgrounds and childhoods deliver learners with different reference frameworks. Louw (2012) who carried out research on another branch of engineering at the same university pointed out that the gaps and shortcomings among the learners within such a group must be bridged by applying multiple teaching methods.

Surely, there have been a number of studies on students’ learning difficulties as alluded to in the foregoing sections and sub-sections. The problem was that no study could be located not only in the Eastern Cape Province but also nationally in South Africa on students’ learning difficulties in PE and exploring ways to enhance the understanding of its concepts and principles.

The PE course has been taught through traditional teaching methods from the time of its introduction. During 2016, the average percentage scores in formative assessment 1, formative assessment 2 and summative assessment were 62%, 58.7% and 45.4%, respectively (see Appendix L-a for score data). The researcher who was also the lecturer was concerned with students not earning high percentage scores and identified low performances as a problem which deserved attention. In an attempt to improve the performance, implementing GEBL as an active learning method for volunteering students was envisaged in consultation with the Head of Department. The focus was to improve core areas such as conceptual understanding, problem solving skills and critical thinking ability of PE students through GEBL which is an AL approach.

1.14 Main Research Question

Would GEBL enhance students’ conceptual understanding, problem solving skills and critical thinking ability in PE course?

1.15 Research Sub-Questions

1.15.1Would a GEBL approach enhance students’ ability to remember PE concepts?
1.15.2 Would a GEBL approach enhance students’ conceptual understanding of PE?

1.15.3 Would a GEBL approach enhance students' conceptual understanding of PE?
1.15.4 Would a GEBL approach enhance students' problem solving skills?
1.15.5 Would a GEBL approach enhance students' critical thinking ability?
1.15.6 What framework can be suggetsed for effective learning of PE through GEBL?

1.16 The Objective of the Study

1.16.1Gauge the enhancement of students' ability to remember PE concepts through GEBL approach;

1.16.2 Judge the enhancement of students' conceptual understanding of PE through GEBL approach;

1.16.3 Measure the impact of GEBL approach to enhance students' problem solving skills;
1.16.4 Determine the effect of GEBL approach to enhance students' critical thinking ability;
1.16.5 Develop a framework for effective learning of PE through GEBL.

1.17 The Purpose of the Study

The purpose of this study is to investigate the effect of GEBL on ND engineering students' enhancement of conceptual understanding, problem solving skills and critical thinking ability in the study of PE.

1.18 The Significance of the Study

Engineers contribute towards the improvement of living standards through application of their knowledge in mathematics and science to the real world (Lamar et al., 2012) With fast changing technology students are required to keep up with the ever changing implications thereof. The future trend of integrating Information and Communication Technologies (ICT) with PE controls makes engineering education more challenging (Avotins, Suzdalenko & Galkin, 2013). Conceptual understanding, problem solving skills and critical thinking ability are therefore key skills to be acquired and enhanced in engineering students.

Traditional teaching and learning approaches in engineering courses are too focused on engineering science without providing sufficient integration of relevant concepts and principles within the learning area. This study focussed on an alternative teaching method viz. GEBL to enhance the above skills and ability among ND students. It is hoped that the above method will improve student pass rates and their academic performance, leading to higher employment rates. It is also hoped that the acquired skills will equip students to better meet the demands of the industry where fresh graduates are expected to solve real world problems.

The study is the first of its kind conducted in South Africa and in the Eastern Cape Province in the context of PE engineering education. Lecturers and academic administrators and academics themselves might pick up lessons from this empirical study to reflect on their own teaching approaches. Curriculum designers and faculty developers are other possible beneficiaries of this study.

1.19 Theoretical Framework

For this study, the researcher used the theory of knowledge creation metaphor. This metaphor integrates Piaget's and Novak's cognitive constructivism (monological) and Vygotsky's social constructivism (dialogical) and brings in a collaborative activity based and student centred (trialogical) learning approach subsuming both cognitive and social constructivism. That means, cognitive and social constructivism interact through collaborative activities.

Researchers have earlier distinguished two central metaphors of learning, which describe the two basic ways of understanding the area of learning. These are the acquisition metaphor and the participation metaphor (Lave & Wenger, 1991; Sfard, 1998; Wenger, 1998). The acquisition metaphor has at its core the idea that knowledge is constructed by an individual mind. According to this view the mind is a container of knowledge, and through the process of learning, the container gets filled embedding the knowledge therein (Bereiter, 2002). This metaphor also links to individualistic versions of active, constructivist theories of learning.

According to the alternative participation metaphor, learning is an interactive process. Here, shared learning activities and cultural practices are said to shape cognitive activity. This in many ways differs from the idea that knowledege is shaped primarily by an individual (Brown, Collins & Duguid, 1989; Lave & Wenger, 1991). Accordingly, in this view, "learning is seen as a process of becoming a member of a community and acquiring the skills to communicate and act according to its socially negotiated norms” (Paavola & Hakkarainen, 2005, p.5 38).

Paavola, Lipponen and Hakkarainen (2004) argued that beyond the above two metaphors, a third metaphor exists viz. the knowledge creation metaphor which addresses learning as a process of knowledge acquisition which includes both the acquisition of knowledge by individuals as well as by participation and social interaction.

> The basic division is as follows: the acquisition view represents a ‘‘monological’’ view on human cognition and activity, where important things are seen to happen within the human mind, whereas the participation view represents a ‘‘dialogical’’ view where the interaction with the culture and other people, but also with the surrounding (material) environment is emphasized. The knowledge-creation view represents a ‘‘trialogical’’ approach because the emphasis is not only on individuals or on community, but on the way people collaboratively develop mediating artefacts (Paavola & Hakkarainen, 2005, p.539)

Paavola et al., (2004) contextualised and explained the knowledge creation metaphor in detail. According to them, it is important to develop new competencies through intense work, as well as improve existing knowledge and understanding, in order to be able to be a productive participant in knowledge work. The significance of collaborative efforts over and above individual efforts is seen as key for the advancement of knowledge. Paavola & Hakkarainen (2005, p. 536) further state that “a kind of epistemological shift is needed within teachers, educational psychologists, cognitive scientists, students and all other participants interested in developing the educational system to answer the emerging challenges”.

It is argued in the paper that a conception of learning adequate for a knowledge society should does not only address the transfer of knowledge from educator to students (acquisition metaphor), nor should it only address processes of socialization through communities and their values (participation metaphor). Though the above two metaphors are valuable, it is required to go beyond these two metaphors. They called the third approach “the knowledge-creation” metaphor “to indicate that it is a kind of individual and collective learning that goes beyond information given and advances knowledge and understanding: there is collaborative, systematic development of common objects of activity" (Paavola & Hakkarainen, 2005, p. 536).

A structured or guided based approach is generally used to guide the students towards open enquiry. The process starts with a teacher-initiated guided task. In the current study, tasks were given to the students and they were encouraged to work in groups. They were also encouraged to ask questions and to solve problems in their respective groups. According to the Vygotsky model of social constructivism, what children can do with the assistance of others is a greater indication of their mental development than what they may be able to do on their own. Students learn from their own questions as well as from the questions of other students. They are also required to do research work to find answers for the questions raised. To achieve effective learning, the students must make use of the correct learning strategies. The teacher will play a role in identifying and developing the right activity to guide the students towards effective learning. The teacher becomes the facilitator of the learning process. The teacher helps students learn the cognitive skills needed for problem solving and collaboration (Hmelo-Silver, 2004). In view of the foregoing, the theoretical framework of knowledge creation metaphor is directly applicable to GEBL.

1.20 Research Methodology

Research paradigm informs the choices about which research questions to address, and what methodology to employ (Okeke & van Wyk, 2016), the types of questions that are to be asked and the sorts of answers that are to be expected (Asiala, Brown, DeVries, Dubinsky, Mathews & Thomas, 1996). The paradigm used for this study is pragmatism. Pragmatists give more importance to actions than ideas and they believe that one learns by experimentation. Hence this paradigm was found to be appropriate for this study.

The quasi experimental non-equivalent group post-test only research design was used where both the experimental group and the control group are selected (without random assignment). Due to the time constraints arising from of the short duration of the semester courses it was decided to use the post-test only design. All students who participated in the study had passed the pre-requisite subject required to register for this course. Mixed method research approach was chosen as the mode of enquiry for the study. Quantitative data was collected from two formative assessments and one summative assessment and the qualitative data was collected by interviewing all students who were taught using the GEBL approach. Cronbach's Alpha was used to test the reliability of the instruments used in the study.

1.21 Limitations of the Study

Due to the small number of students enrolling for the course this study was restricted to a sample size of only 14 students. Traditionally students enrolling for the ND course in this institution come from similar social background. The campus culture, students' commitment and attitude as well as those of the lecturer could influence the outcome of this study. Everything possible was done to ensure that both students and the lecturer stayed committed and focused. Due to the study being done in one institution the findings may not be generalised and a much larger sample from different institutions may be carried out to satisfy the conditions for generalisability. Similarly as the students from both the experimental group and the control group come from the same campus, the likelihood of contamination effects are higher as the possibility of interaction between students cannot be monitored.

1.22 Outline of Chapters

Chapter one deals with a background to the study highlighting the problems that engineering education experiences globally and the reasons for this research. The problem statement, objectives of the study, theoretical framework, research question and sub-questions, significance of the proposed study, limitations and delimitations and rationale were presented and explained. A list with definitions of pertinent terms used, were listed.

Chapter two provides the pertinent literature related to this study. The terms deep learning and surface learning are discussed. The reason for selecting GEBL and outcomes for ND in Electrical Engineering (NDELEC) as specified by SAQA are explained. The impact of AL on the conceptual understanding, problem solving skills and critical thinking skills are discussed.

Chapter three deals with the research methodology. The research paradigm, research approach, research design and the modes of enquiry are explained. Details of the population, sampling and sample size, instruments and data collection are made explicit. A detailed explanation and discussion of how the intervention was introduced is provided together with a detailed description of the instruments.

Chapter four focuses on the data analysis, interpretation and discussions. The findings from the data and their implications for engineering education are discussed. Lessons learned from the research and the impact it had on Power Electronics education at the selected institution is also discussed.

Chapter five presents a summary of the research findings and concludes with recommendations. Recommendations based on the findings are made for future consideration and implementation for PE in the same institution in future and probably for use in other electrical engineering courses.

1.23 Definitions of Operational Terms

Active Learning: "…an instructional method which engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing" (Prince, 2004, p.223)

Conceptual understanding: A network connection of knowledge structures. Conceptual understanding is thus a student's ability to apply and connect what he or she is currently learning to prior learning and other related fields (Hiebert & Carpenter, 1992).

Conceptions: Meaningful features of knowledge specific to understanding a particular domain. Conceptions are in transition, and therefore often not fully developed, fragile and situation-bound (Leinhardt, Zaslavsky & Stein, 1990)

Conceptual Knowledge: Knowledge that is rich in relationships (Hiebert & Carpenter, 1992, p. 3).

Guided Enquiry-Based Learning: "…refers to an array of classroom practices that promote student learning through guided and, increasingly independent investigation of complex questions and problems. Rather than teaching the results of others' investigations, which students learn passively, instructors assist students in mastering and learning through the process of active investigation itself" (Lee, 2004, p.9).

Outcomes: "Anticipated or achieved results of programs or the accomplishment of institutional objectives, as demonstrated by a wide range of indicators such as student knowledge, cognitive skills, and attitudes" (Vlasceanu, Grunberg & Parlea 2007, p.63).

Traditional Teaching and Learning: "Traditional instruction in engineering and science frequently treats new courses and new topics within courses as self-contained bodies of knowledge, presenting theories and formulae with minimal grounding in students' prior knowledge and little or no grounding in their experience" (Prince & Felder, 2006, p.125).

Student-centred Learning: Refers to a wide variety of educational programs, learning experiences, instructional approaches, and academic-support strategies that are intended to address the distinct learning needs, interests, aspirations, or cultural backgrounds of individual students and groups of students (www.edglossary.org).

Experiential learning: Experiential learning is a method of educating through first-hand experience. Skills, knowledge and experience are acquired outside of the traditional academic classroom setting, and may include internships, studies abroad, field trips, field research and service-learning projects (www.edglossary.org).

Scaffolding: A variety of instructional techniques used to move students progressively toward stronger understanding and, ultimately, greater independence in the learning process (www.edglossary.org).

1.24 Summary

The study was introduced and the background of the study was sketched in this chapter. An overview of engineering education and the need for reform in the international context, African context and South African contexts was elaborated on. AL was proposed as a teaching and learning approach to improve the ability to recall, conceptual understanding, problem solving skills and critical thinking ability.

The research question, the purpose of the study and the significance of the study were stated. The problem, together with the rationale and the objective of the study, were identified. A brief overview of the research methodology and the delimitations of the study were explicated. The chapter concluded with a section containing the definition of operational terms used in the study. The next chapter presents a review of the related literature.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature pertinent to the study and elaborates on Bloom's Taxonomy, constructivism and deep and surface learning. The use of the AL approach to promote students' ability to recall, understanding of engineering concepts, problem solving and critical thinking skills are addressed. The use of assessments and the advantages and disadvantages of formative assessments and summative assessments are elaborated.

2.2 Bloom's Taxonomy

Bloom's taxonomy, developed by Benjamin Bloom in 1956, is a hierarchical model used to classify learning objectives and differentiates the increasingly varying complexity with which cognitive learning occurs. The research objectives in this study are guided by this taxonomy to measure the effectiveness of GEBL, in the learning of PE, at different levels of cognitive learning. Educators have generally used Bloom's taxonomy to develop curriculum and assessments.

Adams et al. (2015) use the example of knowing our multiplication tables by memorization versus applying them to solve a word problem. The learning of multiplication tables requires a qualitatively different type of thinking to the one required for applying multiplication skills to solve word problems. In both cases, a teacher could assess knowledge and skills by asking for the demonstration of those skills in action, by **"**doing**"** which is an observable and measurable activity. The classification system in Bloom's taxonomy incorporated these concepts to create a classification of cognitive skills. "This classification system has had significant and lasting influence on the teaching and learning process at all levels of education to the present day" Adams et al. (2015, pg. 152).

Six categories of cognitive skills are contained in Bloom's taxonomy. These cognitive skills which range from "lower-order skills that require less cognitive processing to higher-order skills that require deeper learning and a greater degree of cognitive processing" (Adams et al., 2015, pg. 152), as shown in the figure below.

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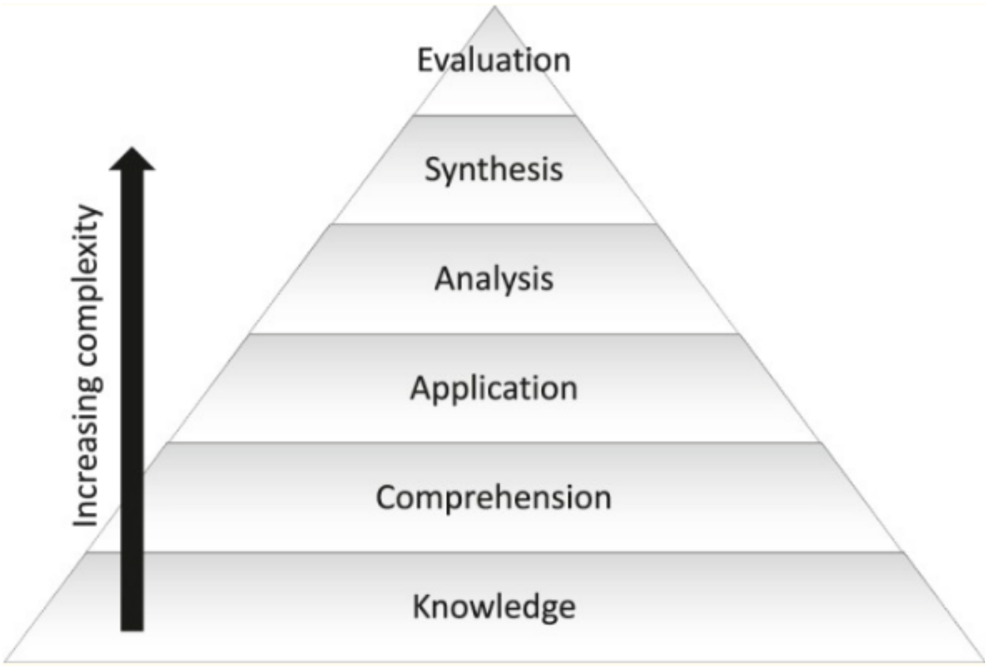


Source: Adams et al. (2015)

Fig. 2. 1 Bloom's Taxonomy

The Table below by Boles, Goncher & Jayalatha (2015) further defines the cognitive domains of Blooms Taxonomy.

Table 2. 1 Defining the Cognitive Domian of Bloom's Taxonomy

Level	Sublevels	**Definition** (Bloom, 1956; Anderson & Krathwol, 2001)
Knowledge	Specifics, Procedure and methodology, Principles and theories.	Student recalls or recognises information, ideas, and principles in the approximate form in which they were learned.
Comprehension	Interpretation, Translation, Estimation.	Student translates, comprehends, or interprets information based on prior learning.
Application	Recall, Comprehension, and Application	Student selects, transfers, and uses data and principles to complete a problem or task with a minimum of direction.
Analysis	Differentiate, compare/contrast, distinguish, relate.	Student distinguishes, classifies, and relates the assumptions, hypotheses, evidence, or structure of a statement or question.
Evaluation	Compare and Evaluate.	Student appraises, assesses or critiques on a basis of specific standards and criteria.
Synthesis/	Design, Construct,	Student originates, integrates, and combines ideas into a

Creating (revised, 2001)	Develop, Formulate	product, plan or proposal that is new to him or her.

Source: Boles, Goncher & Jayalath (2015)

“Knowledge”, the foundational level of the pyramid is the cognitive skill which recognises the retention and recollection of straighforward facts which are discrete in nature. Examples include definitions, or sequences of events. The next higher level in Blooms Taxonomy refers to “comprehension” which takes the knowledge gained and interprets it based on prior learning. This knowledge once applied to solve a problem advances the complexity further. As we move to higher levels of the taxonomy we see the learning objectives relating to analysis. At this level, the skills that we commonly think of as critical thinking enter. Distinguishing between fact and opinion and identifying the claims upon which an argument is built requires analysis. Following analysis is the level of “synthesis”, which entails creating an original understanding of a piece of information or situation. Finally, the pinnacle of Bloom’s taxonomy is evaluation, which is also important to critical thinking. When instructors reflect on a teaching session and use learner feedback and assessment results to judge the value of the session, they engage in evaluation.

The taxonomy is useful firstly to encourage instructors to think of learning objectives in such a way that it brings a about a change in the behaviour of the learner to achieve the intended objectives” Secondly, it encourages the instructor to frame learning objectives in a manner that requires higher levels of cognitive skills, encourages deeper learning and transfering of knowledge and skills which can be applied to various tasks and in differing contexts.

2.3 Constructivism

Most cognitive scientists now believe that the constructivist theory explains well how an individual learns –the theory is shaped by the idea that knowledge is constructed in the mind of the learner (Bodner, 1986). The two most common branches of constructivism found in the literature are, radical or cognitive constructivism and social constructivism. The main assertions of these two branches are discussed here.

2.3.1 Radical or Cognitive Constructivism

The work done by the famous cognitive psychologist, Piaget, in the 10 to 15 years prior to his death is considered to be the psychological basis of constructivism; here Piaget and his colleagues focused on the mechanism of learning rather than discussing global stages as descriptive of learning (Fosnot, 1996). Piaget proposed equilibration as the mechanism promoting change in cognition. He described equilibration as a process of self-regulated behaviour which results out of a balance between two intrinsic polar behaviors, assimilation and accommodation. Knowledge is constructed as the learner strives to organize his or her experiences in terms of pre-existing mental structures or schemes (Bodner, 1986). When a person integrates new stimulus events into existing schemata, the resulting cognitive process is termed as assimilation (Wadsworth, 1971). However, when the new stimulus does not fit into the existing schemata, the person can either create new schemata to place the new stimulus or modify an existing schemata to fit the new stimulus in it.

Even though both assimilation and accommodation results in learning, conceptual change occurs only when the person accommodates. However, for a person who always assimilates, most of the aspects would be seen as similar. On the other hand, if a person always accommodates, such a person would see most of the aspects as different. According to Piaget, a state of balance between assimilation and accommodation is necessary for proper intellectual growth and development; such a state of balance is known as equilibrium and the process by which an individual moves from disequilibrium to equilibrium is known as equilibration (Wadsworth, 1971).

The postulates of cognitive constructivism served as a guideline for many researchers in the design of conceptual change teaching strategies. Following the assertions of constructivism, when learners encounter experiences which conflict their predictions, conceptual change occurs. Vosniadou (2007) suggests the design of Hypothesis-Experiment-Instruction as an instructional strategy which could create the necessary conditions to produce cognitive conflict. Other examples for constructivist-informed teaching approaches are ‘authentic pedagog’ (Newmann & Associates, 1996), ‘child-centered teaching’ (Chung & Walsh, 2000) and ‘The Learning Cycle’ (Atkin & Karplus, 1962). According to Palmer (2005), there are three components which are necessary for constructivist-informed teaching – firstly, the selection of concepts that represent challenge, without the need for extended sequences of learning activities, secondly, the use of dual-purpose teaching techniques, which promote scientific ways of thinking as well as motivation, and lastly, a classroom climate that encourages positive motivational beliefs.

2.3.2 Social Constructivism

Piaget described learning as a cognitive process that adheres to a system of explanations of how learners, as individuals, impose intellectual structure on their worlds (Piaget, 1971). On the other hand, social constructivists see learning as increasing one's ability to participate with others in meaningful activities; according to them knowledge has both individual and social components that cannot be viewed as separate entities (Cobb, 1994). The social dimensions of learning are well explained by Lev Vygotsky in the dialectic between the individual and society; thus, the effect of social interaction, language and culture on learning was the main focus of Vygotsky's work (Fosnot, 1996).

According to Vygotsky, scientific concepts originate in the structured activity of classroom instruction. Moreover, scientific concepts cannot be transmitted to the learner simply with language. There are two different levels of development (Vygotsky, 1978): Zone of actual development and zone of proximal development. The level of development of a child's mental functions that have already been established as a result of certain completed developmental cycles was defined by Vygotsky as the zone of actual development. However, what a child can do with the assistance of others for the first time, s/he will be able to do alone tomorrow; thus, there is a distance between the actual developmental level determined by independent problem solving skill and the level of potential development determined through problem solving in collaboration. This distance is named by Vygotsky as the zone of proximal development.

The main focus Vygotsky has given to the mechanism of learning is the role of the adult and the learners' peers as they conversed, questioned, explained and negotiated meaning (Fosnot, 1996). Thus, social constructivism views knowledge as primarily a cultural product (Vygotsky, 1978); knowledge is shaped by micro- and macro-cultural influences and evolves through increasing participation within different communities of practice (Cole, 1990; Scribner, 1985; Windschitl & Sahl, 2002). According to the social constructivist point of view, a major role of schooling is to create the social contexts for mastery and the conscious awareness of the use of cultural tools so that individuals can acquire the capacity of higher order intellectual activities (Olson, 1986).

Table 2. 2 Constructivist versus Traditional Approaches to Teaching & Learning

Constructivist Instructional Approach	**Traditional Instructional Approach**
Knowledge is subjectively perceived by learners through an active process of construction. Knowledge acquisition is dynamic, multidimensional and systematic.	Knowledge is external to learners and can be objectively specified through representations of various forms. Knowledge acquisition is static, linear and systematic.
Learning is to construct an internal representation of knowledge, a personal interpretation of experience, and therefore an active process of sense-making.	Learning is to transfer some mind-independent entities into the learner through mediation of fixed cognitive structures like plan or schema.
Teaching is to enable learners to experience and manipulate knowledge construction process, and to appreciate multiple perspectives.	Teaching is systematic transmission of knowledge and skills progressing from simple to complex, maximising the communication of fixed concepts.
Ongoing dynamic interaction of the whole system of knowledge and skills defies a reductionist analysis (holistic approach).	Task analysis enhances mastery learning by reducing knowledge and skills to sequences and hierarchies (atomistic approach).
The goal is to teach learners how to think like an expert. Specific objectives emerge and are realised when individual learners solve authentic tasks.	The goal is to make learners attain certain pre-specified performance criteria (e.g. apply the principles of a domain).
Focusing on heterogeneous characteristics of learners.	Focusing on homogeneous characteristics of learners.
Individual differences are inherent in learning and of central concern.	Individual differences are undesirable and difficult to incorporate in instructional programmes.

Metacognitive ability is essential for constructing understanding of a knowledge domain.	Metacognitive skills lead to deviation from prescribed instruction and unpredictable outcome.
Dynamic, changing situations of learning defy predictability of instructional outcome as plausible reasoning situated cognition does allow people to solve real-world problems without using formal academic logic.	Instructional outcomes are predictable because what people learn is relatively stable across situations in which it is used, and people apply what they have learned in logical and planful ways.
Individual differences and metacognitive ability of students render the replicability of instruction questionable.	Iteratively tested-and-revised instructional prototypes can be applied across content domains, contexts, time and students of various characteristics.

Source: Lai-chong & Ka-ming (1995)

2.4 Deep and Surface Approaches to Learning

Marton and Saljo (1976) reported on the different approaches to learning. When students were given an academic text to read, and told that they would be asked questions on it later, it was found that the students adopted two different approaches to learning.

> The first group adopted an approach where they tried to understand the whole picture and tried to comprehend and understand the academic work. These students were identified with adopting a deep approach to learning. The second group tried to remember facts contained within the text, identifying and focusing on what they thought they would be asked later. They demonstrated an approach that we would recognise as rote learning, or a superficial, surface approach (Houghton, 2004, p. 9).

Houghton (2004) states that deep learning leads to long term retention of concepts that assist in problem solving in unfamiliar contexts. In this approach, new ideas are critically analysed and linked to already known concepts and principles which in turn lead to a deep learning. Houghton compares this to surface learning, where information is tacitly accepted and memorised as isolated and unlinked facts. Surface learning therefore does not contribute to the long-term retention of knowledge and information.

Hougton (2004) continues to state that educators should design learning opportunities in ways that encourage students to adopt more beneficial learning approaches. In designing approaches that encourage deep learning, Houghton says that one of the most important factors is the assessment method. For example, short questions testing seperate ideas will encourage surface learning. However, simple questions that require students to demonstrate linkages to previously learnt ideas and concepts lead to application of the knowledge gained. This type of assessment promotes deep learning.

The process of learning therefore becomes important. In a field like engineering Houghton states that attempting to learn complex principles without a good grasp of basic principles leads to frustration and a surface learning approach. Here, students memorise solutions to complex problems they cannot understand.

The following table (Table 2.3), developed by Houghton, is compiled from the work of Ramsden (1992), Biggs (1999) and Entwistle (2003) provides valuable characteristics of the approaches illustrating the importance of managing curriculum impacts on the learning process. It illustrates that clearly stated academic aims, opportunities to exercise choice and well aligned assessment strategies help to build students' confidence and encourage deep learning.

As seen in the table, deep learning assists in making links between old and new ideas. This helps in developing a better understanding of concepts learned and contributes towards long term retention and remembering of concepts. Deep learning also enables students to identify information and evidence given in a problem which assists in the problem solving process. Deep learning assists in making connections between different modules and in developing an intrinsic curiosity in the subject learned. This helps students to mentally engage during academic work and promotes critical thinking. Active learning strategies like GEBL promote deep learning and hence would enable the achieving of learning outcomes especially in engineering where problem solving and critical thinking are of utmost importance.

Table 2.3 Comparison of Deep Learning and Surface Learning

	Deep Learning	Surface Learning
Definition	• Examining new facts and ideas critically, and making numerous links between old and new ideas.	• Accepting new facts and ideas uncritically and attempting to store them as isolated and unconnected items.
Characteristics	• Looking for meaning. • Focussing on concepts needed to solve a problem. • Interacting actively. • Distinguishing between argument and evidence. • Making connections between different modules. • Relating new and previous knowledge. • Linking course content to real life.	• Focussing on outwards signs and the formulae needed to solve a problem. • Receiving information passively. • Failing to distinguish principles from examples. • Treating parts of modules and programmes as separate. • Not recognising new material as building on previous work. • Seeing course content simply as material to be learnt for the exam.
Encouraged by Students'	• Having an intrinsic curiosity in the subject. • Mentally engaging when doing academic work. • Having the appropriate background knowledge for a sound foundation. • Positive experience of education leading to confidence in ability to understand and succeed.	• Studying a degree for the qualification and not being interested in the subject. • Not focussing on academic areas, but emphasising others (e.g. social, sport). • Lacking background knowledge and understanding necessary to grasp material. • High workload and anxiety. • Cynical view of education, believing that factual recall is what is required.
Encouraged by Teachers'	• Showing personal interest in the subject. • Bringing out the structure of the subject. • Concentrating on key concepts. • Confronting students' misconceptions. Engaging students in active learning. • Using assessments that require thought, and expects ideas to be used together. • Relating new material to what students already know and understand. • Allowing students to make mistakes without penalty and rewarding effort. • Being consistent and fair in assessing declared, intended learning outcomes, and hence establishing trust.	• Disinterest or even a negative attitude to the material. • Presenting material so that it can be perceived as a series of unrelated facts and ideas. • Allowing students to be passive. • Assessing for independent facts (short answer questions). • Rushing to cover too much material. • Creating undue anxiety or low expectations of success • Having a short assessment cycle.

Source: Adopted from Houghton (2004).

2.5 Active Learning (AL) Approaches

According to Pesavento, Bator and Ross (2001), AL can take many forms and follow different models, with many of the approaches having areas of overlap and focussing on student-centred instruction and course learning objectives. Hazzan and Lapidot (2004) highlight Silberman's (1996) assertion that above all, students need to 'do it' – figure things out by themselves, come up with examples, try out skills, and do assignments that depend on the knowledge they already have or must acquire.

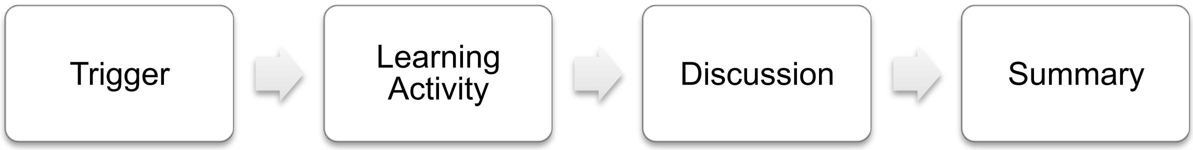
Referring to contstructivist educators such as Kilpatrick (1987), Davis (1990), and Confrey (1995), Hazzan, Lapidotet and Ragonis (2014) describe constructivist learning as an active acquisition of ideas and knowledge construction which requires the individual to be active and to be engaged in the construction of one's own mental models. Winterbottom (2015) describes some of the other terms associated with AL to include:

- **Student-centred**, or **learner centred learning** – where students play an active role in their learning and teachers serve as the activators of learning.
- **Enquiry-based, problem based** or **discovery learning**, where learners learn by addressing scientific questions, analysing evidence, connecting evidence to prior knowledge, drawing conclusions and reflecting upon their findings.
- **Experiential learning**, which describes an individual learning from direct experience.

Winterbottom (2015) goes on to state that AL fosters understanding rather than rote learning of facts, which students can then apply to diverse contexts and problems. This approach gives students greater autonomy, involvement and control over their learning process. The method also gives the learner better ability to revise for examinations through the process of re-visioning' ideas that they already understand.

In the United States (US), North Carolina State University established a highly collaborative, hands-on, computer-rich, inter-active learning environment for large, introductory college courses called SCALE-UP. In the calculus-based introductory physics part of their study, they found that students' attitudes improved, their conceptual understanding and their problem solving abilities improved significantly, the success rates were higher than those achieved when compared to traditional instruction, particularly for females and minorities (Beichner, 2008).

Hazzan et al. (2014) identify a four stage AL Based Teaching Model, designed in this case for the Methods of Teaching Computer Science Course which prepares prospective computer science teachers – see Figure 2.2 below.



Source: Hazzan et al., 2014

Fig. 2. 2 Active learning based teaching model

The first stage: described as the trigger, follows the constructivist perspective and introduces an open ended activity which has the potential to raise an array of questions, dilemmas, attitudes and perceptions in relation to a particular learning objective. The activity is done individually, in pairs or in small groups. The open ended nature of the trigger is intended to prepare teachers to consider multiple reaction options.

In the activity stage, students work on the trigger presented to them, in this case solving the problem that has been presented. The students work either individually, in pairs or in small groups. In the third or discussion stage, the entire class is gathered and during this stage- the products, topics and thoughts emerging from the activity stage are presented to the entire class and discussed. This stage enables the refining of the understanding of concepts, ideas and attitudes leading to the construction of professional perceptions. The instructor highlights principles derived from ideas generated without judging students' positions and opinions and classmates are encouraged to express constructive criticism of the different ideas and materials presented.

In the final stage of the model, the instructor plays the leading role where the topic is put into the context of the course, emphasizing the central concepts that were discussed. The instructor summarizes key concepts, teaching ideas and conceptual frameworks that were raised and discussed during the previous three stages.

2.5.1 Enquiry-Based Learning (EBL)

Anderson (2002) avers that enquiry refers to a learning process in which students are engaged. It is an AL process where both educators and students share responsibility for learning (Anderson, 2002; Capacity Building Series [CBS], 2013). EBL is a creative approach of combining the best approaches to instruction, including explicit instruction and small-group and guided learning. This is done in an attempt to build on students' interests and existing ideas, ultimately moving students forward in their paths of intellectual curiosity and understanding. One of the challenges of EBL is to move students beyond initial curiosity to a path of regular enquiry. In this process, educators play an important role. Educators are responsible for starting the enquiry process, promoting student dialog and intervening to clear misconceptions or developing students' understanding of content material (CBS, 2013; Warner & Myers, 2014).

Though the process is student-centred, fostering critical thinking, reflection and self-criticism, team-work, independence, autonomous thinking and information literacy, EBL is motivated by facilitation, which is designed to provide appropriate forms of support (Hutchings, 2007).

2.5.2 Guided Enquiry-Based Learning (GEBL)

Nilson (2016) states that the GEBL method requires students to engage in higher order thinking which typically involves knowledge acquisition and comprehension, analysis of information or data, evaluation of evidence and the application of findings to solve a problem as well as synthesise resolutions. As Bransford, Brown & Cocking (1999) aver, the inductive nature of GEBL renders it a powerful learning method. Nilson (2016) further states that when compared to lecture-based instruction, GEBL fosters greater student academic achievement and improves their critical thinking, problem solving, and laboratory skills. "For this method to be effective, students must have sufficient guidance and scaffolding through the inquiry process - that is, explicit directions about what to do and how to do it, assuming they are dealing with new material" (Nilson, 2016, p. 176).

Nilson (2016), in a study identifies two forms of guidance to help students in the learning process. The first form includes worked examples which provides procedures and logic for working through problems. Worked examples assist students to learn more before being able to solve similar problems by themselves. The second form includes the process work-sheets which provide a sequence of steps to follow for problem-solving. They help students to identify the information provided, classify the problem and perform other prescribed steps for reasoning through the type of problem.

Lee (2012) states that in recent years learning outcomes have become the starting point for planning courses, curricula and assessments to ensure accountability in higher education. Most universities identify problem solving, critical thinking and desire for lifelong learning as important outcomes. GEBL promotes these outcomes and associated skills like formulation of good questions, analyse and interpret the evidence provided and to identify and justify solution to the problem (Lee, 2011 & Lee, 2012). Thus GEBL, which is a subset of active learning strategies, promotes independent investigation of questions, problems, information and evidence provided which enables attainment of new knowledge, skills, abilities and attitudes which equip students for the requirements of the workplace.

2.6 Active versus Traditional Approaches to promote students' ability to Remember and Recall

Markant et al. (2016) state that for over more than half a century, educational theories have taken forward the notion and benefits of being active during learning as compared to learning through passive methods. Markant et al. (2016) state that theories including discovery learning (Bruner, 1961), inquiry learning (Kuhn, Black, Keselman & Kaplan, 2000), experiential learning (Kolb, 1984), constructivism (Steffe & Gale, 1995), and self-regulated learning (Boekaerts, 1997) leads to improved outcomes.

This claim is supported while comparing AL with more traditional forms of passive, lecture-based teaching (Bonwell & Eison, 1991; Freeman et al., 2014). Markant et al. (2016) observe that methods of AL have grown to include various instructional techniques which combine increased interaction, deeper processing and explanation of material, asking of questions, planning of learning activities and social collaboration. Current research also suggests that metacognitive monitoring also affects learning (Loizidou & Koutselini, 2007). Metacognition has been defined as the ability to monitor, evaluate, and make plans for one's learning (Flavell,1979; Brown,1980).

Markant et al. (2016) argue that because of the multiple ways in which AL takes place, it is often unclear why AL succeeds and also difficult to identify the causes that lead to performance. They continue to say that one approach for understanding the effects of active instruction is to identify how it engages underlying cognitive processes related to learning and memory (Gureckis & Markant, 2012). It is noted in the above work that the principle highlighted and shared by various researchers is that students should have the opportunity to be able to control their learning experience, including the selection, sequencing and pacing of new information. The study highlights a set of mechanisms through which active control influences memory, and which are diminished or absent during passive, observational experience and approaches to learning.

Greenberg, Keane, Ryan and Verfaellie (2009), define episodic memory as a category of long term memory that involves the recollection of specific events, situations, and experiences. Markant et al. (2016) state that Anderson and Bower (1973), Craik and Tulving (1975), and Tulving and Thomson (1973) have all found that a basic function of episodic memory is to make associations between different features of an experience, which then forms the basis for later recollection. They propose that retrieval of a specific element of memory is "more likely when it is involved in a rich network of associations than when it is encoded in isolation" (Markant et al., 2016, p.3). The example used to describe this was that it would be easier to remember what was eaten for breakfast when other features of the same event could be recalled, e.g. the morning news report that was playing in the background at the time.

Markant et al. (2016, p.3) also concur with the view by Hommel (2004) that actions involved in exploration may play a role in memory recall by generating additional cues as stimuli e.g. "the physical act of exploring—moving to a new location, manipulating an object, searching for a toy in a bin, and the like—leads to a richer episodic representation that increases the likelihood of retrieving information about experienced stimuli from memory". A further view developed by Gibson (1962), states that the act of *obtaining* a stimulus through physical exploration is 'encoded' in the memory for an event and provides additional prompts that can facilitate later remembering as compared to that same stimulus being *applied* externally. This is also demonstrated in the research carried out by Trewartha et al. (2014).

A third factor which influences memory, referred to by Markant et al. (2016) as attentional control, is the level of control exerted by a learner in the learning process as well as the pacing or speed at which information is processed. “In many interactive environments, active control implies that learners can adjust the pacing of new information to match their own attentional state. In contrast, passive observers may experience momentary lapses in attention (e.g., because of mind wandering or continued processing of earlier information) coinciding with the presentation of new material” (Markant et al., 2016, p. 4). In a recent study by Markant, DuBrow, Davachi, and Gureckis (2014), it is highlighted that this attentional co-ordination during actively controlled learning leads to improved memory for materials encountered during exploration.

Markant et al. (2016) also state that the results of episodic encoding depend on attentional control, because memory performance declines when attention is divided during the process of encoding (Craik, Govoni, Naveh-Benjamin & Anderson, 1996). Whereas, retention improves when the amount of time spent encoding each item is self-paced (Craik, Naveh-Benjamin, Ishaik & Anderson, 2000), the results from the study carried out by Craik et al. (2000), suggest that activities in which the flow of information is external or independent of the learner’s control, such as that in the case of passive observation, the episodic memory will be poorer as compared to a case where the learner is actively in control of the pace at which new knowledge is absorbed.

A fourth factor in enhancing memory, outlined by Markant et al. (2016) is metacognitive monitoring. Grainger et al., (2016) define metacognition as consisting of two processes, viz. monitoring processes - the ability to accurately represent one’s own mental states and control processes - the ability to control one’s cognitive processes. Both these processes are seen as playing a vital role in self-regulated learning. Markant et al. (2016) state that the metacognitive monitoring involved in making study decisions may itself facilitate memory, especially when these processes attempt to retrieve information from memory. According to Kimball and

Metcalfe (2003), Roediger and Karpicke (2006) and Karpicke (2009), the process of retrieving information from memory is shown to be more effective than re-presentation of the same item in the absence of a retrieval attempt. Markant et al. state that a further benefit of active control may be that it naturally encourages students to engage in metacognitive monitoring. Dunlosky, Rawson, Marsh, Nathan, and Willingham (2013) highlight that maximizing the benefits of active control may depend on training students in study strategies that improve memory, by way of designing AL tasks that directly engage metacognitive decision making.

In terms of determining the right balance between learner control and structured guidance in educational settings, the study by Markant et al. (2016) confirms the following:

(a) In relation to passive observation, active control has positive effects on memory across a wide range of activities and student populations;
(b) Interactive, simulation based instruction (De Jong et al., 2013) and controlling how to study through active enquiry has a powerful influence on memory and learning, though it is mentioned that the strategies for structuring learning events increase with the level of experience of the active learner;
(c) The evidence also suggests that the complete absence of control during learning results in a less memorable learning experience where learners engage in unnecessary searches at the expense of meaningful learning (Mayer, 2004; Kirschner et al., 2006);
(d) Although active instruction and how it is implemented is greatly variable, the extent of influence of the content guidance in relation to individual difference among students is unclear;
(e) Identifying how AL interacts with episodic memory is an important step toward understanding and predicting its benefits and one that poses further open questions for basic research.

There have also been other studies using AL in engineering education. Getty (2009) alludes to a full-year Laboratory Electronics sequence at Montana State University (MSU). It was an introduction to DC and AC electric circuits, controlled sources (such as operational amplifiers), and time-varying signals and their interaction with the reactive elements, capacitors and inductors. The views gathered from physics-by-inquiry methodology was used to modify the curricula. The purpose of the project was to determine if the new method improved retention, understanding and problem solving skills among students. From earlier observations it was identified that students had misconceptions in the mental model of voltage and current. Getty (2009) further states that with studies showing misconceptions could be extinguished, attention was given to finding ways to measure the expected improvement.

During the first three weeks learning was carried out entirely in the three-hour laboratory sessions. McDermott's "Physics by Inquiry" curriculum was used to cover Ohm’s and Kirchhoff’s laws. The students took pre-test to help assess the effectiveness of the improved curriculum. In the fourth week the class returned to the traditional lecture method where the concepts of element and circuit constraints via Kirchhoff’s laws were introduced. The idea was to connect the prior knowledge from the first three weeks with the concepts learned in the fourth week. Getty (2009) states that the goal was to continue to provide the students with the required understanding of circuit analysis, including voltage and current division techniques. The students were supported to develop an accurate mental model of voltage and current. Various assessment methods were used to collect data to determine the effect of the improved curricula on students’ performance. Formative and summative assessment methods were used to assess the performance. Individual assessment was conducted using knowledge inventory instrument, Determining and Interpreting Resistive Electric circuits Concepts Test (DIRECT) which is a practical test (Engelhardt & Beichner, 2004). DIRECT was designed to evaluate understanding and misconceptions in students about electric circuits.

DIRECT instrument showed an improved performance by students from the treated group when compared to the students from the untreated population. Though the t-test result came very close to be statistically significant, the small sample size made it impossible to make this claim. The results from the study showed an improved ability in physics students to qualitatively evaluate electric circuits by introducing inquiry method into the course. Getty (2009) observes that even short exposures to inquiry methods encourage students to develop models that are useful in solving qualitative circuit problems. Data required to measure the effect of inquiry method on students' ability to solve quantitative problems were not obtained. The results from the study indicate that implementation of inquiry methods in university courses significantly contribute towards extinguishing common misconceptions. It also helps in improving the long term recall and understanding of the learning material (Getty, 2009).

2.7 Active versus Traditional Approaches to promote students' Conceptual Understanding of PE Concepts and Principles

PE is an important course in Electrical Engineering. The Traditional Approach with lectures, practical exercises and laboratories shows that many students have difficulties in learning Power Electronics. In this approach students play a very passive role. In order to overcome this problem, at the School of Technology of the Polytechnic Institute of Setubal in Portugal, an advanced PE course was introduced with a different teaching approach. In this approach the teaching is in the form of learners self-learning. Learners were expected to do research work and develop a power converter prototype in the lab. At the end, each group of students did a small chapter to develop a book with all the works. A questionnaire was made in order to confirm if this system was effective. 90% of the learners said that this system was much more effective than the traditional approach. 75% of learners said that their communication skills improved. (Pires, Pires & Dias, 2011)

The use of active methodologies based on student learning facilitates the development of competences and skills. One of the methodologies for continuous learning used in engineering education is the PBL approach alluded to earlier. It allows students to gain a better understanding of difficult concepts and promotes the retention of the knowledge acquired for a long period of time (Lacuesta, Palacios & Fernande, 2009).

In the University of Cordoba, Spain a change in paradigm from lecture teaching to student learning using AL methodology was successfully carried out for PE courses. The university has carried out many experiments with the aim of adapting teaching methodologies. Satisfaction surveys showed an approval of the adopted AL methodology (Flores-Arias, Moreno-Munoz, Bellido & Linan, 2010).

The AL Approach was introduced at Riga Technical University, Baltics to improve quality of the PE course. The evaluation results showed that the students had a better understanding of the topics covered in the workshop and students gave the feedback that the teaching method of the workshop was interesting and exciting (Avotins et al., 2013).

Another study by Kock, Taconis, Bolhuis and Gravemeijer (2015) focused on Grade 9 students' understanding of concepts in direct current electric circuits. The aim was to test the students' ability to interpret the circuit diagrams, the ability to distinguish the concepts of electric current, voltage and resistance in simple circuits and to explain the role of battery/power supply in the circuit. The instructional material was designed by the researcher and three physics teachers and contained brief instruction, research questions and some circuit diagrams for experiments. The expectations from students were clearly stipulated in the material. The teachers took the student ideas and whole-class discussion was used to build on these ideas. This stimulated student thinking and enabled deeper understanding and kept students interested in the inquiry process. The analysis of data collected from the study showed an increased student conceptual understanding.

2.8 Active versus Traditional approaches to promote students' Problem Solving Skills

Team-based learning (TBL) is a learner-centred instructional strategy which has the potential to promote AL and improve students' problem-solving skills, knowledge and practice performance (Thompson, Schneider, Haidet, Levine, McMahon, Perkowski & Richards, 2007; Kim, song, Lindquist & Kang, 2016).

In studying the learning outcomes and problem-solving abilities of Korean nursing students, instructed in two groups over a three week period, the first being a control group of 31 learners taught using traditional lecture based methods vs a second group of 32 learners who used the TBL method, it was found that problem solving ability tested after the period of three weeks was higher in the TBL group when compared to the same students' abilities at baselines, prior to the students being exposed to the two teaching strategies (Kim et al., 2016).

Mason and Singh (2010), describe a study in which algebra based introductory physics groups were divided into Peer Relection (PR) groups and groups taught in the traditional manner. The PR group was provided guidance and support where they were required to reflect upon problem solving both with their peers as well as graduate and undergraduate teaching assistants. The second group of students attended classes run in a traditional manner with a quiz at the end of each class.

In the PR group, small teams reflected on selected problems from their homework and discussed different problem solving strategies from the team and why some strategies were better than others. At the same time guidance and coaching from teaching assistants was provided to help the students learn through trial and error effective problem solving methods.

Research by Kaput (1985) and Larkin (1989) show that converting a problem from a verbal representation to a diagrammatic, tabular, graphical or algebraic representation can make analysis of the problem easier. Mason and Singh (2010) also find that there is a positive correlation between the number of diagrams drawn and the final exam performance of students.

Gick and Holyoak (1987) and Singh (2009) have found that using analogies and considering limiting cases are also useful strategies for solving problems. Mason and Singh (2010, p.2) state that "without guidance, most textbook problems do not help students monitor their learning, reflect upon the problem solving process and pay attention to their knowledge structure… students do not perceive problem solving as an opportunity for learning to interpret the concepts involved and to draw meaningful inferences from them. Instead, they solve problems using superficial clues and cues, and apply concepts at random without concern for their applicability."

Chi et al. (1989) , Hardiman, Dufresne and Mestre (1989), Dufresne et al. (2005), and Singh (2009) state that quantitative and conceptual problem solving can enhance problem solving and reasoning skills, when students use effective problem solving strategies rather than treating tasks purely as a mathematical chore or guess-work. They state that with explicit training, problem solving tasks can be turned into learning experiences that help students organize new knowledge coherently and hierarchically.

Mason and Singh (2010), say that the abstract nature of the laws of physics and the chain of reasoning required to make meaningful inferences make it even more critical to teach students effective methods and strategies for problem solving. Chi et al. (1989) found that, students who constantly explained to themselves what they were reading and made an effort to connect the material read to their previous knowledge performed better on problem solving.

In addition to the above, Mason and Singh's research also found that the second activity that helped students learn effective problem solving strategies was reflection with peers. The process of reflecting on solutions and discussing their own answers as well as their peers responses through peer interaction and engagement led to greater problem solving effectiveness.

Mason and Singh (2010) state that this peer interaction strategy keeps students alert during lectures and helps them monitor their own learning. Through the processes of discussing and answering questions as well as explaining their answers to peers, students keep themselves actively engaged in the learning process. This also lets them take advantage of each other's strengths as well as helps them organize and solidify the concepts learned in their minds. Marzano et al. (1988) state that peer-reflection processes sustained throughout the semester requires students to evaluate their solutions and those of their peers leading to a high level of mental processing. Heller et al. (1992) have also shown that group problem solving is valuable both for learning physics as well as for developing effective problem solving strategies.

Research by Singh (2009) has shown that, even with minimal guidance from the instructors, students can benefit from peer interaction. In their study, those who worked with peers outperformed a similar group of students who worked alone on the same task. It was also found that collaboration with a peer led to what is termed as "co-construction" of knowledge in 29% of the cases. Singh states that co-construction of knowledge occurs when peer collaboration leads to the solving of problems on an individual basis in a post-test, where neither was able to answer the questions before the collaboration.

2.9 Active versus Traditional Approaches to promote students' Critical Thinking Ability

Ennis (1987) describes critical thinking as reasonable, reflective thinking which enables one to decide what to believe or do. Ennis identifies critical thinking dispositions which reflect a commitment and inclination to act critically. These characteristics include trying to be well informed, using credible sources, searching for reasons, looking for alternatives, having an open mind and trying to be as precise as possible. Ennis (1987) further describes the cognitive abilities that enable one to rationally decide what to do or believe to include focussing on one question, asking or clarifying challenging questions, analysing arguments, assessing the credibility of sources, making and assessing observations and inferences and deciding a course of action.

In line with Ennis's definition above, Hatcher (2011) define critical thinking as thought which seeks to achieve judgement after alternatives have been clearly and accurately assessed and considered, respecting the arguments and evidence available. The importance of research that provides evidence to support or rebut an argument before making a judgement is seen as critical, together with the assessment of alternatives and differing points of view. The ability to think and act rationally, impartially and with objectivity as well as the openness to change a position in the light of new information or evidence, are all seen as key to the critical thinking process.

Teaching critical thinking as an important life skill has gained significance as a crucial component of general education (Halpern, 2001; Roksa & Arum, 2011). Critical thinking is also viewed as a key competence for many medium- and high-complexity jobs (Peterson, 1997). Critical thinking is an under-graduate attribute that engineering courses claim to produce in students and is seen by academics as a particularly desirable outcome of student learning. It is said to be an important characteristic of university education by researchers (McRuairc et al., 2012).

However, although there is a high value placed on teaching critical thinking, the actual effectiveness of higher learning institutions in teaching critical thinking remains disputed (Huber & Kuncel, 2016). Their study suggests that students make substantial gains in critical thinking during college and that college attendance strengthened the effects of critical thinking. However, Huber and Kuncel (2016) continue to say that despite the effects of college education on critical thinking, it may be the case that critical thinking increases naturally with age and that some of the observed changes may not necessarily be due to college education. The findings however suggest that larger gains in critical thinking could be achieved by focussing on effective types of intervention. It is noted that when considering educational interventions, the amount of value added relative to other potential investments must be evaluated. For example, the time spent teaching critical thinking is time taken away from the teaching of other key domain specific skills, such as reading, writing, mathematics, and or profession-specific knowledge. It is emphasized that although the teaching of domain-general critical thinking is helpful, it is unlikely that it will provide a solution to all problems.

Defining the construct of critical thinking has also been problematic. McPeck (1984) argued that the ability to think critically about a broad range of domains is not possible with the acquiring of a general skill (such as analyzing arguments), and concluded therefore that critical thinking ability should be conceptualized as a domain-specific skill. However, McMillan (1987) and Pascarella (1989) state that the traditional generalist view of critical thinking conceptualizes it as a broad ability to interpret information and approach problems correctly, and that it can be applied across a wide variety of domains. There are therefore conflicting view. Personal experiences in teaching for several years however show that McPeck (1984) is favoured.

Development of critical thinking skills in Higher Education in general and engineering education in particular has been the subject of research and the South African regulatory bodies on engineering education have also identified it as a pertinent component in South African Higher Education (see for example Ceylan & Lee, 2003; Felder & Brent, 2003; Stein, Haynes & Unterstein, 2003; Lacuesta et al., 2009;

Felder, 2012; McRuairc et al., 2012; Benjamin, Klein, Steedle, Zahner, Elliot & Patterson, 2013; CHE's report, 2013).

Critical thinking skills are required in personal and professional life and are especially important to engineering education and engineers. It helps in solving problems and designing products, systems and processes. Improved critical thinking skills would result in increased ability to comprehend a problem and to identify key parameters in a problem. Analysis of complex engineering problems can substantially improve with higher levels of critical thinking and would provide higher quality solutions. (Benjamin et al., 2013). There are critical thinking appraisal tests, such as ACT tests and Watson-Glaser Test which could be used to assess the levels of critical thinking (Ceylan & Lee, 2003).

There is a clear need for standardized assessments that measure critical thinking skills. Performance assessments like the Collegiate Learning Assessment (CLA) evaluate whether students are learning the critical-thinking skills required of today's workforce. Such assessments also spur educational advances in pedagogy. The CLA presents students with the type of problems they would encounter in the real world. Students are then asked to generate solutions to these problems. The assessment enables to evaluate the level of critical thinking (Benjamin et al., 2013). Multiple-choice and short-answer tests are commonly used to test the critical thinking skills. In the United States, they are used extensively by the Educational Testing Service (ETS) and the College Board.

To evaluate critical thinking skills, Stein et al. (2003) administered the test in two different courses in junior level classes. The course for the experimental group was specifically designed to improve students' critical thinking and problem solving skills. The other course served as the control group. Students from both courses took the pre-test during the first two weeks of the course. The post-test was administered during the last week of classes which was after approximately 13 weeks. The pre-tests and the post-tests were scored by the same group of academics. Sixteen students from the control group took both the pre-test and post-test. The test-retest reliability coefficient=0.6, $p<.01$ showed that there was no significant change in the performance of students between the pre-test and the post-test. The test performance was remarkably similar between the pre-test and the post-test in the control group. Nineteen students from the experimental group took both the pre-test and post-test. A significant improvement ($p<.05$) was observed between scores on the post-test and scores on the pre-test for students from this group. The pre-test and post-test evaluations of these two courses indicate that the CAT Critical Thinking Test may be sensitive enough to identify the positive effects of a course on a student's critical thinking and problem solving skills.

In researching the significance of critical thinking in science education Vieira and Tenreiro-Vieira (2016) researched the significance of both critical thinking (CT) and scientific literacy (SL) in teaching science. Their research found that the two together formed key components in science education, preparing students to think and function responsibly in a world progressively influenced and affected by science and technology (S&T). Vieira and Tenreiro-Vieira (2016) state that students should be given opportunities in their science classes to engage in learning experiences that promote SL and CT. Vieira and Tenreiro-Vieira (2016) quote Rocard, Csermely, Jorde, Lenzen, Walberg-Henriksson and Hemmo (2007) and the National Research Council (2012) that several recent international science education reforms have included scientific literacy, science practices, critical thinking and socio-scientific issues as learning outcomes.

2.10 Teaching Approaches to enhance understanding to bring about competence with the relevant technology in the Industry

Avotins et al. (2013) suggest industry typically demands graduates with certain practical skills and design abilities, closer to technology application in order to solve different automation problems in industry or new product development. According to Lacuesta et al. (2009), learning models based on competences will facilitate the integration of students into the professional world, allowing further integration into the society, where learning is a necessity. In this scenario, a change in teaching methods will be necessary; new methods of work must not be based on teaching (focusing on the lecturer) but on learning (student-centred). The following Table outlines the major teaching methods found to be effective for helping students achieve different learning outcomes.

Table 2. 4 Major teaching methods for different learning outcomes.

Outcome Method	Knowledge	Compre-hension	Application	Analysis	Synthesis	Evaluation
Lecture	**X**					
Interative Lecture	**X**	**X**				
Recitation	**X**	**X**				
Directed Discussion		**X**				
Writing/ Speaking Excercises	**X**	**X**	**X**	**X**	**X**	**X**
Classroom Assessment Tech.		**X**	**X**	**X**		**X**
Group Work Learning		**X**				
Student-Peer Feedback		**X**		**X**		**X**
"Cookbook Science Labs"		**X**	**X**			
Just-in-Time Teaching	**X**	**X**				
Case Method			**X**	**X**	**X**	**X**
Inquiry-Based/ Inquiry-Guided	**X**	**X**	**X**	**X**	**X**	**X**
Problem-Based Learning (PBL)	**X**		**X**	**X**	**X**	**X**
Project- Based Learning	**X**	**X**	**X**	**X**	**X**	**X**
Role Plays and Simulations		**X**	**X**	**X**		**X**
Service Learning with Reflection			**X**	**X**	**X**	**X**
Field Work/ Clinicals	**X**		**X**	**X**	**X**	**X**

Note: x indicates this method can help students achieve this learning outcome if the method is properly implemented. Source: (Nilson, 2016)

2.11 Assessments

Anikweze (2010) defines assessment as a process of taking decisions after measuring and evaluating the results. It also provides a reason for the decision that has been taken after evaluation. Assessments are meant to be a part of learning and teaching in order to assess the students (Anikweze, 2010). Teaching will be nullified if there is no provision for an assessment of students' progress even if the teacher is efficient, students are brilliant and learning devices in lab are satisfactory. It is a process of attaining information that is used for constructing judgments about students, syllabus and courses (American Federation of Teachers, National Council on Measurement in Education, and national Education Association, 1990).

Assessment is vital to the education process (Shuichi, 2016). The most common assessments are summative and formative. In summative assessments, teachers measure the understanding of students in their learning making students responsible their performance through testing. On the other hand in formative assessments, students are assessed continuously, learning needs are identified and teaching is brought into a modern classroom (Shuichi, 2016).

2.11.1 Use of assessment information

According to Education review office (2007), assessment information is only useful to learning and teaching if it is analysed and used. Achievement of students is likely to be enhanced if assessment information is used by teachers and school leaders to:

(a) motivate students and boost their confidence to make more progress.

(b) construct the learning programmes that suit students' prior achievement and learning.

(c) identify students' subsequent learning steps.

(d) identify causes of difficulties in learning and to design targeted teaching programmes.

(e) notify all students and their respective parents regarding students' progress or achievement;

(f) enlighten curriculum review and policies and teachers training or professional development;

(g) report to the local community.

2.11.2 Formative Assessment

Over the past two decades, a prominence on formative assessment has emerged in many parts of the world (Shuichi, 2016). Scriven (1967) first introduced formative assessment to improve curriculum planning. Thereafter, Bloom (1969) extended it to enhance learning and teaching in education. Many other researchers such as Sadler (1989), Torrance and Pryor (1998) and Torrance (2012) have worked to extend the theory of formative assessment. However, a remarkable change was made by Black and Wiliam (2009) and they aver that formative assessment is one of the most effective strategies to encourage student learning. Formative assessments help identify where the students are in relation to a learning goal and what can be done to improve subsequent performance. Formative assessments are planned to improve student learning and to make assessment on what is working in the class and what needs to be improved (Dixson & Worrell, 2016).

OECD (2008) defines formative assessment as an active approach in order to attain better learning for students. Confrey and Kazak (2006, p. 329) state that "Assessment was viewed as a means to support constructivist practices in a variety of ways". Students understanding need to be evaluated adequately and they should be conscious of their own learning. Similarly, teachers need to understand extensively students' cognitive skills (Confrey & Kazak, 2006). Assessment was used to achieve the aforementioned objectives.

There are four guiding principles set by Lutz and Huitt (2004) for the teachers using constructivist framework. Among these, the last principle describes the assessment. Lutz and Huitt (2004) argue that "Assessment, measurement, and evaluation should be a natural part of the learning process rather than an activity completed at the end of the learning process" (Lutz & Huitt, 2004, p. 14). In Black and Wiliam's (2009, p. 7) point of view, formative assessment can be defined as follows:

> Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be

better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited.

According to Black and Wiliam (2009, p. 7), formative assessment consists of five fundamental approaches:

(a) Making students aware that they themselves are the knowledge recipients of their learning;

(b) Making students as teaching resources for one another;

(c) Providing them knowledge on the importance of learning and benchmarks for the success;

(d) Providing regular feedback of their progress which makes students move forward;

(e) Setting up an effective classroom environment for discussion and learning that stimulate the knowledge of the students.

Formative assessment is a constant process that updates both students learning and academics teaching (Stull et al., 2011). Student engagement together with good questions allow constant, effortless formative assessment along with Peer Discussion and immediate feedback. Peer discussion provides an opportunity for students to learn in the form of discussion with a small group and convey each participant's point of view. Peer interaction is an opportunity for them to collaborate with their peers, discussing the solutions and developing knowledge.

Student engagement and peer discussion satisfy the second, fourth and fifth of the fundamental approaches developed by Black and Wiliam (2009). The lecturer will be the responsible agent to activate the first and third of the approaches. As assessments are done regularly, student engagement together with peer discussion are the ultimate formative assessment methods. Nonetheless, Black and William (2009) highlight that learning and teaching can be enhanced with the continuous use of formative assessment. Furthermore, the effective use of formative assessment in classroom will boost the level of confidence both among students and academics (Black & William, 2009).

2.11.3 Advantages of Formative Assessment

Black and Wiliam (1998) state the advantages of formative assessments as follows:

(a) Students' achievements in their performances can be discovered through formative assessments by teachers as well as students;

(b) Students' specific existing problems can be also be detected through formative assessment;

(c) While this assessment may be used by students to find their strengths, it also offers assistance to them if required, such as boosting their confidence and accomplishing their goals;

(d) It is used to evaluate students' level of English language and vocabulary;

(e) Students' quality of learning can be improved through formative assessments and its high quality feedbacks.

2.11.4 Disadvantages of Formative Assessment

Brookhart (2011) highlight three disadvantages of formative assessments as follows:

(a) Some students are introverts and they cannot present themselves in front of their classmates;

(b) Vague responses from inefficient students cannot be assessed and will be considered as irrelevant;

(c) Some students need a longer time to respond during the formative assessment.

2.12 Summative Assessment

Bloom (1981) highlight that it is an evaluation of the course, validity of the education program and education research for the purpose of identifying and evaluating progress after a period of teaching term. Shaoqian (2003) posits that the teacher ensures what students have understood from the teaching period in order to determine a grade or mark for each student. Chappuis and Stiggins (2008) articulate that these assessments are used to check the learning part of students and it tries to capture the evaluated result of students' achievements within a particular time duration.

Unlike formative assessments, which are used to provide feedback to teachers and learners, summative assessments are generally used to get a final assessment of how much learning has taken place (Dixson & Worrell, 2016). Summative assessments generally occur at the end of a unit, chapter, semester or year and are almost always graded. Summative assessments provide students an opportunity to demonstrate their conceptual understanding. They also allow students to think critically and apply their understanding to solve problems (Dixson & Worrell, 2016). Summative assessments are generally used to assess if the student qualifies to advance to the next level or to assess qualifications for awards.

2.12.1 Advantages of Summative Assessment

Two advantages of summative assessment are:

(a) It enables the teacher to make a choice regarding the students' competencies in that particular module (Swart & Hertzog, 2017);

(b) "Summative assessment can be used to: derive a final grade, allow progression to further studies, assure suitability for work, predict success in future studies, and signal employability" (Swart & Hertzog, 2017, p.779).

2.12.2 Disadvantages of Summative Assessment

Shaoqian (2003) and Swart & Hertzog (2017) cite four disadvantages of using summative assessment. Shaoqian (2003) cites three of them and Swart and Hertzog (2017) highlight one.

(a) Students can score marks by guessing the answer even if they do not know the right answer or do not have time (Shaoqian, 2003);

(b) Students are forced to choose one answer from the options which limits the subjective opinion of students in writing the answer, even if they know how to write the answer (Shaoqian, 2003);

(c) More choices in the tests may mislead education into undesirable routes (Shaoqian, 2003);

(d) Results collected from teacher can only be used for improvement in the next term (Swart & Hertzog, 2017).

2.13 Comparison between Formative and Summative Assessments

According to Dixson and Worrell (2016), Surbhi (2016) and Swart and Hertzog (2017), the key differences between formative and summative assessments are the following:

(a) Formative assessments are procedures that provide information to make required changes during the learning process to achieve the required outcomes from the course whereas summative assessments are used for evaluating the learning by students. Therefore Formative assessments are investigative in nature whereas summative assessments are evaluative in nature;

(b) Formative assessments are carried out on an on-going basis whereas summative assessments occur at specific intervals generally at the end of the course;

(c) Formative assessments are generally not graded or marked whereas summative assessments are graded;

(d) Formative assessments indicate students' understanding whereas summative assessments determine if a student could be promoted to the next level.

The following Table developed by Surbhi (2016) summarises a comparison between formative and summative assessments.

Table 2. 5 Comparison between formative and summative assessments

Basis For Comparison	Formative Assessment	Summative Assessment
Meaning	Formative Assessment refers to a variety of assessment procedures that provides the required information, to adjust teaching, during the learning process.	Summative Assessment is defined as a standard for evaluating learning of students.
Nature	Diagnostic	Evaluative
What is it?	It is an assessment for learning.	It is an assessment of learning.
Frequency	Monthly or quarterly	Term end
Aims at	Enhancing learning	Measuring student's competency.
Goal	Monitor student learning.	Evaluate student learning.
Weight of grades	Low	High

2.14 Summary

This chapter reviewed the literature on Bloom's taxonomy and constructivism. The differences between deep learning and surface learning were elaborated on. It is established that deep learning links prior knowledge, concepts and principles to new ideas. This in turn leads to long term retention of concepts that assist in problem solving. The literature showing the impact of an AL approach on students' ability to recall, understand engineering concepts, problem solving skills and critical thinking skills were reviewed. The reviewed studies showed that AL approaches such as PBL, TBL and GEBL enhanced learning outcomes in science, technology and engineering education. Use of formative and summative assessments and their advantages and disadvantages were discussed. The literature review has set the scene to view AL as an approach for deep learning to occur.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter elaborates on the research methodology adopted and includes the research paradigm, research approach and research design. The mode of enquiry, description of the population and sample are explicated. The data collection instruments are discussed and the validity and reliability of instruments, insider-outsider conflict, data collection procedure and methods of data analysis are addressed. The ethical considerations are examined.

3.2 Research Paradigm

A research paradigm informs the choices about which research questions to address, and what methodology to employ (Okeke & van Wyk, 2016). The paradigm used for this study is pragmatism. Paradigms create new worldviews and social contexts that have widespread impacts on the conduct of inquiry (Morgan, 2014). From the perspective of pragmatism, new paradigms create new sets of beliefs that guide new kinds of actions (Morgan, 2014).

The term pragmatism is derived from the Greek word “Pragma” which means action. In pragmatism, what is stressed is that knowledge is not abstract philosophy but that which works in practice. According to Wikipedia, James (1909) states that pragmatism considers thought as a tool for prediction, problem solving and action. It rejects the idea that the purpose of thought is merely to describe, represent, or mirror reality. Pragmatists give more importance to actions than just ideas and therefore believe that one should learn by experimentation. According to John Dewey (1982), who introduced pragmatism in education, education is of no use if it does not promote human welfare. Therefore the system of education should be changed so that it becomes beneficial to learners by way of application of what is learnt. Education should provide real life experiences to the learners so as to make them more enterprising, innovative and able to contribute meaningfully to the real world. Pragmatists believe that the students must be comfortable in their learning environment. Educators must be able to replicate real life problems to students, and then guide, motivate and stimulate them to find the solution to the problem. The subject matter exists ready to be explored, but the real concern must always be for the interaction of the students with the subject matter for the current needs and concerns (Agarwal, Bansal & Maheshwari, 2010). Learning becomes meaningful when students are able to make a connection between knowledge and experience. John Dewey maintains that the educational institution is a "Miniature Society" where students experience activities according to their interests, aptitudes and capacities. According to Pragmatism, research design should be planned and conducted based on what will best help answer the research questions (Johnson & Christensen, 2008).

3.3 Research Approach

Mixed method approach was chosen for this study because this approach provides an in depth information about the problem (Venkatesh, Brown & Sullivan, 2016). Creswell (2002) states that in a mixed method the use of quantitative and qualitative data provide a better understanding of the problem under study. Quantitative research has the weakness in understanding the context in which the data is collected whereas qualitative data has the weakness of introducing bias. Use of mixed method approach counterbalances these weaknesses and provides detailed information about the problem being studied. Mixed method approach was used to include both statistical analysis and observations to provide additional evidence and backing for the findings.

3.3.1 Quantitative mode of Enquiry

Quantitative research is associated with a deductive approach where a theory is tested. Here researchers try to find common patterns in thought and behaviour and the use of scientific methods for data collection and analysis makes it possible to generalize results from a larger sample population. The data collected is formatted and structured. The researcher follows clear guidelines and objectives as the research approach relies on testing of hypothesis. This research approach gives room for the use of control and study groups. The researcher might decide to split the participants into groups giving them the same teaching, but using different teaching methods (Daniel, 2016).

Two formative assessments and a summative assessment were used to gather quantitative data from the students. These data were then analysed to determine the impact of the intervention in the students' performance in these assessments.

3.3.2 Qualitative mode of Enquiry

Qualitative researchers study phenomena is discovery oriented and is conducted in their natural settings (Johnson & Christensen, 2008). Qualitative research is inductive in nature (Atieno, 2009; Creswell, 2014) and uses exploratory scientific method to develop an understanding about people, their opinion, perceptions and experiences (Johnson & Christensen, 2008). Qualitative research explores phenomena in their natural settings and uses different methods to interpret, understand and bring the meaning to them. Qualitative enquiry is in the form of words as opposed to quantitative enquiry which is in the form of numbers (Punch, 2005). Qualitative data instruments such as observation, open-ended questions, in-depth interview and field notes are used to collect data from participants in their natural settings. The data is collected through an interactive and unstructured approach. The students who attended the GEBL sessions were interviewed individually to gather qualitative data. The data was gathered to find out the students' experience with the new mode of teaching and learning through GEBL.

3.3.3 Mixed Method Research

In quantitative research, the study is carefully planned including the tests and other data collection instruments. Each subject is identically studied and there is little room for human bias to create problems with the data. Qualitative research is also planned carefully but yet they leave open the possibility of change, of asking different questions, and of going in the direction that the observation may lead the researcher (Best & Kahn, 2016). The chances of bias are high as the researcher has presumptions about the situation being observed. The purpose of the quantitative approach is to describe and explain whereas the purpose of the qualitative approach is to understand.

In a mixed method the researcher collects the quantitative data as well as the qualitative data. The research involves mixing and combining qualitative and quantitative research in a single research study. Creswell (2008) states that it is a procedure, in a study, of collecting, analysing and combining both quantitative and qualitative data at some stage of the research process to understand the research problem completely. The qualitative and the quantitative parts of the research study could be carried out concurrently, where both parts are carried out almost at the same time, or they could be carried out sequentially where one part is conducted first and then followed by the second part to address the research questions.

In this study both qualitative and quantitative modes of enquiry were used to find the correlations between the quantitative data collected through the formative and summative assessments and the qualitative data collected through unstructured interviews.

3.4 Research Design

A research design provides a framework for how a research study can be carried out and gives direction to the investigation (Best & Kahn, 2016). It outlines the logical plan for data collection and analysis of the collected data (Chawla & Sondhi, 2011). There are various designs available to investigate the research objectives. The research design used for this study was quasi-experimental non-equivalent control group post-test only design. A quasi-experiment design tests the causal hypotheses and offers practical options for conducting impact evaluations in real world settings (White & Sabarwal, 2014). The post-test only design group can be presented symbolically as:

Experimental Group:	R	X	O_1
Control Group:	R		O_2

The experimental group was subjected to the treatment X and post-test measurements were taken on both experimental group (O_1) and control group (O_2) at the same time (Chawla & Sondhi, 2011).

Participants of this study were all the second year students registered for the INDE course. 14 students had registered for the course and they had all passed Electrical Engineering II which was the pre-requisite course for INDE. The control group had seven students and they attended classes where they were taught using the traditional approach. The experimental group also had seven students who had voluntarily agreed to participate where teaching and learning was carried out using the GEBL approach. The marks for the pre-requisite subject were used for the t-test to determine if the two groups were comparable. The t-test showed that there was no statistically significant evidence to suggest that the means are different for the two groups. Post-tests were used to analyse the participants' ability to remember PE concepts, conceptual understanding of PE, problem solving skills and the critical thinking ability. Two formative assessments and one summative assessment were used to collect the quantitative data. The students from the GEBL group were interviewed to collect the qualitative data. A mixed method approach was used to analyse the data to anser the research questions. The same lecturer conducted classes for both traditional and the GEBL group.

3.5 Population

INDE course was taught in the first semester of the second year of the three year ND programme. The population was all students enrolled for the INDE course at the campus where the study was conducted. The study was planned to be conducted with 21 students in the population expecting that the enrolment will be similar to that of the previous year for INDE course. Unfortunately the enrolment during the year of study (2017) was only 14. Since all other logistics including the permission to conduct research and ethical clearances were obtained from the institution at which the present researcher was registered (See Appendix A) and from the institution where the research site was situated (See Appendix B), it was decided to continue with this study in consultation with the supervisor. Furthermore, since cancelling the study due to the drop in enrollment would have caused the loss of a research report on PE students. This was especially so since no other report on PE within South Africa could be located.

3.6 Sample

Sampling is the process of selecting units from a population of interest so that by studying the sample, the researcher may fairly generalise results by inferring back to the population from which the sample was drawn (Tipton, Hallberg, Hedges & Chan, 2017).

All 14 students were informed about the details of the study and the responsibility that the students will have during the course of the study. The population and sample were the same due to the small number enrolled for INDE. Seven students voluntarily showed interest to take part in the study and they constituted the sample for GEBL after signing the Informed Consent Form. The Head of Department gave permission to teach these seven students through GEBL and those who did not volunteer for GEBL using the traditional approach. As such, there was no sample selection since only those seven students who volunteered constituted the GEBL sample and the remainder constituted the traditional teaching group sample. It is only coincidental that 50% of the population happened to be in both samples. However, the tests were the same for both cohorts and the test scores of those in the traditional teaching group were included in the data analyses.

3.7 Instruments for Data Collection

In this section the instruments used to gather data are discussed. The following instruments were used for data collection and will be discussed in detail here.

(a) Two written formative assessments (Appendices C & D).

(b) One summative assessment (Appendix E).

(c) Open-ended interview schedule (Appendix F).

3.7.1 Formative Assessments

There were two formative assessments to test the students for the modules covered in the syllabus. The formative assessments were designed to test the students' ability to recall a few topics that were covered in the syllabus. These questions required students to briefly explain the topic and in some cases they had to sketch the circuit diagrams and output waveforms. This was done in order to determine the students' ability to remember and recall previously learned materials. For some questions the students were also required to compare certain circuits or devices and they were required to give explanation for their choices between those devices or circuits. To justify the choices made, the students were required to provide explanation or derivation. This was done to determine students' understanding of certain PE concepts. The students were also required to think critically to make these choices and to justify their choices. There were also questions where the students were required to analyse and solve problems. The students were required to understand the concepts to analyse the question and to solve these problems.

The students were required to have good understanding with deep knowledge to answer the questions. No marks were awarded if the students were unable to justify the reason for their answer. The data from the formative assessments were used to provide remedial teaching to those who scored lower marks and also assisted the lecturer to do reflective assessment on his own teaching.

3.7.2 Summative Assessments

A summative assessment was written at the end of the semester by all students from both from the GEBL and TTG. The duration of the assessment was 3 hours. Here again the students were tested for their knowledge and recalling ability for the entire syllabus of PE, but more emphasis was placed on the ability to use the concepts learned to analyse, evaluate and solve problems and also to think critically to answer the questions. This was done to determine if the students understood the concepts and if they could use the learned concepts in solving problems and finding solutions to problems presented. The students were expected to have understood the whole PE syllabus to answer the summative questions.

3.7.3 Open-ended Interviews

An open-ended interview was designed to gather detailed qualitative data to analyse students' experience with the GEBL approach. Each student from the GEBL group was given about 30 minutes to answer these questions (Appendix F). The interview schedule consisted of questions similar to the structured questionnaire but the students were asked follow-up questions to get more information. Questions focused on issues such as: the students' experience with GEBL approach; their opinions about the GEBL approach; whether GEBL benefited them in the understanding of the course; if GEBL motivated them to attend classes; whether GEBL enhanced a positive attitude towards the course; whether they preferred the GEBL approach over the traditional approach and if they would recommend GEBL approach for other subjects. The questionnaire was adopted from a similar study that was done in the same University in the Department of Mechanical Engineering.

3.8 Instrument Validity and Reliability

3.8.1 Validity

Ary, Jacobs, Irvine and Walker (2010) define validity as the extent to which an instrument measures what it intended to measure. Validity "refers to the appropriateness, meaningfulness, and usefulness of the specific inferences made from test scores" (APA, 1985, p.9). Validity is further differentiated into internal validity and external validity.

3.8.1.1 Internal validity

Internal validity examines the cause and effect relationship or validity in a study. It examines the causes of certain outcomes in a study and answers the key question of whether alternative causes could explain observations or findings in a study. It therefore tests the accuracy and validity of findings which have been studied and is concerned with controlling extraneous variables and outside influences that may impact the outcome of the study. Coetzee (2017, p. 145) states that "a study has internal validity if the constructs were measured in a valid manner, the collected data are accurate and reliable, the analyses are relevant for the type of data, and the final conclusions are adequately supported by the data.".

3.8.1.1.1 Threats to internal validity

Chawla and Sondhi (2011), Centre for Research in Innovation and Teaching (n.d) and Coetzee (2017) state the following threats to internal validity:

- **History:** This refers to specific events that are external to the experiment but occur at the same time as the experiment. These external events may impact the results of the experiement. For example if an event influenced one of the groups and not the other, differences between groups may be attributed to the event, and not necessarily to the intervention.
- **Maturation:** This refers to changes that occur to participants over the period of time of the study. These may be natural changes, biological or psychological changes which influence the maturity of the participants over the time of the

study, having an impact on the results of the study. This is particularly relevant if the study occurs over a prolonged period or time.

- **Testing:** Pre-tests may influence the performance of sparticipants on subsequent tests due to the fact that they have already seen or completed the test before and are therefore sensitised, effecting a bias to their responses. In this study only Post-test was used to collect data.
- **Instrumentation:** This refers to the effect caused by the changes in an instrument used for measuring an observation. Modifications in testing instrumentation during a study may affect how it is measured. In this study, both experimental and control groups wrote the same Post-tests which minimised the threat to internal validity due to instrumentation.
- **Statistical Regression:** This occurs when participants with extreme differences in performance are chosen to take part in an experiement. When this occurs, the results will tend to move towards an average score with the passage of time.
- **Selection bias:** If the participants placed into groups are selected in a non-random manner at the beginning of the study, the results of the study could be biased when making comparisons between the groups at the end. In this study the students were given a chance to volunteer to be part of the GEBL group. This was done so that no student was forced to be in the experimental or control group.
- **Test Unit Mortality:** Test subjects or partiicipants may drop out of studies for a variety of reasons. The loss of participants from control groups may impact the study if the withdrawal rate is higher in one group or if it is particularly high in both groups. For this research no student from either group dropped out during the study.
- **Selection Interaction:** The participants from experimental and control groups may interact with one another and impact results. In this study, the experimental group and the control group were located at the same campus and hence the possibility of them coming into contact was high which could be a threat to the internal validity.
- **The Hawthorne and John Henry Effects:** The Hawthorne Effect is a psychological effect that produces an improvement in human behaviour or performance as a result of increased attention from superiors, clients or

colleagues. The John Henry Effect refers to the tendency for people based in a control group to perceive themselves at a disadvantage to the experimental group and work harder in order to overcome the perceived deficiency. Although students may benefit from GEBL in the long term, this benefit is central to the method of teaching and should not be classed as a Hawthorne effect. Furthermore, such benefits should diminish when the GEBL methodology is selected as the regular pedagogy.

3.8.1.2 External validity

External validity refers to the generalisation of the results of an experiment (Chawla and Sondhi, 2011). The best evidence for external validity is whether or not the research findings can be reproduced with different populations, settings, treatment variables or times. “In true experimental studies, the random selection of participants and random assignment of the study participants into groups ensure that the members of the study are truly representative of the larger population” (Centre for Innovation in Research and Teaching, Grand Canyon University, Arizona (n.d). This webiste also states random selection ensures that results can be generalised. Quasi-experimental studies present challenges because participants are not randomly selected. Selection of a reasonably similar control group is therefore important. In this study, a t-test was carried out to check for similarity between the two groups. The results showed that there was no statistically significant evidence to suggest that the mean values were different for both groups.

3.8.1.2.1 Threats to external validity

The Centre for Innovation in Research and Teaching (n.d) and Coetzee (2017), further state the threats to external validity to be the following:

- **Interaction Effects of Testing:** The Pre-test may make the participants more aware of the issues to be studied and may therefore influence the response to the treatment. However, in this study the students only took a post-test and therefore both groups were equally affected.
- **Selection Bias:** This occurs when subjects are selected in a manner that does not ensure that they are representative of the overall population. The random selection of subjects is a critical factor in determining external validity. In educational research, this is however not always possible.

The researcher took necessary steps with the development of the instruments to ensure their validity. Assessment criteria and allocation of marks were clearly indicated for this purpose. The instrument was validated by giving it to the experts in the field of PE and their responses and comments were addressed.

3.8.2 Reliability

Reliability refers to the degree to which an instrument provides consistent results if repeated on the same sample. The four most common ways of measuring reliability for any empirical method include; inter-rater reliability, test-retest reliability, parallel forms reliability and internal consistency (Cronbach's Alpha) reliability (LoBiondo-Wood & Haber, 2014). One of the most popular reliability statistics in use today is Cronbach's Alpha, which determines the internal consistency or average correlation of items in an instrument (Santos, 1999). Coetzee (2017) states that if the items are strongly correlated with each other, their internal consistency is high and the alpha coefficient will be close to one. In this case, some of the items may be redundant. On the other hand, if the items are poorly formulated and do not correlate strongly, the alpha coefficient will be close to zero. The following guidelines for the interpretation of Cronbach's Alpha coefficient are generally accepted by researchers: 0.90-high reliability; 0.80-moderate reliability and 0.70-low reliability (Vosloo, 2014). For the purposes of the current study, a pilot study was conducted and Cronbach's Alpha calculated.

3.8.2.1 Test of reliability for internal consistency

If repeated measurements of the same phenomenon shows consistency then the instrument is said to be reliable (Carmines and Zeller, 1979). The Cronbach's Alpha confirmed the internal consistency of the instrument as per the table below.

Calculating the value of N for Cronbach's Alpha Test

To calculate the value of N, the total number of questions in the instruments were taken into account. This number was then multiplied by the number of students who wrote the assessments. All 14 students registered for the course wrote all three assessments. The total number of questions in all assessments combined together is 72. All 14 students wrote the test and hence the value of N was obtained by multiplying the total number of assessments with 14 which gives the value of 1008 for N.

Table 3. 1 Calculation of N for Cronbach's Alpha

Assessment	Number of questions in assessments	Number of students	N (= Number of questions in assessments * number of students)
Formative Assessment 1	20	14	280
Formative Assessment 2	16	14	224
Summative Assessment	36	14	504
Total	**72**	**42**	**1008**

Table 3. 2 Cronbach's Alpha Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.809	0.810	1008

The above table represents the results of Cronbach's Alpha. The observed value is 0.809. However, the standardised value is 0.810. According to statistical understanding, the value to be used is 0.809.

The least accepted Cronbach's Alpha is 0.70. a value greater than or equal to 0.70 is proof that the instrument reliability is good and in fact, it passes the test of reliability. A value less than 0.70 raises questions regarding the internal consistency of the instrument in view of the data collection. Overall, the instrument was consistent.

Table 3. 3 Item Statistics

	Mean	Std. Deviation	N
Method of Learning	1.5000	.50025	1,008
Assessment Type of Assessment	2.2222	.85388	1,008
Level Type of Question	3.9861	2.47044	1,008
Sub-question Type of Question	2.9306	2.05803	1,008

Table 3. 4 Scale Statistics

Mean	Variance	Std. Deviation	N of Items
10.6389	10.686	3.26891	4

3.8.3 Triangulation

Triangulation requires the researcher to use a multi-method approach to data collection (Creswell, 2014; Okeke & van Wyk, 2016). The purpose of triangulation is to collect data on the same topic using multiple methods and compare the responses of the participants. Okeke and van Wyk (2016) states that "…triangulation arises from the need to achieve internal validity, and enables researchers to overcome any problem linked with the use of single-method approach to data collection". When the evidences lead to the same conclusion then the researcher can make a statement with confidence (Johnson & Christensen, 2008; Hussein, 2009).

Though qualitative and quantitative methods differ epistemologically and ontologically, the use of both methods in research is becoming popular amongst researchers. The use of mixed methods is advocated for the purpose of expanding and deepening the understanding of the topic under study (Hussein, 2009; Creswell & Clark, 2017). When combined, the flaws of one method is neutralized and strengthens the benefits of the other for better research results (Hussein, 2009). The use of more than one source of data to re-affirm the findings in a research is called triangulation. According to some authors, triangulation is used for a wider and deeper understanding of the topic which is under study while others argue that triangulation is used to increase the accuracy of the study. Triangulation is used when the researcher seeks convergence and corroboration of results from different methods studying the same phenomenon (Johnson & Christensen, 2008). Triangulation requires the researcher to follow a multi-method approach to data collection. It involves mixing various methods and instruments to enable researchers to obtain a variety of information from the participants in a particular study (Okeke & van Wyk, 2016). Triangulation can minimise bias and enhance validity. It can substantially increase credibility and trustworthiness of a research finding (Johnson & Christensen, 2008; Jick, 1979). In this study data, triangulation was used to integrate and corroborate the quantitative data from the assessments and qualitative data from the interviews. Triangulation was used for both formative and summative assessments. The quantitative data was collected from formative assessment 1, formative assessment 2 and the summative assessment. The students who participated in the GEBL approach were interviewed about two weeks prior to the summative assessment. The qualitative data was collected from the students' response to the interview questions.

3.9 Insider Outsider conflict

Insider, refers to the context when researchers conduct research with populations of which they are also members (Kanuha, 2000) so that the researcher shares an identity, language, and experiential base with the study participants (Asselin, 2003). Insiders in a research setting often have views which are very different to the views of the outside researchers. These differences in the views of researchers could have significant implications for the quality of knowledge that will be gained from the research (Bartunek & Louis, 1996).

A disadvantage of the research being conducted by an insider is that he or she does not maintain enough distance and objectivity necessary for research validity (Brannick & Coghlan, 2007). Outsiders argue that they are more likely to be objective and observe the study without distorting their meanings (Mullings, 1999).

It is becoming common for researchers to be part of the group they study as insiders (Kanuha, 2000; Bonner & Tolhurst, 2002). As an insider, the researcher has a good understanding of the type of data to be gathered (Hodkinson, 2005). By becoming part of the group, the researcher is accepted by the participants. It becomes easier for the researcher to build a rapport with the participants. The researcher shares the identity and the experience with the participants in the study (Asselin, 2003). This prior knowledge enables the researcher to gather richer and focussed data. During the interviews, the participants are more open to the researcher and it enhances the quality and effectiveness of the collected data (Hodkinson, 2005; Louw, 2012). On the other hand there is also a possibility that the participant might make assumptions of similarity and hence may not explain their experience fully to the researcher.

It is important for the insider researcher to be careful and watchful while gathering the data and must assume that he or she does not know anything about the phenomenon being studied (Asselin, 2003). It is important for the researcher to separate himself or herself from the participants to avoid a bias during the collection of data. The researcher must be careful to capture the data exactly as provided by the participant and the captured data must not be influenced by his or her own personal experience. If the researcher finds it difficult to separate himself or herself from the participants' experience, the analysis of the data and the findings from the study might be biased due to the influence of the researchers' experience and not the participants' experience necessarily.

The researcher being an insider raises the issue of his or her avoidable influence but being an outsider does not necessarily avoid this influence completely. Also, being an outsider, the researcher might find it difficult to have the same freedom with the participants as being an insider researcher. It might take time to build a rapport with the participants but even then the participants might be hesitant to open up fully during the interview. The positive and the negative sides of being an insider or an outsider must be assessed carefully before the start of the study.

The researcher must be disciplined and must at all times be aware of the possibility of a personal bias. He or she must be honest during the research process and must be interested in capturing the participants' experience. The researcher must at all times have the commitment and discipline to capture the data without the influence of the personal experience. The researcher must accurately understand, use and present the participants' subjective insider and the researchers' objective outsider views. The researcher must view back and forth to fully understand the worlds of the participants and the world of the "objective" researcher. The researcher has to then produce the viewpoint that is based on both of these perspectives. (Johnson & Christensen, 2008).

For this study, in order to minimise this insider-outsider impact, the researcher worked closely with a colleague, an appropriately qualified and experienced lecturer in PE, to develop the course material and the assessments. The interview questionnaires were also prepared together with the researcher's colleague. Another lecturer working in the same department but on another campus was also continuously consulted throughout the study. The assessments were marked by the researcher and the scripts were given to the colleague to check for the correctness and consistency of the award of marks for each question. To avoid any research bias, the researcher conducted a preliminary data analysis of randomly selected questions and answers from the two formative and summative assessments. All collected data was not used for the preliminary analysis. The preliminary analysis was done before the statistical analysis of variance was done for the whole data set.

All participants in the GEBL group were interviewed to take care of the omission bias. No participant was given any priority and no one was selected with the intention to prove any research objective. The researcher made each participant feel comfortable in both the experimental group and in the control group throughout the study and also during the data collection. During the interview the participants were given enough time to settle down before the interview started. The participants were made to feel relaxed before the interview in order to avoid procedural bias. The participants were also made aware of the importance of being open and honest during the interview. They were informed that their responses will impact the outcome of the study. The open-ended questionnaire was designed by the researcher and his colleague. It was also discussed with other experts in the field to make sure that it measures what it is supposed to measure. Every effort was made to avoid any measurement bias. The participants were told that it is important to recognise that they should respond to the questions based on their experience and should not try to tell the interviewer what they think he wants to hear instead of the truth.

The researcher involved the colleague for the analysis of the collected data. The researcher took the help of an external statistician for the statistical analysis. This external statistician had no personal interest in the study and all the analyses were done and recorded together with the researcher and the colleague involved during the study. Every effort was made to avoid any reporting bias during the analysis and capturing of results.

Table 3. 5 Advantages and Disadvantages of Insider/Outsider Researchers

Insider	Outsider
Advantages: • Not seen as 'strangers' but members of group. • Incorporate traditionally ignored or unrecognised perspectives into theory. • More economical-know the culture, language (jargon), familiar with local conditions. • Less inclined to construct stereotypes. • Easier to gain acceptance, trust and cooperation. • No decision needed whether to go native or not; question of understanding the group is minimised. • No lengthy preparation necessary as already in 'field' or study setting. • Involve yourself fully with the participants and their activities.	**Advantages:** • Free of commitment to the group. • Advantages in observation and analysis of events and structures. • Can see properties lost to the insider because of familiarisation and discover something of value to theory or to his hosts. • Seen as objective observer. • May be more privy to some sensitive information because of temporary stay.
Disadvantages: • Not seen as researchers but advocates by some. • May be biased towards interpretation /findings. • May initially have difficulty re-establishing ties with local 'culture'. • Unknown researcher qualities. • Reliance on participants with whom the researcher feels comfortable. • Focusing on the dramatic events rather than the routine. • Experiencing role conflicts.	**Disadvantages:** • Experience 'culture' shock which may delay or interfere with research. • Take time to establish trust or may never be seen as trustworthy. • 'Cultural" or linguistic (jargon) distance may desensitise researcher to group's needs/meanings. • May receive 'expected' responses rather than true attitudes or knowledge. • Lengthy time required understanding the 'culture' and language (jargon). • Less economical- may need to hire and train 'experts from the filed'

Source: Adapted from Schatzman & Strauss, 1973; Tom-Orme, 1991; Lipson, 1994; Miles & Huberman, 1994; Gerrish, 1997; Kite, 1999

3.10 Data Collection Procedures

3.10.1 Pre-data collection scenario

Learning occurs when students have the opportunity to compare and share their ideas with others. In a classroom, discussions within the entire class provide students the opportunity to vocalize their knowledge and to learn from others (Kocevar-weidinger, Cooperstein & Kocevar-weidinger, 2014). In this approach, the activities lead to the development of concepts and students construct the meanings.

They further emphasise that with this approach the concepts become meaningful, transferable, and are retained because they are attached to the performance of a concrete activity. This was in line with the knowledge creation metaphor which the researcher used for this study. For this study the researcher provided the students with a comfortable learning environment with proper ventilation and enough lighting arrangements in the room. Students were provided with a learner guide which gave the outline of the syllabus and topics to be covered during the semester. The students in the GEBL group were briefed about the new teaching and learning approach which the students were going to be exposed to. Students were briefed about the importance of asking the right questions, relating the topics learned to the real world, interpersonal communication and assisting each other with the learning process. They were also briefed about how all of these activities would assist them in their learning process. The researcher used the first couple of sessions to introduce students to all these concepts which were relatively new to them. It was noticed that students showed initiative and a sense of responsibility right from the beginning of the process. The process of AL where the lecturer’s role will be that of a guide was explained to the students. The expectations from the students were explained and they were assured of adequate support by the lecturer throughout the process. The expected outcomes from the course was clearly stated. This brought a sense of seriousness, confidence and responsibility among the students belonging to the GEBL group.

The main strategies to be used in GEBL for each topic were clearly explained to the students and these are tabulated in a summary form in the table below.

Table 3. 6 Topics and GEBL strategies

Topics	GEBL Strategies
Introduction to PE	Lecture, Group Assignment (to work together in pairs), introduction to GEBL approach, familiarising with practical equipment, library search for related material.
Power Semiconductor Diodes	Group Discussion, Class Presentation, Group Work (individuals to work in different pairs compared to the first topic), introduction to critical thinking
Diode Circuits and Rectifiers	Simulation, Practicals, Class Presentation and Group Discussion, more emphasis was given to ask questions to peers, emphasis on analysing the given problem using examples provided by discussing in groups. Identify PE components in scrapped electronic equipment and explain the use of the component.
Thyristors and Controlled Rectifiers	Class Presentation, group assignment, You tube videos, discussion about concepts learned, differentiate between controlled and uncontrolled rectifiers by linking the topic learned in the previous topic, extracting elements of a problem using the parameters provided.
AC Voltage Controllers	Group discussion, class presentation, extract main highlights from textbook chapters as homework.
Power transistors	Simulation, Group Assignment, Problem Solving Exercise (group), peer discussion followed by class presentation
DC Choppers	Group work, Videos, library search for materials related to the topic.
Protection of Devices and Circuits	Group Work (Discussion about various semiconductor devices where each student learns about one topic and shares the information with others), Class Presentation

Appendix G gives more details.

The present researcher has been teaching this course for the past four years and it was only during this research that seven were taught using the GEBL method while others were taught following the previously used traditional method. Therefore, the students from the traditionally taught group were not included in the above GEBL strategies as the teaching style for the former group remained unchanged. The control group was taught in the the same traditional manner as they had been exposed to in all other courses where the main form of teaching was through lectures. However, as shown later, their test evaluation scores were compared with the scores of the GEBL group for the same tests.

3.10.2 Data Collection

The data was collected through two formative assessments, one summative assessment and an open-ended interview. The duration of each of the two formative assessments were 90 minutes and the duration of the summative assessment was 180 minutes. The answer scripts from the students were the data sources in both formative and summative assessments.

The first formative assessment covered the first three chapters out of a total of nine chapters of the syllabus: Introduction to PE; Power Semiconductor Diodes and Diode Circuits and Rectifiers. The second assessment covered the next four chapters of the syllabus: Thyristors; Controlled Rectifiers; AC Voltage Controllers and Power Transistors. Although the last two chapters, DC Choppers and Protection of Devices and Circuits were taught, the contents were not part of the formative assessments and as such data on these was not collected. This was due to teaching time lost as a result of a continued university-wide student strike during the course of the study. Nonetheless, all chapters in the syllabus were covered in the summative assessment.

The duration of the open-ended interview was about 30 minutes although it varied slightly depending on the interviewees. All students from the GEBL group were interviewed. The interviews were conducted to gather students' thoughts, feelings and opinions about the GEBL approach. An interview room was prepared and the students were shown the room before the interview was conducted so that they could feel comfortable when attending the interview. The fear of a strange place was excluded by doing this. The students were given enough time to get comfortable in the interview set-up and the interviews were started only after the students indicated that they are ready for the interview. All interviews were recorded using an audio device and interviews were later transcribed *verbatim* (Appendix H). The authenticity of the *verbatim* transcription was later verified by an academic colleague. The Table below shows the link between the research sub-questions and the questions in the instruments.

Table 3. 7 The link between research sub-questions and questions in the instrument.

Research Sub-Question	Formal Assessment-1	Formal Assessment-2	Summative Assessment	Interview
SQ 1	1a, 1b, 1c, 2b, 4a, 5a	2, 4.1, 6.1	1.1c, 2.1a, 2.1b, 5.2	1, 1a, 1b, 5, 5a, 5b
SQ 2	1d, 1e, 1f, 2a, 2c, 6a	1, 7.1, 7.2	1.1a, 1.1b, 1.1g, 2.1c, 3.1.1, 4.2	2, 2a, 2b,2c, 3, 3a, 3b, 4, 4a, 4b, 4c, 4d
SQ 3	7a, 7b, 7c	5, 10a, 10b, 10c, 10d	2.2.1, 2.2.2, 2.2.3, 2.2.4, 3.1.2, 3.1.3, 3.1.4, 3.1.5, 4.1.1, 4.1.2, 4.1.3, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 5.1.1, 5.1.2, 5.1.3, 5.1.4	6, 6a, 6b, 6c
SQ 4	3, 4b, 5b, 6b, 6c	3, 4.2, 6.2,8, 9	1.1d, 1.1e, 1.1f, 5.2.1, 5.2.2, 5.2.3, 5.3	7, 7a, 7b, 7c, 7d

3.11 Data Analyses Procedures

Document analysis was used as the method to analyse the responses from students for the formative and summative assessments. The data collected from the formative assessments, summative assessments and open-ended interviews were analysed to find out answers for each of the research questions. For formative and summative assessments, students' responses for each question were grouped, based on the number of errors they made in answering the question. The answers where the explanation and interpretation were completely correct were allocated code – 'c'. Answers where the student made a minor error (single error) were allocated code – 'mie'. Answers with more than one error but where the students were able to explain with some misinterpretations were given a code – 'ce'. Answers with just one correct statement were given code – 'mje' and answers which were completely incorrect were given code – 'i'. This code was then used to mark the answers in the script in order to keep the marking consistent (See Appendix I). Marks for each answer were then captured for all students belonging to both the TTG as well as the GEBL group. These marks were then statistically analysed to determine if there were significant differences between the two groups.

The responses from the open-ended interview were analysed using thematic analysis. During the interview, the responses from students were recorded. These were then transcribed *verbatim* into word documents after all interviews were completed. The responses were then carefully studied and “coding” was used to identify important ideas in their responses. The responses were then grouped together for each code. This was then used to identify patterns in the responses from students.

3.11.1 Statistical Analysis

For this study, Anova was used to analyse quantitative data. An Anova test is a way to find out if the survey or experiment results are significant. In other words, they help to find out if it will be needed to reject the null hypothesis or accept the alternate hypothesis. The purpose is to test groups to see if there’s a difference between them.

One-way or two-way refers to the number of independent variables (IVs) in the Analysis of Variance test. One-way has one independent variable (with 2 levels) and two-way has two independent variables (and can have multiple levels).

3.11.2 Thematic Analysis

Thematic analysis is a process of categorizing, analysing, and recording themes from the data collected (Braun & Clarke, 2006). It nominally shapes and labels the data extensively. However, it also interprets numerous aspects of the research topic (Boyatzis, 1998). Marks and Yardley (2004) emphasise that thematic analysis is the most suitable analysis for any research that seeks to discover using interpretation, as it enables the understanding of the research problem. Braun and Clarke (2006) argued that thematic analysis should be a basic method for qualitative analysis, as it offers fundamental skills for leading numerous other forms of qualitative analysis. Many authors such as Holloway and Todres (2003), Ryan and Bernard (2000) and Boyatzis (1998) state that thematic analysis is an analysis that is used to assist researchers in analysing the qualitative data. However, Leininger (1992), Thorne (2000), King (2004), Braun and Clarke (2006) and Nowell, Norris, White and Moules (2017) claim that it should be considered as a method in its own way.

Advantages of Thematic Analysis

(a) Thematic analysis is very useful in qualitative studies due to its high flexibility. It provides a rich set of data and it can be adapted in many other researches (King, 2004; Braun & Clarke, 2006).
(b) High level of technological and theoretical understanding of other qualitative methods are not required for thematic analysis. It therefore provides more accessibility in the form of analysis (Braun & Clarke, 2006).
(c) As the guidelines and procedures are very less for thematic analysis, it is very easy for the new researchers to understand and learn (King, 2004; Braun & Clarke, 2006).
(d) It is very beneficial when it comes to understanding the views of different respondents (King, 2004; Braun & Clarke, 2006).
(e) It emphasises differences and similarities in the data and also generates unanticipated findings (King, 2004; Braun & Clarke, 2006;).
(f) It generates a clear and organized summary of a large data set (King, 2004).

Apart from advantages listed above, it important to acknowledge the disadvantages as well.

Disadvantages of Thematic Analysis

(a) Lack of knowledge for new researchers to perform a rigorous thematic analysis is a risk as there is inadequate literature on thematic analysis compared with phenomenology, ethnography and grounded theory (Braun & Clarke, 2006).
(b) As the researchers cannot make claims about the use of language, use of simple thematic analysis will lack when compared to other methods (Braun & Clarke, 2006).
(c) Flexibility of thematic analysis may create conflict and lack of consistency while constructing themes from the collected data (Holloway & Todres, 2003).

3.12 Ethical Considerations

To conduct investigations, the researcher obtained permission from the University where the study was carried out. As it is a university requirement, the researcher obtained the approval of the Ethical Committee before undertaking the study.

The participants were informed about the purpose of the study and the method of instruction which they would be subjected to. The participants were provided with informed consent forms (See Appendix J). The informed consent forms included the nature of the study and a description of the activities that the participants were involved in. The researcher informed participants about confirming their willingness to participate in the study and about their right to withdraw at any time during the study (Babbie, 2015). The researcher ensured that the rights of the participants were protected throughout the duration of the study. Participants were made aware that the study would be conducted according to the applicable international ethical codes for research.

Participants were assured of confidentiality and privacy. Data and findings of the study were reported without alteration. Data gathered through questionnaires and interviews were verified by participants before the compiling process. The participants were made aware that this study would not reveal their identities, unless they granted permission for the same. The anonymity of the participants were indeed maintained. Their responses were not linked to their identities to prevent any harm as suggested by Gay, Mills, and Airasian (2011).

Participants were assured that the findings from the study would be the result of the experiences and ideas of the participants, rather than the characteristics and preferences of the researcher (Shenton, 2004). The issue of researcher's membership in the group or area being studied is relevant as the researcher played a direct role in both data collection and analysis. Whether the researcher is an insider or an outsider is an essential and ever-present aspect of an investigation (Dwyer & Buckle, 2009). Participants were informed that when data is interpreted, the researcher would remain objective.

3.13 Summary

This chapter described the research paradigm, research approach and research design. The mode of enquiry, population, sampling methods and data collection instruments were discussed. Issues such as validity and reliability, triangulation, insider-outsider conflict were addressed. The data collection procedures and the ethical considerations were discussed.

CHAPTER FOUR

DATA ANALYSIS, INTERPRETATION AND PRESENTATION

4.1 Introduction

This chapter presents the analysis of the data collected during the study to address the research questions. A preliminary analysis using the data collected from the formative and summative assessment is presented first. The quantitative data from the formative and summative assessments and the qualitative data from the open-ended interviews are then analysed statistically and then interpreted.

4.2 Population and Sample

The average number of students registering for the INDE course every semester is about 25. The researcher had planned and organised the classroom to carry out the study for approximately 25 students. But the semester starting January 2017, when the study was carried out, there were only 14 students who registered for the course. The classroom and other facilities including the table and chairs as well as the layout of the class was then rearranged for 14 students. Seven of these students volunteered to be in the group where GEBL was used as the teaching and learning approach. All students in this group were male. The other seven students were in the group where the traditional approach was used for teaching and learning. This group had five male and 2 female students. All 14 students had passed Electrical Engineering II which is a pre-requisite for PE.

4.3 Quantitative Data Analysis, Interpretation and Discussion

The quantitative data recorded from the two formative assessments and the one summative assessment is analysed and interpreted in this section.

Anova is used to test two groups to see if there is a difference between them. It is used to compare two means from two independent groups using the F-distribution. The null hypothesis for the test is that the two means are equal. Therefore, a significant result means that the two means are unequal. Anova compares the means between the two groups in the study and determines whether any of those means are statistically significantly different from each other.

Table 4. 1 Relation between assessment item numbers and research sub-questions

Research Sub-Question	Formative Assessment 1	Formative Assessment 2	Summative Assessment
SQ 1	1a, 1b, 1c, 2b, 4a, 5a	2, 4.1, 6.1	1.1c, 2.1a, 2.1b, 5.2
SQ 2	1d, 1e, 1f, 2a, 2c, 6a	1, 7.1, 7.2	1.1a, 1.1b, 1.1g, 2.1c, 3.1.1, 4.2
SQ 3	7a, 7b, 7c	5, 10a, 10b, 10c, 10d	2.2.1, 2.2.2, 2.2.3, 2.2.4, 3.1.2, 3.1.3, 3.1.4, 3.1.5, 4.1.1, 4.1.2, 4.1.3, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 5.1.1, 5.1.2, 5.1.3, 5.1.4
SQ 4	3, 4b, 5b, 6b, 6c	3, 4.2, 6.2,8, 9	1.1d, 1.1e, 1.1f, 5.2.1, 5.2.2, 5.2.3, 5.3

4.3.1 PRELIMINARY ANALYSIS

An initial preliminary analysis was carried out on the average percentage scores of PE students during the year (2016) before the year of the present research (2017). This revealed that in 2016, the average percentage scores for formative assessment 1, formative assessment 2 and summative assessment were 62%, 58.7% and 45.4%, respectively (see Appendix L-a for details). A similar analysis was done also for the two groups of students in 2017 (see Appendix L-b for details). The average percentage scores in 2017 for similar assessments for the TTG of students were 49.14%, 42.71% and 44.14%, respectively and those for the GEBL group were 69.71%, 53.29% and 48%, respectively. The 2017 TTG performed lower than the 2016 group in all assessments. However, the 2017 GEBL group performed higher than the 2016 TTG only in formative assessment 1 and summative assessment but their performance was lower than the 2016 TTG students in formative assessment 2. As such the researchers assumption that the performance of the GEBL group in all assessment types would be improved from that of the 2016 TTG students was disproved. However, the gains of GEBL students in formative assessment 1 and summative assessment indeed is an achievement, although the lower performance of GEBL students in formative assessment 2 was a disappointment. The present rearcher could not identify any obvious reason through the qualitative data.

A preliminary analysis was carried out with the main data collected in relation to the research sub questions before in-depth statistical analyses were carried out on the full set of data. The questions to be analysed were selected randomly without any specific criterion. For each research sub-question a similar proportion of questions were selected from each type of assessment. The following table shows the questions from the two formative assessments and the summative assessments that were used for preliminary analysis. A brief explanation of the expected answer is provided. Questions for which explanations are provided in the preliminary analysis will not be elaborated in section 4.3.2 again to avoid repetition.

Table 4. 2 Item Numbers for Preliminary Analysis

Research Sub-Question	Question numbers for preliminary analysis		
	Formative Assessment 1	**Formative Assessment 2**	**Summative Assessment**
SQ 1	4a	2	2.1b
SQ 2	2c, 6a	7.1	1.1g, 4.2
SQ 3	7a	5, 10c	2.2.1, 2.2.2, 2.2.3, 4.1.2, 4.1.3
SQ 4	3, 4b	6.2, 8	1.1f, 5.2.2

4.3.1.1 Addressing Research Sub-Question One

SQ1: Would a GEBL approach enhance students' ability to remember PE concepts?

Formative Assessment 1

Question 4a tested the students' ability to remember PE concepts. The graph shows the comparison of students' responses from the GEBL and traditionally taught groups.

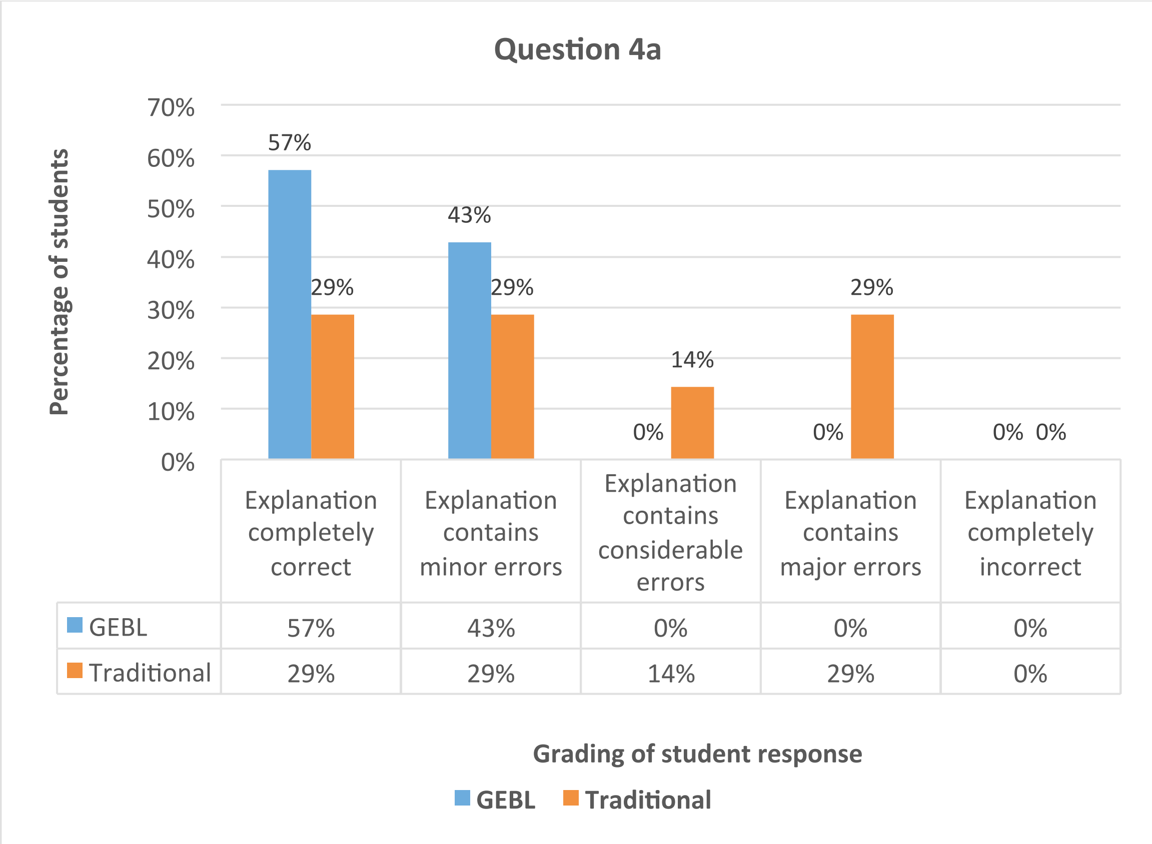


Fig. 4.1 Grading of student response for Question 4a

For Question 4a, the students had to state what Peak Inverse Voltage (PIV) is and the reason why PIV is an important parameter for diodes. Four students from the GEBL group were able to either answer the question correctly and three answered with minor errors. Only two students from the TTG answered the question correctly. Two made minor errors and four made considerable to major errors. in answering this question. Most of these students were able to explain what PIV is, but made mistakes in stating the reason why PIV is an important parameter for diodes.

Formative Assessment 2

Question 2 tested the students' ability to remember PE concepts. The graph shows the comparison of students' responses between the GEBL group and the TTG.

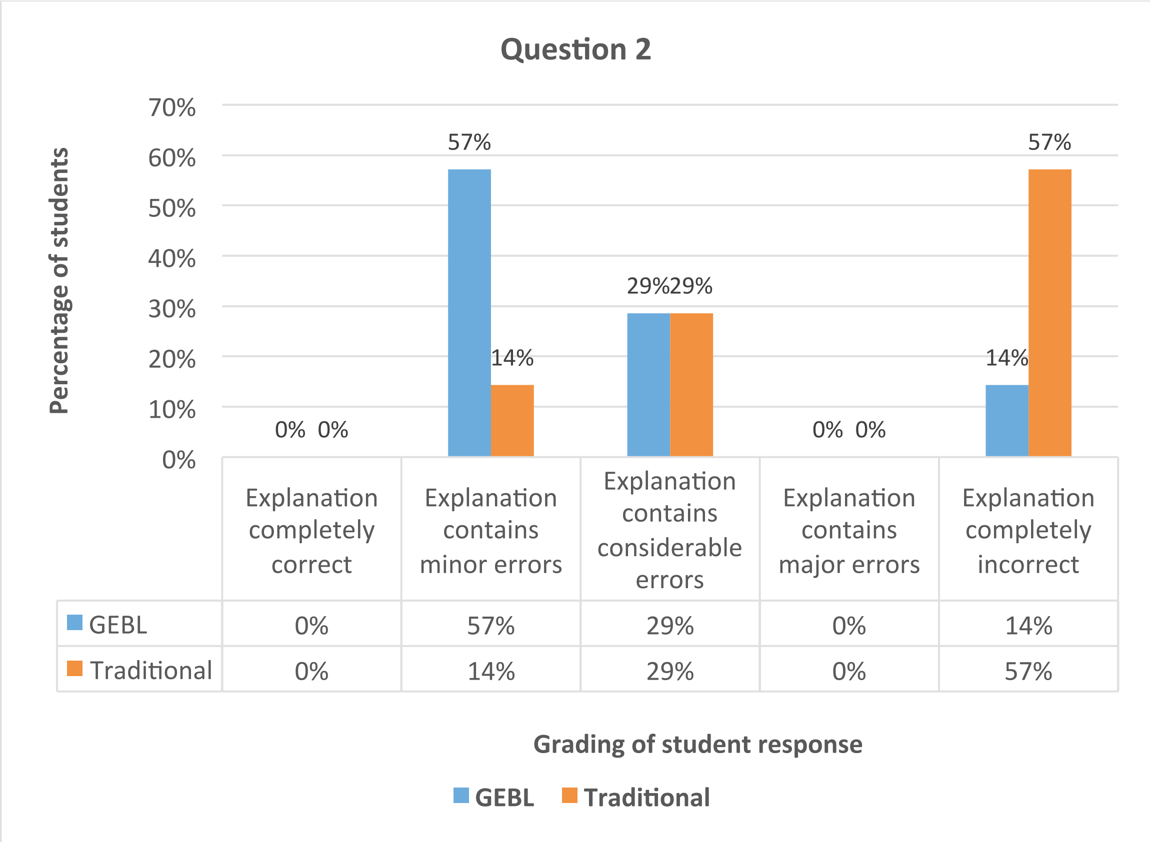


Fig. 4. 2 Grading of student response for Question 2

For Question 2, the students were required to recall three ways to trigger an SCR to its “ON” state. No student could answer this question correctly showing lack of conceptual understanding of the topic. Four students from the GEBL group were able to answer the question with minor errors but the majority of students from the TTG made considerable errors in answering the question or got the answer completely wrong.

Summative Assessment

Question 2.1b tested the students' ability to remember PE concepts. The graph shows the comparison of students' responses between the GEBL group and the TTG.

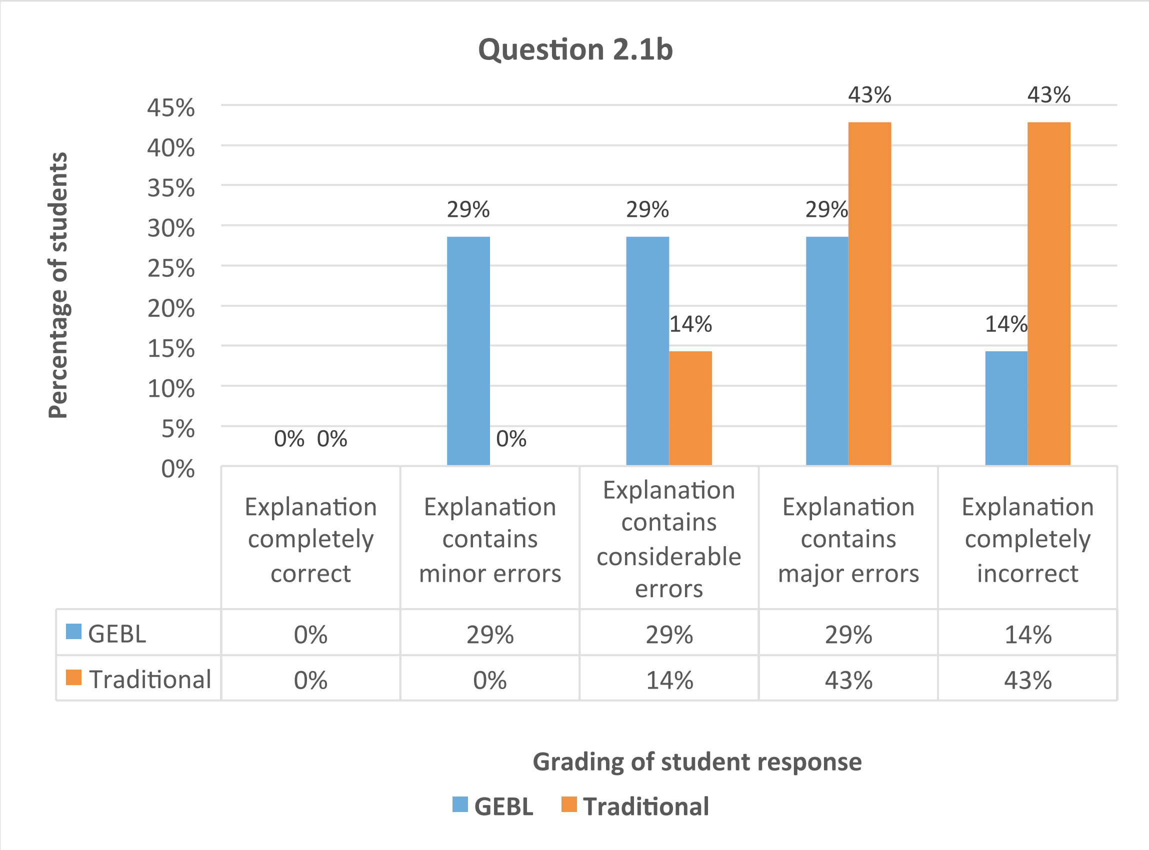


Fig. 4. 3 Grading of student response for Question 2.1b

For Question 2b, the students were required to list four differences between an ideal diode and a real diode. No student answered this question correctly by listing four differences. Two students from the GEBL group answered the question listing three differences while the students from the TTG could not list more than two differences. Two students from the TTG listed two differences. Three students from each of the two groups made major errors in answering the question and three from each group answered the question incorrectly.

Observations for Research Sub-Question One

From the data it was observed that the students from the GEBL group were able to recall the topics relatively better when compared to the students from the TTG. For most of the questions where students were required to recall the studied topics, the GEBL group performed better than the traditional group. This could be because during the group discussions in the GEBL group, the topics were discussed in detail which may have helped them understand the topics in depth, thereby assisting them in better recalling these topics.

4.3.1.2 Addressing The Research Sub-Question Two

SQ2: Would a GEBL approach enhance students' conceptual understanding of PE?

Formative Assessment 1

The following questions tested the students' understanding of PE concepts: Question 2c and Question 6a. The graph shows the comparison of students' responses from the GEBL group and from the TTG.

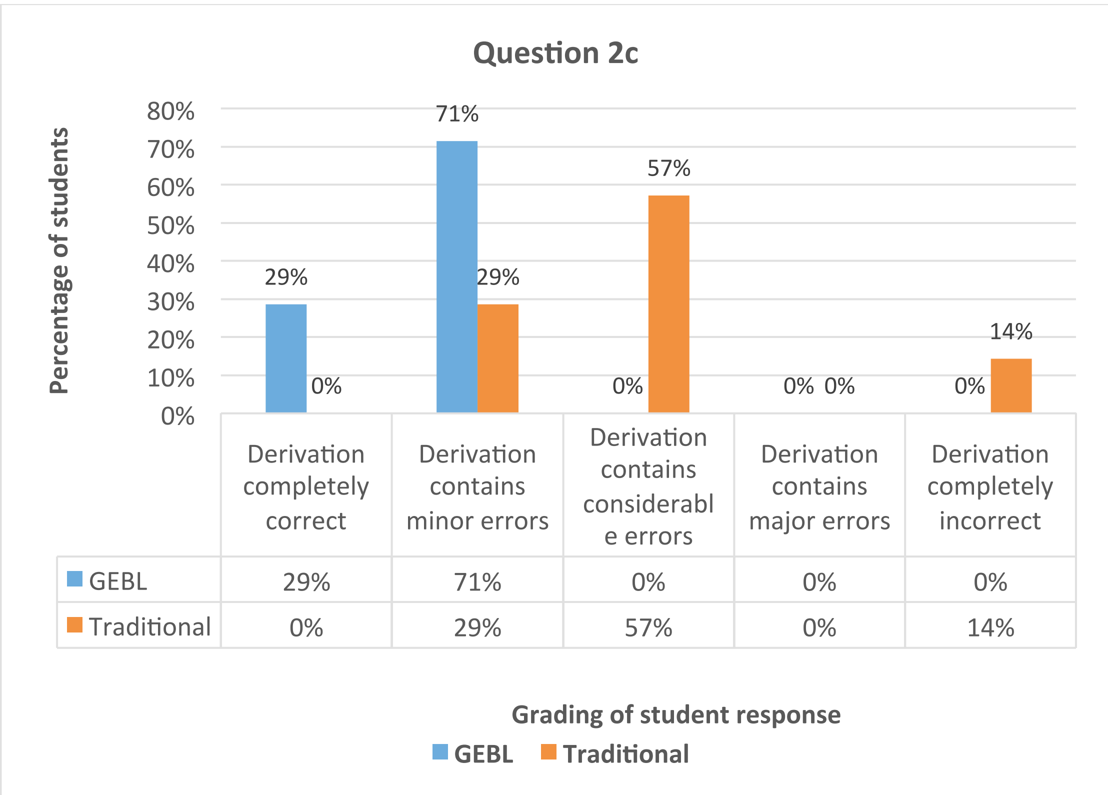


Fig. 4. 4 Grading of student response for Question 2c

For Question 2c, the students were required to analyse the output waveforms of the uncontrolled centre-tapped full wave rectifier and then derive an equation for the average voltage and average current for these rectifiers. Two students from the GEBL group analysed the output correctly and derived the equations correctly. Another five students from the GEBL group derived the equation with minor mistakes. No student from the TTG analysed the output correctly and three explained with considerable errors. Two from both groups got the derivation completely incorrect.

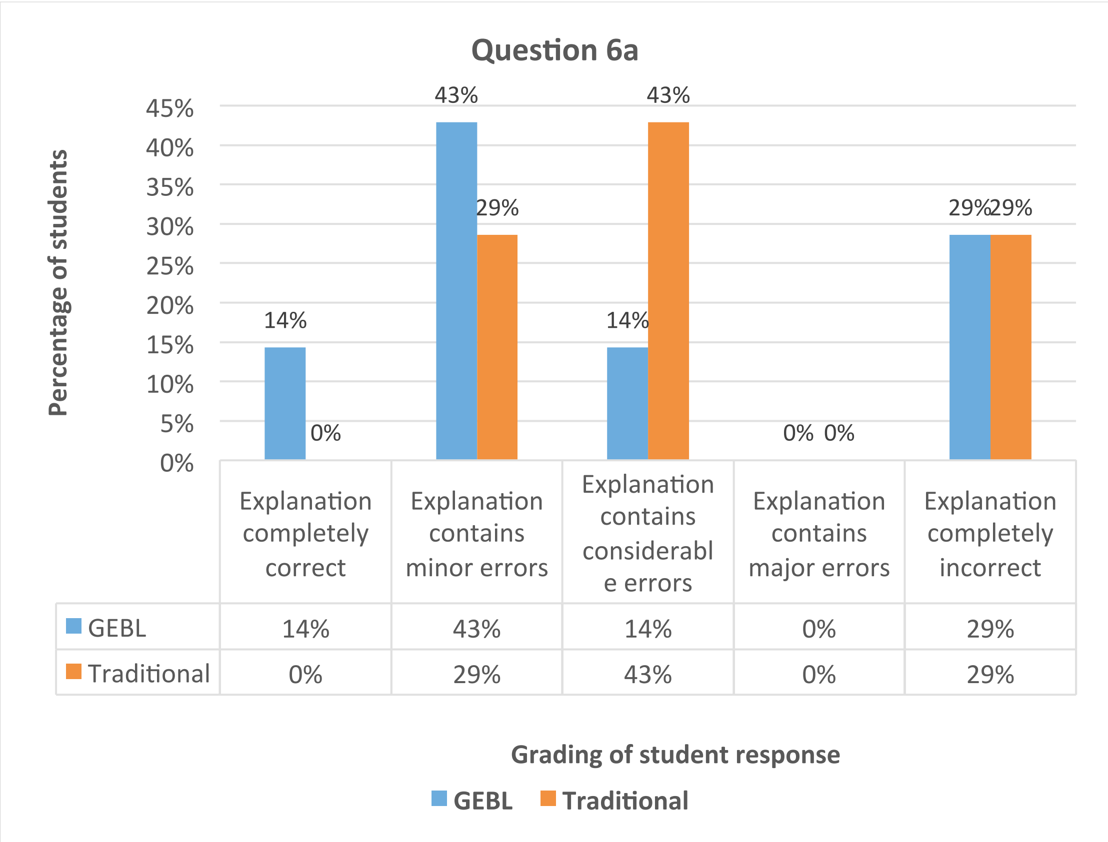


Fig. 4. 5 Grading of student response for Question 6a

Formative Assessment 2

Question 7.1 tested the students' understanding of PE concepts. The graph shows the comparison of students' responses between the GEBL group and the TTG.

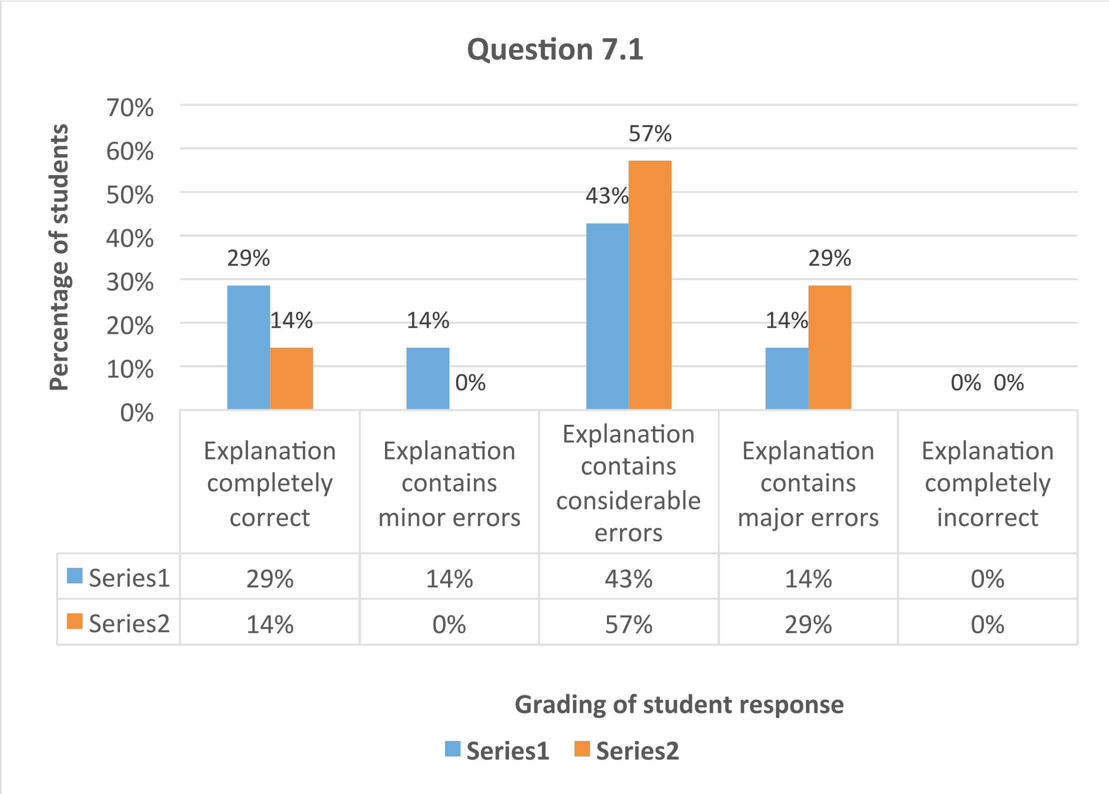


Fig. 4. 6 Grading of student response for Question 7.1

Summative Assessment

The following questions tested the students' understanding of PE concepts: Question 1.1g and Question 4.2. Figure 4.4 shows the comparison between students' responses in the GEBL group and the TTG. For Question 1.1g, six students from the GEBL group showed a complete understanding of the controlling of a MOSFET. One student made a minor error in the explanation. This showed a good understanding of the concept among GEBL students. Four students from the TTG answered the question correctly while two students made two errors in the explanation and one student answered the question incorrectly.

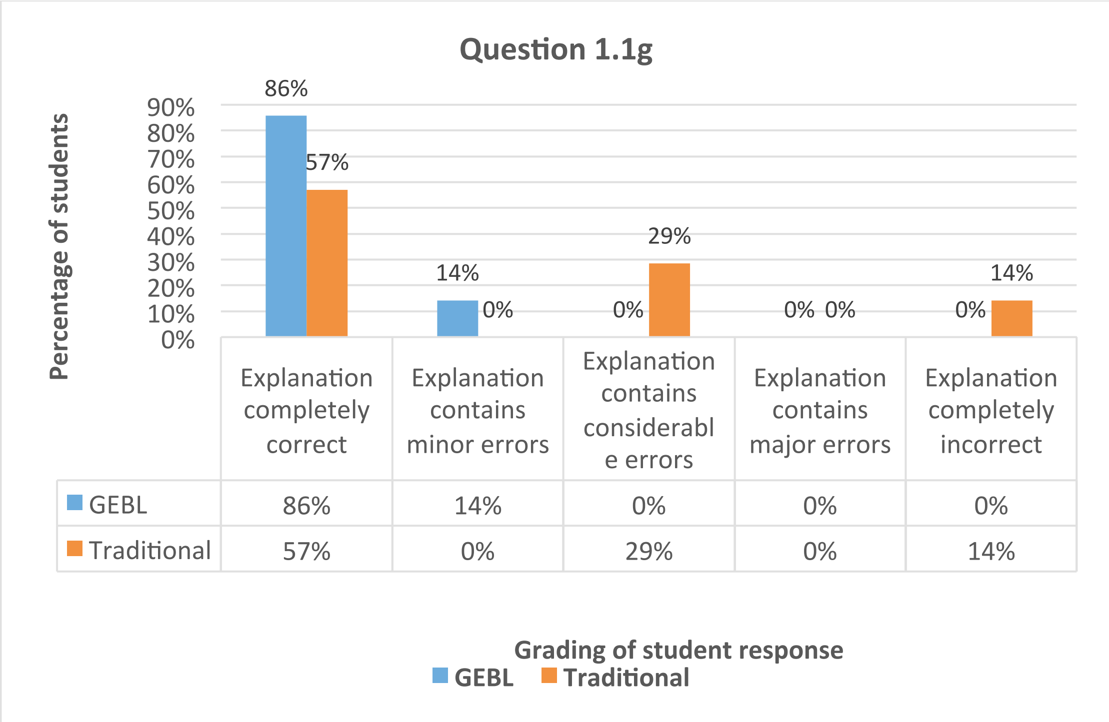


Fig. 4. 7 Grading of student response for Question 1.1g

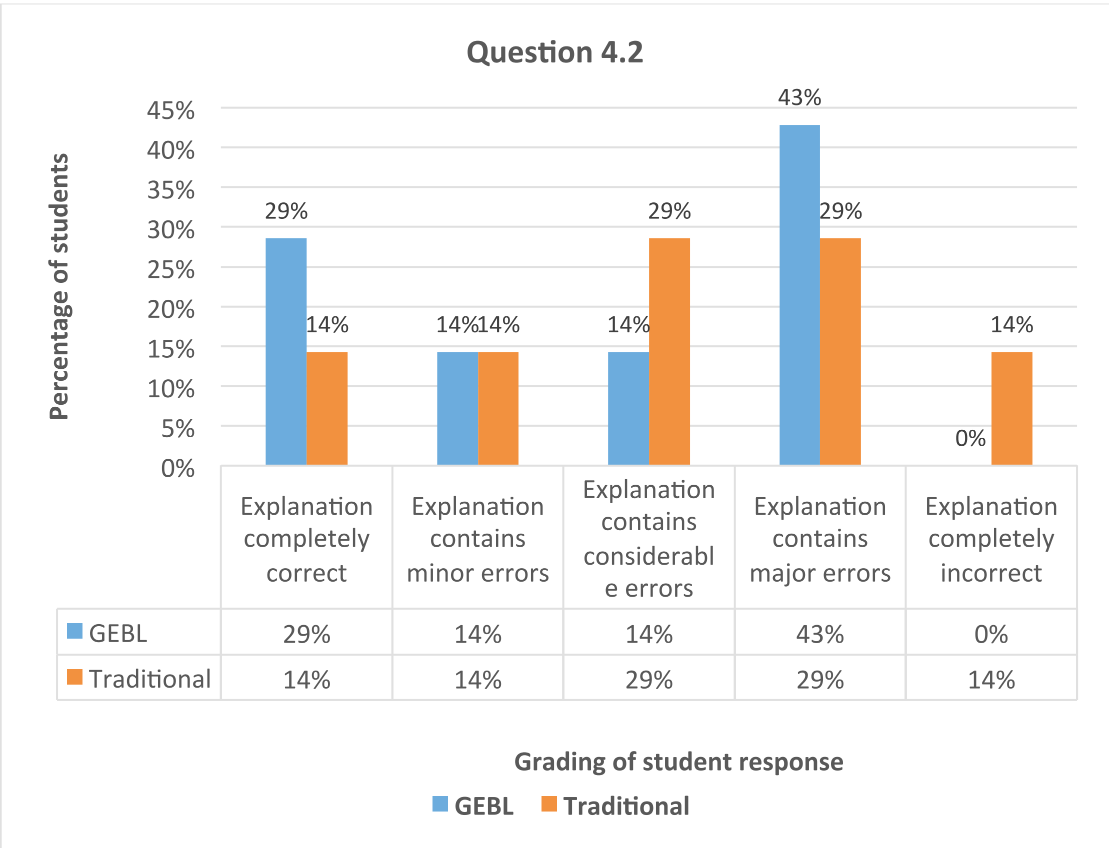


Fig. 4. 8 Grading of student response for Question 4.2

For Question 4.2, two students from the GEBL group demonstrated an understanding by answering the question correctly while one student from the TTG answered correctly. One student from each of the two groups made minor errors in answering. Four students from each of the two groups made two or more mistakes again demonstrating a lack of clear understanding of DC converters. More detailed coverage of these topics could assist in understanding these concepts better.

Observations for Research Sub-Question Two

From the data it was observed that the students from the GEBL group were able to understand the topics relatively better when compared to the students from the TTG. For most of the questions where they were required to explain the studied topics, they could answer the question correctly or with minor errors. Collaborative learning in the GEBL group could have helped the students to gain a better understanding of the topics learned. The GEBL group was also required to use various resources to understand the topic in depth compared to students from the TTG.

4.3.1.3 Addressing The Research Sub-Question Three

SQ3: Would a GEBL approach enhance students' problem solving skills?

Formative Assessment 1

The following question tested the students' problem solving skills: Question 7a. The graph shows the comparison between students' responses in the GEBL group and the TTG.

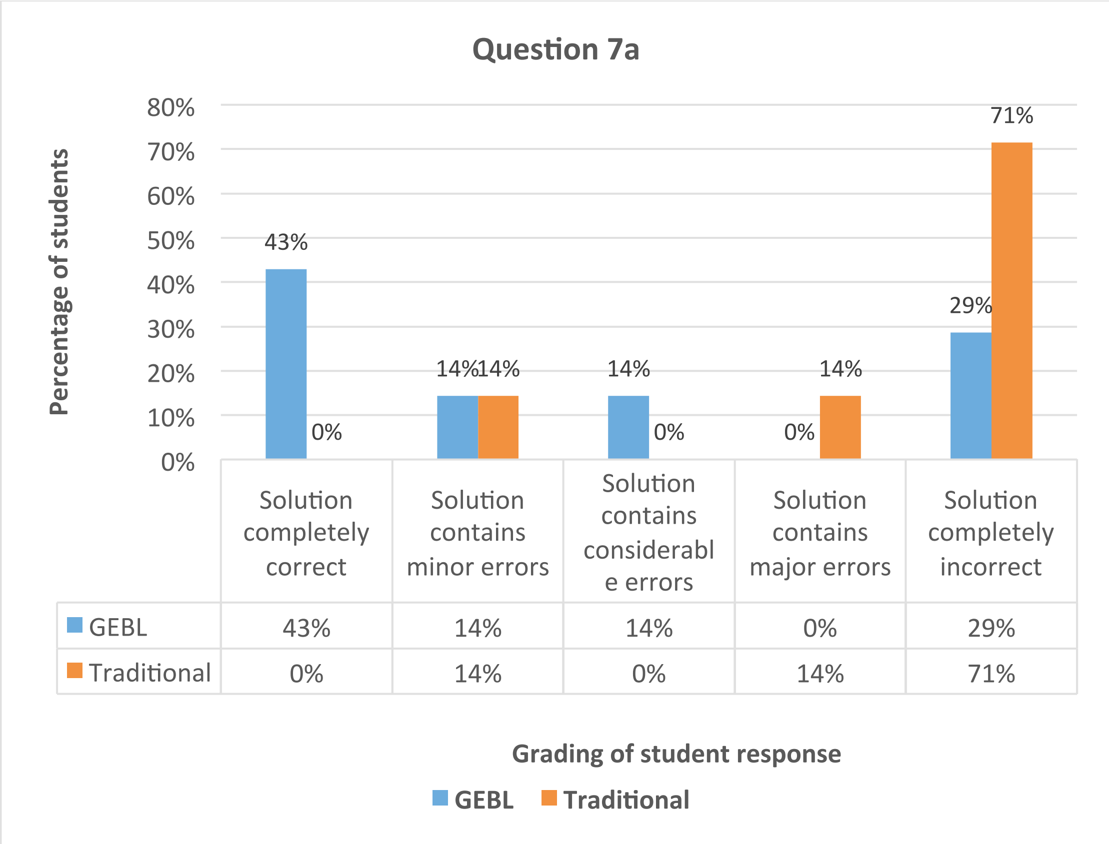


Fig. 4. 9 Grading of student response for Question 7a

Questions 7a, 7b and 7c are grouped together for analysis because in order to solve all these questions the students are required to understand and analyse the information given as well as use the given parameters to solve the problem.

For questions 7a, 7b and 7c, GEBL students demonstrated a better ability to use the information provided to solve the problem. From the TTG, five students for Question 7a, six students for Question 7b and two students for Question 7b could not solve the problem using the parameters provided. This clearly indicates that students need to spend more time solving problems after learning the theory to the related topics. GEBL students performed slightly better than students from the TTG but data indicates that some students from this group also lacked the ability to analyse the information and solve problems.

Formative Assessment 2

The following questions tested the students' problem solving skills: Questions 5 and 10c. The graph shows the comparison between students' responses in the GEBL group and the TTG.

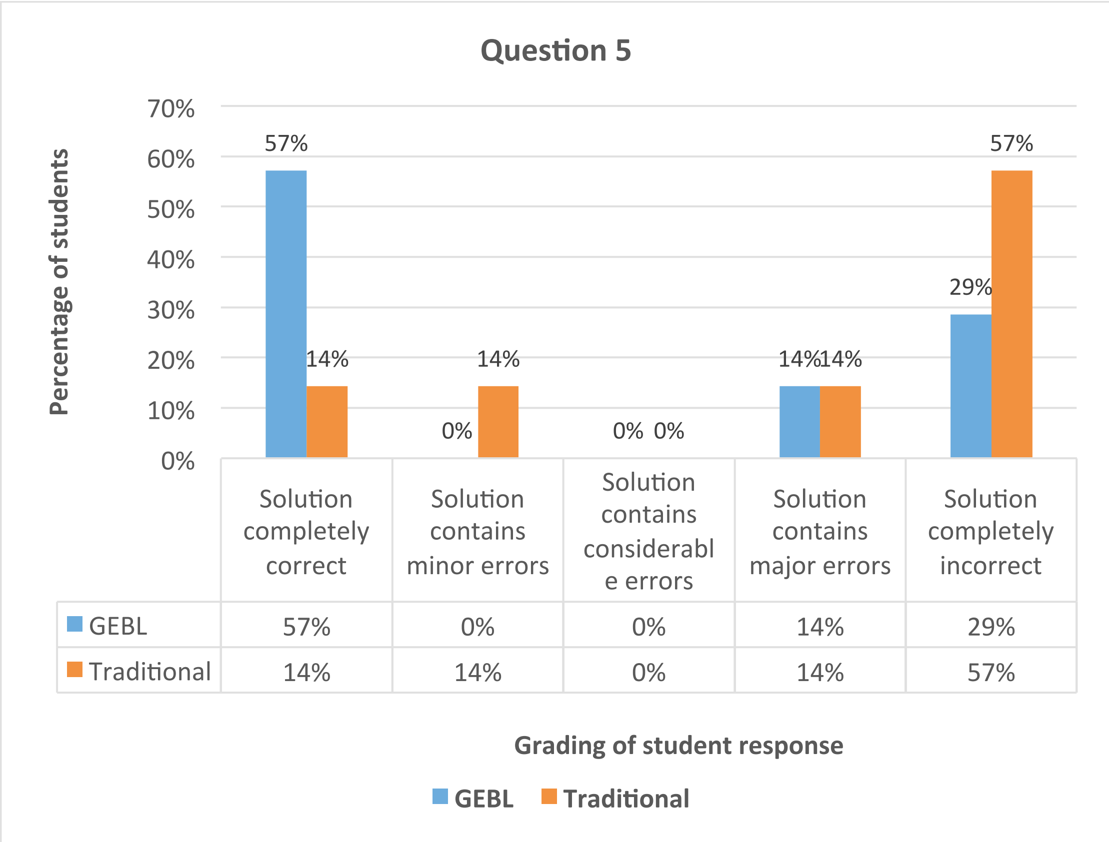


Fig. 4. 10 Grading of student response for Question 5

For Question 5, the students from the GEBL group demonstrated a better ability to solve problems with the information provided. Four students from the TTG could not solve the problem in comparison to two students from the GEBL group. Only one student from the TTG could solve the problem without any mistake in comparison to four students from the GEBL group. The data again demonstrates that the GEBL students are better equipped to understand the information provided and process the information effectively to solve problems.

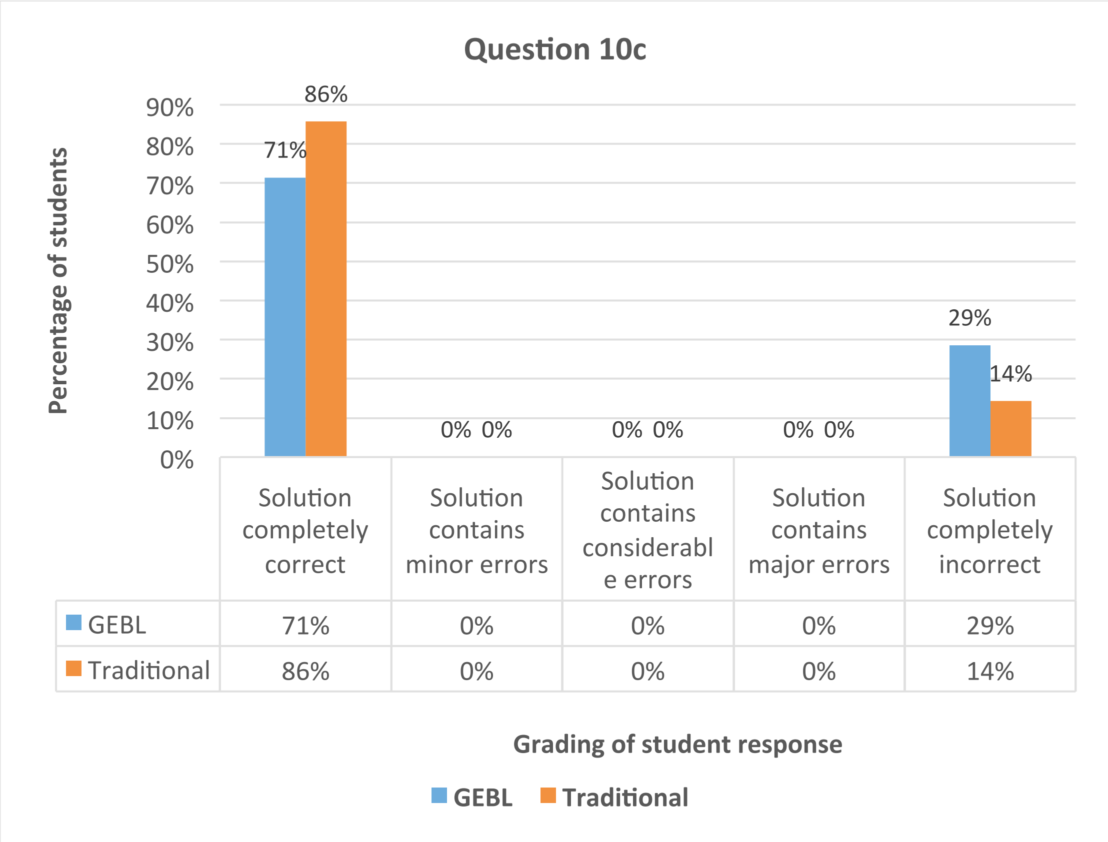


Fig. 4. 11 Grading of student response for Question 10c

For questions 10a, 10b, 10c and 10d, the data shows a very similar ability, from the students of both groups, to process the information provided and to solve the problem. In most cases, the majority of students were able to solve the problem correctly. For Question 10d, the students from the TTG performed slightly better than the GEBL group in solving the problem and getting the correct answer.

Summative Assessment

The following questions tested the students' problem solving skills: Questions 2.2.1, 2.2.2, 2.2.3 and 4.1.2. The graph shows the comparison of students' responses between the GEBL group and the TTG.

For analysis Questions 2.2.1, 2.2.2, 2.2.3 and 2.2.4 are grouped together as they are part of the same question where the students are required to analyse the working of the circuit and use the parameters providedto solve the problem.

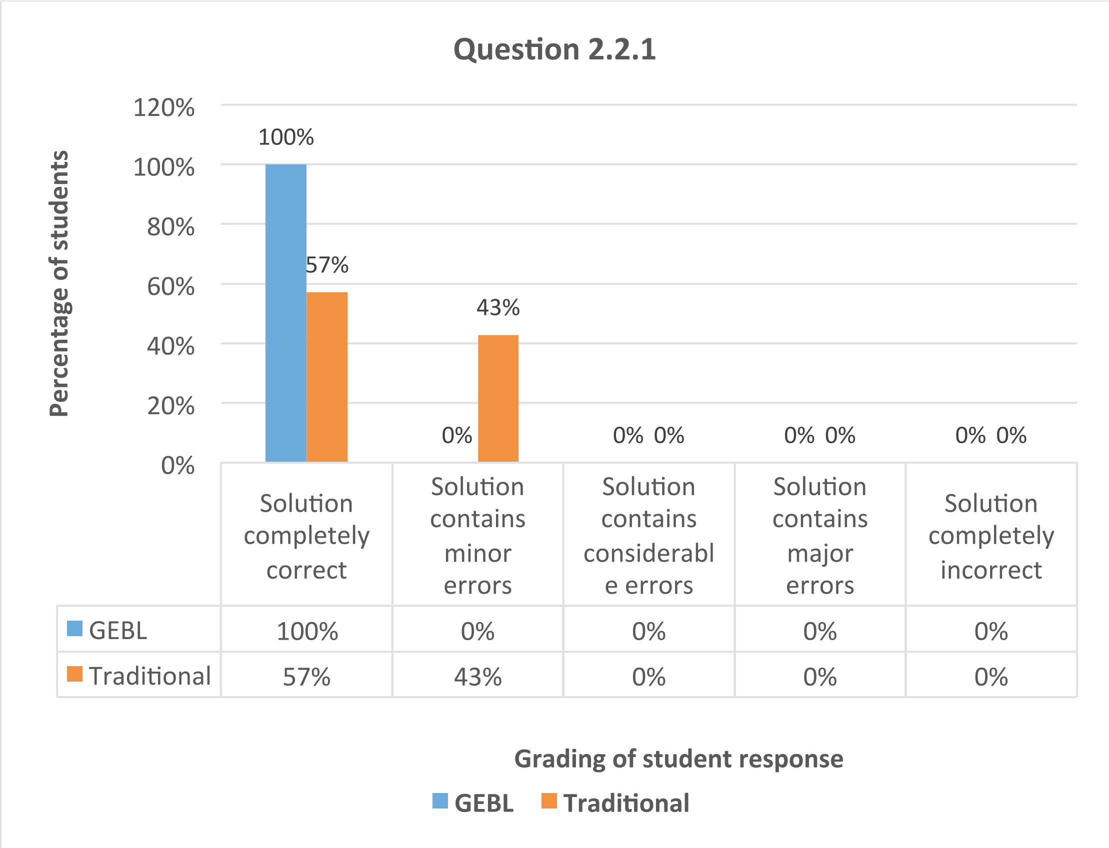


Fig. 4. 12 Grading of student responses to Question 2.2.1

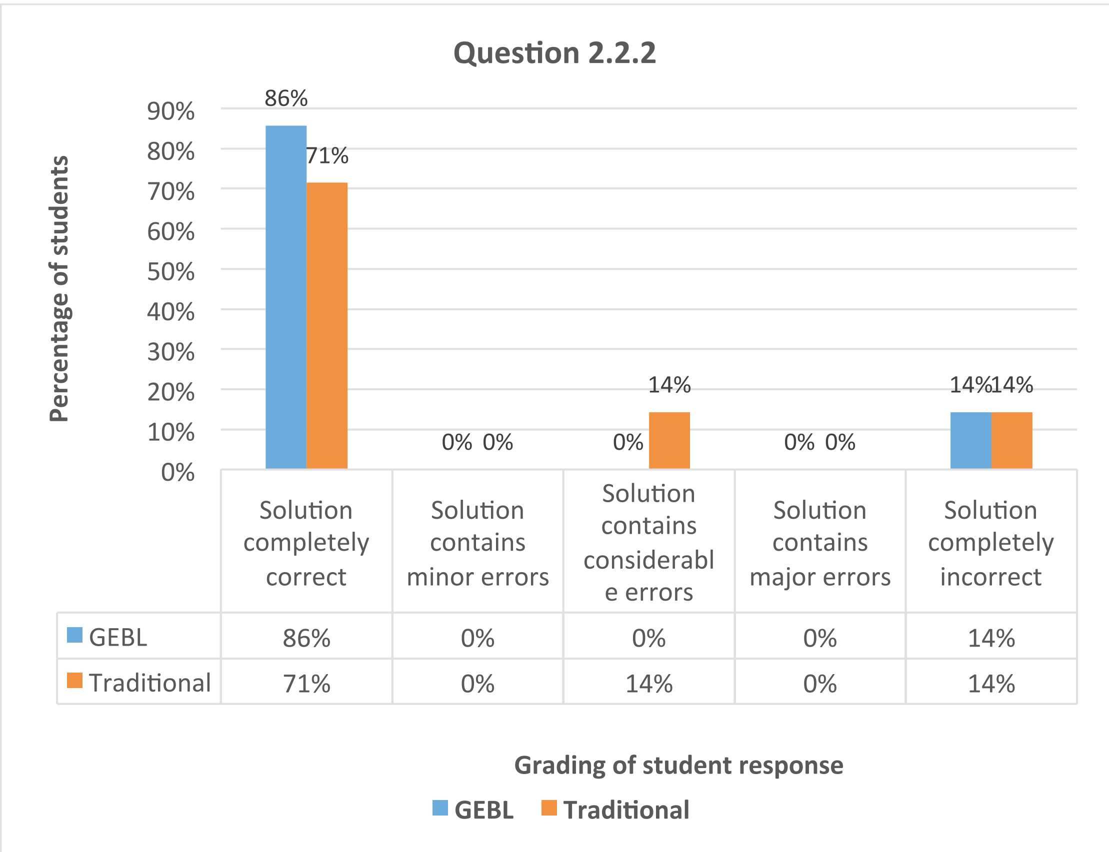


Fig. 4.13 Grading of student responses to Question 2.2.2

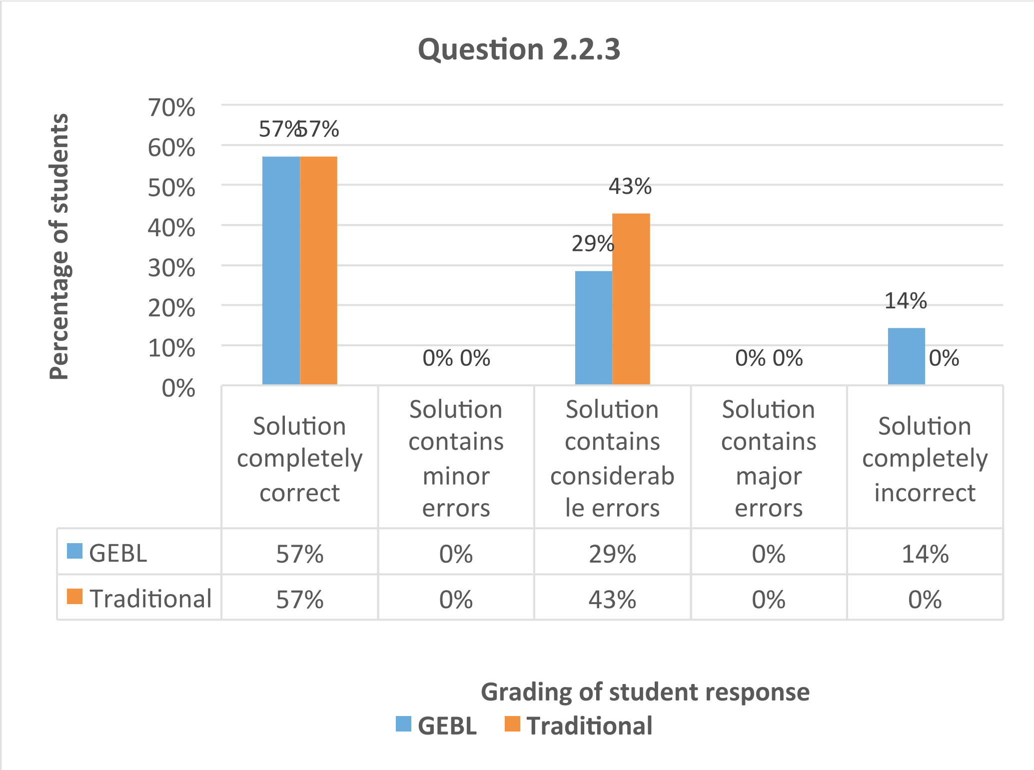


Fig. 4. 14 Grading of student responses to Question 2.2.3

For Questions 2.2.1, 2.2.2, 2.2.3 and 2.2.4 the majority of students from both groups were able to analyse the circuit and solve the problem correctly with the provided parameters. The data showed a similar problem solving ability among students from both groups (Fig size reduced in-order to avoid large blank space).

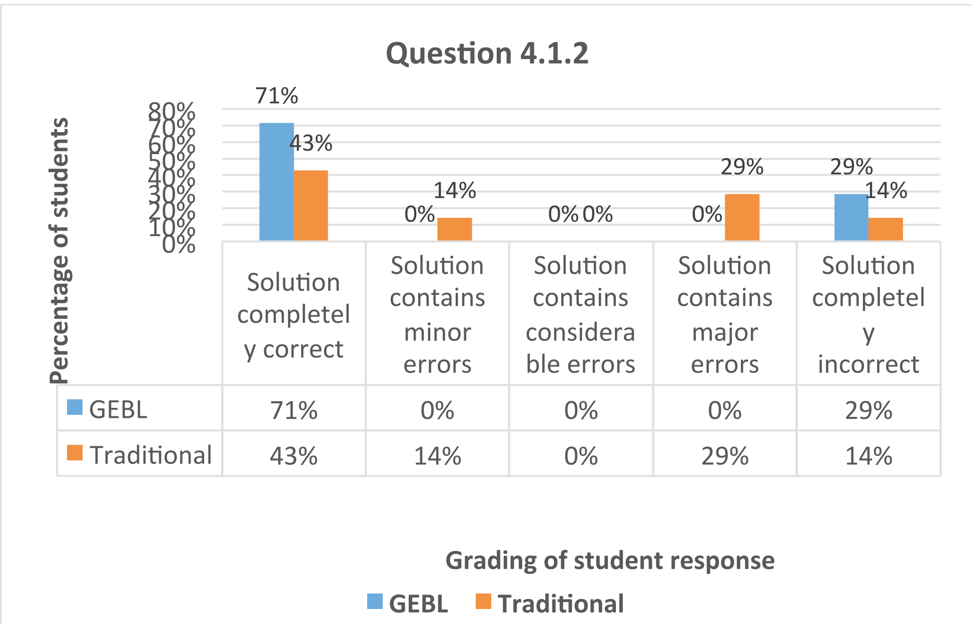


Fig. 4. 15 Grading of student responses for Question 4.1.2

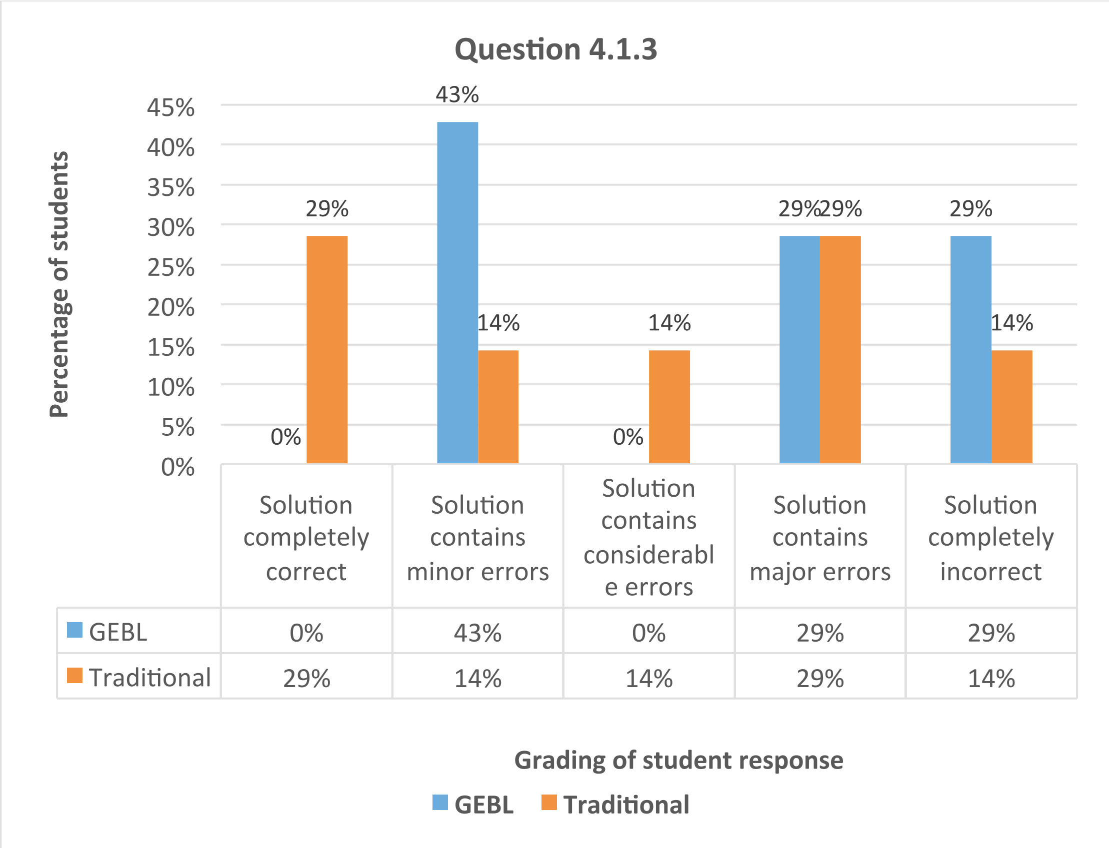


Fig. 4. 16 Grading of student responses for Question 4.1.3

For Question 4.1.1 the data showed identical problem solving ability among students from both groups. For Question 4.1.2, five students from the GEBL group got the correct answer compared to three from the TTG. For Question 4.1.3, no student from the GEBL group got the correct answer. Two students from the TTG solved the problem correctly. One common mistake the students made in the calculation was not considering the voltage drop across the thyristor which affected the calculation of V_{rms}.

Observations for Research Sub-Question Three

From the data it was observed that the students from the GEBL group were able to analyse the problem and were able to solve the problems. The performance of GEBL students was relatively better than the students from the TTG. Solutions to the problem showed that GEBL students were able to analyse the problem step-by-step. Their performance in analysis was better and hence more students from the GEBL group were able to solve the problems correctly.

4.3.1.4 Addressing The Research Sub-Question Four

SQ4: Would a GEBL approach enhance students’ critical thinking ability?

Formative Assessment 1

Question 3 tested the students’ critical thinking ability. The graph shows the comparison of students’ responses between the GEBL group and the TTG.

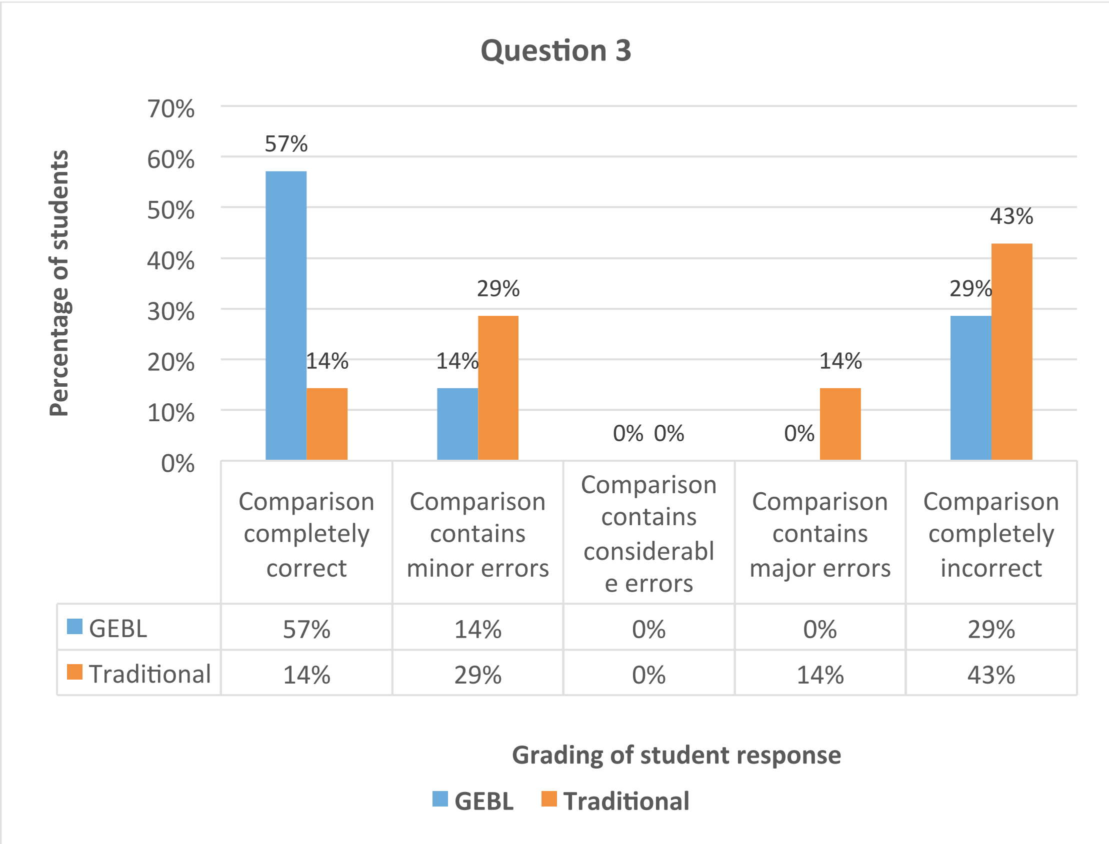


Fig. 4. 17 Grading of student response for Question 3

For Question 3, the students were required to compare a diode half wave rectifier and a diode full wave rectifier and using a mathematical expression show that the full wave rectifier is more efficient than the half wave rectifier. The students were required to use their understanding of the topics and think critically and prove that one type of rectifier is more efficient than the other type. Four students from the GEBL group were able to evaluate and compare the two types and mathematically prove that full wave rectifiers are more efficient than the half wave rectifier. Only one student from the TTG was able to do the same. One student from GEBL and two from the TTG were able to prove the same with one mistake. The data showed that GEBL students had a clear thinking process and were able to justify the answer.

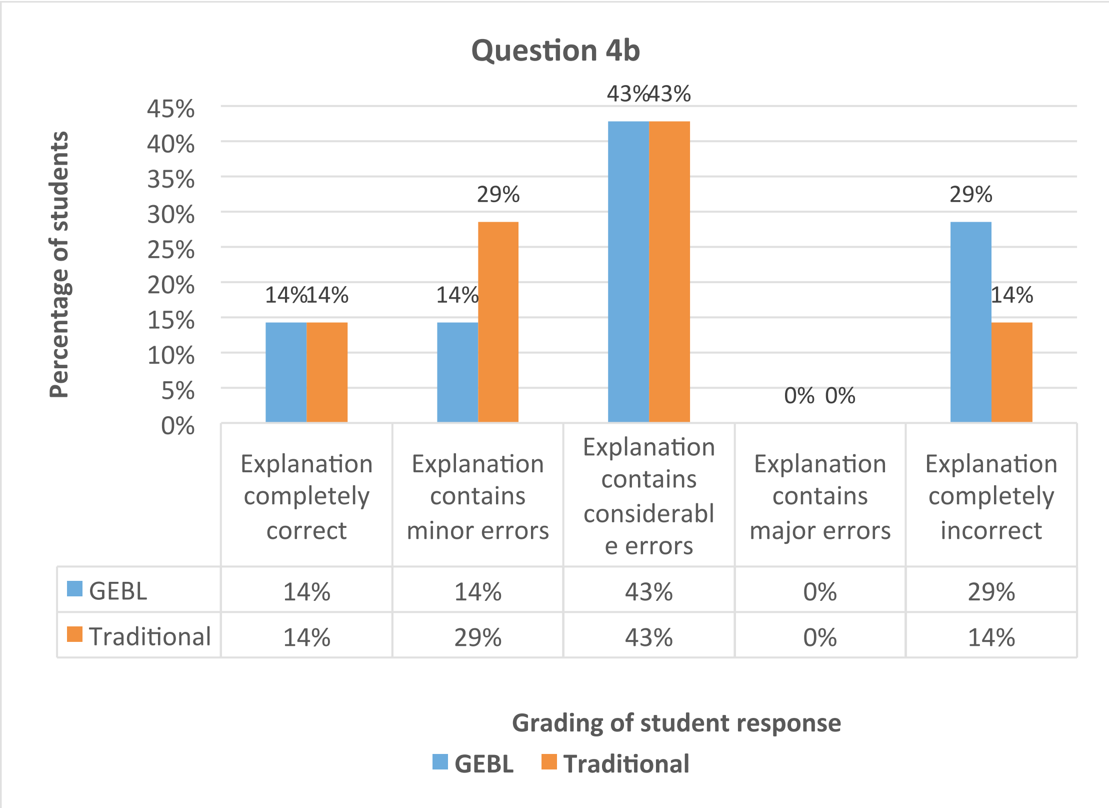


Fig. 4. 18 Grading of student response for Question 4b

For Question 4b, the students were required to analyse a half wave rectifier and a full wave rectifier circuit and measure the peak reverse voltage across the diodes. This is important during the design of circuits so that the diodes are not damaged during the working of the rectifiers. Data showed that the evaluation and justification from students from both groups were similar. It showed a similar understanding of topics for students from both groups.

Formative Assessment 2

Question 6.2 tested the students' critical thinking ability. The graph shows the comparison of students' responses between the GEBL group and the TTG.

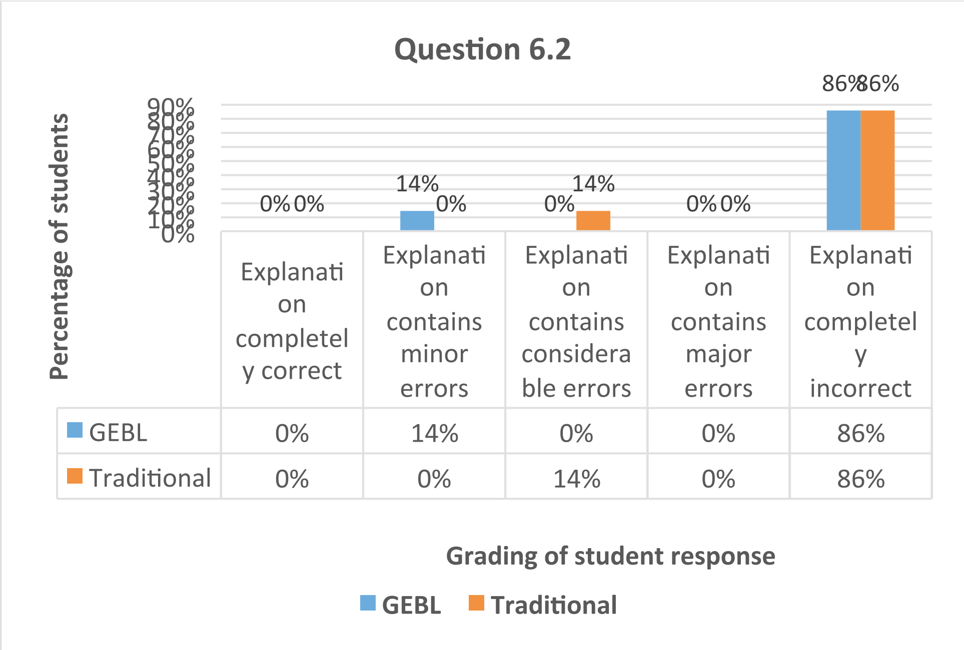


Fig. 4. 19 Grading of student response for Question 6.2

For Question 6.2, the students were required to use their knowledge about the characteristic curve of the thyristor and the effect of the gate trigger pulse in the working of the thyristor. They were required to think and analyse to answer this question. No student from either group managed to answer the question correctly. Majority of students got the answer wrong (Fig size reduced in-order to avoid large blank space).

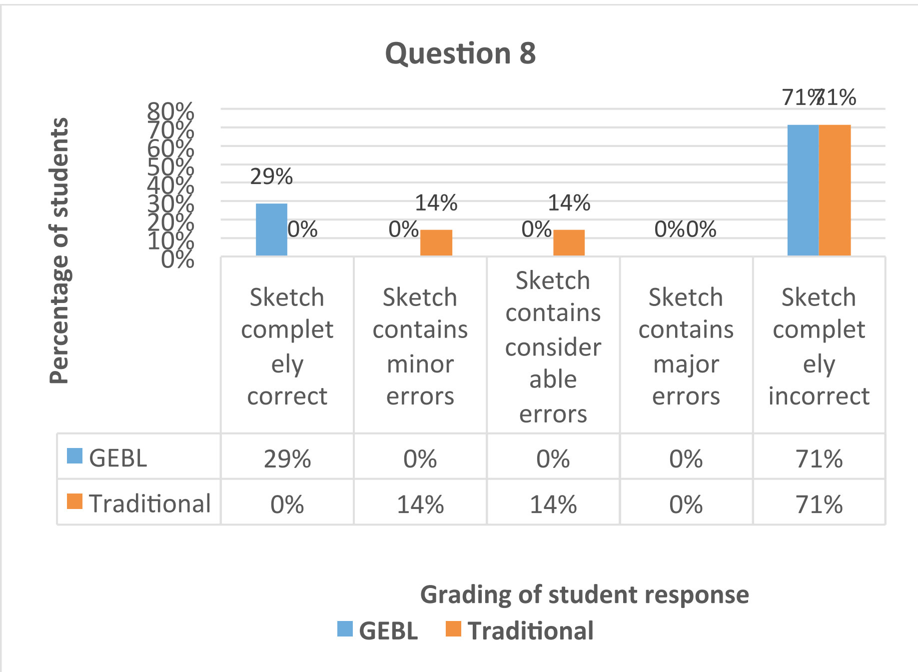


Fig. 4. 20 Grading of student response for Question 8

For Question 8, the students were required to use their knowledge about the working of bi-directional voltage controllers and using that knowledge they were required to evaluate the given circuit and draw the output waveforms for the circuit. Two students from the GEBL group analysed the circuit and sketched the output correctly. One student from the TTG sketched the output with one error and another student made two errors in sketching the output waveform. Five students from each group got the answer wrong or were not able to answer the question.

Summative Assessment

The following questions tested the students' critical thinking ability: 1.1f and 5.2.2. The graph shows the comparison of students' responses from the GEBL group and from the TTG. For the analysis, Questions 1.1d, 1.1e and 1.1f are grouped together.

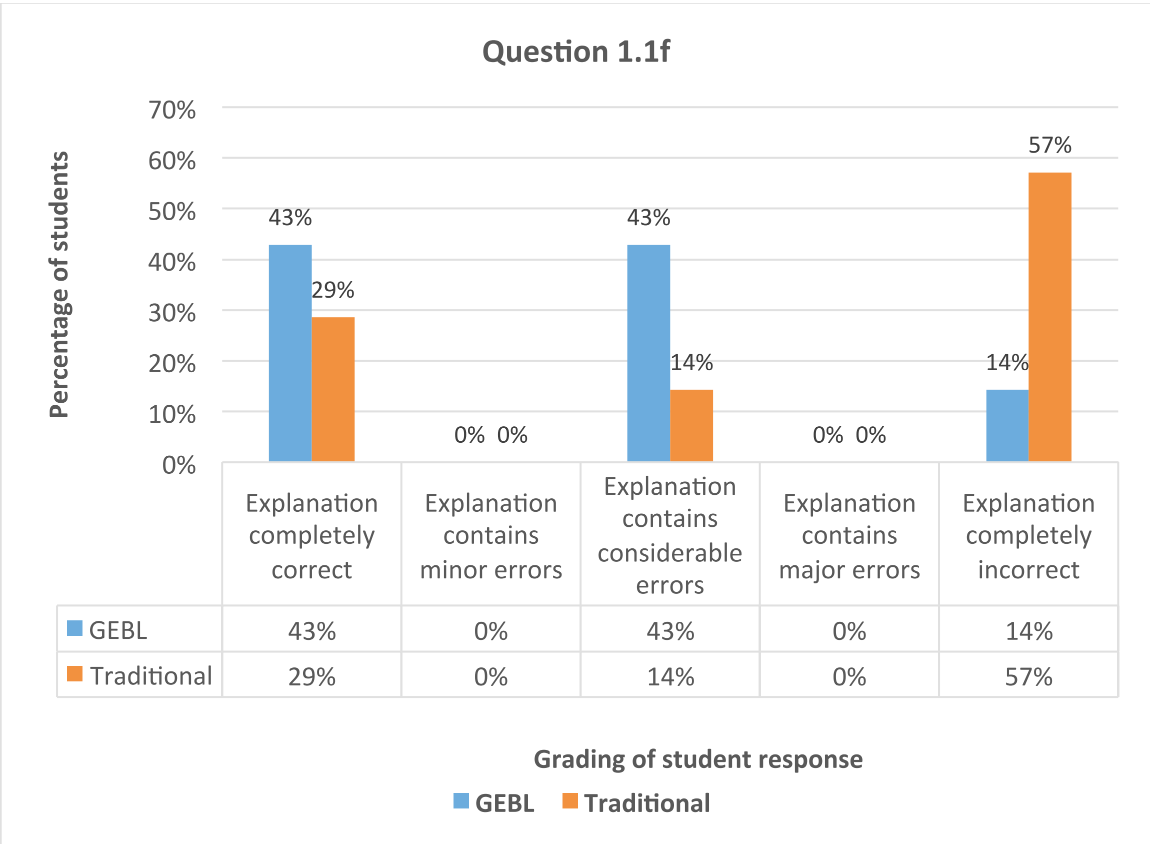


Fig. 4. 21 Grading of student response for Question 1.1f

For Question 1.1f, the students were required to explain the requirements to switch "OFF" an n-channel MOSFET and to keep it "OFF". Three students from the GEBL group were able to think and answer the question correctly and two students from the TTG got the answer completely correct. Three students from the GEBL and two from the TTG answered the question but made some errors in answering the question. One student from the GEBL group and four students from the TTG got the answer completely wrong. GEBL students showed a better thinking ability when compared to the students from the TTG.

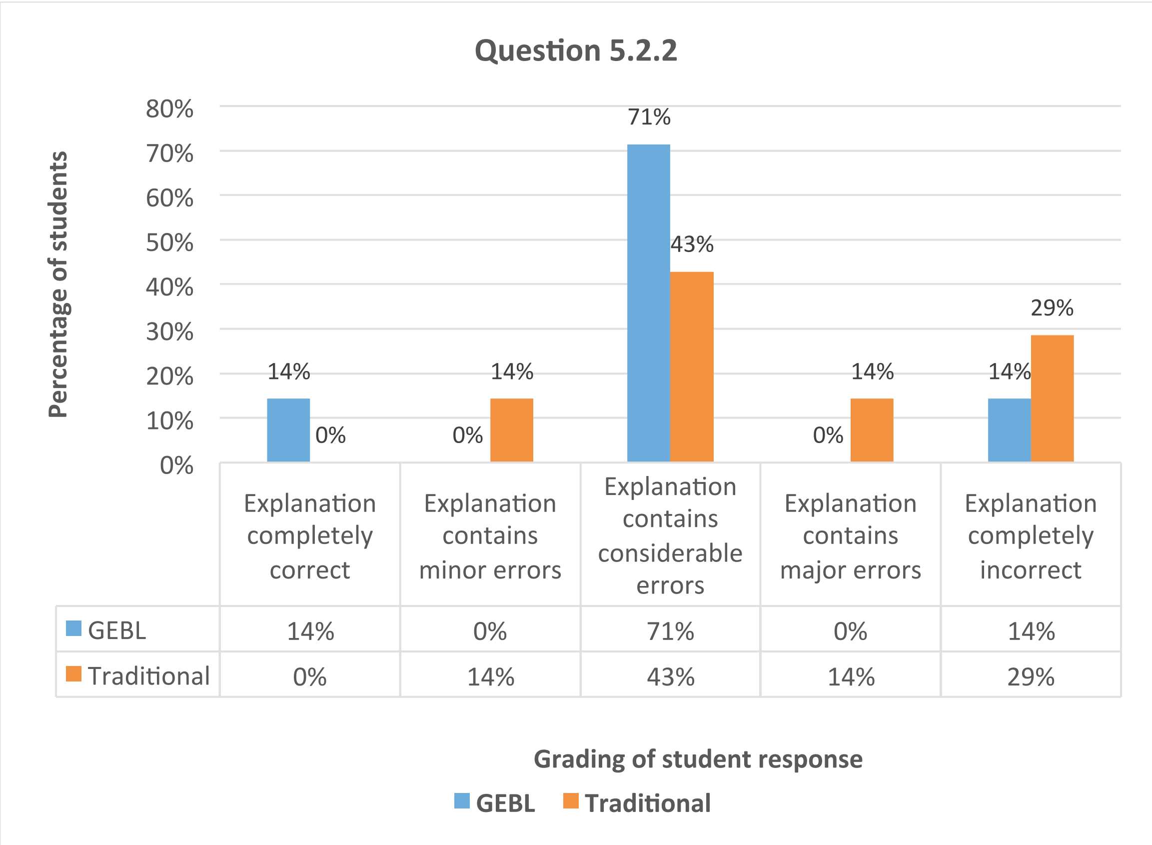


Fig. 4. 22 Grading of student response for Question 5.2.2

Question 5.2.2 required the students to use the characteristics curve of an SCR to answer the question. The responses from the students from both groups showed that they struggled to understand the question. Only one student from the GEBL group was able to answer the question correctly. No student from the TTG gave the correct answer. One student from the TTG answered the question with one error. Five students from the GEBL group and three students from the TTG answered the question with considerable errors. One student from the GEBL group and two students from the TTG anwered the question incorrectly. Though the question was simple the student response suggests that the the students struggled to understand the question when it is put in a different form.

Observations for Research Sub-Question Four

From the data it was observed that the students from the GEBL group were able to use higher levels of thinking. Students from the TTG struggled to analyse and think critically for these type of questions in general. GEBL students were always required to question each other when preparing a topic and this could have helped them to develop the critical thinking skill when the questions were given to them. For most questions, students from the GEBL group performed better than the students from the TTG.

4.3.2 STATISTICAL ANALYSIS

4.3.2.1 Addressing Research Sub-Question One

SQ1: Would a GEBL approach enhance students' ability to remember PE concepts?

Formative Assessment 1

The following questions tested the students' ability to remember PE concepts: 1a, 1b, 1c, 2b, 4a and 5a. For Question 2b, the students were required to draw the output waveforms for an uncontrolled centre-tapped full wave rectifier. Majority of students from both groups were able to recall and draw the waveforms for the rectifier. Only one student from the TTG was not able to draw the waveform and one student from the GEBL group made a minor error drawing the waveform.

For Question 4a, students from the GEBL group were able to either answer the question correctly or with minor errors. Students from the TTG made few errors in answering this question. Most students who made mistakes could not explain the importance of PIV.

For Question 5a, the students had to recall what a controlled rectifier is and what an uncontrolled rectifier is. Students from the GEBL group were able to answer the question either correctly or with minor errors. The reason for this could be that during group discussions, it was observed, that the students discussed about the difference between these rectifiers. So the students had a clear understanding of the difference between these two types of rectifiers which enabled them to recall the difference correctly.

Formative Assessment 2

The following questions tested the students' ability to remember PE concepts: Questions 2, 3, 4.1 and 6.1. For Question 2, four students from the GEBL group were able to answer the question with minor errors but majority of students from the TTG made considerable errors in answering the question or got the answer completely wrong.

For Question 4.1, the students had to recall what a crowbar thyristor is. Two students from the TTG answered the question correctly. Most of the students answered this question with lots of mistakes but students from the TTG answered the question relatively better. Only two students from the TTG got the answer completely wrong compared to five students from the GEBL group who got the answer completely wrong.

For Question 6.1, the students were required to sketch the characteristics curve of an SCR when the gate current is zero. The answers reflected similar level of recalling ability from the students from both groups. Four students from each group sketched the curve correctly. One student from the GEBL group made a minor error sketching the curve.

Summative Assessment

For Question 1.1c, only two students out of the total 7 students got the answer correct, which is the drain voltage must be greater than the source voltage. This reflects a low level of factual understanding. All other students got the answer wrong.

For Question 2.1a, the students were required to sketch the curves of an ideal diode and a real diode. Five students from the GEBL group sketched the curve correctly while one student made a minor error. Only two students from the TTG sketched the curve correctly, while three students sketched the curve with few errors. This showed that students from the TTG had difficulty recalling the curves for ideal and real diode.

For Question 2b, two students from the GEBL group answered the question listing three differences between ideal diodes and practical diodes while the students from the TTG could not list more than two differences. Two students from the TTG listed two differences. Three students from each of the two groups made major errors in answering the question and three from each group answered the question incorrectly.

For Question 5.2, students were required to recall the characteristic curve of a thyristor and to label the curve. Except one GEBL student who got the curve wrong, all others were able to sketch and label the curve correctly or with a minor error. From TTG only two students were able to sketch and label correctly or with minor errors. Five students from this group made major errors in plotting and labelling the curve or plotted the curve incorrectly.

Note that the labelling and references in Anova to General Population refers to the combination of both GEBL and traditionally taught students (N=14).

4.3.2.1.1 Analysis of Variance in Research Sub-Question One

4.3.2.1.1.1 Comparison among Assessment Methods

Hypotheses:

Null Hypothesis:	H_0: There is no difference between the assessment methods.
Alternative Hypothesis:	H_a: There are differences between assessment methods.
Level of significance is:	0.10
The obtained p-value:	0. 004

Observation: The observed p-value (0.004) is far less than the level of significance (0.10).

Conclusion: Since the observed p-value is less than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis. The assessment methods differ significantly under this setup. This means that the observed assessment means for formative 1, formative 2 and summative assessment methods have different effects on the performance of students. In other words, it means that the performance resulting from the influence of formative 1, formative 2 and summative methods were different based on the performance of students.

Subject matter Inference: The rejection of the null hypothesis means that the assessments are significantly different. Some or one of the assessment procedures are/is more superior to the other/others.

4.3.2.1.1.2 Comparison between Learning Methods

Hypotheses:

Null Hypothesis:	H_0: There is no difference between the learning methods.
Alternative Hypothesis:	H_a: There are differences between the learning methods.
Level of significance is:	0.10
The obtained p-value:	0.056

Observation: The observed p-value (0.056) is far less than the level of significance (0.10). The learning methods differ significantly under this setup. This means that the observed learning method means for traditional approach and GEBL approach have different effects on the performance of students. In other words, it means that the performance resulting from the influence of the learning methods were different based on the performance of students.

Conclusion: Since the observed p-value is smaller than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis.

Subject matter Inference: The rejection of the null hypothesis means that the learning methods are different from each other. The difference between the learning methods is statistically significant. In summary, this means that the difference between the learning methods is genuinely different. The learning method with a bigger mean is superior to the learning method with a smaller mean.

Calculation of N for analysis

The value of N is calculated for all analysis using the number of questions to answer each research sub-question multiplied by the number of students. The number of students who participated in the experiment was 14 and all participants wrote both the formative assessments and the summative assessment. Considering the distribution of participants in the table below, the researcher replicated the participation for the sake of reducing the experimental error. Table 4.3 shows the calculation of N for the analysis of variance in the first sub-research question.

Table 4. 3 Calculation of N for Research Sub-Question One

Assessment	Number of questions in assessments to test recalling	Number of students	N (= Number of questions in assessments * number of students)
Formative Assessment 1	6	14	84
Formative Assessment 2	3	14	42
Summative Assessment	4	14	56

Table 4. 4 Between-Subjects Factors for Research Sub-Question One

		Value Label	N
Type of Assessment	1.00	Formative-1	84
	2.00	Formative-2	42
	3.00	Summative	56
Method of Learning	1.00	Traditional method	91
	2.00	GEBL methos	91

Table 4. 5 Anova table for Research Sub-Question One

Dependent Variable: Marks obtained

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Model	225.756[a]	6	37.626	33.745	.000
Assessment	12.583	2	6.292	5.643	.004
Learning Method	4.128	1	4.128	3.702	.056
Assessment * learn.method	.239	2	.119	.107	.899
Error	196.244	176	1.115		
Total	422.000	182			

Estimated Marginal Means

Table 4.6 below shows the grand mean and the corresponding standard error of the data used for the analysis, which are 1.063 and 0.081 respectively. From the table below, we learn that the 95% confidence interval of the mean constitutes of the values .903 (Lower Confidence Limit) and 1.224 (Upper Confidence Limit).

Table 4. 6 Grand Mean and the Standard Error for Research Sub-Question One

Dependent Variable Marks obtained

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
1.063	.081	.903	1.224

Table 4. 7 Comparison of Assessments for Research Sub-Question One

Dependent Variable: Marks obtained

Type of assessment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Formative-1	1.226	.115	.999	1.454
2.00 Formative-2	1.286	.163	.964	1.607
3.00 Summative	.679	.141	.400	.957

Table 4.7 presents the marginal means of type of assessments (formative 1, formative 2 and summative). From the table, it is observed that the formative 1 mean

is 1.226 with a 95% confidence interval with limits .999 and 1.454. Similarly the formative 2 mean is 1.286 with a 95% confidence interval with limits .964 and 1.607 and with an observed summative mean of .679 with a 95% confidence interval with limits .400 and .957.

A 95% confidence mean, means that in a 100 cases of samples of a similar nature, 95% of them have means which fall in the identified lower and upper limits as stated.

Table 4. 8 Comparison of Methods of Learning for Research Sub-Question One

Dependent Variable: Marks obtained

Method of learning	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Traditional Method	.907	.115	.679	1.134
2.00 GEBL Method	1.220	.115	.993	1.448

The table 4.9 below present the breakdown of the means, standard deviations and sample sizes according to assessment method and the learning methods. It is noted that the formative-2 assessment method and the GEBL learning method both combined to produce the highest mean (1.500). However, the overall interaction effect was not found to be significant. This meant that emphasis was to be placed on the learning methods and assessment methods.

The above analysis and interpretation stems from the fact that to determine an interaction effect, one fixes one level of a factor and vary all other levels of the other factor and observes their means. From the table below, one observes that when assessment method is fixed at formative level 1, the different means over learning methods are: Traditional method (1.095) and GEBL method (1.357). A direct comparison finds the GEBL method more superior than the traditional method. Similarly when assessment is fixed at level 2 we observe: Traditional method (1.071) and GEBL method (1.500) and when it is fixed at level 3, we record: Traditional method (.554) and GEBL method (.804). From the three stated cases, it is perceived that the differential factor observes a common phenomena at the three levels demonstrating the superiority of the GEBL procedure as compared to the traditional method.

However, the overall assessment based on their probability value, provides a value of 0.899 which is far higher than the level of significance selected by the researcher. This, in effect, means that inspite of the individual level differences according to different learning methods, the final valuation rates a nonsignificant interaction effect.

4.3.2.1.1.3 Type of Assessment versus Method of Learning

Table 4. 9 The Assessment and Learning Method interaction for Research Sub-Question One

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1.00 Formative-1	1.00 Traditional method	1.095	.163	.774	1.417
	2.00 GEBL method	1.357	.163	1.036	1.679
2.00 Formative-2	1.00 Traditional method	1.071	.230	.617	1.526
	2.00 GEBL method	1.500	.230	1.045	1.955
3.00 Summative	1.00 Traditional method	.554	.200	.160	.947
	2.00 GEBL methos	.804	.200	.410	1.197

4.3.2.1.1.4 Multiple comparisons for Type of Assessment

The following table shows detailed comparisons among significant assessment methods. The means are labelled I and J. Their difference is determined and compared to a standard difference (a least significant difference). Any difference greater than this is significant. Also in the table are p-values for these comparisons under the label “Sig”.

Table 4. 10 Multiple Comparisons for Type of Assessment for Research Sub Question One

Dependent Variable: Marks obtained

(I) Type of assessment	(J) Type of assessment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00 Formative-1	2.00 Formative-2	-.0595	.19956	.956	-.5522	.4331
	3.00 Summative	.5476*	.18217	.012	.0979	.9973
2.00 Formative-2	1.00 Formative-1	.0595	.19956	.956	-.4331	.5522
	3.00 Summative	.6071*	.21554	.021	.0750	1.1393
3.00 Summative	1.00 Formative-1	-.5476*	.18217	.012	-.9973	-.0979
	2.00 Formative-2	-.6071*	.21554	.021	-1.1393	-.0750

Homogeneous Subsets

Homogeneous treatments are those, which are under the same group as shown below.

Table 4. 11 Grouping of Assessments for Research Sub-Question One

Type of assessment	N	Subset	
		1	2
3.00 Summative	56	.6786	
1.00 Formative-1	84		1.2262
2.00 Formative-2	42		1.2857
Sig.		1.000	.956

Error plot of Assessment Methods

Error plot of assessment methods. These plots shows marked differences between two selected assessment means.

Error plot of Learning Methods

The error plot below shows the superiority of the GEBL method, which was compared to the traditional learning method. This is the justification of the significant result under the Anova investigation.

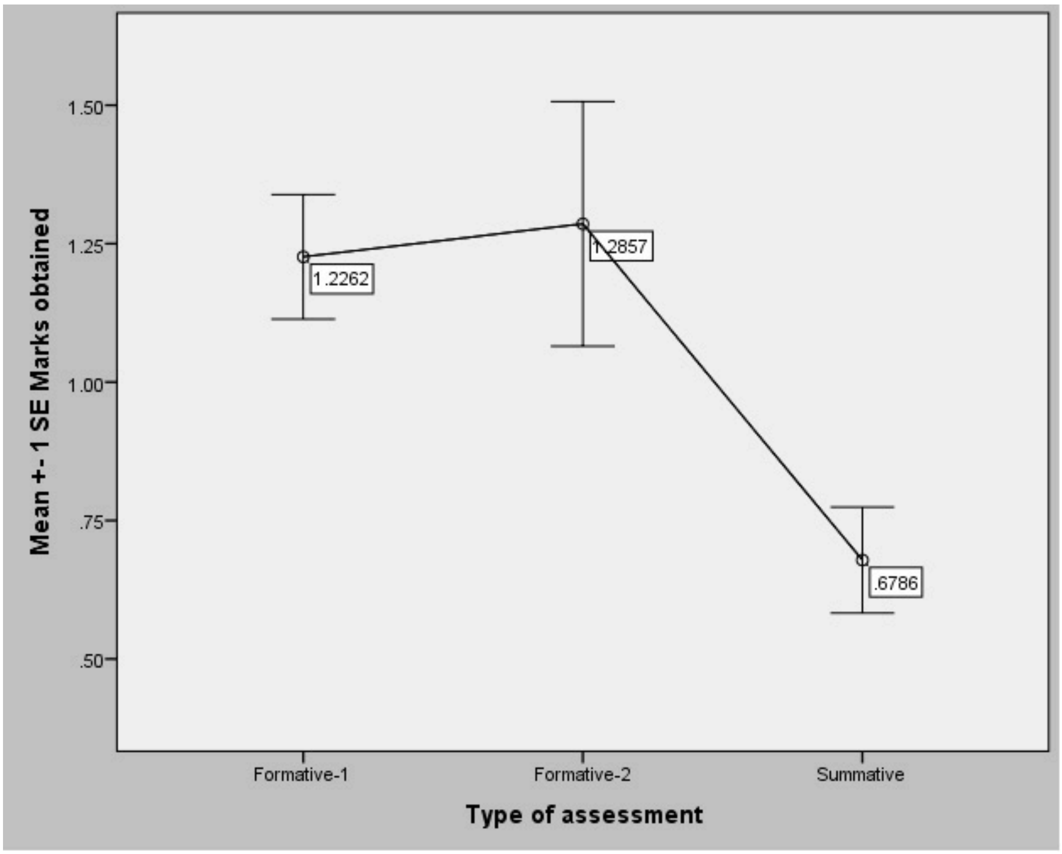


Fig. 4. 23 Error Plot of Assessment Methods for Research Sub-Question One

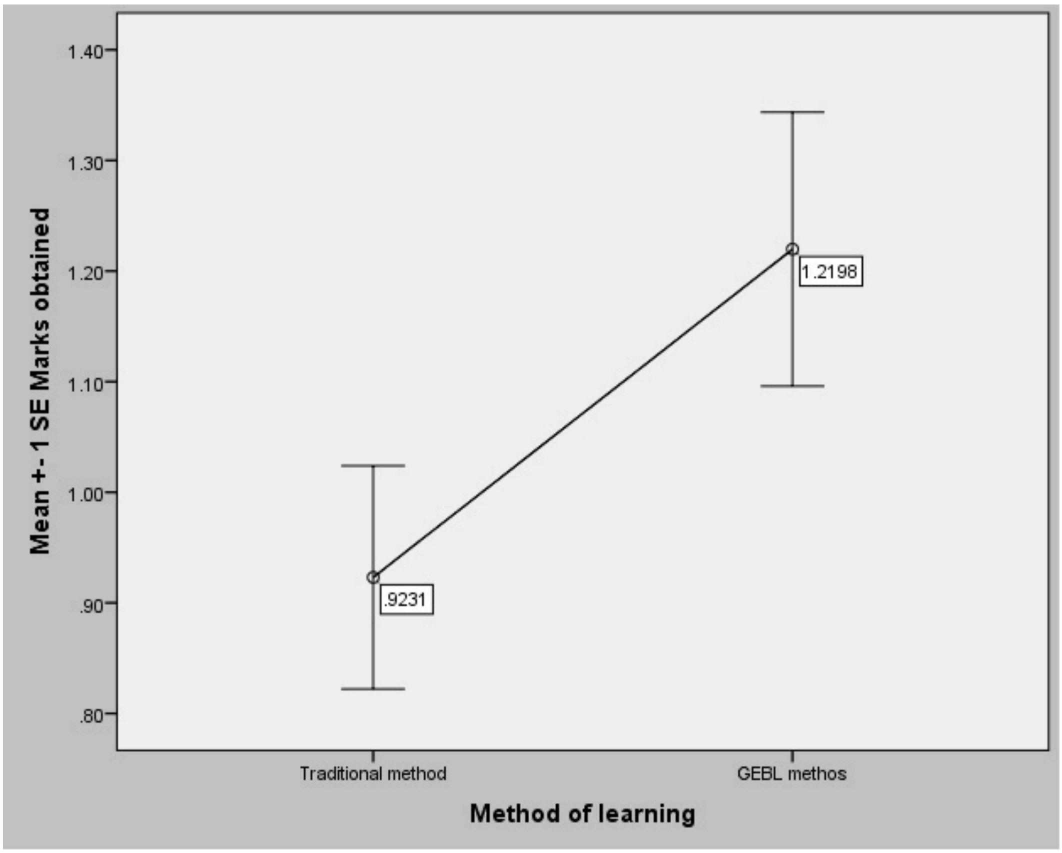


Fig. 4. 24 Error Plot of Learning Method for Research Sub-Question One

4.3.2.1.2 Observations for Research Sub-Question One

The p-value for Research Sub-Question one from the Anova table is 0.056. As this value is less than 0.10 we can reject the null hypothesis. This means that there is a statistical difference between the two methods of learning. From the data it was observed that the students from the GEBL group were able to recall the topics relatively better when compared to the students from the TTG. GEBL enabled students to connect prior knowledge to newly acquired knowledge (Hay, 2007; Warner & Myres, 2014) and resulted in deep learning leading to remembering of key concepts (Drake & Battaglia, 2014). For most of the questions where they were required to recall the studied topics, students in the GEBL group could answer the question correctly compared to students from the TTG.

4.3.2.2 Addressing Research Sub-Question Two

SQ2: Would a GEBL approach enhance students' understanding of PE concepts?

Formative Assessment 1

SQ2: Would a GEBL approach enhance students' understanding of PE concepts?

The following questions tested the students' understanding of PE concepts: 2a, 2c and 6a.

For Question 2a, the students had to explain the working of an uncontrolled centre-tapped full wave rectifier. All students from the GEBL group answered this question correctly. From the TTG, only two students answered the question correctly. Two students from the TTG drew the circuit diagram correctly but made mistakes in the explanation about the working of these rectifiers.

For Question 2c, two students from the GEBL group analysed the output correctly and derived the equations correctly. Another five students from the GEBL group derived the equation with minor mistakes compared to two students from the TTG. No student from the TTG got the derivation completely correct.

For Question 6a, the students had to demonstrate an understanding of the rectification concepts and explain why they would choose one rectifier over the other. Only one student from the GEBL group gave the correct explanation while no student from the TTG was able to give a correct answer. Three students from the GEBL group explained with minor errors and two students from the TTG explained with minor errors.
Two students from each group got the answer completely wrong.

Formative Assessment 2

The following questions tested the students' understanding of PE concepts: 1, 7.1 and 7.2.

For Question 1, students had to demonstrate an understanding of the working of the two transistor model for an SCR. GEBL students demonstrated a better understanding of the concepts compared to the traditional students. Five GEBL students were able to explain the two transistor model correctly while no student from the TTG was able to answer this correctly. Majority of students from the TTG made major mistakes or got the answer completely wrong. It showed a lack of understanding of related transistor and SCR concepts.

For Question 7.1 and 7.2, the students had to explain the concept of the different modes of operation of a MOSFET. For question 7.1, two students from the GEBL group and one from the TTG explained the concept correctly. One student from the GEBL group made minor error in the explanation. Four GEBL group students and six TTG students made two or more errors in explaining the concept. For question 7.2, only two students from each group were able to answer the question correctly or with minor errors. All other students made two or more mistakes in the explanation of the concept.

Summative Analysis

The following questions tested the students' understanding of PE concepts: 1.1a, 1.1b, 1.1g, 2.1c, 3.1.1 and 4.2.

Questions 1.1a, 1.1b and 1.1g are analysed together as all of them test the concepts of n-channel enhanced MOSFET

For questions 1.1a, the responses from the students from both groups were similar. Two students from each group showed a complete understanding of the switching ON and OFF of an n-channel MOSFET. Majority of students made one or two mistakes in the explanation of the concept. For question 1.1b, only one student from the GEBL group could explain the logic behind the symbol and all other students made either 3 or more mistakes or explained the logic incorrectly. For question 1.1g, six students from the GEBL group answered the question correctly. One student made a minor error in the explanation. Four students from the TTG answered the question correctly while two students made two errors in the explanation and one student answered the question incorrectly.

For Question 2.1c, three students from each group showed a good understanding of the reverse recovery characteristics of the diode and were able to show that $I_{RR} = 2Q_{RR}/t_{rr}$. Two students from the TTG made minor errors and another two made two errors in showing their understanding. Two students from the GEBL group answered the question incorrectly and one student made more than two errors in explaining the answer. Students from the TTG performed better in answering this question.

For Question 3.1.1, the students were required to understand the working of the circuit with the knowledge they had acquired from learning different topics in the course. Three students from the GEBL group and two students from the TTG showed a clear understanding of the working of the circuit and sketched the output waveforms for the circuit. Two students from the GEBL group and four students from the TTG made two errors sketching the waveform. The mistakes demonstrated a lack of clear understanding of some of the rectification concepts by students in both groups.

For Question 4.2, two students from the GEBL group demonstrated the understanding by answering the question correctly while one student from the TTG answered correctly. One student from each of the two groups made minor errors in answering. Four students from each of the two groups made two or more mistakes.

4.3.2.2.1 Analysis Of Variance in Research Sub-Question Two

4.3.2.2.1.1 Comparison among Assessment Methods

Hypotheses:

Null Hypothesis:	H_0: There is no difference between the assessment methods.
Alternative Hypothesis:	H_a: There are differences between assessment methods.
Level of significance is:	0.10
The obtained p-value:	0. .000

Observation: The observed p-value (0.000) is far less than the level of significance (0.10).

Conclusion: Since the observed p-value is less than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis. The assessment test methods differ significantly under the setup of research sub-question 2.

Subject matter inference: The rejection of the null hypothesis means that the assessment tests are significantly different. Some or one of the assessment procedures are/is more superior to the other/others. When analysed over all the collected data, the formative 2 test method is superior to its two counterparts.

4.3.2.2.1.2 Comparison between Learning Methods

Hypotheses:

Null Hypothesis: H_0: There is no difference between the learning methods.

Alternative Hypothesis: H_a: There are differences between the learning methods.

Level of significance is: 0.10

The obtained p-value: 0. 000

Observation: The observed p-value (0.000) is far less than the level of significance (0.10).

Conclusion: Since the observed p-value is less than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis.

Subject matter Inference: The rejection of the null hypothesis implies that the learning methods differ significantly from each other. The difference between the two learning methods is statistically significant.

Calculation of N for analysis

The table below shows the calculation of N for the analysis of variance for Research Sub-Question Two.

Table 4. 12 Calculation of N for Research Sub-Question Two

Assessment	Number of questions in assessments to test conceptual understanding	Number of students	N (= Number of questions in assessments * number of students)
Formative Assessment 1	6	14	84
Formative Assessment 2	3	14	42
Summative Assessment	6	14	84

Table 4. 13 Between-Subjects Factors for Research Sub-Question Two

		Value Label	N
Type of Assessment	1.00	Formative-1	84
	2.00	Formative-2	42
	3.00	Summative	84
Method of Learning	1.00	Traditional method	104
	2.00	GEBL method	106

Descriptive Statistics

The table below shows the two-way distribution of means according to assessment and learning methods. It is seen that the mean for a combination of the formative 2 assessment method and the GEBL learning method is the highest among all combinations of means. This talks of the combined contribution of the two treatments.

Table 4. 14 Two-way distribution of means according to Assessement and Learning Methods

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Deviation	N
1.00 Formative-1	1.00 Traditional method	1.3049	1.28879	41
	2.00 GEBL method	1.9651	1.56371	43
	Total	1.6429	1.46561	84
2.00 Formative-2	1.00 Traditional method	1.8095	1.15625	21
	2.00 GEBL method	3.2143	.91613	21
	Total	2.5119	1.25177	42
3.00 Summative	1.00 Traditional method	1.5833	1.31091	42
	2.00 GEBL method	1.5833	1.27794	42
	Total	1.5833	1.28671	84
Total	1.00 Traditional method	1.5192	1.27508	104
	2.00 GEBL method	2.0613	1.46174	106
	Total	1.7929	1.39589	210

The Analysis of Variance Table

The following is the Analysis of Variance Table, which was used for the initial interpretations In it, are the treatments being tested, the sums of squares, the respective mean squares, the f-ratios and the p-values for all the treatments in the prescribed research data.

Table 4. 15 Anova Table for Research Sub-Question Two

Dependent Variable: Marks obtained

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	57.162[a]	5	11.432	6.662	.000
Intercept	689.450	1	689.450	401.762	.000
assessment	27.493	2	13.746	8.010	.000

Learning method	22.384	1	22.384	13.044	.000
assessment * learning method	14.278	2	7.139	4.160	.017
Error	350.077	204	1.716		
Total	1082.250	210			
Corrected Total	407.239	209			

Estimated Marginal Means

Grand Mean

The observed grand mean for this data setup is 1.910 with a standard error of 0.095. This will always be between small and large sub-treatment records.

Table 4. 16 Grand Mean and the Standard Error for Research Sub-Question Two

Dependent Variable: Marks obtained

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
1.910	.095	1.722	2.098

Type of Assessment

The observed assessment test means are as shown in the table below. The highest being 2.512 belonging to the formative assessment 2.

Table 4. 17 Comparison of assessments for Research Sub-Question Two

Dependent Variable: Marks obtained

Type of assessment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Formative-1	1.635	.143	1.353	1.917
2.00 Formative-2	2.512	.202	2.113	2.910
3.00 Summative	1.583	.143	1.302	1.865

Method of Learning

The following table contains the information on learning methods. The GEBL method has a mean of 2.254 which is higher than that of the traditional method

Table 4. 18 Comparison of Methods of Learning for Research Sub-Question Two

Dependent Variable: Marks obtained

Method of learning	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Traditional method	1.566	.135	1.299	1.832
2.00 GEBL method	2.254	.134	1.989	2.519

4.3.2.2.1.3 Type of Assessment versus Method of Learning

We learn here that the formative assessment 2 when combined with the GEBL method performed the best among all treatment combinations

Table 4. 19 The Assessment and Learning Method interaction for Research Sub-Question Two

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1.00 Formative-1	1.00 Traditional method	1.305	.205	.902	1.708
	2.00 GEBL method	1.965	.200	1.571	2.359
2.00 Formative-2	1.00 Traditional method	1.810	.286	1.246	2.373
	2.00 GEBL method	3.214	.286	2.651	3.778
3.00 Summative	1.00 Traditional method	1.583	.202	1.185	1.982
	2.00 GEBL method	1.583	.202	1.185	1.982

Post Hoc Tests

4.3.2.2.1.4 Multiple Comparisons for Type of Assessment

The table below shows the comparisons of means for the assessment test methods. This was done for every two assessments tests at a time. The objective is to understand the significance of differences between two assessment methods using by Cheffe multiple range test. p-values (Sig) have been calculated for easy conclusions and for each pair comparison. Consider the comparison between the summative and formative 1 assessment methods have a p-value of 0.958, meaning that the two test methods are statistically different. Now the p-value between formative 1 and formative 2 is 0.003. Since 0.003 is less than 0.100, the two assessment test methods are equally statistically and significantly different.

Table 4. 20 Multiple comparisons for Type of Assessment for Research Sub-Question Two

Dependent Variable: Marks obtained

(I) Type of assessment	(J) Type of assessment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00 Formative-1	2.00 Formative-2	-.8690*	.24756	.003	-1.4795	-.2586
	3.00 Summative	.0595	.20214	.958	-.4389	.5580
2.00 Formative-2	1.00 Formative-1	.8690*	.24756	.003	.2586	1.4795
	3.00 Summative	.9286*	.24756	.001	.3181	1.5390
3.00 Summative	1.00 Formative-1	-.0595	.20214	.958	-.5580	.4389
	2.00 Formative-2	-.9286*	.24756	.001	-1.5390	-.3181

Profile Plots

The profile figure below shows that the summative method had the lowest performance (from the traditional method to the GEBL method) whereas, the formative 1 method, as expected, had the highest performance across the two learning methods. This finding agrees well with the finding in the ANOVA table.

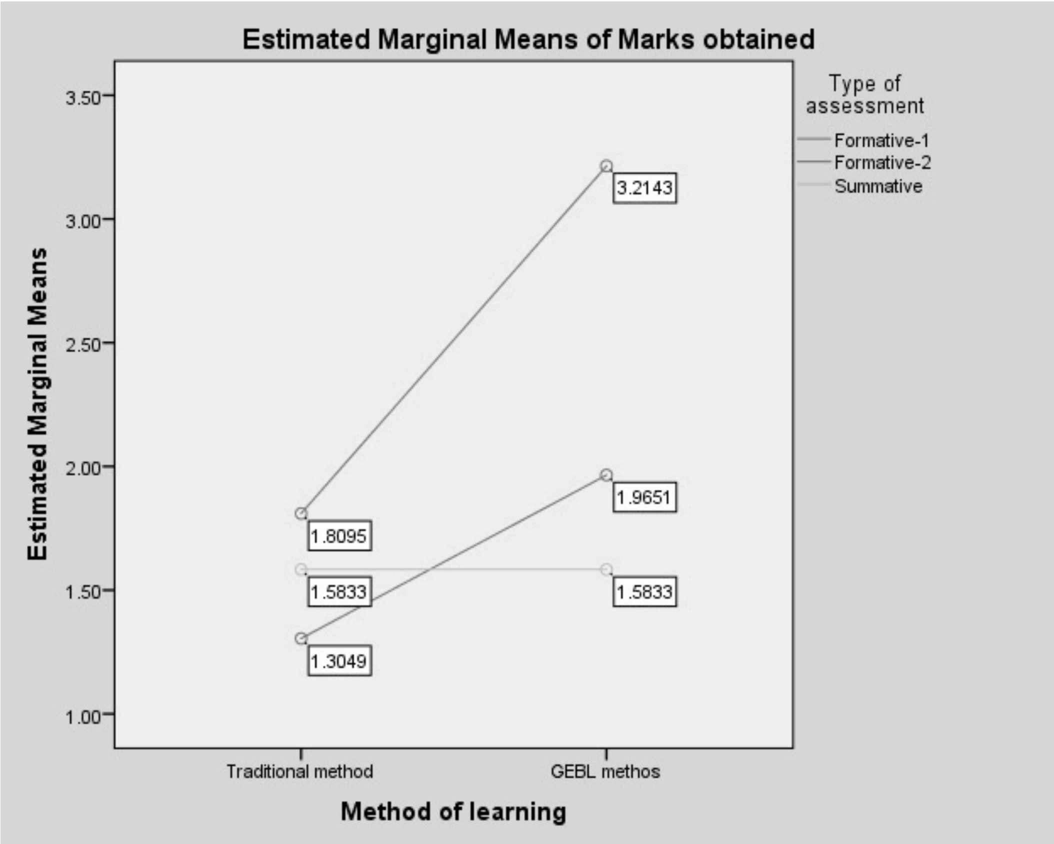


Fig. 4. 25 Profile Plots for Methods of Learning for Research Sub-Question Two

The figure below shows that there is a strong interaction effect between the two types of treatments in the experiment namely; the assessment test methods and the learning methods. This is seen by the two lines, which cross each other showing a high degree of interaction. Furthermore, the p-value of 0.017 far less than the level of significance (0.100), showing a high significance of the interaction effect between the two factors.

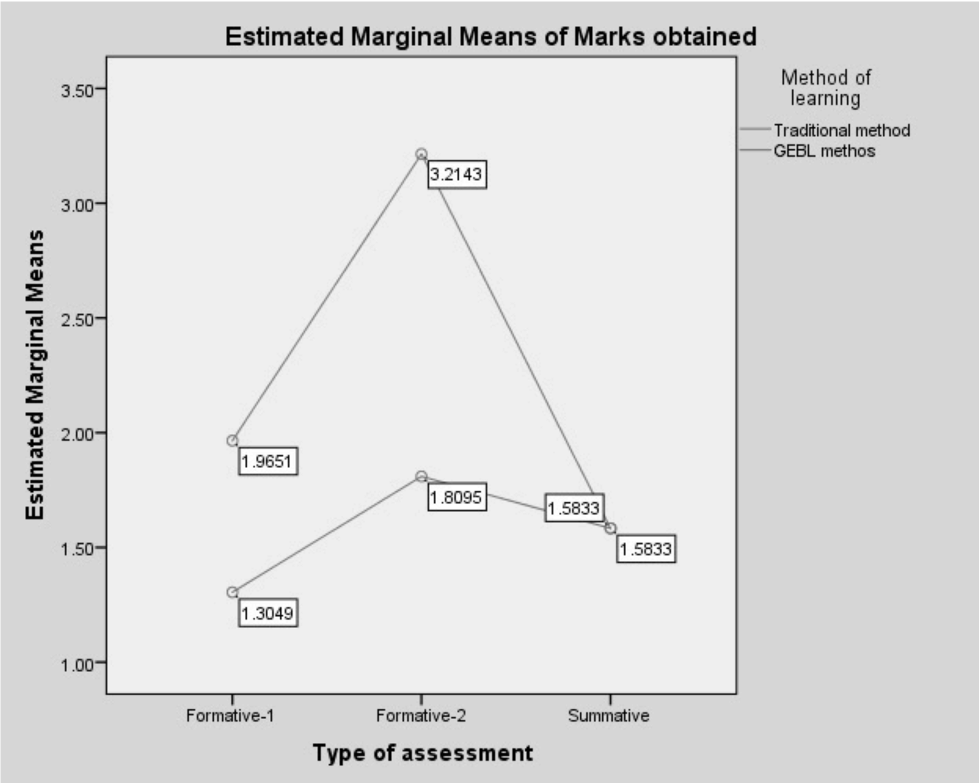


Fig. 4. 26 Profile Plots for Type of Assessments for Research Sub-Question Two

The figure below compares visually the performance of the assessment methods. It is noted that the formative assessment 2 emerged most superior among the assessment methods.

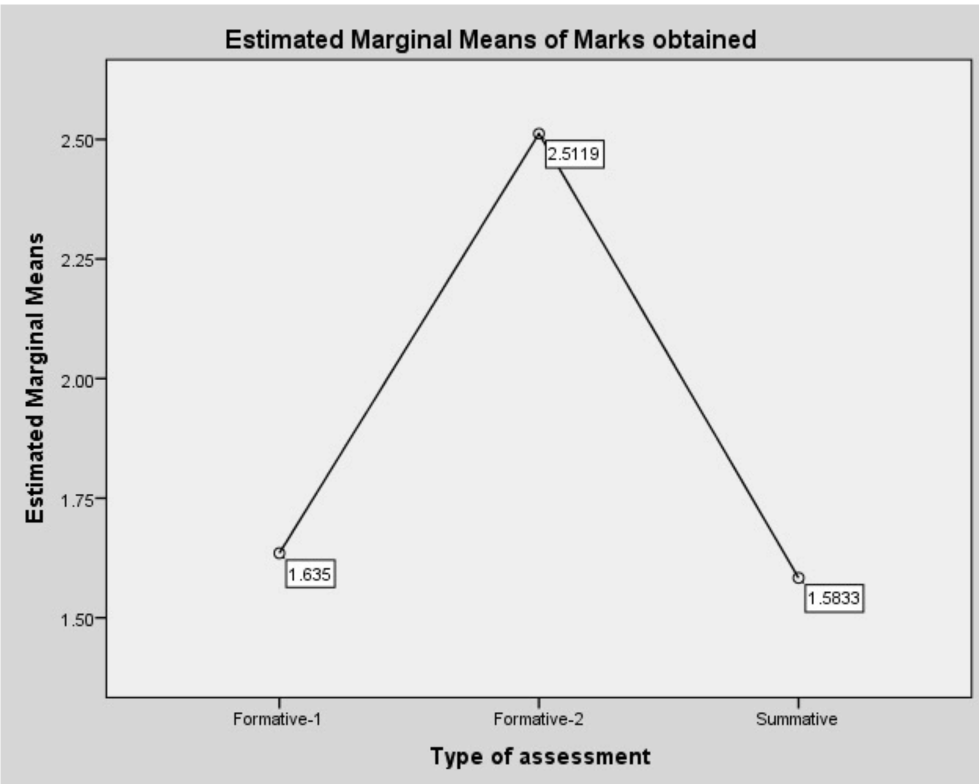


Fig. 4. 27 Comparison of Type of Assessments for Research Sub-Question Two

The figure below is a direct comparison of the two learning methods. It turns out that the GEBL learning method has a higher mean than does its counterpart. This shows the significant effect of the GEBL learning method as compared to the traditional learning method. This agrees quite well with the findings in the ANOVA table shown above.

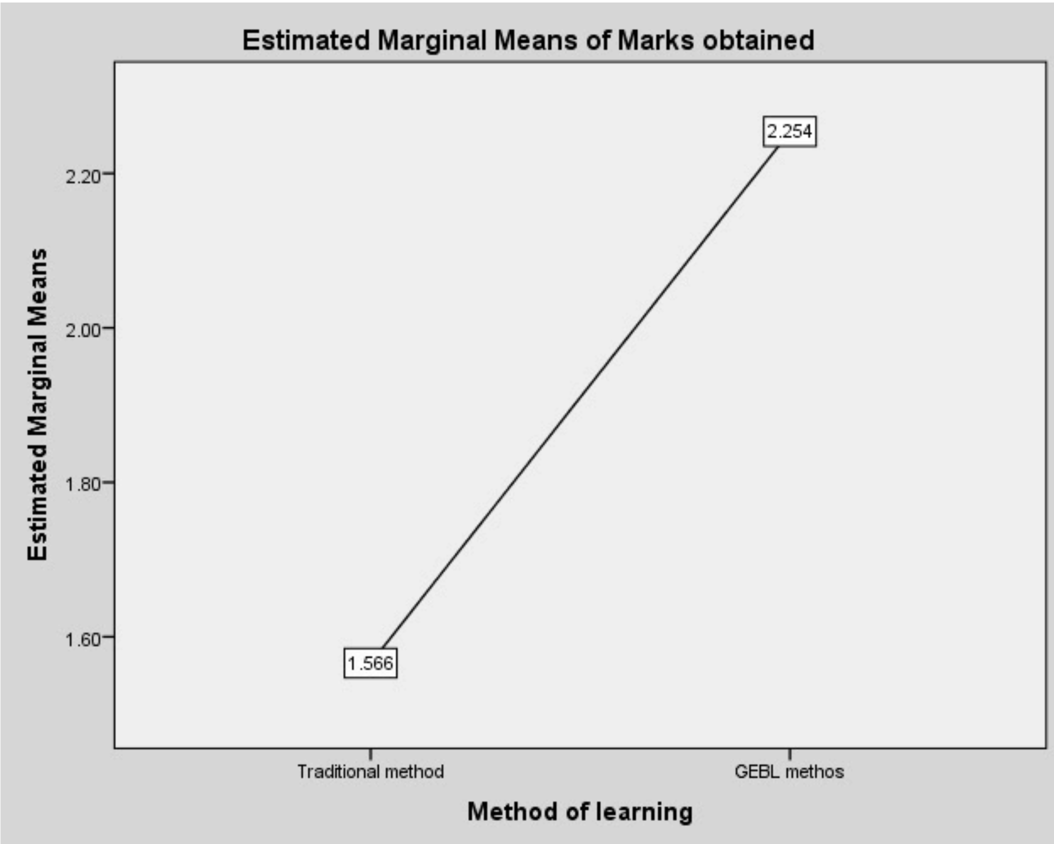


Fig. 4. 28 Comparison of Methods of Learning for Research Sub-Question Two

4.3.2.2.2 Observations for Research Sub-Question Two

The p-value for Research Sub-Question two from the Anova table is 0.000. As this value is less than 0.10 we can reject the null hypothesis. The rejection of the null hypothesis implies that the learning methods differ significantly from each other. The difference between the GEBL method and the traditional method is statistically significant showing that the students from the GEBL group understood the topics covered better than the students from the TTG. This in line with the findings from other studies refered to in the literature review where AL strategies improved students' understanding of key concepts (Kollofel & Jong, 2013; Sekwena, 2014).

4.3.2.3 Addressing Research Sub-Question Three

SQ3: Would a GEBL approach enhance students' problem solving skills?

Formative Assessment 1

The following questions tested the students' problem solving skills: Questions 7a, 7b and 7c. Questions 7a, 7b and 7c are grouped together for analysis because to solve all these questions the students are required to understand and analyse the information given and use the given parameters to solve the problem. For Questions 7a, 7b and 7c, GEBL students demonstrated a better ability to use the information provided to solve the problem. From the TTG, five students for Question 7a, six students for question 7b and two students for question 7b could not solve the problem using the parameters provided.

Formative Assessment 2

The following questions tested the students' problem solving skills: Questions 5, 10a, 10b, 10c and 10d. For Question 5, the students from GEBL group demonstrated a better ability to solve problems with the information provided. Four students from the TTG could not solve the problem in comparison to two students from the GEBL group. Only one student from the TTG could solve the problem without mistakes in comparison to four students from the GEBL group. The data again demonstrates that the GEBL students are better equipped to understand the information provided and process the information effectively to solve problems.

For Questions 10a, 10b, 10c and 10d, majority of students were able to solve the problem correctly. For question 10d the students from the TTG performed slightly better than the GEBL group to solve the problem and get the correct answer.

Summative Assessment

The following questions tested the students' problem solving skills: Questions 2.2.1, 2.2.2, 2.2.3, 2.2.4, 3.1.2, 3.1.3, 3.1.4, 3.1.5, 4.1.1, 4.1.2, 4.1.3, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 5.1.1, 5.1.2, 5.1.3 and 5.1.4.

For analysis Questions majority of students from both groups were able to analyse the circuit and solve the problem correctly with the provided parameters. The data showed a similar problem solving ability among students from both groups.

For analysis, Question 3.1.2, 3.1.3, 3.1.4 and 3.1.5 are grouped together where students were required to analyse the given full wave rectifier circuit and calculate the delay angle, efficiency, ripple factor and the peak inverse voltage of one thyristor. For Questions 3.1.2, 3.1.3, 3.1.4 and 3.1.5 the students analysed the working of the circuit and solved the problem. To find the delay angle (q 3.1.2), students from both groups used the parameters correctly and used the right formula. The problem solving ability of students in both groups was found to be similar from the data gathered. For Question 3.1.3, students from both groups made few mistakes in solving the problem. Most of them got the formula right but made mistakes in further calculations. The same was observed for question 3.1.4. More emphasis must be given to make the students understand the methods of calculating the concepts so that they will be able to solve these kinds of problems. For question 3.1.5, students were required to analyse the circuit and find the PIV for each thyristor. Almost half the students in both group were able to analyse and give the correct answer.

For analysis, Questions 4.1.1, 4.1.2 and 4.1.3 are grouped together. Students were required to calculate the average output voltage, rms output voltage and efficiency of a DC chopper. For Question 4.1.1, the data showed identical problem solving ability among students from both groups. For question 4.1.2, five students from the GEBL group got the correct answer compared to three from the TTG. For question 4.1.3, no student from the GEBL group got the correct answer. Two students from the TTG solved the problem correctly.

For analysis, Questions 4.3.1, 4.3.2, 4.3.3 and 4.3.4 are grouped together.

For Questions 4.3.1, 4.3.2, 4.3.3 and 4.3.4 the students were required to analyse a DC–DC converter and solve for the duty cycle, ripple current of the inductor, peak current for the inductor and the ripple voltage of the capacitor. Almost all students were unable to solve the problem to get the values asked for except few students who solved question 4.3.1. The reason for poor performance by students could be because for the last two chapters students got very limited time to practise the problems. As the university lost some time due to student protests the time allocated for the last few topics had to be reduced for all subjects. Focus was more on theory for this chapter (DC-DC converters) and the following chapter (Device Protection). The data from students clearly indicate that students did not adequately practise to solve problems in this chapter. Data shows that it was the same for all students from both groups.

For analysis, Questions 5.1.1, 5.1.2, 5.1.3 and 5.1.4 are grouped together. The students were required to analyse the question and draw the circuit and calculate the values of the resistor and the capacitor. They were also supposed to determine the snubber loss and the power rating of the snubber resistor.

For Question 5.1.1, almost all students from both groups were able to draw the circuit described in the problem. As this was related to the theory part, students were able to answer this question. The remaining questions (5.1.2, 5.1.3, 5.1.4) required the students to calculate the values using the parameters given in the question. Again here the data shows clearly that the students did not spend enough time practising the problems in this chapter. As mentioned earlier this was also a topic where the teaching and learning time was lost by the protect action by the students. This also shows that students did not practise solving problems on their own also for this topic.

4.3.2.3.1 Analysis Of Variance in Research Sub- Question Three

4.3.2.3.1.1 Comparison among Assessment Methods

Hypotheses:

Null Hypothesis:	H_0: There is no difference between the assessment methods.
Alternative Hypotheis:	H_a: There are differences between assessment methods.
Level of significance is:	0.10
The obtained p-value:	0.068

Observation: The observed p-value (0.068) is far less than the level of significance (0.10).

Conclusion: Since the observed p-value is less than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis. The assessment test methods differ significantly under the setup of sub-research question 3.

Subject matter Inference: The rejection of the null hypothesis means that the assessment tests are significantly different. Some or one of the assessment procedures are/is more superior to the other/others with an overall mean of 1.293 under the two learning methods. When analysed across the two learning methods, the summative test method was still superior to its two counterparts though its mean under the traditional method was slightly higher than its mean under the GEBL method.

4.3.2.3.1.2 Comparison between Learning Methods

Hypotheses:

Null Hypothesis:	H_0: There is no difference between the learning methods.
Alternative Hypothesis:	H_a: There are differences between the learning methods.
Level of significance is:	0.10
The obtained p-value:	0.417

Observation: The observed p-value (0.417) is far more than the level of significance (0.10).

Conclusion: Since the observed p-value is more than the level of significance, the null hypothesis cannot be rejected in favour of the alternative hypothesis.

Subject matter Inference: The failure to reject the null hypothesis implies that the learning methods do not differ significantly from each other. The difference between the learning methods is not statistically significant.

Calculation of N for Analysis

The table below shows the calculation of N for the analysis of variance in the Research Sub-Question Two.

Table 4. 21 Calculation of N for Research Sub-Question Three

Assessment	Number of questions in assessments to test problem solving ability	Number of students	N (= Number of questions in assessments * number of students)
Formative Assessment 1	3	14	42
Formative Assessment 2	5	14	70
Summative Assessment	19	14	266

Table 4. 22 Between-Subjects Factors for Research Sub-Question Three

		Value Label	N
Type of Assessment	1.00	Formative-1	42
	2.00	Formative-2	70
	3.00	Summative	266
Method of Learning	1.00	Traditional method	189
	2.00	GEBL method	189

Descriptive Statistics

The table below shows the two-way distribution of means according to assessment method and learning method. It is obvious that the mean for a combination of the summative assessment method and the traditional learning method is the highest among all combinations of means.

Table 4. 23 Descriptive Statistics for Research Sub-Question Three

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Deviation	N
1.00 Formative-1	1.00 Traditional method	.4048	.58350	21
	2.00 GEBL method	.9286	1.05221	21
	Total	.6667	.88115	42
2.00 Formative-2	1.00 Traditional method	1.1143	.79600	35
	2.00 GEBL method	1.1857	.97079	35
	Total	1.1500	.88199	70
3.00 Summative	1.00 Traditional method	1.3195	1.79998	133
	2.00 GEBL method	1.2669	1.90846	133
	Total	1.2932	1.85170	266
Total	1.00 Traditional method	1.1799	1.58346	189
	2.00 GEBL method	1.2143	1.69020	189
	Total	1.1971	1.63562	378

Tests of Between-Subjects Effects

The Analysis of Variance table below shows the observed test of statistic values justifying the significance among assessment methods and the insignificance of the learning methods discussed earlier. The interaction effect is not significant

Table 4. 24 Anova Table for Research Sub-Question Three

Dependent Variable: Marks obtained

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17.585[a]	5	3.517	1.320	.255
Intercept	231.073	1	231.073	86.741	.000
Assessment	14.431	2	7.215	2.709	.068

Learning method	1.759	1	1.759	.660	.417
Assessment * Learning Method	3.043	2	1.521	.571	.565
Error	990.982	372	2.664		
Total	1550.250	378			
Corrected Total	1008.567	377			

Estimated Marginal Means

Table 4. 25 Grand Mean and the Standard Error for Research Sub-Question Three

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
1.037	.111	.818	1.255

Method of Learning

When the learning methods are compared, the GEBL learning method with a mean of 1.127 is superior to the traditional method.

Table 4. 26 Comparison of Methods of Learning for Research Sub-Question Three

Dependent Variable: Marks obtained

Method of learning	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Traditional method	.946	.157	.637	1.256
2.00 GEBL method	1.127	.157	.818	1.437

Type of Assessment

The table below shows the means according to assessment methods. It has been proved that the summative assessment has the highest mean of 1.293 with the smallest standard error of 0.100. This shows the consistence of the formative assessment 1 as compared to other assessment methods.

Table 4. 27 Comparison of Assessments for Research Sub-Question Three

Dependent Variable: Marks obtained

Type of assessment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Formative-1	.667	.252	.171	1.162
2.00 Formative-2	1.150	.195	.766	1.534
3.00 Summative	1.293	.100	1.096	1.490

Post Hoc Tests

4.3.2.3.1.4 Multiple Comparisons for Type of Assessment

The table below shows the comparisons of means for the assessment methods. This was done for every two assessments tests at a time. The objective is to understand the significance of differences between two assessment methods using Cheffe multiple range test. p-values (Sig) have been calculated for easy conclusions and for each comparison. Consider the comparison between the summative and formative 2 assessment methods have a p-value of 0.808, meaning that the two test methods are not statistically different. Now the p-value between formative 1 and summative is 0.070. Since 0.070 is less than 0.100, the two assessment methods are statistically and significantly different.

Table 4. 28 Multiple comparisons for Type of Assessment for Research Sub-Question Three

Dependent Variable: Marks obtained

(I) Type of assessment	(J) Type of assessment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00 Formative-1	2.00 Formative-2	-.4833	.31856	.317	-1.2662	.2996
	3.00 Summative	-.6266	.27100	.070	-1.2926	.0395
2.00 Formative-2	1.00 Formative-1	.4833	.31856	.317	-.2996	1.2662
	3.00 Summative	-.1432	.21925	.808	-.6821	.3956

3.00 Summative	1.00 Formative-1	.6266	.27100	.070	-.0395	1.2926
	2.00 Formative-2	.1432	.21925	.808	-.3956	.6821

Profile Plots

The profile plot below shows that the summative assessment has a higher mean than the other two assessments.

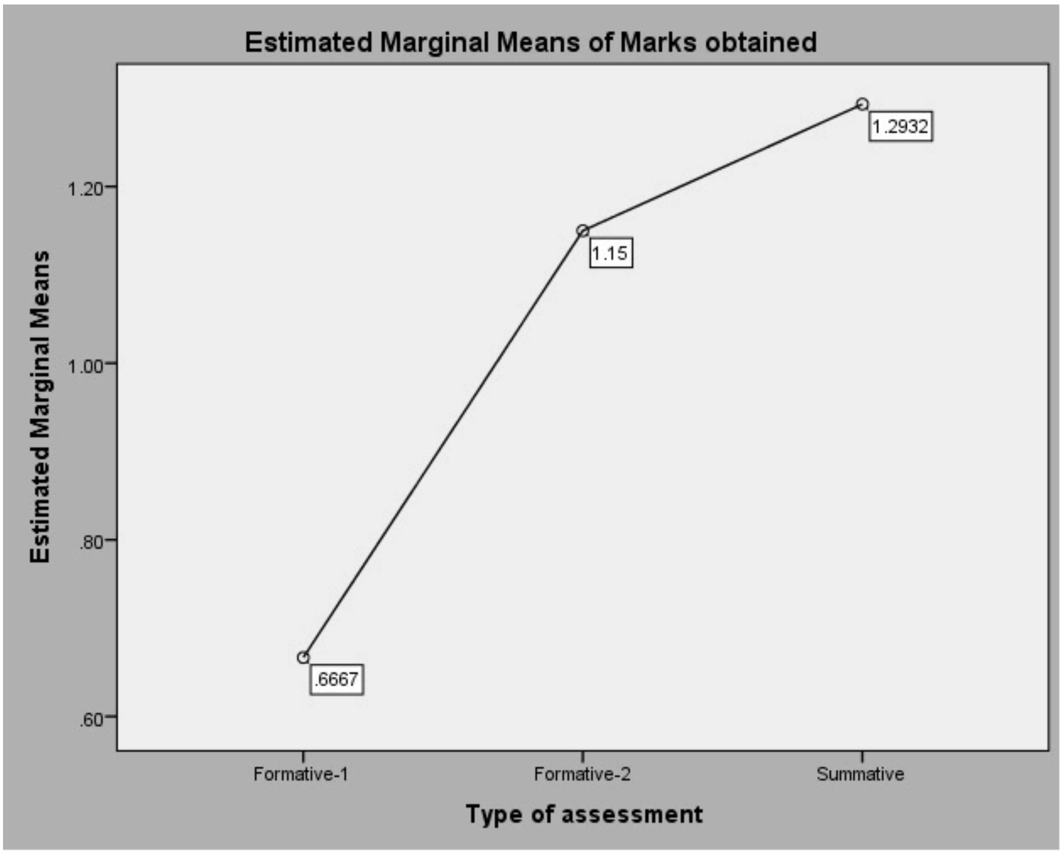


Fig. 4. 29 Profile Plot for Type of Assessment for Research Sub-Question Three

The graph below shows that the GEBL method is more superior when compared to the traditional method.

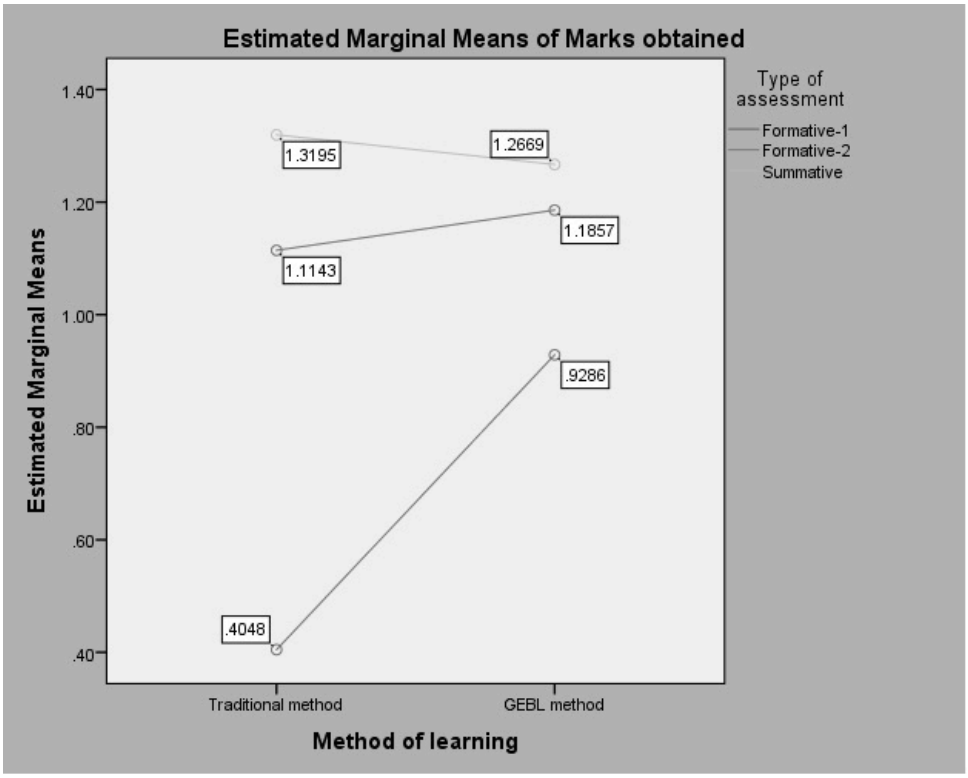


Fig. 4. 30 Profile Plot for Methods of Learning for Research Sub-Question Three

The figure below further confirms that the summative assessment is better than the other two assessments. Its higher performance occurring at the GEBL level of learning method.

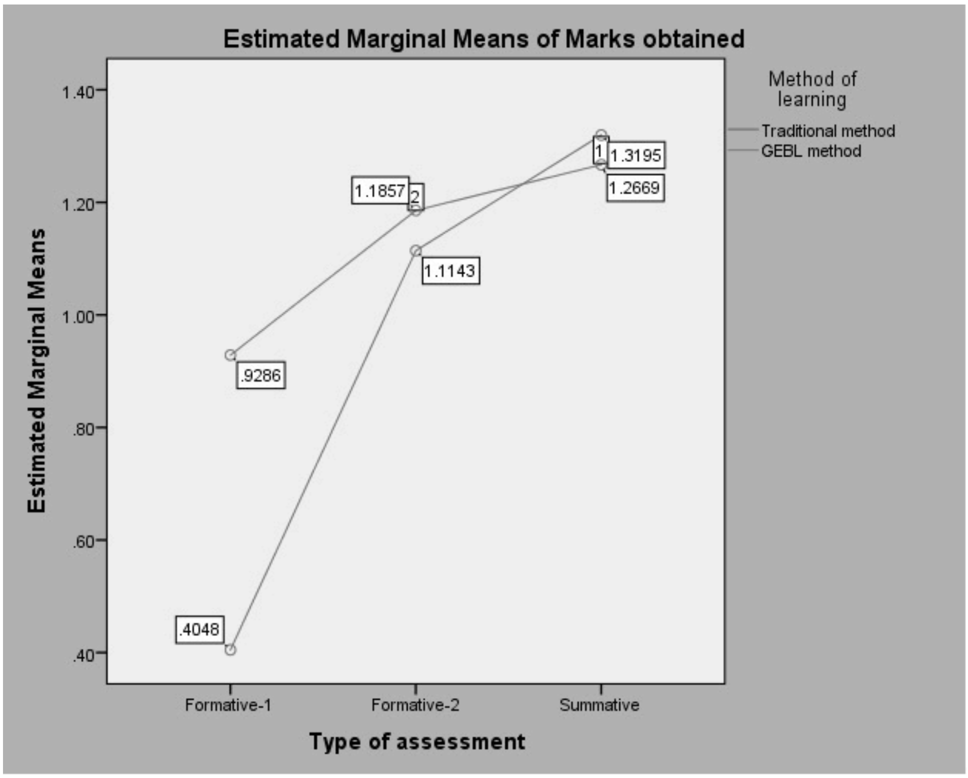


Fig. 4. 31 Comparison of Assessment Methods for Research Sub-Question Three

The profile plot below demonstrates the superiority of the GEBL method when compared to the traditional learning method.

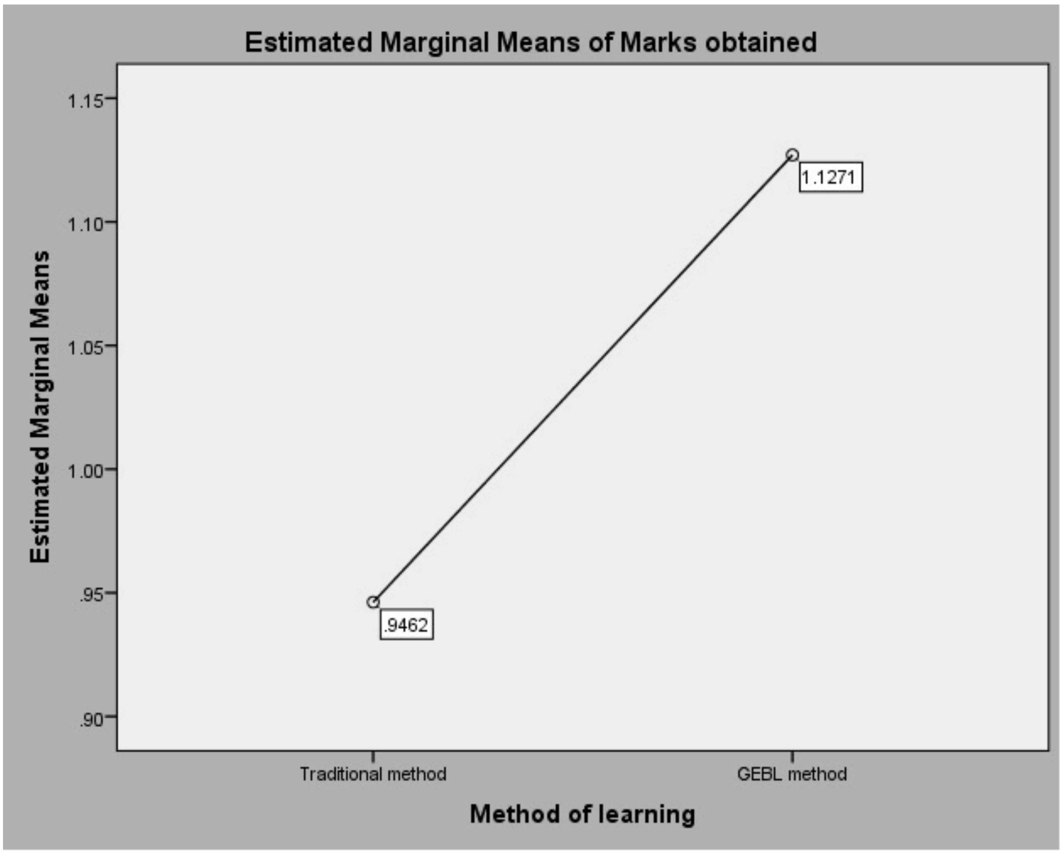


Fig. 4. 32 Comparison of Learning Method for Research Sub-Question Three

4.3.2.3.2 Observations for Research Sub-Question Three

The p-value for Research Sub-Question three from the Anova table is 0.417. As this value is greater than 0.10 we cannot reject the null hypothesis. Also the grand mean for the data set is 1.037. So from the statistical values we can conclude that both teaching methods had the same effect when the problem solving abilities of the students are considered. We cannot conclude that any one method is better than the other. Though studies referred to earlier in the literature review showed that a GEBL strategy led to improvements in students' ability to analyse and solve problems (Mohd-Yusof et al., 2014; Adams et al., 2015), results in the present study could not conclude similarly.

4.3.2.4 Addressing Research Sub-Question Four

SQ4: Would a GEBL approach enhance students' critical thinking ability?

Formative Assessment 1

The following questions tested the students' critical thinking ability: Questions 3, 4b, 5b, 6b and 6c.

For Question 3, four students from the GEBL group were able to prove that full wave rectifiers are more efficient than the half wave rectifier. Only one student from the TTG was able to do the same. One student from GEBL and two from the TTG were able to prove the same with one mistake.

For Question 4b, data showed that the evaluation and justification from students from both groups were similar. It showed a similar understanding of topics for students from both groups. Only one student from each group answere the question correctly. Three students from each group answered with some mistakes.

For Question 5b, the students were required to compare a controlled rectifier and an uncontrolled rectifier and assess which rectifier could be used to control the power delivered to the load. Here the students were required to explain how the power delivered to the load could be controlled by using phase control for thyristors. Students were required to have a proper understanding of the working of diodes and thyristors. They had to then think how these devices work in rectifiers and how the power delivered could be controlled. Four students from the GEBL group correctly evaluated and justified their choice. No student from the TTG was able to answer this correctly. Data showed that the students from the TTG struggled to evaluate it correctly and could not justify their choice.

For analysis Question 6b and 6c are grouped together as the students are required to draw the circuit diagram of a practical power supply in question 6b and then justify their choice in question 6c.

For Question 6b, the students were required to draw a circuit diagram for a DC power supply which would be efficient and cost effective for practical purposes. The students had to use their knowledge of designing a power supply and connect it to their knowledge about the working of various rectifiers. They also were required to have a good understanding of diodes and the cost of the diodes. They were required to think and connect all these knowledge to design an efficient and cost effective DC power supply. Data showed identical responses from students from both the GEBL group and the TTG.

For Question 6c, the students were required to justify their choice of rectifiers. Again for this question the data showed a similar level of critical thinking to answer this question.

Formative Assessment 2

For Question 4.2, here the students were required to explain how crowbar thyristors could be used for overcurrent protection. No student could answer this correctly. One student from the TTG answered the question with a minor error. All students from the GEBL group got the answer wrong. This could be because this topic was not discussed in class. But the students in the GEBL group were told to prepare this topic for the assessment. Data showed that four students from the TTG were able to answer with two or more errors and two students got the answer wrong.

For Question 6.2, no student from either group managed to give a complete correct answer. Student answered the question with minor errors. Majority of students got the answer wrong.

For Question 8, two students from the GEBL group analysed the circuit and sketched the output correctly. One student from the TTG sketched the output with one error and another student made two errors in sketching the output waveform. Five students from each group got the answer wrong or were not able to answer the question.

For Question 9, the students were required to think and evaluate how the triggering angle of the thyristor could be used to control the power delivered to the load. Only two students from the GEBL group answered the question correctly. One student from the TTG made one minor error in answering the question. All other students from both groups made two or more errors in answering the question.

Summative Assessment

Summative Assessment: Addressing Research Sub-Question Four

SQ4: Would a GEBL approach enhance students' critical thinking ability?

The following questions tested the students' critical thinking ability: 1.1d, 1.1e, 1.1f, 5.2.1, 5.2.2, 5.2.3 and 5.3.

For question 1.1d and 1.1e the students from both groups performed badly. Though the marks showed that GEBL students performed slightly better than the students from the TTG. For question 1.1f three students from the GEBL group the answered the question correctly compared to two from the TTG. Three other students from the GEBL group answered the question but with some misinterpretation. Four students from the TTG got the answer completely wrong.

For questions 5.2.1, 5.2.2 and 5.2.3 the student responses from both groups were unsatisfactory. The question was a very simple question but the responses showed that the students from both groups had difficulty in understanding the question.

For question 5.3 none of the students from either group answered the question correctly. The students were required to analyse a given circuit and were required to identify the problem with the circuit. Five students from the GEBL group and four students from the TTG answered the question with major errors.

4.3.2.4.1 Analysis Of Variance in Research Sub-Question Four

4.3.2.4.1.1 Comparison among Assessment Methods

Hypotheses:

Null Hypotheis:	H_0: There is no difference between the assessment methods.
Alternative Hypothesis:	H_a: There are differences between assessment methods

Level of significance is: 0.10

The obtained p-value: 0.000

Observation: The observed p-value (0.000) is far less than the level of significance (0.10).

Conclusion: Since the observed p-value is less than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis. The assessment test methods differ significantly under the setup of sub-research question 4.

Subject matter Inference: The rejection of the null hypothesis means that the assessment tests are significantly different. Some or one of the assessment procedures are/is more superior to the other/others. When analysed over all the collected data, the formative 1 assessment method is superior to its two counterparts.

4.3.2.4.1.2 Comparison between Learning Methods

Hypotheses:

Null Hypotheis: H_0: There is no difference between the learning methods.

Alternative Hypotheis: H_a: There are differences between the learning methods.

Level of significance is: 0.10

The obtained p-value: 0. 257

Observation: The observed p-value (0.257) is far higher than the level of significance (0.10).

Conclusion: Since the observed p-value is higher than the level of significance, the null hypothesis is not rejected.

Subject matter Inference: The failure to reject the null hypothesis implies that the learning methods do not differ significantly from each other. The difference between the learning methods is statistically inconsequential.

Calculation of N for analysis

The table below shows the calculation of N for the analysis of variance in the second sub-research question.

Table 4. 29 Calculation of N for Research Sub-Question Four

Assessment	Number of questions in assessments to test recalling	Number of students	N (= Number of questions in assessments * number of students)
Formative Assessment 1	5	14	70
Formative Assessment 2	5	14	70
Summative Assessment	7	14	98

Univariate Analysis of Variance

Table 4. 30 Between-Subject Factors for Research Sub-Question Four

		Value Label	N
Type of Assessment	1.00	Formative-1	70
	2.00	Formative-2	70
	3.00	Summative	98
Method of Learning	1.00	Traditional method	119
	2.00	GEBL method	119

Table 4. 31 Descriptive Statistics for Research Sub-Question Four

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Deviation	N
1.00 Formative-1	1.00 Traditional method	1.8000	1.69428	35
	2.00 GEBL method	2.3286	1.83489	35
	Total	2.0643	1.77323	70

2.00 Formative-2	1.00 Traditional method	1.4286	1.54892	35
	2.00 GEBL method	1.3143	1.83546	35
	Total	1.3714	1.68688	70
3.00 Summative	1.00 Traditional method	.9388	.92777	49
	2.00 GEBL method	1.1735	.90457	49
	Total	1.0561	.91911	98
Total	1.00 Traditional method	1.3361	1.41438	119
	2.00 GEBL method	1.5546	1.59021	119
	Total	1.4454	1.50567	238

The Analysis of Variance Table

The following is the Analysis of Variance Table, which was used for the initial interpretations. In it, are the treatments being tested, the sums of squares, the respective mean squares, the f-ratios and the p-values for all the treatments in the prescribed research data.

Table 4. 32 Anova Table for Research Sub-Question Four

Dependent Variable: Marks obtained

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	48.512[a]	5	9.702	4.605	.001
Intercept	520.344	1	520.344	246.983	.000
assessment	42.045	2	21.023	9.978	.000
Learning method	2.715	1	2.715	1.289	.257
assessment * learning method	3.627	2	1.814	.861	.424
Error	488.778	232	2.107		
Total	1034.500	238			
Corrected Total	537.290	237			

Estimated Marginal Means

Grand Mean

The observed grand mean for this data setup is 1.497 with a standard error of 0.095. This will always be between small and large sub-treatment records.

Table of interactions of Type of Assessment and Method of learning

We learn here that the formative assessment when combined with the GEBL method performed the best among all treatment combinations.

Table 4. 33 Grand Mean and the Standard Error for Research Sub-Question Four

Dependent Variable: Marks obtained

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
1.497	.095	1.310	1.685

Type of Assessment

The observed assessment test means are as shown in the table below. The highest being 2.064 for formative assessment 1.

Table 4. 34 Comparison of Assessments for Research Sub-Question Four

Dependent Variable: Marks obtained

Type of assessment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Formative-1	2.064	.173	1.722	2.406
2.00 Formative-2	1.371	.173	1.030	1.713
3.00 Summative	1.056	.147	.767	1.345

Method of Learning

The following table contains the information on learning methods. The GEBL method has a mean of 1.605 which is higher than that of the traditional method.

Table 4. 35 Comparison of Methods of Learning for Research Sub-Question Four

Dependent Variable: Marks obtained

Method of learning	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Traditional method	1.389	.135	1.124	1.655
2.00 GEBL method	1.605	.135	1.340	1.871

4.3.2.4.1.3 Table of interactions of Type of Assessment and Method of Learning

The table below shows the two-way distribution of means according to assessment and learning methods. It is seen that the mean for a combination of the formative 1 assessment and the GEBL learning method is the highest among all combinations of means. This talks of the combined contribution of the two treatments.

Table 4. 36 The Assessment and Learning Method interaction for Research Sub-Question Four

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1.00 Formative-1	1.00 Traditional method	1.800	.245	1.317	2.283
	2.00 GEBL method	2.329	.245	1.845	2.812
2.00 Formative-2	1.00 Traditional method	1.429	.245	.945	1.912
	2.00 GEBL method	1.314	.245	.831	1.798
3.00 Summative	1.00 Traditional method	.939	.207	.530	1.347
	2.00 GEBL method	1.173	.207	.765	1.582

4.3.2.4.1.4 Multiple Comparisons for Type of Assessment

The table below shows the comparisons of means for the assessment test methods. This was done for every two assessments tests at a time. The objective is to understand the significance of differences between two-assessment methods using *Cheffe* multiple range test. p-values (Sig) have been calculated for easy conclusions and for each pair comparison. Consider the comparison between the summative and formative 1 assessment methods with a p-value of 0.000, meaning that the two test methods are highly statistically different. Now the p-value between formative assessment 1 and formative assessment 2 is 0.020. Since 0.020 is less than 0.100, the two assessment test methods are equally statistically and significantly different.

Post Hoc Tests

Table 4. 37 Multiple comparisons for Type of Assessments for Reseach Sub-Question Four

Dependent Variable: Marks obtained

(I) Type of assessment	(J) Type of assessment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00 Formative-1	2.00 Formative-2	.6929*	.24535	.020	.0884	1.2973
	3.00 Summative	1.0082*	.22715	.000	.4486	1.5678
2.00 Formative-2	1.00 Formative-1	-.6929*	.24535	.020	-1.2973	-.0884
	3.00 Summative	.3153	.22715	.383	-.2443	.8749
3.00 Summative	1.00 Formative-1	-1.0082*	.22715	.000	-1.5678	-.4486
	2.00 Formative-2	-.3153	.22715	.383	-.8749	.2443

Profile Plots

The following figure compares visually the performance of the assessment methods. It is noted that the formative assessment 1 emerged most superior among the assessment methods. This is easily observed from the figure below.

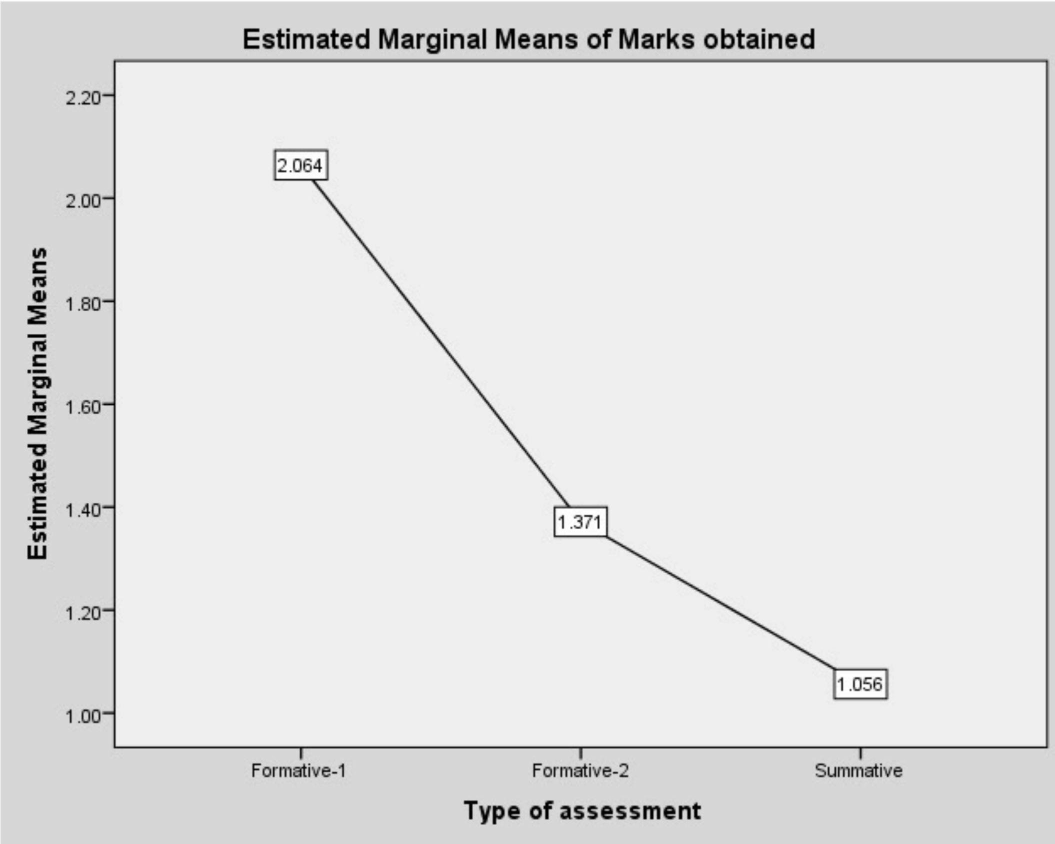


Fig. 4. 33 Profile Plot for Type of Assessments for Research Sub-Question Four

The figure below is another visual comparison of the two learning methods. It shows that the GEBL method with a mean of (1.605) has a higher mean than the traditional method. This shows the significant effect of the GEBL learning method as compared to the traditional learning method. This agrees quite well with the findings in the ANOVA table shown above.

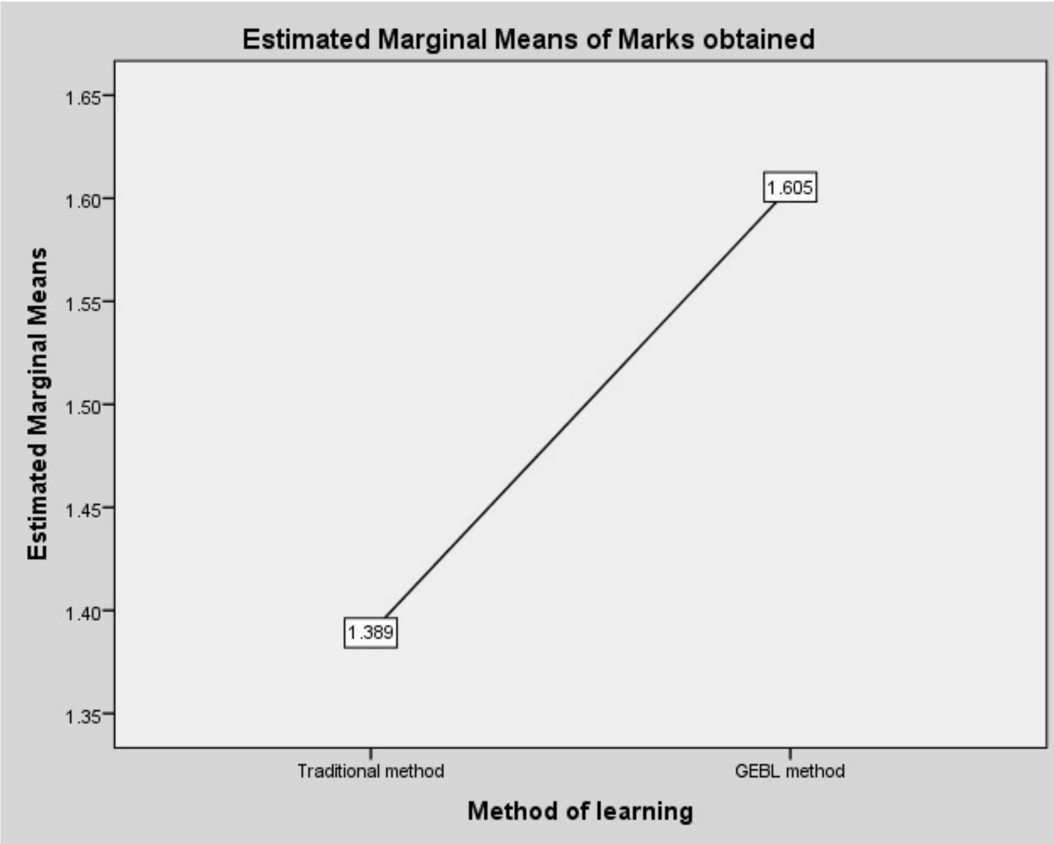


Fig. 4. 34 Profile Plot for Methods of Learning for Research Sub-Question Four

Understanding the Interaction Effect

The figure below shows that the three assessment methods strongly interact with the learning methods. The assessment methods and the learning methods interact. This is seen by the two lines which cross each other showing the high degree of interaction. Contrary to this result, the p-value is quite high. When the p-value is 0.424, far higher than the level of significance (0.100) it is an indication of lack of significance.

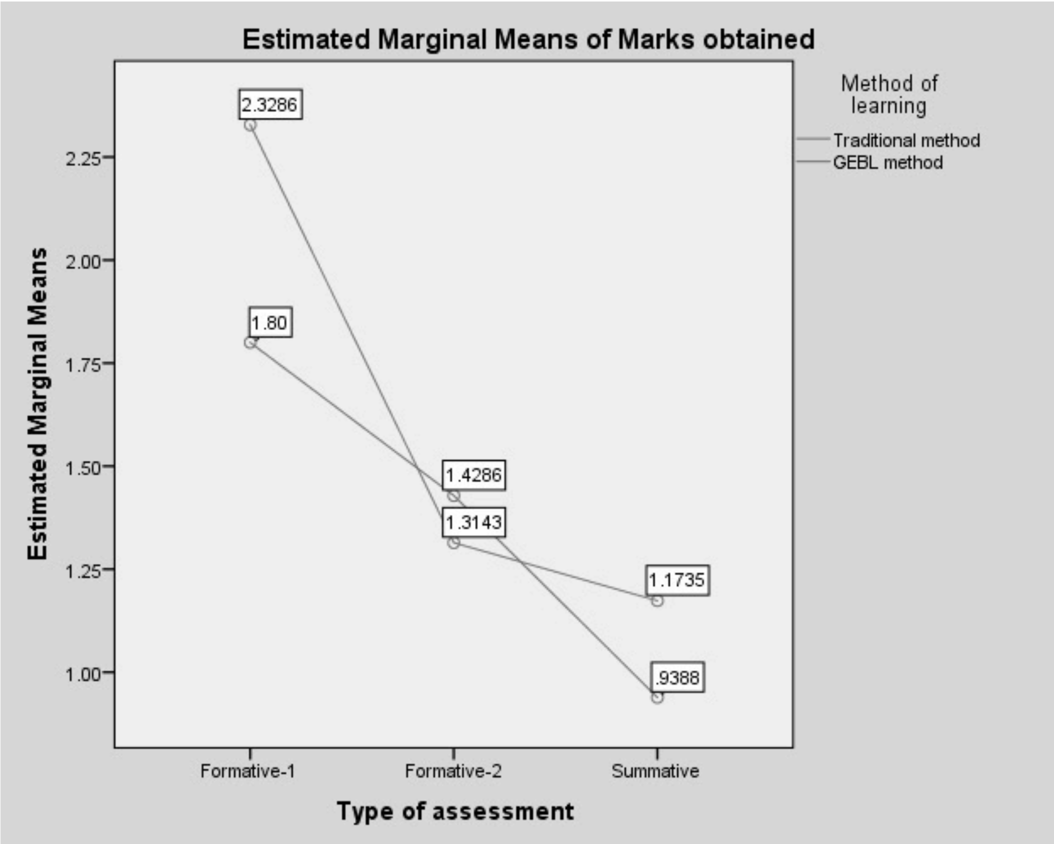


Fig. 4. 35 Comparison of Assessment Methods for Research Sub-Question Four

The figure below is a demonstration of a plot of means of assessment method against the method of learning. It is noted that except for formative assessment 2, other assessment methods when plotted in the manner shown in the figure below, show a similar plotting that there is always a higher mean as one moves from traditional to the GEBL learning method. In short, the result shows that the GEBL method is superior.

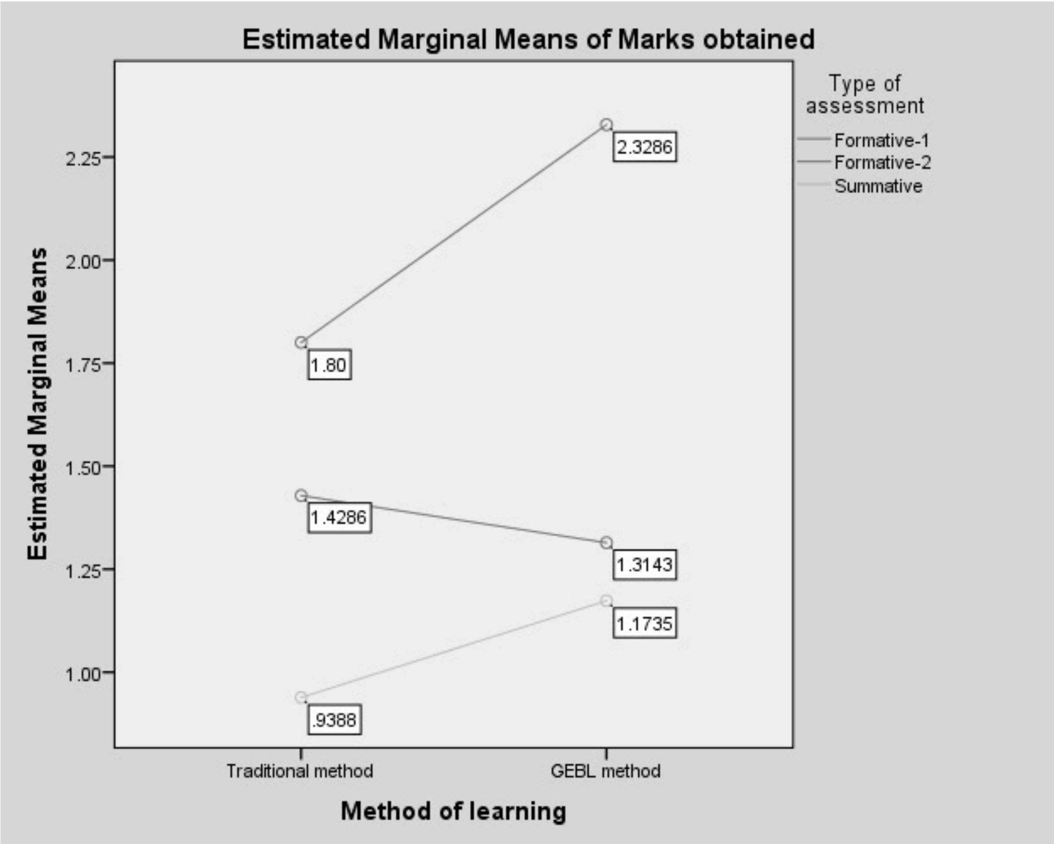


Fig. 4. 36 Comparison of Learning Methods for Research Sub-Question Three

4.3.2.4.2 Observations for Research Sub-Question Four

The p-value for Research Sub-Question four from the Anova table is 0.257. As this value is greater than 0.10 we cannot reject the null hypothesis. Also the grand mean for the data set is 1.497. So from the statistical values we can conclude that both teaching methods had almost the same effect when critical thinking abilities of the students are considered. We cannot conclude that any one teaching method is better than the other. As shown in the study by Kim et al. (2013), critical thinking ability develops with time and practice. The observation indicates that the GEBL approach did not considerably enhance critical thinking ability in students. This could have been influenced by the limitation of time during the semester which restricted the time spent on practice of numerical and theoretical problems.

4.3.2.5 Analysis Of Variance In The General Population

Introduction

This analysis is a combination of all the data under different sub-research questions. This step gives a summary of the analysis for all the analyses done earlier. The analysis agrees with some of the findings under the single research questions, while not agreeing with others. A good example is its agreement with significant main learning methods and main assessment test methods effects. On the other hand, like most findings, the combined analysis did not record a significant interaction effect. This was observed among the pervious analyses too. The population overall mean suggests a middle position stand, which, of course, is expected. The analysis was conducted following the analyses done under the split data approach. This analysis has equally provided the sub-group means according to the situation. Different standard errors have been computed for all the calculated means. One measure of test was the number of observations under a given category. The number in question had to tally. The total number was also of concern for the researcher. The total sample size for the researcher was 1008. Different splits sub-samples had different sample sizes. The analysis and interpretation continues as follows:

4.3.2.5.1 Comparison among Assessment Methods

Hypotheses:

Null Hypothesis:	H_0: There is no difference between the assessment methods.
Alternative Hypothesis:	H_a: There are differences between assessment methods.
Level of significance is:	0.10
The obtained p-value:	0. 077

Observation: The observed p-value (0.077) is less than the level of significance (0.10).

Conclusion: Since the observed p-value is less than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis. The assessment methods differ significantly under the setup of general population data. The researcher notes, however, that the significance is not too high due to the high observed p-value.

Subject matter Inference: The rejection of the null hypothesis under the general population means that the assessments are significantly different. Some or one of the assessment procedures are/is more superior to the other/others with an overall mean of 1.418 under the two learning methods. When analysed across the two learning methods, the formative assessment 2 method was superior to its two counterparts though its mean under the traditional method was less than its mean under the GEBL method. The combination of formative assessment 2 was superior when combined with the GEBL method.

4.3.2.5.2 Comparison between Learning Methods

Hypotheses:

Null Hypothesis: H_0: There is no difference between the learning methods.

Alternative Hypothesis: H_a: There are differences between the learning methods.

Level of significance is: 0.10

The obtained p-value: 0.002

Observation: The observed p-value (0.002) is far less than the level of significance (0.10).

Conclusion: Since the observed p-value is less than the level of significance, the null hypothesis is rejected in favour of the alternative hypothesis.

Subject matter Inference: The rejection of the null hypothesis implies that the two learning methods differ significantly from each other. The difference between the learning methods is statistically significant.

Descriptive Statistics

The table below shows the two-way distribution of means according to assessment method and learning method. It is obvious that the combination of formative assessment 1 and the GEBL method with a mean of 1.7286 is the highest among all combinations of means. Formative assessment 2 when combined with the GEBL method produced a mean of 1.6652, which was the second largest among the combinations.

Calculation of N for analysis

The table below shows the calculation of N for the analysis of variance in the second sub-research question.

Table 4. 38 Calculation of N for General Population

Assessment	Number of questions in assessments to test recalling	Number of students	N (= Number of questions in assessments * number of students)
Formative Assessment 1	20	14	280
Formative Assessment 2	16	14	224
Summative Assessment	36	14	504

Table 4. 39 Between-Subjects Factors for General Population

		Value Label	N
Type of Assessment	1.00	Formative-1	280
	2.00	Formative-2	224
	3.00	Summative	504
Method of Learning	1.00	Traditional method	504
	2.00	GEBL method	504

Descriptive Statistics

The table below shows the two-way distribution of means according to assessment method and learning method. The mean value of 1.7286 as a result of the combination of formative assessment 1 with the GEBL learning method is the highest among all combinations of means.

Table 4. 40 Descriptive Statistics for General Population

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Deviation	N
1.00 Formative-1	1.00 Traditional method	1.2250	1.31308	140
	2.00 GEBL method	1.7286	1.51060	140
	Total	1.4768	1.43509	280
2.00 Formative-2	1.00 Traditional method	1.3348	1.21623	112
	2.00 GEBL method	1.6652	1.59587	112
	Total	1.5000	1.42527	224
3.00 Summative	1.00 Traditional method	1.2202	1.51556	252
	2.00 GEBL method	1.3313	1.58124	252
	Total	1.2758	1.54821	504
Total	1.00 Traditional method	1.2470	1.39688	504
	2.00 GEBL method	1.5159	1.57318	504
	Total	1.3814	1.49298	1,008

The Anova Table

As stated above, the p-values for assessment and learning methods are lower than the level of significance. The interaction effect is not significant.

Table 4. 41 Anova Table for General Population

Dependent Variable: Marks obtained

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Model	1960.404	6	326.734	148.284	.000

assessment	11.319	2	5.660	2.569	.077
Learning method	22.283	1	22.283	10.113	.002
assessment * learn.method	7.204	2	3.602	1.635	.196
Error	2207.846	1,002	2.203		
Total	4168.250	1,008			

Estimated Marginal Means

Table 4. 42 Grand Mean and Standard Error for General Population

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
1.418	.050	1.320	1.515

Assessment Means and Standard Errors

The table below shows the means for the assessment methods. Formative assessment 2 has the highest mean.

Table 4. 43 Comparison of Assessments for General Population

Dependent Variable: Marks obtained

Type of assessment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Formative-1	1.477	.089	1.303	1.651
2.00 Formative-2	1.500	.099	1.305	1.695
3.00 Summative	1.276	.066	1.146	1.406

Table 4. 44 Comparison of Methods of Learning for General Population

Method of learning	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00 Traditional method	1.260	.070	1.123	1.397
2.00 GEBL method	1.575	.070	1.438	1.712

4.3.2.5.1.1 Type of Assessment versus Method of Learning

The table below shows the two-way means over different combinations of the treatments being tested.

Table 4. 45 The Assessment and Learning Method interaction for General Population

Dependent Variable: Marks obtained

Type of assessment	Method of learning	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1.00 Formative-1	1.00 Traditional method	1.225	.125	.979	1.471
	2.00 GEBL method	1.729	.125	1.482	1.975
2.00 Formative-2	1.00 Traditional method	1.335	.140	1.060	1.610
	2.00 GEBL method	1.665	.140	1.390	1.940
3.00 Summative	1.00 Traditional method	1.220	.094	1.037	1.404
	2.00 GEBL method	1.331	.094	1.148	1.515

4.3.2.5.1.2 Multiple Comparisons for Type of Assessment

The table below shows the comparisons of means for the assessment methods. This was done for every two assessments methods at a time. The objective is to understand the significance of differences between two assessment methods using Cheffe multiple range test. p-values (Sig) have been calculated for easy conclusions and for each comparison. Consider the comparison between the summative and formative assessment 2, which has a p-value of 0.171, meaning that the two assessment methods are not statistically different. Now the p-value between formative assessment 1 and summative assessment is 0.193. Since 0.193 is greater than 0.100, the two assessment methods are not statistically and significantly different.

Table 4. 46 Multiple comparisons for Type of Assessment for General Population

Dependent Variable: Marks obtained

(I) Type of assessment	(J) Type of assessment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00 Formative-1	2.00 Formative-2	-.0232	.13306	.985	-.3494	.3030
	3.00 Summative	.2010	.11064	.193	-.0702	.4722
2.00 Formative-2	1.00 Formative-1	.0232	.13306	.985	-.3030	.3494
	3.00 Summative	.2242	.11920	.171	-.0680	.5164
3.00 Summative	1.00 Formative-1	-.2010	.11064	.193	-.4722	.0702
	2.00 Formative-2	-.2242	.11920	.171	-.5164	.0680

4.3.2.5.1.3 Profile Plots of Assessment Method across Learning Methods

It is of interest to note that while the figure below shows serious interactions between learning methods and assessment test methods, the overall analysis did not yield the same result. The conclusion is that when the assessment methods are assessed separately, the interaction with learning methods is significant. A significant interaction effect shows that the means of one treatment (say assessment methods) increase as one changes from one level of learning method to the other.

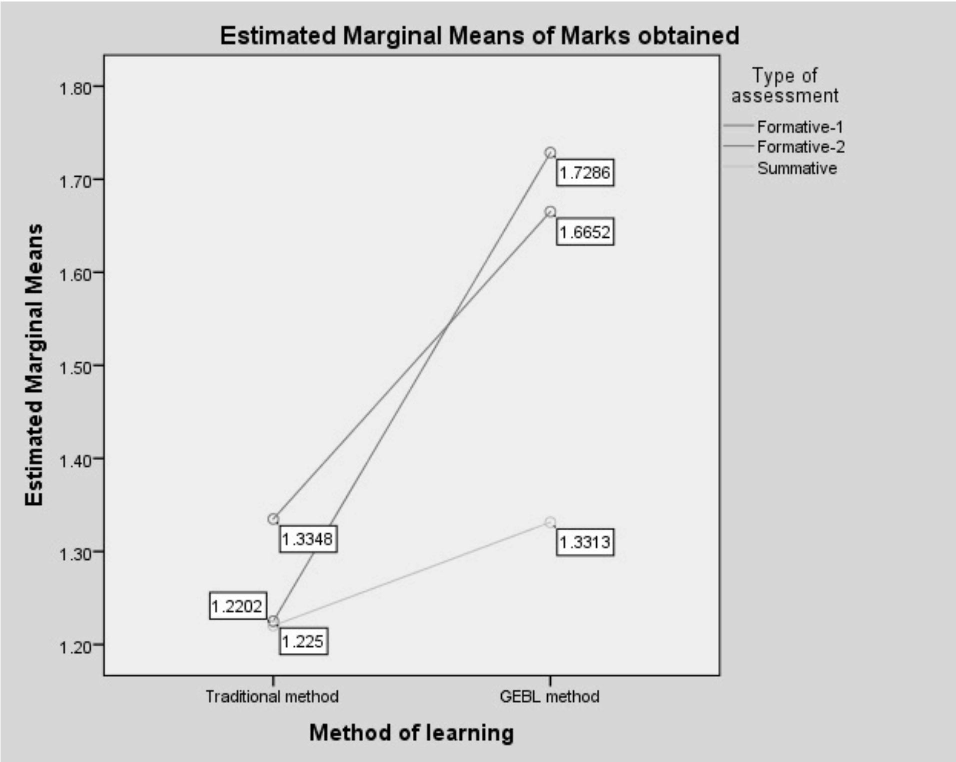


Fig. 4. 37 Profile Plot for Assessment Method for General Population

The Assessment Mean Error Plot

The assessment error plot below shows that the formative assessment 2 has the highest mean in a mono-variable plot. The lowest performer being the summative assessment.

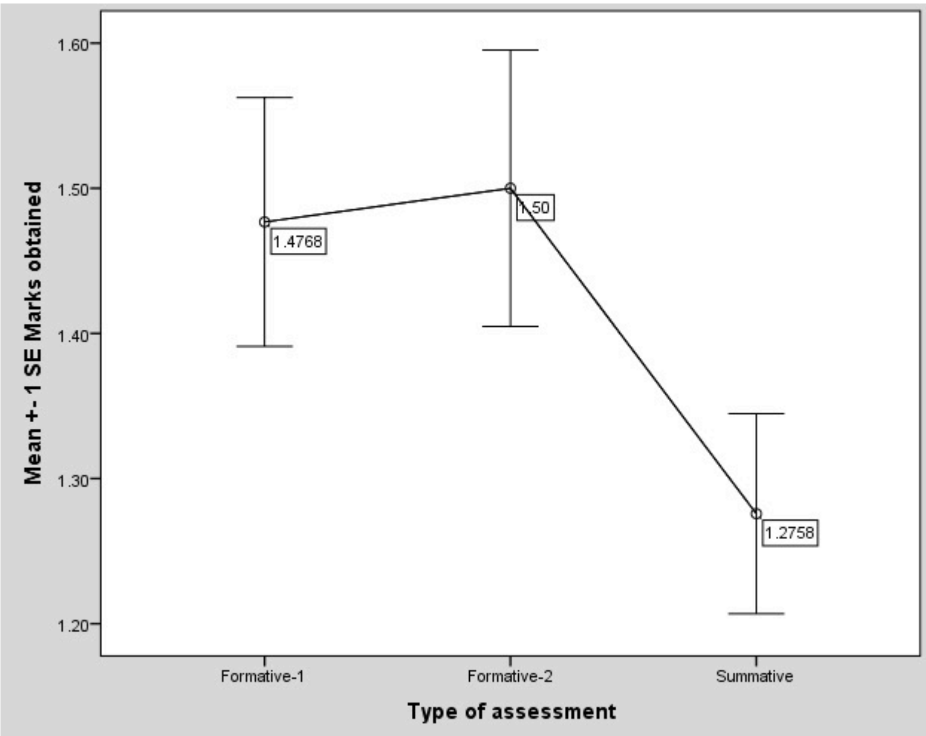


Fig. 4. 38 Comparison of Type of Assessment for General Population

The Learning Methods Error Plot

The error plot below shows the high performance of the GEBL method with a mean of 1.5159 when compared to the traditional method whose mean is 1.247.

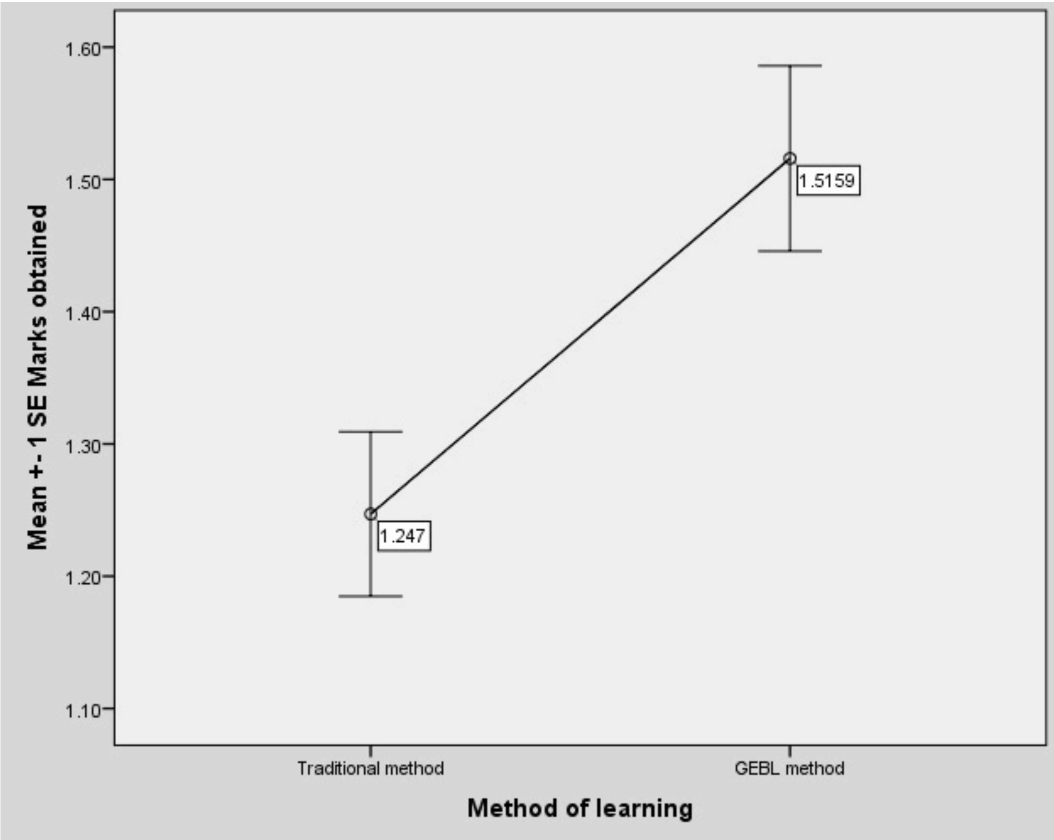


Fig. 4. 39 Comparison of Methods of Learning for General Population

4.3.2.5.2 Observations for General Population

Here the analysis was done on all data under different research sub-questions. This gives the summary of all the statistical analysis done earlier. From the Anova table the p-value obtained was 0.002. As this value is less than 0.10 we can reject the null hypothesis. This means that there is a significant statistical difference between the two methods of learning. The students from GEBL approach performed better than the students from the Traditional method.

4.4 Qualitative Data Analysis, Interpretation and Discussion

This section focuses on the data gathered during the interviews. The purpose of the interview was to find out more about students views to the GEBL approach in the learning of PE. As it was the first time for the students to be exposed to a new learning strategy the students were interviewed to determine the impact of the new approach in their learning.

The questions were structured in a way to get answers for the research sub-questions. The interview schedule is included in Appendix D. Students' responses were recorded using an audio device during the interview. This was later transcribed *verbatim* and is included in the Appendix F.

Each of the seven students in the GEBL sample was assigned a number code to identify them individually, that is, all seven students are numbered. As such, student 1 represents a particular student and this type of reference is maintained throughout. Only those responses which were relevant to the question are quoted. Therefore if a particular student number code is missing in the data presentation, it means that number coded students response was irrelevant.

4.4.1 Addressing Research Sub-Question One

With reference to the Research Sub-Question One "Would a GEBL approach enhance students' ability to remember PE concepts", Questions 1, 1a, 1b, 5, 5a and 5b from the interview schedule were asked. Thematic analysis was done to capture the themes that emerged from the responses from students.

The following themes emerged for Question 1, 1a and 1b:

Table 4. 47 Themes from Question 1, 1a and 1b:

Major Themes	Minor Themes	Responses
Remembering PE Concepts	Connect prior knowledge to the new topic	Preparing new topics in class helped connect the topics learned earlier.
	Group sessions helped connect prior knowledge	Discussions in GEBL sessions clarified topics learned in previous semesters, discussing the topic in depth helped making connections with previously learned topics.
	Good understanding of the topic helped recall	Researching a topic to present in the class requires a good understanding of the topic. A good understanding of the topic helps to recall easily.

	Preparation and group discussions helped to understand the topics in depth	Learn at own pace, taking notes and reviewing them later helped understand the topic better. Researching about the topic helps to learn more.
	Understanding other courses	A good understanding of the new topics also helps in understanding other courses.
	Concentration and application in the class	To be able to answer questions from other students requires concentration and participation in the class.

With reference to Question 1 of the interview schedule, students found that to prepare the topics for the next class they had to be familiar with some topics already learned in courses like Electronics 1 and Electrical Engineering 1 and 2 from previous semesters. While preparing for the topics the students were required to use books and other resources like internet. Generally students, in the institution where the research was undertaken, are reluctant to use these resources. They depend heavily on lecture notes provided in the class. The knowledge from these resources were then shared with each other in the group discussions.

As students were encouraged to work in groups for the preparation of new topics, the discussions in the group enabled them to connect the previous topics to the current one.

Selected student responses from interviews about the influence of GEBL sessions to connect prior knowledge to the current topic (See Appendix H for full details):

Student 1

"Okay…I can say that usually in class we usually do take notes. In class when we come back on having not read those notes. So… the prior knowledge was like we felt not comfortable with connecting the prior knowledge…like if we doing S1 we are not connecting that information with S2 as well. So now it needed that part where you go to go…take some books of S1…do and you try to understand the concept in S3….yes".

Student 3

"I can say yes because before I come to the class I am given the topic to prepare. Then I go to make a research and when I research about it, then I see about what I have to teached before then I connect with it and then I present it".

With reference to question 5, 5a and 5b of the interview schedule, the following themes emerged:

Students were encouraged to read about the topic on their own and then come together as a group to discuss the topic. So students came with different information. Group discussion and participation in group discussions helped them in sharing the knowledge and this helped them to understand the topics better. They didn't have to memorize the topics. Students found that it was much easier to recall the topics learned during GEBL sessions compared to the traditional approach.

Selected student responses from interviews about the influence of GEBL sessions to recall the topics learned (See Appendix H for full details):

Student 1

"Yes. Even when we are writing the tests it is a thing of going there; just check, check, check, because all those topics that are covered…we try to discuss them in depth so it's easy to recall. Yes, so I can say GEBL is doing a very good job there".

Student 3

"It helped me because when I study the topic, then it connects to the other topics I have learnt before".

Student 5

"Like in GEBL session, as we are most of the time as a student are the one who are working, the lecturer is there to assist. So it is… sometimes the question can come and maybe you were the one who was doing that question so it becomes easier for you to recall".

4.4.2 Addressing Research Sub-Question Two

With reference to the second research sub-question "Would a GEBL approach enhance students' understanding of PE concepts", Questions 2, 3 and 4 from the interview schedule were asked. The following themes emerged from the answers given by the students:

Table 4. 48 Themes emerging from answers given by students.

Major Themes	Minor Themes	Responses
Understanding of Concepts	Difference of approach used in the course	GEBL approach required active participation from students unlike in traditional classrooms where the lecturer use to talk and students may not necessarily be involved. Students do not come prepared for the class.
	Sharing of information	Sharing information with others required more thinking about the concepts and a better understanding of the concepts.
	GEBL sessions required more thinking	To be able to answer questions from fellow students required to think more about the topic and research more about the topic.
	In-depth understanding of the topic	Group discussions and class presentations helped in a deeper understanding of the topic. Coming to the class with a good idea about the topic and a further discussion about the topic helped in-depth understanding of the topic.
	Group sessions encouraged to come prepared to the class	Coming prepared to the class and then more discussions on the same topic helped in better understanding of the topic.
	Asking questions to group members	Asking questions to other group members and to the presenter in the class helped to clarify areas which were not clear.

The students were required to present the topics in class to other students and other students were encouraged to ask questions. The students were chosen randomly to present the topic in class. So all students had to come prepared to present. This forced students to read, understand and discuss the topics in depth. As students were encouraged to ask questions, it was observed that students asked intelligent questions. The student presenting had to give answers to the question. If the presenter could not answer then other students were encouraged to answer. This also encouraged students with extra information to ask question because if the presenter was not able to answer then this student could answer correctly. Students' confidence level increased when they were in a position to provide the correct answer to the class. It motivated them to come prepared for the class at all times. They felt to be part of the whole process.

Before presentation time, students were given time to discuss the topic. If students had any doubt, they assisted each other to clarify the doubts. Students were given topics in advance to come prepared for the class. This gave them enough time to read and prepare for the topic unlike traditional approach where generally the lecturer comes to class and starts a topic. Some students feel lost from the beginning of the class. They just sit and take notes in the class which they generally don't read after the class. Students indicated that generally they read the notes only just before the tests or exams. This limits their understanding of the topics. As students are always actively involved in learning, they do not want to be left behind by coming to the class unprepared. Selected student responses from interviews about the influence of GEBL sessions to enhance students' conceptual understanding (See Appendix H for full details):

Student 1

"The subject content…okay, I can say that in GEBL we are a group of students. Then the chances are like where we meet, discuss, go back, try to read what has not been clear in class. You come and present it. It motivates them to come back in class and present what you have understood about that content. Like the subject which was discussed".

Student 3

"It helped me because when I am given a topic I try to find about more about what I am given. So I read about it and then I understand more than when I am teached".

"Yes, it makes me to understand it easier than when I am studying it alone".

"Yes, it made me think more because I have to prepare to answer some questions from others".

Student 4

"Yes, it, because of the different approach because first of all we are just researching about the topics it is one of the other approaches we are doing. We research the topic then we discuss as a group so that we come with… with something and you get something from the group".

“Yes, Sir, since you are…you are giving us some topics to research, uh, we research about the… the topic and then we get some information, but it, the information we get it is not enough. We have to dig the deep information from that information we get. For example from the internet, internet it just give you the information that is up, so we just have to find deep information down so that you can understand what…what actually happens”.

Student 7

“As I have said, you are discussing, you learn on your own and you come into the class discuss about what you have learnt on your own from the topics that were given to you. That’s what helping us to understand the PE concepts”.

4.4.3 Addressing Research Sub-Question Three

With reference to the Research Sub-Question Three “Would a GEBL approach enhance students’ problem solving skills”, Questions 6, 6a, 6b and 6c from the interview schedule were asked. The following themes emerged from the answers given by the students:

Table 4. 49 Themes emerging from answers given by students: Enhancing Problem-Solving Skills

Major Themes	Minor Themes	Responses
Enhance Problem Solving Skills	Group sessions helped to analyse the problems step by step	Working with others helped to understand the problem and to analyse the problem step by step. It helps to understand what is given in the problem and what is to be calculated.
	GEBL sessions helped to analyse the problems effectively	Discussing in the group about the given problem helped in analysing and finding more information that is given in the problem. This helped in improving the analysing skills.
	GEBL sessions helped to interpret the problems effectively	Practise in GEBL sessions enabled to interpret and understand the parameters given in the problem which helped in finding the solution to the problem.

GEBL sessions enabled students to analyse the problem effectively. Students took time to understand the information provided. Students were encouraged to go through the problem individually and collect all the information provided. They had to analyse the problem step by step. They were then required to note down the information provided in the problem and indicate if there was any information missing to solve the problem. They then had to check if this information could be obtained from the information already provided. This exercise trained them to tackle problems in a systematic way. Once they had all the information they could get then they had to discuss as a group. Here again the students helped each other in case there were some clarification required by any student. Lecturer used to assist only if no one in the class could solve it. In some instances the students were required to do some research work to be able to understand the missing link and solve the problem. This was then discussed in the following class. Generally every time the students came with the right solution after referring text books or using other resources.

Selected student responses from interviews about the influence of GEBL sessions to enhance problem solving skills (See Appendix H for full details):

Student 3

"It help me because when I think when I ask the question I am not just answering I try to think about it and analyse it more about what I have learnt in the class than about what I have researched".

"It help me about how to face the question and I don't feel that way that I cannot write when the question is asked to me. So each and every question I try by all means to analyse it then I have something to write".

Student 6

"It helps, because for you to be able to answer or to work on the problem you must first know what is given and what are you going to do to in order to get to solve the problem".

Student 7

"It has helped me by giving me the time to think, because when we are thinking about the problems where we can easily analyse it, not only waiting for others to discuss. But if you give yourself the time to think about the problem that is given it is easy for you to analyse the problem".

4.4.5 Addressing Research Sub-Question Four

With reference to Research Sub-Question Four "Would a GEBL approach enhance students' critical thinking ability", Questions 7, 7a, 7b, 7c and 7d from the interview schedule were asked. The following themes emerged from the answers given by the students:

Table 4. 50 Themes emerging from the answers given by the students: Enhancing Critical Thinking Skills.

Major Themes	Minor Themes	Responses
Enhance Critical Thinking Skills	Group sessions helped in improving your thinking skills	GEBL approach requires students to think in order to interpret the topics being learned. This is then discussed in the class to confirm if the interpretation and the thinking was correct. It requires students to be active and to think in the class in order to answer the questions which also helps other students.
	Group sessions helped in comprehending the problem	Group sessions helped students to take time and understand what the problem is about. It also enables to share information and ask questions regarding the problem.
	Group sessions helped determine the key parameters in a problem	GEBL approach helped to think and understand the problem. It helps to determine the given parameters in the problem.

Critical thinking ability enables students to identify and comprehend a problem. The information provided is analysed and a judgement is reached. In GEBL sessions problems or questions were given to the students and the students were required to analyse the information provided and reach a conclusion. They were required to make an informed decision.

Selected student responses from interviews about the influence of GEBL sessions to enhance students' critical thinking ability (See Appendix H for full details):

Student 7

"Sir, as I have said we are given problems there and we were also given the chance to think about the problem and analyse it. So GEBL sessions… it helped me to critically to solve the problem that is given".

"Yes, it helps sir because we are given time when the problem is there on the board. We are given the time to discuss about it and ask question where we don't understand, so it helps them".

Student 4

"Yes, Sir, as I have said, Sir, as I have said, it makes me improve the… the thinking skills because if I came with something and then I found out I was… I was correct when I was interpreting something and then I come to class and ask my members then they correct me so that I can confirm that that answer I was thinking, it was correct".

4.5 Summary

This chapter presented the results obtained by analysing the data collected during the study. The data from the two formative assessments and one summative assessments were analysed. The performance of students from both the traditional and the GEBL group were analysed and interpreted using Anova. The data obtained from the open ended interviews were also analysed.

CHAPTER FIVE

DISCUSSION OF FINDINGS, IMPLICATIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter, the findings of the study are discussed and interpreted. The findings are addressed in relation to the reviewed literature and the research questions of the study. A comparison was made to determine if there was a correlation between the quantitative data from the assessments and qualitative data from the interviews. The conclusion of the study is presented and recommendations are made for further research.

5.2 Findings

The problem in sub-section 1.12 was based on a perceived low achievement of TTGs in 2016. Therefore, before going to the findings regarding the research sub-questions and the main study, it is appropriate to bring the conclusions from Appendix L-a and L-b as discussed in sub-section 4.3.1. In 2016 there was only TTG. The 2017 TTG performed lower than the 2016 TTG in all assessments. However, the 2017 GEBL group performed higher than the 2016 TTG only in formative assessment 1 and summative assessment but their performance was lower than the 2016 TTG students in formative assessment 2. As such the researchers assumption that the performance of the GEBL group in all assessment types would be improved from that of the 2016 TTG students was disproved. However, the gains of GEBL students in formative assessment 1 and summative assessment indeed is an achievement, although the lower performance of GEBL students in formative assessment 2 was a disappointment. The present rearcher could not identify any obvious reason through the qualitative data.

The data collected from the two formative assessments and the summative assessments were used for statistical analysis. An open-ended interview was used to collect qualitative data from the students belonging to the GEBL group. The quantitative data was analysed using Anova and thematic analysis was used for qualitative data to answer the research questions.

5.2.1 Answering Research Sub-Question One

Would a GEBL approach enhance students' ability to remember PE concepts?

Fig 4.1 in Sub-section 4.3.1.1 and the description that follows show that, for example, in question 4a, students from the GEBL group performed better in recall than those in the other group. In the same sub-section Fig 4.2 and its description indicates that majority of those in the TTG made considerable errors in answering the question as compared to the GEBL group. Fig 4.3 in the same sub-section shows that there was no major difference in recall between both groups. It is of interest to note that both groups had exposure to this concept in the previous semester. However, this previous exposure could have prompted the lecturer not to emphasise the concept. It is difficult to find another reason for the performance difference. Overall, as indicated in sub-section 4.3.1.1, the better performance of the GEBL group than the TTG could be due to the discussion sessions in the GEBL group.

The p-value for Research Sub-Question one from the Anova table is 0.056. As this value was less than 0.10, the null hypothesis was rejected. This showed that there was a statistical difference between the two methods of learning. The mean value obtained for the students from the GEBL group was higher than that of the students from the traditionally taught group. This indicated that the students from the GEBL group were able to recall factual knowledge better than the students from the traditionally taught group.

In sub-section 4.3.2.1.1.1, the assessments methods were compared through Anova. The assessment means for the two formative and summative assessments there were different effects on the performance of students. In the same sub-section it was concluded that there were differences between the learning methods.

In sub-section 4.3.2.1.1.2, as indicated in the description under Table 4.8, GEBL has been seen as a superior method when compared to the traditional method in recalling PE concepts. Fig 4.20 and the Anova plot on Anova error plot of learning methods show the superiority of GEBL method compared to tradional learning method.

The thematic analysis in Table 4.47 under section 4.4.1 and the description show that the students from the GEBL group were more familiar with the use of technology - and this originated through group sessions in GEBL as opposed to those in the TTG. Group sessions enabled GEBL students to connect the prior knowledge to the current topic as evident from the transcripts.

Students' responses from the GEBL group suggested that this learning approach assisted them in remembering the learned topics. Some responses from students shown here suggested that discussions in GEBL sessions clarified topics learned in previous semesters, discussing the topic in depth helped making connections with previously learned topics and this assisted them to remember the topics.

The following are selected verbatim transcriptions of students' responses. (See Appendix H for transcriptions of all students). These are evidences on how GEBL assisted their learning:

"As I have said in GEBL sessions we are researching, we are not spoon fed. So when we are researching something , I understand it as well as I go and ask questions to my group members".

"when you are discussing things... it becomes more easier like when you are taking notes, learning or I think it becomes very easy to understand and recall when you are discussing".

The above results and responses demonstrated that the students from the GEBL group performed better in recalling the topics learned. Overall, from the above discussion it was concluded that the GEBL method was superior to the traditional method in enhancing recall of information. The students from the GEBL group performed better than the students from the TTG. This is in line with similar findings from other studies, where active learning strategies were used to improve students' ability to remember facts and explain processes and procedures (Felder & Brent, 2003; Prince, 2004). Lecturers are responsible for starting the enquiry process and encouraging student interaction (Warner & Myres, 2014). Increased interaction with other students (intra-students interaction) and asking questions help in deeper understanding of the topic (Warner & Myres, 2014; Markant et al., 2016). Such learning was cited earlier as deep learning (Houghton, 2004). Surface learning does not link new knowledge to the prior knowledge (Hay, 2007). Markant et al. (2016)

also subscribe to similar observations. Biggs (1999), Entwistle (2003) and Ramsden (2003) also emphasised similar approaches. GEBL approach enables students to learn at their own pace (Craik et al., 2000) and clarify doubts with their peers (Windschitl, 2002; Mason & Singh, 2010). Such intra-student interactions are also in line with Vygotskys' social constructivism which was part of the theoretical framework in this study. AL strategies such as GEBL activates and sustains recall of pertinent concepts and principles for appropriate application later on (Drake & Battaglia, 2014). Designing well-planned GEBL tasks to train students as part of study strategies improves memory and retention ability (Dunlosky et al., 2013).

5.2.2 Answering Research Sub-Question Two

Would a GEBL approach enhance students' conceptual understanding of PE?

As can be seen from the Fig 4.4 in sub-section 4.3.1.2 and the description that follows show that in question 2c, students from the GEBL group showed a significantly better performance in the conceptual understanding of rectifiers. Similarly, Fig 4.6 and Fig 4.7 for questions 7.1 in formative assessment 2 and question 1.1g in summative assessment respectively, show that the GEBL students demonstrated a greater understanding of the concepts as compared to the students from the TTG. GEBL students were also encouraged to use the internet in their individual and group searches which could have broadened their exposure to the topic. Overall, individual research, group discussions and collaborative learning by GEBL students using various resources could have helped them to gain an in-depth understanding about the topics.

Quantitative analysis of the data gave a p-value of 0.000. As this value is less than 0.10, the null hypothesis was rejected. The rejection of the null hypothesis falls in favour of the alternative hypothesis that the learning methods differ from each other. It was seen that the difference between the GEBL and traditional methods was statistically significant and the mean value (see table 4.18) indicated that students from the GEBL group understood the topics better than students from the TTG.

In sub-section 4.3.2.2.1.1, the assessment methods were compared using Anova. Similar to the finding in research sub-question one, the analysis showed that the different assessments had different effects on the performance of the students.

Under the same sub-section, it was concluded that the difference between the two learning methods was significantly different which was indicated by the p-value of .000 (see table 4.15).

In sub-section 4.3.2.2.1.2, Table 4.18 showed that the GEBL method was superior to the traditional method in enabling the understanding of PE concepts. The Fig 4.2 under the same sub-section depicts a direct comparison of the two learning methods and the plot illustrates a significant effect of the GEBL method in enabling the understanding of PE concepts when compared to the traditional method.

The thematic analysis in Table 4.48 under section 4.4.2 and the description indicate that the students from the GEBL group found that the collaborative learning and sharing of information followed by group discussion enabled them to understand the concepts in depth. The class presentations followed by question and answer sessions clarified doubts that the students had about the topic.

The student responses from the interview also highlighted the following: sharing information with others required enhanced thinking about the concepts and a better understanding of the concepts. Group discussions and class presentations resulted in a deeper understanding of the topic. Coming to the class having researched the topic, followed by a further discussion about the topic helped students to gain an in-depth understanding of the topic.

The following are selected verbatim transcriptions of students' responses. (See Appendix H for transcriptions of all students). These are evidences on how GEBL approach enhanced students' conceptual understanding of PE:

"…Since we are…we are doing a research, then you research and then we come as a group; we share the information and then we explain…."

"If someone come with something and if we do not understand, we ask him or her the questions…the questions… so that he can explain to us…"

Students from the GEBL group demonstrated a better understanding of PE concepts when compared to those from the TTG. These results are in line with the findings from other studies that active student-centred learning improves knowledge retention and develops higher order thinking skills (Prince, 2004; Klentschy & Thompson, 2008; Louw, 2012; Kolloffel & Jong, 2013). Students learn contents on their own providing opportunities to develop a deeper understanding of concepts (Wang & Posey, 2011). GEBL as an AL strategy allows students to get a better understanding of difficult concepts and let them retain the knowledge acquired for a longer time (Lacuesta et al., 2009). The results confirm those from the study by Kolloffel and Jong (2013). Furthermore, as discussed in literature, the results from the study concur with report by various researchers such as Steyn and Steyn (2002), Sekwena (2014) and Freeman et al. (2014).

The students from the GEBL group performed better than the students from the TTG. The quantitative and the qualitative analyses of data led to the above conclusion and confirmed that the GEBL method was superior to the traditional method.

5.2.3 Answering Research Sub-Question Three

Would a GEBL approach enhance students' problem solving skills?

Although students from the GEBL and TTGs performed similarly, as shown in Fig 4.9 and Fig 4.10 in sub-section 4.3.1.3 and the description that followed, in Question 7a and Question 5, those from the GEBL group had a higher edge in problem solving than the TTG. Nonetheless, the difference in performance was not significant. The GEBL students used group sessions to analyse the problems step-by-step and had spent more time solving problems compared to the TTG but this did not make a considerable difference in their performance in the assessments. It could be that during group sessions some students within the GEBL group were more involved than others in analysing and solving problems.

As indicated in the quantitative analysis in Table 4.24, the p-value was 0.417. As this value was greater than 0.10, the null hypothesis could not be rejected. This led to the conclusion that both teaching methods had the same effect on students' problem solving skills. Despite there being no considerable difference between the two groups, the mean value and the preliminary analysis showed that GEBL students performed marginally better than the traditionally taught students. However, there was no significant difference between the two groups.

In sub-section 4.3.2.3.1.1, the assessment methods were compared using Anova. The results revealed that the assessments differed significantly and had different effects on the performance of the students. However under the same sub-section, it was inferred that the difference between the two learning methods was not significant.

In sub-section 4.3.2.3.1.2, Table 4.26 shows that the mean value for the GEBL method is greater than that for the traditional method in problem solving skills. Fig 4.27 under the same sub-section shows a direct comparison of the two learning methods and the plot shows that the marginal means of the GEBL method is greater than that of the traditional method. Though the marginal means for the GEBL method is greater than the traditional method, the difference is not statistically significant.

The thematic analysis in Table 4.49 under section 4.4.3 and the description showed that students from the GEBL group found that the intra-student interaction arising out of working with other students in the group sessions helped them to understand the problem and to improve their analysing skills. Solving problems in groups enabled them to interpret and understand the parameters given in the problem. The GEBL students spent more time solving examples compared to the students from the TTG.

The student responses from the interviews indicated that working with others helped them to understand the problem and carry out step-by-step analysis. It helped to understand the pertinent elements in the problem and the purpose of the problem, that is, what was to be calculated. Though the response from the students indicated that GEBL sessions helped them to analyse and solve problems better than those in the other group, the quantitative analysis showed that there was no considerable difference in the performance of students between the two groups.

The following are selected verbatim transcriptions of students' responses. (See Appendix H for transcriptions of all students). These are evidences on how GEBL assisted enhance students' problem solving skills:

"…when I think when I ask the question I am not just answering I try to think about it and analyse it more…"

“…because for you to be able to answer or to work on the problem you must first know what is given and what are you going to do to in order to get to solve the problem”.

The responses from students indicated that GEBL sessions helped them to understand and analyse the problems better. Good problem solving skills can be achieved through good understanding of concepts and phenomena (Savander-Ranne & Kolari, 2003; Walsh et al., 2007). In this study, though GEBL students displayed a good grasp of concepts, it did not considerably improve their problem solving skills.

A similar outcome was observed in a study conducted by Montana State University where the results showed that the class average of the treated group showed some improvement but statistically it could not be claimed because of the small sample size and standard deviation score (Getty, 2009), though other studies (Louw, 2012; Kim et al., 2016) have shown an improvement in problem solving skills among students who were taught using active learning strategies.

Preliminary analysis in this study showed that, for problem solving type questions, students’ from the GEBL group scored higher marks than the students from the other group. GEBL strategy helped students to analyse and understand the parameters given in the question. During group sessions GEBL students were required to convert a problem from a verbal representation to a diagrammatic or tabular representation (Kaput, 1985; Larkin, 1989) which made analysis of the problem easier. This could probably be the reason for the GEBL students’ better performance in problem solving type questions. Although preliminary analysis and response from the students indicated that GEBL strategy helped the students to analyse and solve problems (Millar et al., 1998; Haupt & Webber-Youngman, 2018), the statistical analysis of the quantitative data indicated that the difference in the marks was not statistically significant. This could be due to the fact that the students were new to this learning strategy and had been exposed to this only for a short duration.

Haupt and Webber-Youngman (2018) aver that research reports have shown that traditional curricula propagate linear thinking which does not develop the kind of skills required to solve problems in today’s work environment. Through problem solving experiences engineering students are taught to solve well-structured problems although they may not be similar to the kind of problems they would face in the real world after graduation. It is this argument which resaearchers such as Mohd-Yusof et al. (2014), Adams et al. (2015) and Haupt and Webber-Youngman (2018) puts forth. Therefore, a good engineering education must train the students methods to identify and solve problems so that when they are faced with real world challenges in their engineering career, they will have the necessary skills to solve the problems.

5.2.4 Answering Research Sub-Question Four

Would a GEBL approach enhance students' critical thinking ability?

As can be seen from Fig 4.14 in sub-section 4.3.1.4 and the description that followed illustrate that in Question 3, students from the GEBL group were able to think, analyse and answer the question correctly. Although, the students from GEBL group had slightly better scores than those from the TTG, Fig 4.15 and Fig 4.16 for questions 4b and 6.2 respectively, demonstrate that performance of both groups in the above questions (4b and 6.2) was very similar. Fig 4.18 and Fig 4.19 however shows that the students from the GEBL group showed a better performance than the students from the TTG but the difference was not significant. Overall, it can be concluded that the thinking ability of the GEBL students was better than those from the TTG.

As presented in Table 4.32, the p-value from the quantitative analysis was 0.257. As this value was greater than 0.10, the null hypothesis could not be rejected. Hence, it could be concluded that both teaching methods had similar effects on students' critical thinking ability. It could not be concluded that any one teaching method was better than the other. Nonetheless, the mean value from Table 4.35 in section 4.3.2.4.1.2 showed that the students from the GEBL group displayed better critical thinking ability when compared to the other group. The Fig 4.29 under the sub-section 4.3.2.4.1.4 shows a direct comparison of the two learning methods and the plot shows that the marginal means of the GEBL method is greater than that of the traditional method in critical thinking ability. Though the marginal means for the GEBL method was greater than the traditional method, the difference was inconsequential.

In sub-section 4.3.2.4.1.1, the assessment methods were compared through Anova. The assessment means for the two formative and summative assessments showed different effects on the performance of the students. Under the same sub-section, it was concluded that the difference between the two learning methods was statistically inconsequential.

The thematic analysis in Table 4.50 under section 4.4.5 and the description showed that GEBL sessions required students to think in order to interpret the topics and tasks given to them. Experiments and tasks given to the GEBL group were different from the tasks given to the TTG. For example, the GEBL students were given problematic circuits and they had to identify the problem in the circuit but traditional teaching did not include such circuits and for the TTG, the *status quo* continued. The GEBL Students were allowed to work in groups to discuss the circuit, which enabled collaborative learning while those in the TTG missed that opportunity as the practice has been in the previous years .

Some of the responses from students indicated that the GEBL approach required students to "think harder" (in their own words) in order to interpret the topics at hand. This is then discussed in the class to confirm if the interpretation and the thinking were correct. It required students to be active thinkers in the class in order to answer the questions which, in turn, also benefited their peers in the GEBL group.

The following are selected verbatim transcriptions of students' responses. (See Appendix H for transcriptions of all students). These are evidences on how GEBL assisted enhance students' critical thinking ability:

"…but you can try to find it and then you have to think critically because your lecturer is not in front of you during that time you are doing your research…"

"…as a GEBL student you have to think, you have to think. Each time you are given a thing you just look what has been asked so that you answer accordingly to what is being asked…"

Though the responses from students during the interview were positive about the GEBL approach, the quantitative analysis showed that the critical thinking ability of students from this group was not considerably better than those from the other group. Similar to the observation in problem solving type questions, the students from the GEBL group did not show a considerable improvement in their critical thinking ability. In essence, in problem solving and critical thinking ability, the GEBL approach did not present significant difference between the GEBL and TTGs.

Critical thinking is a learned skill that requires both training and practice (Kim et al., 2016). GEBL model requires students to learn contents on their own and this provides an opportunity to develop critical thinking ability (Wang & Posey, 2011). There is a probability that the results could have been better and the students might have shown more improvement in their critical thinking ability if they had been exposed to this strategy for a longer duration of time. However, the limitation of time allocated for the course did not allow for such an exposure. The above discussions show that the method of teaching and learning has a positive impact on the learning abilities of the students.

In sub-section 4.3.2.5, an analysis of all the data under different research sub-questions was done and that provided the summary of all the analyses. In sub-section 4.3.2.5.1, the assessment methods were compared and their assessment means displayed different effects on the performance of students. In sub-section 4.3.2.5.2, a comparison was made between the learning methods and the GEBL method was found to be superior in recall of information and conceptual understanding. The Anova table shows the p-value to be 0.002 and as such, there was a significant statistical difference between the two methods of learning. The students from the GEBL method showed a considerably better performance in recalling and understanding of PE concepts than the traditional method. Nevertheless, the performance of both groups were similar in problem solving and critical thinking type questions, those in the GEBL group had a slightly higher edge in these than the other group. It is worthy to note that the difference was not statistically significant.

5.3 Conclusions

The following overall conclusions can be made from the analysis of quantitative and qualitative data collected for this study: In general, there was a positive impact on student learning by the introduction of GEBL in teaching PE. Generally, the responses to questions in the interview schedule (Questions 8, 9, 10, and 11) revealed that the students who volunteered for GEBL began feeling excited to have been part of the group as they were actively involved throughout the process and their positive attitude to the tasks enhanced as the journey continued. It was observed that the learning environment in the GEBL class continued to be active and vibrant when compared to the other traditionally taught classes. The students were also willing to co-operate with the lecturer for the course. The GEBL students showed good interest in learning new topics using GEBL and it was observed that they enjoyed the process. The positive attitude from students helped in the teaching and learning process. Discussing the topic with other students contributed to a faster conceptual understanding. This student-centered learning approach helped students to learn individually, through intra-student participation in the GEBL group and the accompanying social interaction. As such, the theory of knowledge creation metaphor was apt for this study. The collected data supported this observation and similar views are supported by studies conducted by other researchers, for example, Prince (2004) and Fuehne (2007).

The analysed data from the mixed method approach and the triangulation gave evidence that GEBL improved students' factual recall of PE concepts and their understanding of PE concepts. Though the preliminary analysis and the mean values showed that the students from the GEBL group performed better than those in the TTG in problem solving and critical thinking type questions, the quantitative analysis indicated that this difference was not statistically significant. This means that further efforts can be made to improve the problem solving skills and the critical thinking ability of students.

The main research question was 'Would GEBL enhance students' conceptual understanding, problem solving skills and critical thinking ability in Power Electronics (PE) course?'. The conclusions based on the presented data and the discussions for each sub-question in the foregoing sections indicate that GEBL enhanced students' conceptual understanding, problem solving skills and critical thinking ability.

5.4 Recommendations

It is recommended that students must be encouraged to be more active in the learning process to make the learning process a fun and to make students interested in learning. The shift of strategy from traditional to AL methods such as GEBL must be introduced gradually so that students and lecturers improve their familiarity with such strategies. The popularization of the benefits of this approach and exposure to GEBL ought to develop positive attitudes not only among students, but also teaching staff. This will facilitate students and teaching staff to gradually get rid of the fear of making use of AL methods such as GEBL. Since the data showed no significant differences between the GEBL and TTGs in problem solving and critical thinking ability of students against the present researcher's personal assumptions, the following recommendations may be useful:

- Pre-inform students on the topic to be discussed in the upcoming lesson and this will facilitate effective scaffolding during the teaching-learning phase.
- Introduce the new topic in the class and encouraged students to work in small groups immediately after the lecture to formulate questions in order to understand the topic;
- Ensure that all members of the small groups actively participate in the activities in order to ensure that everyone both individually and collectively benefit from the collaborative learning;
- Give problems to solved individually so as to provide an indication about the learning process of each student and the subsequent improvement in their problem solving and critical thinking skills;
- Make use of formative assessments for self-reflection by not only the students, but also teaching staff to improve learning and teaching respectively.

The following proposed framework may serve as a guide to lecturers to improve student learning and teaching in PE.

5.5 Developing a Framework for Effective Learning through GEBL

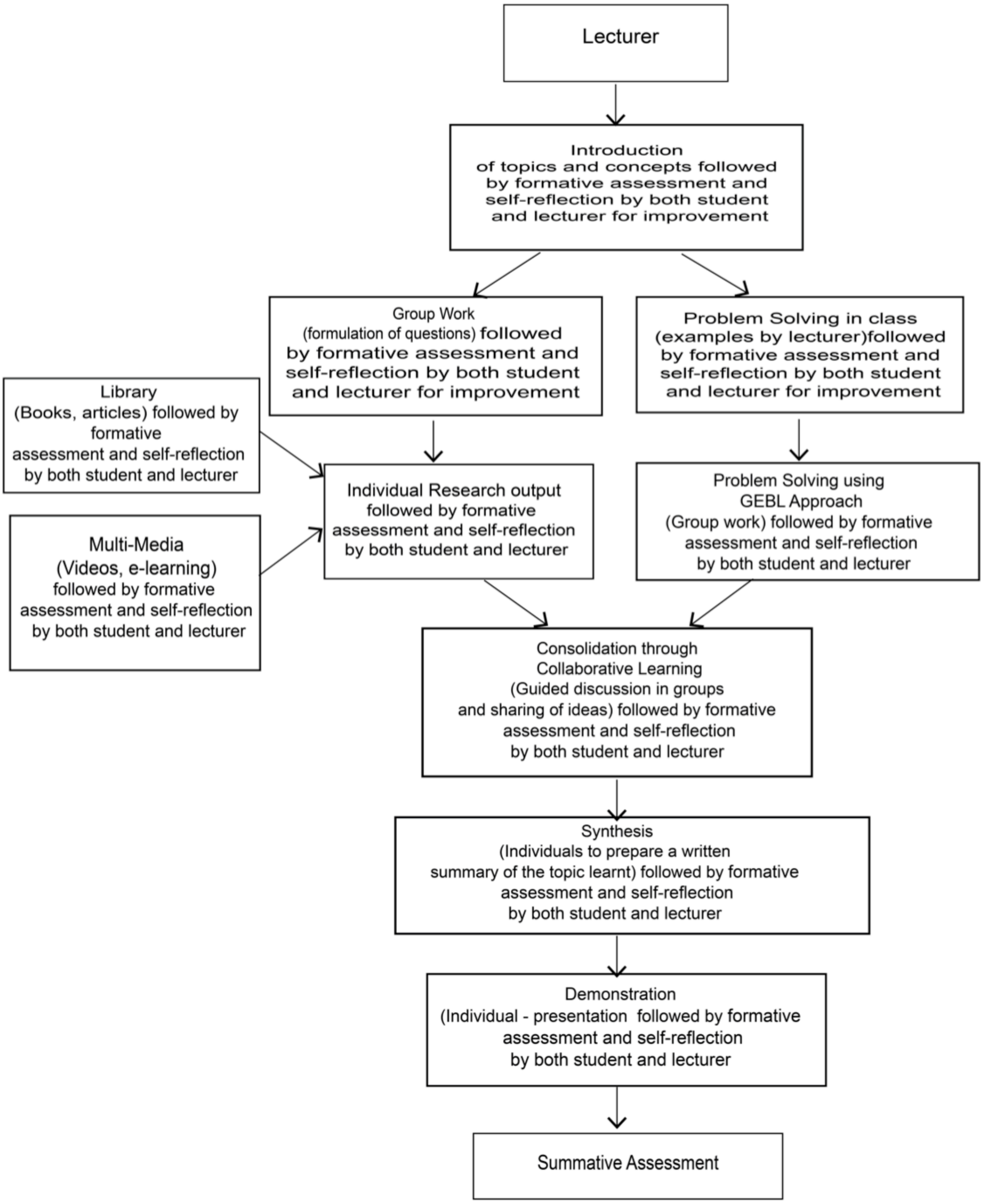


Fig. 5 1 Proposed framework for effective learning through GEBL

A framework was developed based on the findings from this study (Refer Fig. 4.37 above). Even though the framework was based on the teaching of PE using GEBL, this framework could be used for any course in an Engineering discipline.

The lecturer acts as facilitator in the GEBL process. For each learning area, the lecturer first introduces the topic/s and related concepts in the class. Following this session the students are expected to have a basic understanding of the topic/s and key concepts covered. Two or three problems are solved in the class covering the topic/s introduced. During this exercise, students are expected to do a step-by-step analysis of the problem and suggest solutions. The lecturer assists the students during this process but students are expected to take the lead role in the analysis. Students are allowed to interact with each other during this process. Students are also allowed to work in groups if the problem is complex.

The next step involves students working in pairs or groups to discuss the topic/s introduced during the beginning of the session. After this discussion, students are expected to have developed a deeper understanding of the topic/s covered. They are then expected to carry out individual research to gather more information on the topic/s using various resources including books and articles from the library as well as multi-media resources from the internet. The students then meet in pairs or in their groups to discuss the topics once again. Here they share information and ideas acquired through individual research on the topic. During this session students help each other develop a clearer understanding of the topic. Students clarify any doubt with peers and consolidate the topics learned. The lecturer is present in the class during this group session and is actively listening to the discussion and correcting them if required. Students are allowed to ask doubts to the lecturer during this discussion and the lecturer guides them to the correct understanding of the topic.

To make sure that all students have a clear understanding of the topic/s, in the next step - students are required to write a summary of the topic/s learned. This individual submission gives an indication of the depth in understanding of the topics and also helps the students to synthesise the topic/s learned. Each student then prepares a powerpoint presentation to present the topic/s in front of the class. Due to time constraints the lecturer randomly chooses one or two students to do the presentation. At the end of the presentation, other students are allowed to ask questions and the presenter clarifies the doubts. The lecturer also fills the gap as required. Formative assessments constantly provide feedback of student progress in the learning process. A summative assessment at the end of the course measures student competency and evaluates student learning to determine progression to further studies.

The researcher found this process to be very effective during the course of this study. Apart from enabling effective teaching and learning of the topic/s, it was observed that this process helped in improving communication skills, writing skills and presentation skills of students. Students appeared to be more confident and willing to share information with each other thus helping each other learn in the process.

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LIST OF APPENDICES

APPENDIX A – ETHICAL CLEARANCE CERTIFICATE

University of Fort Hare
Together in Excellence

ETHICAL CLEARANCE CERTIFICATE
REC-270710-028-RA Level 01

Certificate Reference Number:	MAM091SKUM01
Project title:	**Guided Enquiry Based Learning (GEBL) strategy, Gender and Critical Thinking Skills as determinants of National Diploma Engineering students' academic achievement in Power Electronics.**
Nature of Project:	PhD
Principal Researcher:	Vinod Kumar
Sub-Investigator:	
Supervisor:	Prof K.J Mammen
Co-supervisor:	

On behalf of the University of Fort Hare's Research Ethics Committee (UREC) I hereby give ethical approval in respect of the undertakings contained in the above-mentioned project and research instrument(s). Should any other instruments be used, these require separate authorization. The Researcher may therefore commence with the research as from the date of this certificate, using the reference number indicated above.

Please note that the UREC must be informed immediately of

- Any material change in the conditions or undertakings mentioned in the document
- Any material breaches of ethical undertakings or events that impact upon the ethical conduct of the research

The Principal Researcher must report to the UREC in the prescribed format, where applicable, annually, and at the end of the project, in respect of ethical compliance.

Special conditions: Research that includes children as per the official regulations of the act must take the following into account:

Note: The UREC is aware of the provisions of s71 of the National Health Act 61 of 2003 and that matters pertaining to obtaining the Minister's consent are under discussion and remain unresolved. Nonetheless, as was decided at a meeting between the National Health Research Ethics Committee and stakeholders on 6 June 2013, university ethics committees may continue to grant ethical clearance for research involving children without the Minister's consent, provided that the prescripts of the previous rules have been met. This certificate is granted in terms of this agreement.

The UREC retains the right to

- Withdraw or amend this Ethical Clearance Certificate if
    - Any unethical principal or practices are revealed or suspected
    - Relevant information has been withheld or misrepresented
    - Regulatory changes of whatsoever nature so require
    - The conditions contained in the Certificate have not been adhered to

- Request access to any information or data at any time during the course or after completion of the project.

- In addition to the need to comply with the highest level of ethical conduct principle investigators must report back annually as an evaluation and monitoring mechanism on the progress being made by the research. Such a report must be sent to the Dean of Research's office

The Ethics Committee wished you well in your research.

Yours sincerely

Professor Gideon de Wet
Dean of Research

10 March 2016

APPENDIX B – PERMISSION LETTER

DIVISION OF ACADEMIC AFFAIRS AND RESEARCH
DIRECTORATE OF RESEARCH DEVELOPMENT

Nelson Mandela Drive
Mthatha Campus
Private Bag X1
MTHATHA 5117
Tel: + 27 47 502 2947/2647
Fax: +27 47 502 2185

Web Fax: 0866 541 093
E-mail: ecishe@wsu.ac.za
bandlac@gmail.com

Buffalo City
Potsdam Campus
EAST LONDON
Tel: + 43 708 5444
Fax: + 43 708 5458

5 September 2016

Mr Vinod Kumar
University of Fort Hare
South Africa

Dear Sir

Re: Request to conduct a Research stud

Permission is hereby granted for the study entitled **Guided Enquiry based learning strategy, gender and critical thinking skills as determinants of national diploma engineering students academic achievement in power electronics"** provided that copies of your completed study will be submitted to the Campus Rector of the campus in which the study will be conducted and the Research, Innovation and Development Directorate.

Regards

Dr. E.N. Cishe
Acting Director: Research Development

Identity masked for ethical purposes

APPENDIX C – FORMATIVE ASSESSMENT 1 (SEMESTER TEST 1)

SUBJECT	**: Industrial Electronics II**
SUBJECT CODE	**: INDE2B0**
QUALIFICATION	**: ND: Engineering: Electrical**
EXAMINERS	**:**
DURATION	**: 90 Minutes**
FULL MARKS	**: 50 Marks**
NUMBER OF PAGES	**: 3 Pages (Including the cover)**
INSTRUCTIONS	**: Answer all questions**

EXAMINATION RULES ARE NOW IN EFFECT.

DO NOT TURN THE PAGE BEFORE BEING TOLD TO DO SO.

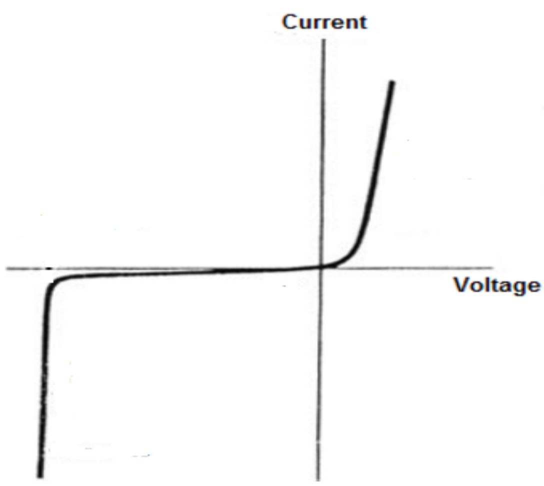
Q.1 For the diode characteristics curve indicate the following (on the question paper):

a) Knee Voltage [0.5]

b) Forward Region [0.5]

c) Reverse Breakdown voltage [0.5]

Briefly explain the above three [4.5]



Q.2

a. Explain the working of an uncontrolled Center-tap Full wave rectifier. [4]

b. Draw the output waveforms for this rectifier. [2]

c. Derive the equation for average voltage and average current for the above rectifier. [4]

Q.3 By deriving a mathematical expression for each, show that the full-wave diode rectifier is more efficient than the half-wave rectifier [6]

Q.4

a. What is PIV? Why is PIV an important consideration in diodes? [3]

b. Compare the PIV for diodes used in half wave rectifier and full wave rectifier. Which diodes should have the higher PIV and why? [4]

Q.5

a. What is the difference between controlled and uncontrolled rectifiers [3]

b. Which of the above rectifiers can be used to control the power delivered to the load. Explain your choice. [3]

Q. 6 You are required to build an efficient and cost effective DC power supply for practical purposes.

a. Which uncontrolled rectifier will you choose and why? [4]

b. Draw the circuit of the rectifier that you would choose for the design of your power supply. [3]

c. Explain the benefits of using the rectifier of your choice over other rectifiers [3]

Q.7 A center tapped diode rectifier with a purely resistive load R = 20Ω and V_s = 400 sin 314t and unity transformer ratio. Determine

a) The efficiency

b) Ripple factor

c) The peak inverse voltage of each diode

[5]

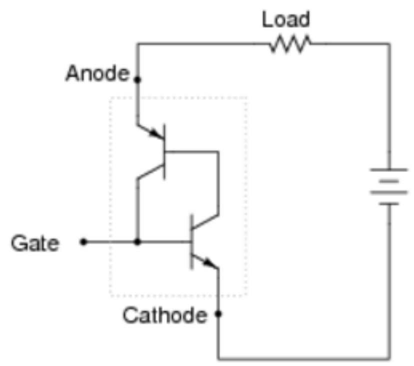
APPENDIX D – FORMATIVE ASSESSMENT 2 (SEMESTER TEST 2)

SUBJECT	**: Industrial Electronics II**
SUBJECT CODE	**: INDE2B0**
QUALIFICATION	**: ND: Engineering: Electrical**
EXAMINERS	**:**
DURATION	**: 90 Minutes**
FULL MARKS	**: 50 Marks**
NUMBER OF PAGES	**: 3 Pages (Including the cover)**
INSTRUCTIONS	**: Answer all question**

EXAMINATION RULES ARE NOW IN EFFECT.

DO NOT TURN THE PAGE BEFORE BEING TOLD TO DO SO.

Q.1 Silicon-controlled rectifiers (SCRs) may be modeled by the following transistor circuit. Explain how this circuit functions, in the presence of and absence of a “triggering” voltage pulse at the gate terminal: (4)



Q.2 Explain three different ways that an SCR may be triggered into its “on” (conducting) state

(6)

Q.3 What is the difference between AC voltage regulators and cycloconverters? (4)

Q.4

4.1 What is a crowbar thyristor? (2)

4.2 How is an electronic crowbar circuit used for overcurrent protection? Explain the operation of the circuit. (4)

Q.5 In an SCR half wave rectifier circuit, what peak load current will occur if we measure an average

DC load current of 1A at a firing angle of 30^0? (3)

Q. 6 For an SCR:

6.1 Draw the characteristics curve of an SCR for gate current I_G when $I_G = 0$ (2)

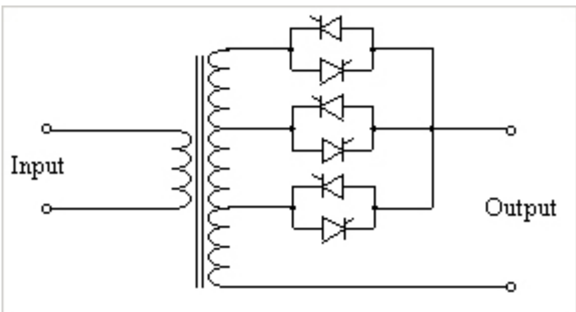
6.2 If $I_{G3} > I_{G2} > I_{G1}$ show how the characteristics curve will change with I_{G1}, I_{G2} and I_{G3} (2)

Q.7 Explain the following operational mode for a D-MOSFET

7.1 Depletion Mode (4)

7.2 Enhancement Mode (4)

Q.8 Draw the output waveform for the Electronic Tap Changer shown below:



(5)

Q.9 For an SCR, with the help of a waveform, explain how the power delivered to the load

can be varied by using phase angle control (4)

Q. 10 A bidirectional ac voltage controller has a resistive load of R = 10 Ω and the root mean square

(rms) input voltage is V_s = 120 V, 60 Hz. The thyristors switch is on for n = 25 cycles and is off for m = 75 cycles. Determine

a) The duty cycle (1)
b) The rms output voltage (2)
c) The rms load current (1)
d) The input power factor (PF) (2)

APPENDIX E – SUMMATIVE ASSESSMENT (MAIN EXAMINATION PAPER)

JUNE 2017

SUBJECT	**: Industrial Electronics II**
SUBJECT CODE	**: INDE2P0/INDE2B0**
QUALIFICATION	**: ND: Engineering: Electrical**
EXAMINERS	**:**
MODERATOR	**:**
DURATION	**: 3 Hours**
FULL MARKS	**: 100 Marks**
NUMBER OF PAGES	**: 4 Pages (Including the cover)**
INSTRUCTIONS	**: Answer all questions**

EXAMINATION RULES ARE NOW IN EFFECT.

DO NOT TURN THE PAGE BEFORE BEING TOLD TO DO SO.

QUESTION 1 **[13]**

1.1 a) For an n-channel enhanced MOSFET, carefully explain the requirements to switch the component ON and OFF: (2)

b) Draw and label the circuit diagram symbol of the component. Explain or indicate the logic behind the chosen circuit diagram. (3)

c) What is the voltage biasing requirement before switching the component? (1)

d) What are other steps involved in switching the device ON and keeping it ON? Motivate. (3)

e) Does the current also determine whether this component is ON? Explain. (2)

f) Explain carefully how this device is switched OFF and kept OFF. (2)

g) Is this component voltage controlled or current controlled? Motivate. (2)

QUESTION 2 **[20]**

2.1 (a) Draw the characteristic curves of an ideal diode as well as a real diode on one set of axes. Label the axes and indicate important regions. (2)

(b) List 4 differences between an ideal diode and a real diode (4)

(c) Draw a diode's reverse recovery graph, indicate t_a, t_b, t_{rr} and I_{rr}. Softness factor S.F = t_b / t_a. Approximate the graph as a triangle, and prove the following mathematically, clearly stating any assumptions! $I_{RR} = 2Q_{RR}/t_{rr}$ (4)

2.2 The rectifier shown in Figure 2.2 is operated from $480V/50Hz$ supply and the load resistance is $R = 100\Omega$. If the source inductance is negligible.

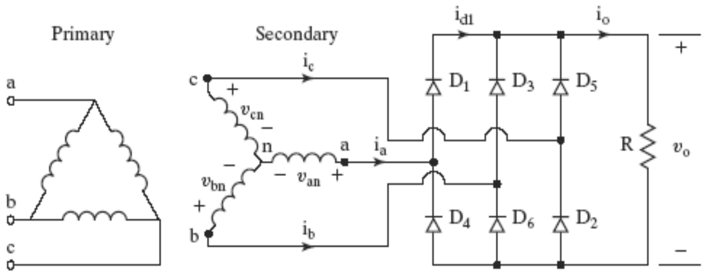


FIGURE 2.2: Three-phase full wave diode bridge rectifier

2.2.1 Determine the efficiency (7)

2.2.2 Determine the Form factor (1)

2.2.3 Determine the Ripple factor (1)

2.2.4 Determine the Peak inverse voltage (PIV) of each diode. (1)

QUESTION 3 **[14]**

3.1 Consider a single-phase full-wave rectifier below in Figure 3.1, which has a resistive load of $R = 30\Omega$ and, $V_s = 240\sin 314t$ and unity transformer ratio. If it is required to obtain an average output voltage of 70% of the maximum possible output voltage.

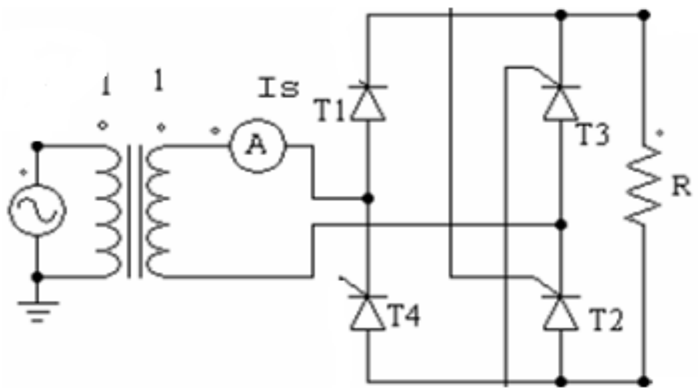


Figure 3.1: Single-phase fully controlled Rectifier Bridge with resistive load

3.1.1 Draw the output voltage and current waveform of the circuit provided below. (2)

3.1.2 Calculate the delay angle α (2)

3.1.3 Calculate the efficiency, (7)

3.1.4 Calculate ripple factor of output voltage (2)

3.1.5 Calculate the peak inverse voltage (PIV) of one thyristor (1)

QUESTION 4 **[19]**

4.1 The DC chopper has a resistive load of $R = 50\Omega$ and input voltage is $V_s = 280V$. When the chopper switch remains on its voltage drop, $V_d = 4V$, duty cycle, $D = 50\%$ and the chopping frequency is $f = 1.5kHz$. Determine:

4.1.1 The average output voltage, (1)

4.1.2 The rms output voltage (3)

4.1.3 Chopper efficiency. (3)

4.2 With the aid of circuit diagram and switching waveforms for one cycle of a step-up (boost) DC converter describe the operating principle of this switching converter type. (4)

4.3 The dc-dc converter has input voltage $V_{in} = 10V$. The required output voltage is $V_{out} = 35V$ and the average load current $I_{av} = 0.8A$. If the switching frequency $f = 25kHz$, $L = 250\mu H$ and $C = 100nF$. Determine:

4.3.1 The duty cycle D (2)

4.3.2 The ripple current of inductor ΔI (2)

4.3.3 The peak current of inductor I_2 (3)

4.3.4 The ripple voltage of filter capacitor ΔV. (2)

QUESTION 5 **[35]**

5.1 The Snubber Circuit for a Thyristor Circuit has an input voltage $V_s = 220V$, with load resistance of $R = 10\Omega$. The load and stray inductances are negligible and the thyristor is operated at the frequency of $f_s = 5kHz$. If the required dv/dt dv/dt is $100V/\mu s$ and the discharge current is to be limited to $100A$.

5.1.1 Draw the above circuit. (4)

5.1.2 Determine the values of R_s and C_s. (7)

5.1.3 Determine the snubber loss. (1)

5.1.4 Determine the power rating of the snubber resistor. (1)

5.2 Draw a typical characteristics i vs v curve for a thyristor. Label the axes clearly.(3)

5.2.1 Carefully explain, referring to the graph drawn in 5.2, why a thyristor can block voltage in both directions. (2)

5.2.2 Carefully explain with the help of the graph drawn in 5.2, what the requirements are for a thyristor to switch from OFF to ON in the first quadrant. (2)

5.2.3 Carefully explain with the help of the graph drawn in 5.2, what are the requirements for a thyristor to switch from ON to OFF in the first quadrant. (2)

5.3 This crowbar circuit has a problem. It used to work just fine, and then one day it blew the fuse. Upon replacing the fuse, the new fuse immediately blew:

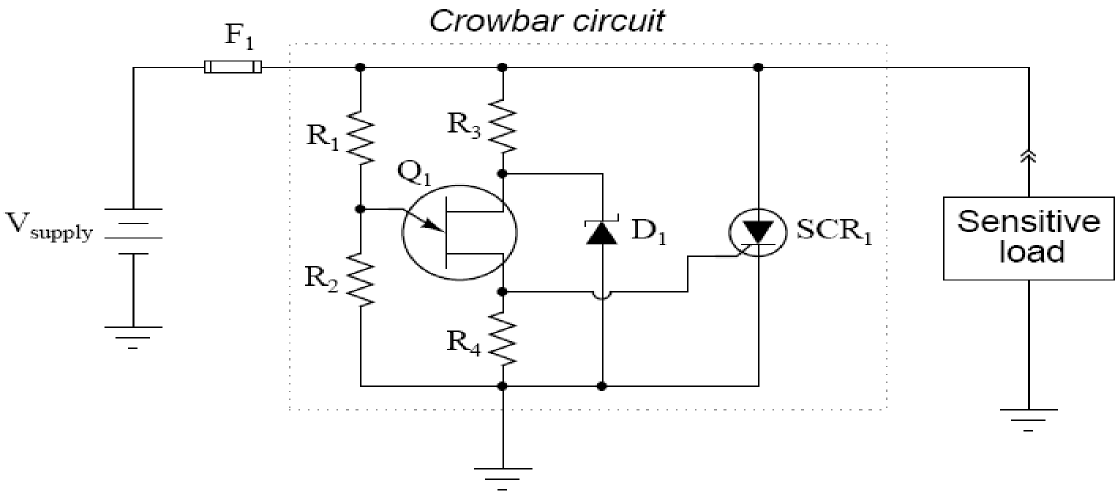


Figure 5.3 Crowbar circuit

Measuring the supply voltage with a voltmeter, everything checks out well. There does not appear to be an over voltage condition causing a legitimate “crowbar” event in the circuit. Disconnecting the load from the crowbar circuit and powering it up with a standard bench-top laboratory power supply reveals the load to be in perfect condition. Thus, both the source and the load have been eliminated as possibilities that may have blown the fuse(s). Moving on to the crowbar circuit itself, identify some component faults that could (each, independently) account for the problem, and explain your reasoning. (6)

Total Marks: [102] **Full Marks: [100]**

SUMMATIVE ASSESSMENT: MEMORANDUM

MEMORANDUM
MAIN JUNE 2017

SUBJECT	**: Industrial Electronics II**
SUBJECT CODE	**: INDE 2/0**
QUALIFICATION	**: ND: Engineering: Electrical**
EXAMINER/S	**:**
MODERATOR	**:**
DURATION	**: 3 Hours**
FULL MARKS	**: 100 Marks**
NUMBER OF PAGES	**: 11 Pages**

I HAVE MODERATED THIS MEMORANDUM AND QUESTION PAPER; COMMENTS ARE AS PER THE MODERATORS REPORT.

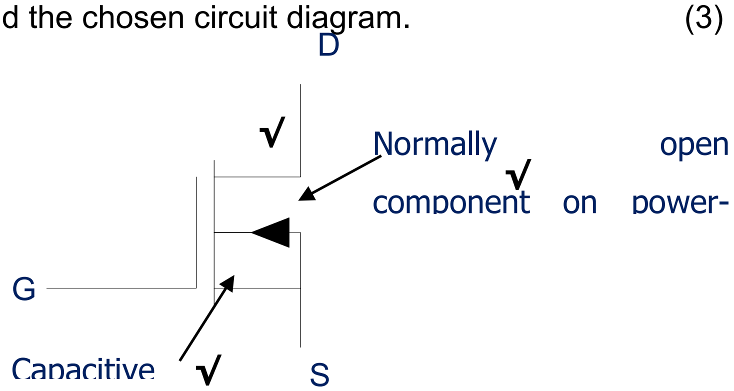
MODERATOR: ____________________________ **DATE:** _____

QUESTION 1 **[13]**

1.2 a) For an n-channel enhanced MOSFET, carefully explain the requirements to switch the component ON and OFF: (2)

a) To use a MOSFET as a switch, you have to have its gate voltage (Vgs) higher than the source. If you connect the gate to the source (Vgs=0) it is turned off.

b) Draw and label the circuit diagram symbol of the component. Explain or indicate the logic behind the chosen circuit diagram. (3)



c) What is the voltage biasing requirement before switching the component? (1)

$V_D > V_S$ for power current to flow down √

d) What are other steps involved in switching the device ON and keeping it ON? Motivate (3)

Now apply $V_{GS} > V_{GSTHRESHOLD}$ √

Typically between 5V and 15V √

Gate should be kept at this voltage to keep component on √

e) Does the current also determine whether this component is ON? Explain √ (2)

Yes,√ enough current has to flow, into gate to change capacitive gate

f) Explain carefully how this device is switched OFF and kept OFF (2)

Empty or discharge gate by removing V_{GS} (or setting it to zero volts) and providing parallel discharge path to help, i.e. 100Ω to earth √√

g) Is this component voltage controlled or current controlled? Motivate (2)

The component is voltage controlled, although current plays a role. Gate voltage vs output current are linearly related. √ √

QUESTION 2

2.3 (a) Draw the characteristic curves of an ideal diode as well as a real diode on one set of axes. Label the axes and indicate important regions. (2)

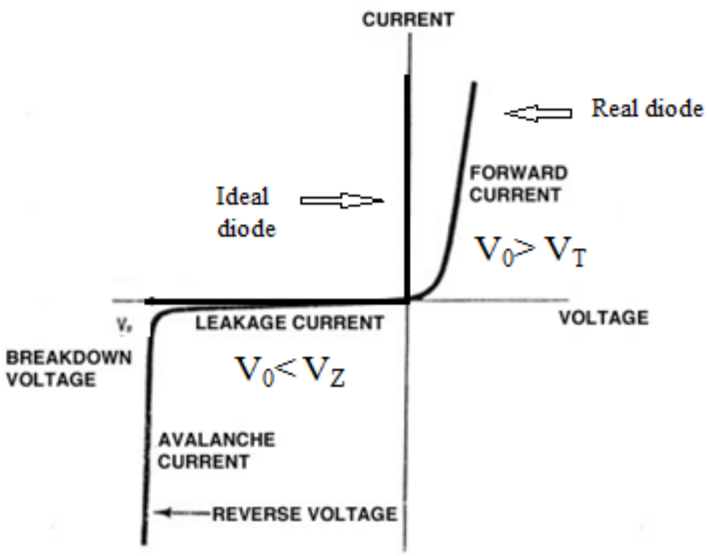
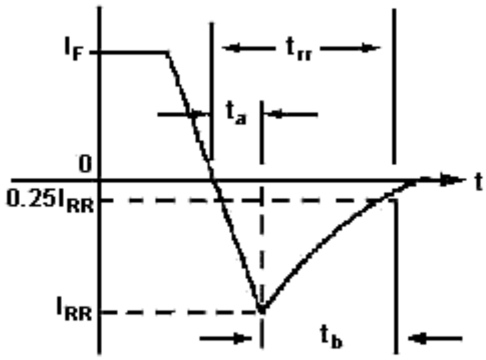


Figure 2.1(a): Ideal diode vs Real diode

(d) List 4 differences between an ideal diode and a real diode (4)

Ideal diode	Real diode
NO R_{ON}	R_{ON} – wasted power
NO V_{ON}	$V_{ON} \approx 1V$ and/or more
NO I_{LEAK}	Small I_{leak} when off
NO V_{BR}	Breaks down at - V_{BR}

(e) Draw a diode's reverse recovery graph, indicate t_a, t_b, t_{rr} and I_{rr}. Softness factor S.F = t_b / t_a. Approximate the graph as a triangle, and prove the following mathematically, clearly stating any assumptions! $I_{RR} = 2Q_{RR}/t_{rr}$. (4)



√√

Figure 2.1(b): Diode's reverse recovery graph

$$Q_{RR} = Area\ under\ \Delta = \frac{1}{2}\ b\ .h\surd$$

$$= \frac{1}{2} \cdot t_{rr} \times I_{RR}$$

$$\therefore\ I_{RR} = 2\frac{Q_{RR}}{t_{RR}} \checkmark$$

2.2 The rectifier shown in Figure 2.2 is operated from $480V/50Hz$ supply and the load resistance is $R = 100\Omega$. If the source inductance is negligible.

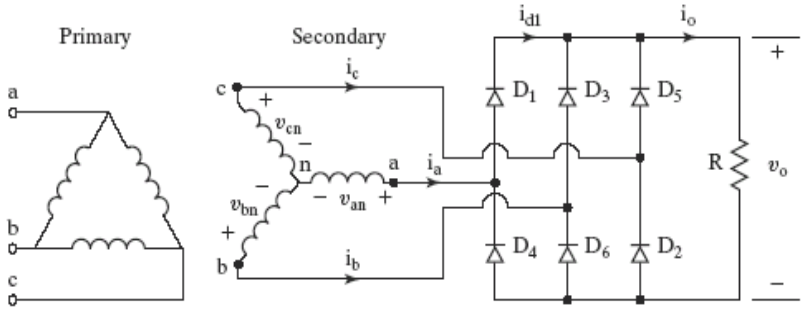


FIGURE 2.2: Three-phase full wave diode bridge rectifier

2.2.1 Determine the efficiency (7)

$$V_S = \frac{480V}{\sqrt{3}} = 277.128V \checkmark$$

$$V_m = 277.128 \times \sqrt{2} = 398.918V \checkmark$$

$$V_{dc} = \frac{3}{\pi}\int_{\pi/3}^{2\pi/3} \sqrt{3}V_m \sin\omega t\, d\omega t = \frac{3\sqrt{3}V_m}{\pi} = \frac{3\sqrt{3}}{\pi} = 1.654V_m = 659.810V \checkmark$$

$$I_{dc} = \frac{3\sqrt{3}V_m}{\pi R} = \frac{1.654V_m}{100} = 6.598A \checkmark$$

$$V_{rms} = \sqrt{\frac{3}{\pi}\int_{\pi/3}^{2\pi/3}\left(\sqrt{3}V_m\right)^2 d\omega t} = \sqrt{\frac{3}{2} + \frac{9\times\sqrt{3}}{4\times\pi}}V_m = \sqrt{\frac{3}{2} + \frac{9\times\sqrt{3}}{4\times\pi}} =$$

$$= 1.6554V_m$$

$$= 1.6554 \times 398.918$$

$$= 660.369V \checkmark$$

$$I_{rms} = \frac{1.6554V_m}{R} = \frac{1.6554 \times 398.918}{100} = 6.604A \checkmark$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc}I_{dc}}{V_{rms}I_{rms}} = \frac{659.810 \times 6.598}{660.369 \times 6.604} = 99.825\% \checkmark$$

2.2.2 Determine the Form factor (1)

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{660.369}{659.810} = 100.085\% \checkmark$$

2.2.3 Determine the Ripple factor (1)

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}^2} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{100.085^2 - 1} = 4.12\% \checkmark$$

2.3 Determine the Peak inverse voltage (PIV) of each diode. (1)

$$PIV = \sqrt{3}V_m = \sqrt{3} \times 398.918 = 690.946V \checkmark$$

QUESTION 3 **[14]**

3.1 Consider a single-phase full-wave rectifier below in Figure 3.1, which has a resistive load of $R = 30\Omega$ and, $V_s = 240\sin 314t$ and unity transformer ratio. If it is required to obtain an average output voltage of 70% of the maximum possible output voltage.

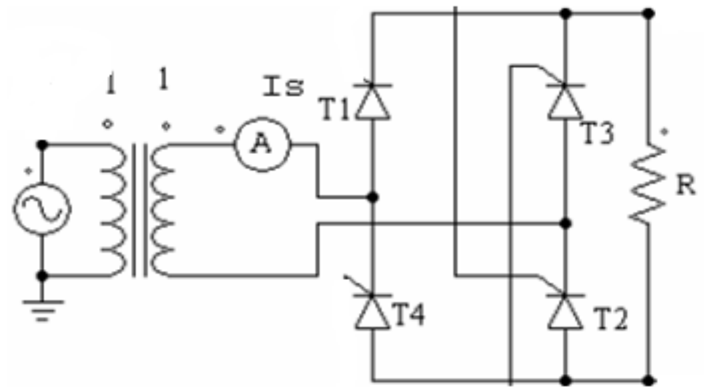
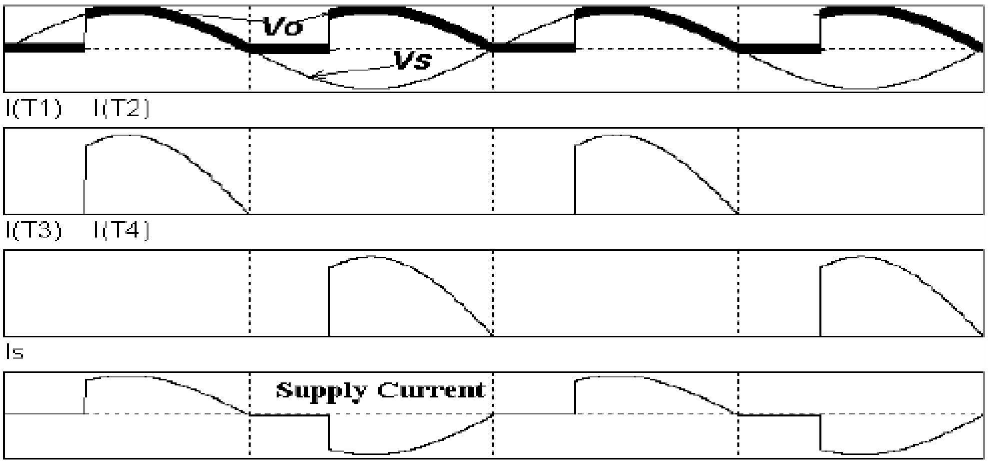


Figure 3.1: Single-phase fully controlled Rectifier Bridge with resistive load

3.1.1 Draw the output voltage and current waveform of the circuit provided below. (2)



3.1.2 Calculate the delay angle α

V_{dm} is the maximum output voltage and can be achieved when $\alpha = 0$

$$V_n = \frac{V_{dc}}{V_{dm}} = 0.5(1+\cos\alpha) = 0.7$$

$$1+\cos\alpha = \frac{0.7}{0.5}$$

$$\cos\alpha = \frac{0.7}{0.5} - 1$$
$$= 1.4 - 1$$
$$= 0.4$$

$$\therefore \alpha = \cos^{-1}(0.4)$$
$$= 66.42^\circ$$

$$or\ \alpha = 1.159 rad$$

3.1.3 Calculate the efficiency,

$$V_m = 240V,\ V_{dc} = 0.7 \times V_{dm} = 0.7 \times \frac{2V_m}{\pi} = 106.95V$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{106.95V}{30} = 3.565A$$

$$V_{rms} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{\sin(2\alpha)}{2}}$$

$$at\ \alpha = 1.159 rad$$

$$V_{rms} = \frac{240V}{\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{\sin(2\alpha)}{2}}$$
$$= \frac{240V}{\sqrt{2\pi}}\sqrt{\pi - 1.159 + \frac{\sin(2\times 1.159)}{2}}$$
$$= 95.746\sqrt{2.349}$$
$$= 146.74V$$

$$I_{rms} = \frac{V_{rms}}{R} = \frac{146.74V}{30\Omega} = 4.891A$$

$$V_s = \frac{V_m}{\sqrt{2}} = \frac{240V}{\sqrt{2}} = 169.71V$$

The value of the transformer secondary current is $I_s = I_{rms} = 4.89A$

Then, the rectification efficiency is

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc}\times I_{dc}}{V_{rms}\times I_{rms}} = \frac{106.95\times 3.565}{146.74\times 4.891} = \frac{381.276}{717.71} = 53.12\%$$

3.1.4 Calculate ripple factor of output voltage

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{146.74}{106.95} = 1.372$$

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.372^2 - 1} = 0.939$$

3.1.5 Calculate the peak inverse voltage (PIV) of one thyristor

The $PIV\ is\ V_m = 240V$

QUESTION 4 **[19]**

4.1 The DC chopper has a resistive load of $R = 50\Omega$ and input voltage is $V_s = 280V$. When the chopper switch remains on its voltage drop, $V_d = 4V$, duty cycle, $D = 50\%$ and the chopping frequency is $f = 1.5kHz$. Determine:

4.1.1 The average output voltage,

(1)

$$V_0 = DV_s$$
$$= 0.5 \times 280V$$
$$= 140V \ \checkmark$$

4.1.2 The rms output voltage (3)

$$V_L = \left(\frac{1}{2} \int_0^{D_T} V_s^2 dt \right)^{1/2} \checkmark$$
$$= \sqrt{D} V_s \ \checkmark$$
$$= 0.5^{1/2} \times (280 - 4)$$
$$= 0.707 \times 276$$
$$= 195.132V \checkmark$$

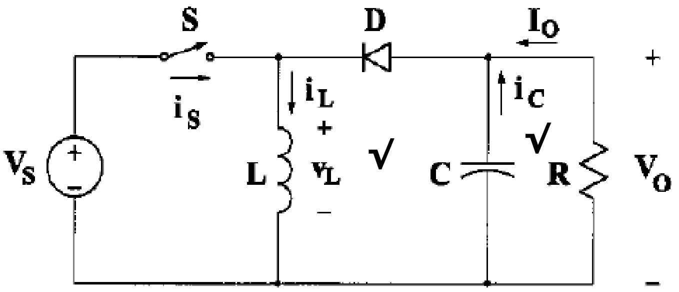
4.1.3 Chopper efficiency. (3)

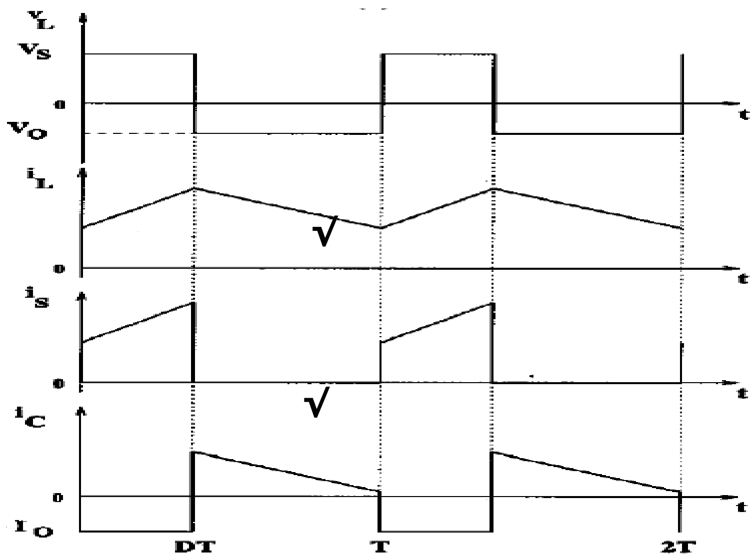
$$P_{out} = \frac{1}{T} \int_0^{D_T} (V_s - V_d) \frac{V_s - V_d}{R} dt = D \frac{(V_s - V_d)^2}{R}$$
$$= 0.5 \times \frac{(280 - 4)^2}{50}$$
$$= 761.8W \checkmark$$

$$P_{in} = \frac{1}{T} \int_0^{D_T} V_s \frac{V_s}{R} = D \frac{V_s^2}{R} = 0.5 \frac{(280)^2}{50}$$
$$= 784W \ \checkmark$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{761.8}{784} = 97.2\% \ \checkmark$$

4.2 With the aid of circuit diagram and switching waveforms for one cycle of a step-up (boost) DC converter describe the operating principle of this switching converter type. (4)





4.3 The dc-dc converter has input voltage $V_{in} = 10V$. The required output voltage is $V_{out} = 35V$ and the average load current $I_{av} = 0.8A$. If the switching frequency $f = 25kHz$, $L = 250\mu H$ and $C = 100nF$. Determine:

4.3.1 The duty cycle D (2)

$$V_{out} = \frac{V_{in}}{1-D}$$

$$35 = \frac{10}{1-D}$$

$$35(1-D) = 10$$

$$D = 1 - \left(\frac{10}{35}\right)$$

$$= 1 - 0.286$$

$$= 0.714$$

4.3.2 The ripple current of inductor ΔI (2)

$$\Delta I = \frac{V_{in}(V_{out} - V_{in})}{LV_{out}f}$$

$$= \frac{10(35-10)}{250\times10^{-6}\times25\times10^{3}\times35}$$

$$= 1.143A$$

4.3.3 The peak current of inductor I_2 (3)

$$I_s = \frac{I_{av}}{1-D}$$ √
$$= \frac{0.8}{1-0.714}$$
$$= 2.8A$$ √

$$I_2 = I_s + \frac{\Delta I}{2}$$
$$= 2.8 + \frac{1.143}{2}$$
$$= 3.372A$$ √

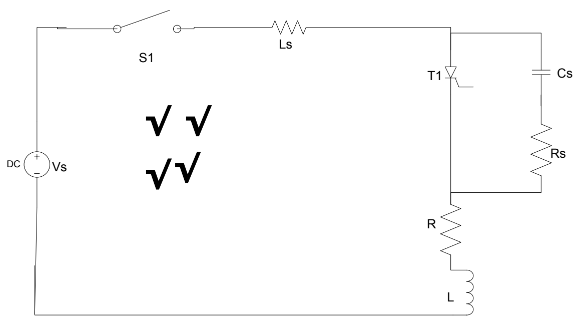
4.3.4 The ripple voltage of filter capacitor ΔV . (2)

$$\Delta V_c = \frac{I_{av} D}{fC} = \frac{0.8 \times 0.714}{25 \times 10^3 \times 100 \times 10^{-6}} = 228.5mV$$ √√

QUESTION 5 **[35]**

5.1 The Snubber Circuit for a Thyristor Circuit has an input voltage $V_s = 220V$, with load resistance of $R = 10\Omega$. The load and stray inductances are negligible and the thyristor is operated at the frequency of $f_s = 5kHz$. If the required dv/dt is $100V/\mu s$ and the discharge current is to be limited to $100A$.

5.1.1 Draw the above circuit (4)



5.1.2 Determine the values of R_s and C_s (7)

Given is the following; $dv/dt = 100V/\mu s$, $I_{DT} = 100A$, $R = 100\Omega$, $L = L_s = 0$ and $V_s = 220V$

The charging current of the snubber capacitor can be expressed as,

$$V_s = (R_s + R)i + \frac{1}{C_s}\int i\,dt + V_c(t=0)$$ √

With initial condition $V_c(t=0) = 0$, then the charging current is found as

$$i(t) = \frac{V_s}{R_s + R} e^{-t/\tau}$$ √

Where $\tau = (R_s + R)C_s$ The forward voltage across the thyristor is

$$V_T(t) = V_s - \frac{RV_s}{R_s + R} e^{-t/\tau}$$ √

√

At $t = 0$, $V_T(0) = V_s = RV_s/(R_s + R)$ and at $t = \tau$, $V_T(\tau) = V_s - 0.368RV_s/(R_s + R)$: √

$$\frac{dv}{dt} = \frac{V_T(\tau) - V_T(0)}{\tau} = \frac{0.632RV_s}{C_s(R_s + R)^2}$$ √

Applying the following Equation $R_s = \frac{V_s}{I_{TD}} = \frac{220}{100} = 2.2\Omega$ √

Therefore $C_s = \frac{0.632 \times 10 \times 220 \times 10^{-6}}{(2.2 + 10)^2 \times 100} = 0.0933\mu F$ √

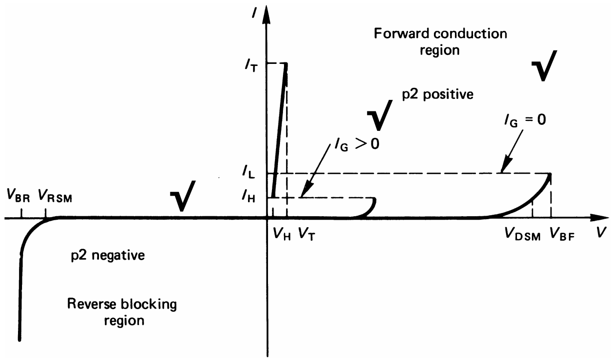
5.1.3 Determine the snubber loss (1)

$$P_s = 0.5C_s V_s^2 f_s = 0.5 \times 0.0933 \times 10^{-6} \times 220^2 \times 5000 = 11.3W$$ √

5.1.4 Determine the power rating of the snubber resistor (1)

Assuming that all the energy stored in C_s is dissipated in R_s only, then the power rating of the snubber resistor is $11.3W$ √

5.2 Draw a typical characteristics i vs v curve for a thyristor. Label the axes clearly (3)



5.2.1 Carefully explain, referring to the graph drawn in 5.2, why a thyristor can both (2)

 √

A SCR blocks even in the forward direction until fired

Switches ON when fired, and I is reached √

5.2.2 Carefully explain with the help of the graph drawn in 5.2, what the requirements are for a thyristor to switch from OFF to ON in the first quadrant (2)

Forward biased $V > 0$ √

Pulse (current) into gate with respect to cathode

Series I needs to reach minimum of I_L √

5.2.3 Carefully explain with the help of the graph drawn in 5.2, what are the requirements for a thyristor to switch from ON to OFF in the first quadrant (2)

I needs to drop below I_H, and it has nothing to do V √

Therefore load current needs to below I_H or extra circuitry, that is a freewheeling diode and forced commutation √

5.3 This crowbar circuit has a problem. It used to work just fine, and then one day it blew the fuse. Upon replacing the fuse, the new fuse immediately blew:

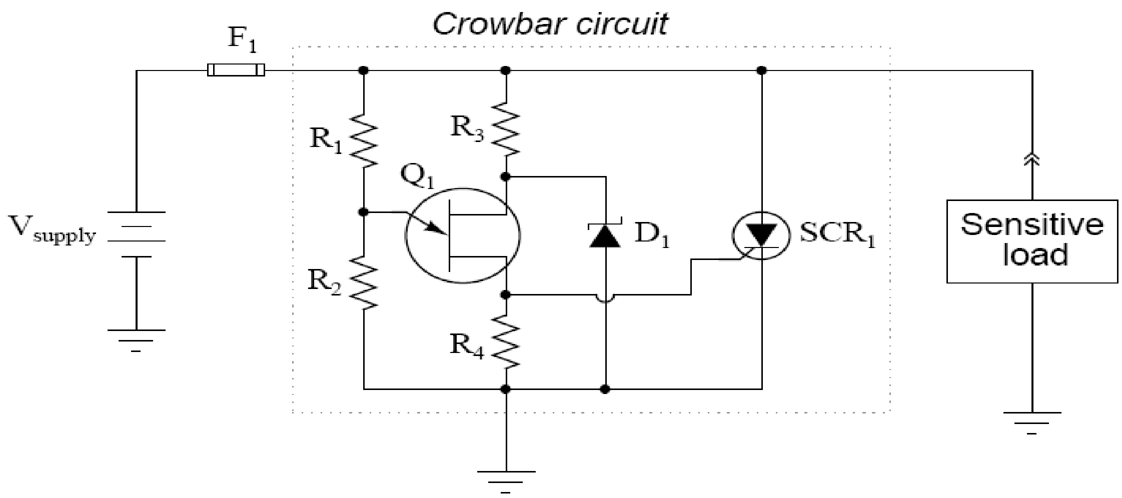


Figure 5.3 Crowbar circuit

Measuring the supply voltage with a voltmeter, everything checks out well. There does not appear to be an over voltage condition causing a legitimate "crowbar" event in the circuit. Disconnecting the load from the crowbar circuit and powering it up with a standard bench-top laboratory power supply reveals the load to be in perfect condition. Thus, both the source and the load have been eliminated as

possibilities that may have blown the fuse(s). Moving on to the crowbar circuit itself, identify some component faults that could (each, independently) account for the problem, and explain your reasoning.
(6)

Possible faults (not an exhaustive list)

- SCR failed shorted √
- Zener diode failed shorted √
- R1 failed shorted √
- R2 failed open √
- R4 failed open (especially if SCR is a sensitive-gate type)√
- UJT Q1 failed shorted between base terminals √

Total Marks: [102] **Full Marks: [100]**

APPENDIX F - INTERVIEW SCHEDULE GRID

Items	Follow-up	
1. Did GEBL sessions help you to connect prior knowledge to the current topic	a) If yes, explain how GEBL sessions helped to connect prior knowledge to the new topics learned in the course b) Did group sessions require you to discuss prior knowledge in Electrical Engineering and Electronics related to the current topic?	a) If no, explain why not b) Did group sessions not require you to discuss prior knowledge from pre-requisite subjects
2. Did GEBL sessions help you to understand the topics	a) If yes, explain how GEBL sessions helped in understanding the subject content b) Was this understanding because of the different approach you used in this course? c) Did sharing of information with other group members make understanding a topic easier?	a) If no, explain why not b) Which topics did you not understand? c) What do you think made it difficult to understand the topics? d) Do you think the traditional teaching method helps in better understanding of the topics?
3. GEBL sessions help you to bring about understanding of the concepts of PE	a) If yes, explain how GEBL sessions helped in understanding the concepts b) Did GEBL sessions require you to think more about the topics covered?	a) If no, explain why not b) Which concepts did you not understand? c) What teaching method would have helped you in understanding the concepts better? d) Did you go to the group session prepared for the topics to be discussed?

		e) Did the group sessions not help in understanding the concepts through discussion?
4. Did GEBL sessions help you to understand the topics in depth	a) If yes, explain how GEBL sessions help to understand the topics in depth? b) Did group sessions encourage you to come prepared for the class? c) Did coming to the class with some knowledge of the topic and further discussion with group members about the same topic help you to understand the topics in depth? d) Did asking questions to group members, help you in a deeper understanding of the topic?	a) If no, explain why not b) Which topics did you not understand in depth? c) What could have been done to make you understand the topics in depth?
5. Did GEBL sessions help you to recall the topics learned	a) If yes, explain how GEBL sessions helped you to recall the topics? b) Did having a good understanding about the topic help to recall the topics c) Do you think it helped	a) If no, explain why not b) Which topics did you particularly find difficult to recall? c) Why did you find it difficult to recall those topics?
6. Did GEBL sessions help you to analyse the problems effectively	a) If yes, explain how the group sessions helped you in analysing the problems b) What exactly about the GEBL sessions helped you to analyse the problems effectively?	a) If no, explain why not b) What can be done to help you analyse the problem effectively?

	c) Did GEBL sessions help you to interpret the problems effectivel	
7. Did GEBL sessions help you to think critically when a problem was given	a) If yes, explain b) Did group sessions help you in improving your thinking skills? c) Did group sessions help you in comprehending a problem? d) Did group sessions help in determining the key parameters in a problem?	a) If no, explain why not b) Were group sessions not helpful in improving your thinking skills c) Were group sessions not helpful in enhancing your ability to interpret a problem?
8. Did GEBL approach motivate you to come to class	a) If yes, explain b) Did group sessions give you a positive attitude towards the course?	a) If no, explain why not b) Did working in a group demotivate you from coming to class?
9. Did GEBL approach assist you to have a positive attitude	c) If yes, explain why GEBL approach gave you a positive attitude towards the course d) Did interaction with other group members make the course more enjoyable? e) Did interaction with other group members motivate you?	c) If no, explain why not d) Did you feel the individual work load was more which demotivated you? e) Did you feel that other group members will judge you if you are not well prepared for the topic?
10. Did GEBL sessions improve your communications skills	a) If yes, explain how did the group sessions develop your communication skills?	a) If no, explain why not b) Did you take part actively in group

	b) Did the sessions encourage you to talk more with other group members	sessions?
11. Did GEBL sessions improve your presentation skills	a) If yes, explain how did the group sessions develop your presentation skills? b) Did presenting the topics to other group members enhance your confidence level	a) If no, explain why not b) Did you take part actively in group sessions? c) Did you present topics during groups sessions?
12. Do you prefer GEBL approach over the traditional teaching method	a) If yes, explain why do you prefer GEBL approach over the traditional method b) What in GEBL sessions particularly helped you in learning the topics	a) If no, explain why not b) What part of traditional teaching method do you like more than the GEBL approach c) What part of GEBL approach did you not like when compared to the traditional approach
13. Should GEBL approach be introduced in other subjects	a) If yes, explain why GEBL approach should be introduced in other subjects b) How will the use of GEBL approach make other courses easier to understand?	a) If no, explain why GEBL approach should not be introduced b) Do you think traditional teaching method will be better than a GEBL approach to understand other courses?

APPENDIX G – POWER ELECTRONICS TOPICS AND GEBL TASKS

1. Introduction to Power Electronics

2. Power semiconductor diodes

3. Diode circuits and rectifiers

4. Thyristors

5. Controlled rectifiers

6. AC voltage controllers

7. Power transistors

8. DC Choppers

9. Protection of devices and circuits

TASKS GIVEN TO GEBL STUDENTS

1. Introduction to Power Electronics
    - Define the field of Power Electronics with the aid of a sketch
    - List some applications of Power Electronics
    - Mention important key events in the history of Power Electronics
    - Know acronyms of important power semiconductor devices
    - Draw the circuit diagram symbol of important power semiconductor devices
    - Compare control characteristics of important power semiconductor devices
    - In detail, explain how each important device is switched on, and kept on.
    - In detail, explain how each important device is switched off, and kept off.
    - Compare certain important power semiconductor devices in terms of frequency and power rating

- List classes of power electronic circuits and classify specific power electronic circuits
- Show appreciation for peripheral effects caused by high currents and high switching frequencies
- List advantages and disadvantages of power modules and intelligent power modules

2. **Power semiconductor diodes**
    - Draw a typical diode characteristic curve and name and explain significance of important regions
    - Understand the cyclical operation of the characteristic curve
    - Use information from the characteristic curve to obtain power losses
    - Compare a real diode with an ideal diode by listing differences
    - Apply the Schockley equation to solve diode voltage or current
    - Understand the piecewise linear models for diodes
    - Use piecewise linear models in circuits to solve voltage and current levels
    - Understand implications of reverse recovery characteristics
    - Prove important reverse recovery equations and solve unknown variables

3. Relate reverse recovery time to maximum switching speed**Diode circuits and rectifiers**
    - Draw circuits and waveforms for rectifiers discussed
    - Describe half-wave and full-wave rectifier operation
    - Use waveforms to obtain voltage and current specifications for diodes
    - Analyse single phase half-wave and full-wave rectifiers with resistive loads
    - Analyse single phase half-wave and full-wave rectifiers with back-e.m.f. loads
    - Do a simple battery charger design, using a resistor for current limiting
    - Draw a comparison between centre-tapped vs. full-bridge rectifiers
    - Analyse three phase half-wave rectifiers with resistive loads
    - Do calculations with respect to dc and ripple components of a waveform

- Utilise performance parameter equations, and interpret results

4. Thyristors

- Draw a typical thyristor characteristic curve and name and explain significance of important regions
- Explain how the operating point moves along the characteristic curve in a typical application
- Distinguish between latching current and holding current
- Explain the concept of commutation with respect to holding current
- Explain the operation of certain natural and forced commutation circuits
- Distinguish between forward break-over voltage and reverse breakdown voltage
- Draw the pnpn layers for a thyristor and show why the two-transistor model can be used to explain the latching operation of a thyristor
- Motivate and prove that a thyristor does not amplify current although it consists of two transistors
- Discuss various ways in which a thyristor may turn on

5. Controlled rectifiers

- Explain operation, draw waveforms and mathematically analyse half-wave and full- wave controlled rectifiers with resistive loads
- Explain operation, draw waveforms and mathematically analyse half-wave and full- wave controlled rectifiers with back-e.m.f. loads
- Do a simple battery charger design, and compare performance with diode chargers
- Distinguish between continuous and discontinuous current in R-L loads
- Qualitatively describe and draw waveforms for rectifiers with R-L loads
- Understand the impact of a freewheeling diode on inductive loads, commutation of
- SCRs, and draw appropriate waveforms
- Explain operation, draw waveforms and mathematically analyse three-phase, half-wave and controlled rectifiers with, and without freewheeling diodes

6. AC voltage controllers

- Explain operation, draw waveforms and mathematically analyse on-off (integral cycle) ac voltage controller with a resistive load
- Explain operation, draw waveforms and mathematically analyse unidirectional phase controller with a resistive load
- Explain operation, draw waveforms and mathematically analyse bi-directional phase controller with a resistive load
- Compare common-cathode two-thyristor full-wave controller with single-thyristor full- wave controller
- Qualitatively describe three-phase unidirectional and bi-directional controller
- Describe operation and waveforms of single-phase transformer tap changer

7. Power transistors

- List certain design equations for bipolar junction transistors
- Distinguish between NPN and PNP BJTs and the implication on design parameters
- Describe different operating regions on the common-emitter output characteristics
- Explain how these regions are linked to power electronic applications
- Design common-emitter circuits for amplification purposes
- Design common-emitter circuits for switching purposes
- Draw the internal structure of depletion as well as enhancement power MOSFETs
- Explain the operation of depletion as well as enhancement power MOSFETs in terms of simple semiconductor theory
- Explain the transfer characteristic graphs of depletion as well as enhancement power MOSFETs
- Explain the advantages of insulated-gate bipolar transistors (IGBTs)
- Discuss the simplified equivalent MOSFET-BJT model for IGBTs

8. **DC Choppers**
    - Explain, with the aid of graphs and sketches, the principle of step-down operation
    - Calculate dc as well as rms values for step-down current and voltage waveforms
    - Do efficiency calculations for step-down choppers
    - Explain, with the aid of graphs and sketches, the principle of step-up operation
    - Explain concept of pulse-width modulation and its application in switching-mode regulators
9. **Protection of devices and circuits**
    - List some characteristics of the harsh operating environment of Power Electronics
    - Name the appropriate measures that are taken to protect a component or circuit from the harsh operating environment of Power Electronics
    - Understand voltage damage vs. current damage, and why both specifications are important
    - Motivate the need to force voltage sharing when using series components
    - Do a design for voltage sharing
    - Motivate the need to force current sharing when using parallel components
    - Do a design for current sharing
    - Explain operation of circuitry for dynamic current sharing (parallel operation)
    - Motivate the necessity of freewheeling diodes in Power Electronic circuits
    - Motivate the necessity for snubber circuits in Power Electronics
    - Explain the general principle of snubber circuit operation
    - Apply di/dt and dv/dt protection principles to thyristors and other semiconductors
    - Distinguish between forward and reverse polarised and unpolarised snubbers
    - Describe fundamental operation of fuses for current protection
    - Qualitatively analyse crowbar-type circuits
    - Do a thermal design for certain circuits and heat sinks

APPENDIX H – VERBATIM TRANSCRIPTIONS OF STUDENT RESPONSES TO EACH QUESTION IN THE INTERVIEW SCHEDULE

Q 1. Did GEBL sessions help you to connect prior knowledge to the current topic?

	Q 1a. Explain how GEBL sessions helped to connect prior knowledge to the new topics learned in the course.	
Positive Response	Student 1:	Okay…I can say that usually in class we usually do take notes. In class when we come back on having not read those notes. So… the prior knowledge was like we felt not comfortable with connecting the prior knowledge…like if we doing S1 we are not connecting that information with S2 as well. So now it needed that part where you go to go…take some books of S1…do and you try to understand the concept in S3….yes.
	Student 2:	GEBL did help me to connect prior knowledge to the new topics learned in the course. That's because as I'm a student doing S3, from S1and S2 I did learn about the diodes as well as rectifiers, Dc and AC but to be honest I didn't know exactly which device to convert from AC to DC or how is DC power generated. But yet I know that like being in GEBL we have to go and research and help go deeper into the topic. So I had enough time to learn more things like listening to things that are being said by professor to you as well as link with the things which are discussed with my group members like. That's how I get learned.
	Student 3:	I can say yes because before I come to the class I am given the topic to prepare. Then I go to make a research and when I research about it, then I see about what I have to teached before then I connect with it and then I present it.
	Student 4:	Sir, since we have been discussing and some topics are in PE or Industrial electronics, we are just connecting the previous knowledge with something that we have learnt before with this, with this current learning that what we are doing now. So it give us that teaching in detail that, uh, I don't know how I can explain it further but at least it help us because we are discussing as a group. So that's why I'm saying it help us to connect to prior knowledge with this one.
	Student 5:	Uh, in GEBL sessions you were given a chance. We are given a topic, then we can go and research about that topic. So we have a chance to discuss with my classmates and then we share the knowledge, and if something has happened that there is confusion then we have to…if…since the PE or industrial it has to deal with the electronics, we have to consult our textbook for electronics. If for example for diodes, we have to go and

		check for diodes and then we can to try to link with the topic we are given with the one… with the older information that we have.
	Student 6:	I can say more especially in power supplies. What we did in power supplies… we did more than we did in the lower level because I can say that in the lower level we are just given formulas; we didn't know how they… how did they came from, we just know. For example, for picking the voltage for a centre tape we just use 2VM; we didn't know how to get 2VM.
	Student 7:	It helped me because before we start the class we were given the topics that we were going to discussed about and given the chance for you… I was given the chance as a student to go and prepared so that when I come back to the class I can be able to explain what I have learned. I was able to connect it, because the thing that we were doing with the… I can say they are things that we also see in our real life. So I can say it was really helping me.
	Q 1b. Did group sessions require you to discuss prior knowledge in Electrical Engineering and Electronics related to the current topic?	
	Student 1:	Yes, I can say…I can say.
	Student 2:	Yes, it did help me. Just because…say our lecturer, did give us topic before like to go and research about it before you going to add other things in class whereby to discuss with our group. That's how we do.
	Student 3:	Yes, Sir, yes, Sir of course.
	Student 4:	Yes, I have said before, yeah, it helped us in group. Although I was not in the group most of the time because of the places, because we live in different places but sometimes I get something in the group.
	Student 5:	Yes.
	Student 6:	Yes, Sir.
	Student 7:	Yes we were, because for an example from Electronics 1, we were discussing about diode and still here in Industrial Electronics, we were still talking about the diode- N type and P type-because of GEBL classes.
Negative Response	N/A	

Q 2. Did GEBL sessions help you to understand the topics?

	Q 2a. Explain how GEBL sessions helped in understanding the subject content	
Positive Response	Student 1:	The subject content…okay, I can say that in GEBL we are a group of students. Then the chances are like where we meet, discuss, go back, try to read what has not been clear in class. You come and present it. It motivates them to come back in class and present what you have understood about that content. Like the subject which was discussed.
	Student 2:	As I have already said that as we are using GEBL session we are given topic, we are given topic by our lecturer to go and research about it. So by doing that I have enough time to dig deep to the topic not like listening to a topic what he taught us how to score and score…and I take that time to do the research as well as having our group meeting to ask the question as we are, as we are discussing in front of the class as, as well as you are researching and keeping some things which are clear to me.
	Student 3:	It helped me because when I am given a topic I try to find about more about what I am given. So I read about it and then I understand more than when I am teached.
	Student 4:	Sir, it help us to understand the topics. If I can just explain that furthermore, it, if we are talking about let's say, let's say about the Power Electronics or, or, or about the diodes, yes I know that the diode, from now onward I will know that the diode it acts as a, it acts as a valve because if it allows the current to pass through but not in reverse again. So just especially those things we've been discussing, but I didn't know before that it will act like that.
	Student 5:	Like in GEBL sessions, as I have said we are given a chance to go and research about the given topic. So as…like a normal class you are given a topic and the lecturer will just write few points about the topic. Unlike in GEBL sessions whereby you have to go and research and write the points that you know…that you understood better in connection to the one that you…that you are given in the class.
	Student 6:	I can say it helps because before we discuss the topic, we have to go and prepare yourself and know a little bit before we discuss it in the GEBL sessions.
	Student 7:	As I have said earlier, before we start the class we are given chance to go and research about the topics, that is for for a student to study on own self by reading and then coming to class and discuss with others, so that's helpful.

	Q 2b. Was this understanding because of the different approach you used in this course?	
	Student 1:	Yes indeed…as I have already highlighted that, if we are in class it is a thing of just copying notes, going home and coming back and opening that notes…those notes without even reading them. So in GEBL you are preparing…like I can say it is the approach. It forces you to prepare...yes.
	Student 2:	Yes.
	Student 3:	Yes.
	Student 4:	Yes, it, because of the different approach because first of all we are just researching about the topics it is one of the other approaches we are doing. We research the topic then we discuss as a group so that we come with… with something and you get something from the group.
	Student 5:	Yes.
	Student 6:	Yes, because in lower level we just listen to the class and the lecturer talks, talks and talks, but in this GEBL class we have to go and research for the topics and what you know then from…from your research then go present it to the other group members. And they will help you to understand what you have missed.
	Student 7:	Yes, I can say yes, Sir, because on the normal class we just come to the class and wait for the lecturer to give the lesson to us and then the lecturer go out and we end up don't know what we know the thing that was discussed in the class, but this approach is giving us the chance to discuss as a class and then we will know where we don't know and where we know about the topics because of that approach.
	Q 2c. Did sharing of information with other group members make understanding a topic easier?	
	Student 1:	Yes…yes, I can say even there you will find that sometime I understand this topic, but someone may be doesn't understand the topic the way I do. So in some point you will find that I did not understand the topic which he didn't understand. So …(clears throat) we are meeting each other half way like to get better knowledge of the subject.
	Student 2:	Yes, it did.
	Student 3:	Yes, it makes me to understand it easier than when I am studying it alone.
	Student 4:	Yes, as I said, Sir, it help us to understand the topic easier because I come with, with some, with some knowledge, I get some knowledge with our members group.
	Student 5:	Yes.

	Student 6:	Yes, because when you do research for your own, if there is something you didn't understand then the other group members will help you.
	Student 7:	Yes, it's easier, Sir.
Negative Response	N/A	

Q 3. GEBL sessions help you to bring about understanding of the concepts of PE. Do you agree?

	Q 3a. Explain how sessions helped in understanding the concepts.	
Positive Response	Student 1:	As far as power electronics, I think GEBL helped us a lot because it was our first time doing power electronics. So we are introduced to some information came from the things that we have already done, but some of those were new…so we tried to go on ourselves, read about these things and come to present them. So it was easy to catch up the information to connect.
	Student 2:	GEBL sessions help me to understand the concepts like, okay, the concept of power electronics. Like GEBL session is not, is not operating like our normal classes, that's because our normal classes we used to be spoon fed I can say so like we listen and take down notes and go where we live like the residence. Sometimes we didn't go to read and just read when you are about to write a test. So GEBL session I can say it force me to read like I have to come prepared to the class always so that I can be able to share what I have learned and asked to our, my, my, group mates.
	Student 3:	It helped me to understand the concept of PE because when I read about it, about the topic that are given, then I read more about that concept to present in front of it.
	Student 4:	Sir, we are just, dis…dis… discussing better more of the concept of the PE. Since we are…we are doing a research, then you research and then we come as a group; we share the information and then we explain, we just uh, presenting it in front of my members' group and then we ask questions and I reply to them. And then if it is a chance for them to present, I ask questions from them so that's why I get understand the concept.
	Student 5:	In understanding this- concepts of PE using GEBL uh… sessions- like if we having… if we met as a group members of GEBL sessions, we had to discuss the…like the topic and come across the terms. Like I can go to in class that we have like, IGBT then we have been told about that from its nature is Insulated Gate Transistor. So that term from its nature is called insulated, so I understood better that term because of we are sharing information in GEBL session.

	Student 6:	Because, I can say in the relevant of the SCR because we… in SCR we used SCR to control the power delivered to the load. So in PE concept… deals with the conversion and control of devices.
	Student 7:	As I have said, you are discussing, you learn on your own and you come into the class discuss about what you have learnt on your own from the topics that were given to you. That's what helping us to understand the PE concepts.
	Q 3b. Did GEBL sessions require you to think more about the topics covered?	
	Student 1:	Uh...I can say yes even there. Because...uh, GEBL, I think I mustn't say it forces it encourages us to think. You must always think about people must always think. Like if…if… if we cover, let me take an example of a SCR. Like If we covered SCR we wouldn't understand SCR coming from S2 because we are not doing SCR there. So only time we will understand SCR is the time when you are in S3 and you are doing power electronics. So power electronics … is like I can say, GEBL gives us a chance to go through something within ourselves without lecturer being like giving us information, notes and everything.
	Student 2:	Yes, it did. I can say it did make me think about the topics covered just because as I said that we are given a topic and research about it more so as you know that we are always sort of competing. So no one is willing to be in a class to not talk and say something which is not good. So we have to highlight some points by whereby we are researching so that I can with something valid and can be heard by everyone so that.
	Student 3:	Yes, it made me think more because I have to prepare to answer some questions from others.
	Student 4:	Yes, Sir, since you are…you are giving us some topics to research, uh, we research about the… the topic and then we get some information, but it, the information we get it is not enough. We have to dig the deep information from that information we get. For example from the internet, internet it just give you the information that is up, so we just have to find deep information down so that you can understand what…what actually happens.
	Student 5:	Yes, like in GEBL session we have to… like even like in class, if lecturer gives us the topic and he say we must discuss about the topic, each one is subjected to think about the topic and the lecturer gave us enough time and say we have to feel free about the… don't be scared about anyone and you have to think about what you think is relevant. I am here to correct you and also the group members are here to correct you.

	Student 6:	Yes, Sir, it did, because I can say in GEBL session we didn't discuss. I can say there were more things we learnt before. We have to think what you knew then connect to it.
	Student 7:	Yes, I can say it requires us to think more because when you are discussing you come with information that you know and then when you are going through analysing with that program, we have to think and tell others and discuss with others what you know about it.
Negative Response	N/A	

Q4: Did GEBL sessions help you to understand the topics in depth?

	Q 4a. Explain how GEBL sessions help to understand the topics in depth.	
Positive Response	Student 1:	In depth…okay…like I think these questions are connecting because like I said before it helps us. Like if you are preparing on your own…(clears throat), you are not meeting with other students something you might not understand but when you are preparing with other students you clearly understand what you understand and what he doesn't understand. So you share the information in between and then it makes the understanding more better.
	Student 2:	GEBL sessions, as I have said that, I have to research before I come to the class. So I have enough time to learn. Like the time of researching to highlight some points. With my group, we used to meet before we meet the lecturer in class and discuss it by and sharing some portion where, uh, where something is not clear, I ask and then I hear and be clarified. As well as, when you are, for example when you are in the class with the lecturer we used to, we used to present for him, to him, and share information. He used to teach us and, and he used to add where there's something we feel like maybe we not discuss it clearly.
	Student 3:	Oh…It makes me to understand the topics in deep detail because when I am given a topic I try by all means to get more information about it by taking some other books, so I get in details to the topic I am given.
	Student 4:	Yes, as I have said sir, we are just… we have to researching and then after we are doing research, we try to understand the topic, uh, deep and then if you…if you didn't get the information we just meet as a group so that we can share some information because we cannot get the same information. It can be the same but it cannot be 100% the same.

	Student 5:	Like as I have said that we have lot to went and research about the topic, so like… I myself, I have in the SCR like method of turning off and on the SCR I want in the right way and my lecturer have wrote some… two methods there about the commutation. Then I have seen that in the text book written introduction to PE also classes about those commutations so that I have understood some of the topics… some…in fact all topics that we have discussed in… in the GEBL that I have understood better than the normal classes.
	Student 6:	Sir, because I can say for example in… for a capacitor I didn't know when it touches the… the voltage increases, but when it shuts the current is also decreasing. And it helps to…to understand the topics. Therefore we have to research.
	Student 7:	In GEBL class, we are discussing, so I can say it help me to understand, because when we are understanding... we ask questions when we don't understand.
	Q 4b. Did group sessions encourage you to come prepared for the class?	
	Student 1:	Yes. I think I have already answered that one because when you are preparing… (clears throat), like a topic is given in class, you go and prepare and the next time you are so willing to come to class and present that information.
	Student 2:	Yes.
	Student 3:	Yes, it did. Because when I come I always needed some questions to the group members.
	Student 4:	Yes, Sir, since I am that person… since I am that person who… who want to share information with others, if I… I have learned something I want to share something to my group members, so it encouraged me so that if I know something I come to the class and then I know that I will… will represent something in front of members.
	Student 5:	Yes.
	Student 6:	Yes, because if you did not come prepared in the class when other group members are discussing few topics then you will be lost because you didn't prepare.
	Student 7:	Yes, Sir, because before we start the class we were given topics. So that's how you can get prepared as a student.
	Q 4c. Did coming to the class with some knowledge of the topic and further discussion with group members about the same topic help you to understand the topics in depth?	
	Student 1:	Yes, yes, yes.

	Student 2:	Yes, it did.
	Student 3:	Yes, it did. Because when I get some question to others I try to think more about it, then I get answers.
	Student 4:	Yes, Sir, since we are… we… since we…when we are coming to the class, we are…we are arguing about the topic. If someone come with something and if we do not understand, we ask him or her the questions…the questions… so that he can explain to us. And if…if you think you know something, if you think you know something and you find out if you do not know anything you know, you will find out you know or do not know something because you will get the right answer from the group members. Or if all of us we do not know something, we ask from the lecturer where we are wrong or where we are right and he correct us.
	Student 5:	Yes.
	Student 6:	Yes, Sir, because other group members will help you in other topics, if you didn't understand when you did the research on the topic.
	Student 7:	Yes, Sir.
	Q 4d. Did asking questions to group members help you in a deeper understanding of the topic?	
	Student 1:	Yes. Sometimes like we have one member in our group, hey that guy is asking. So I can say yes, because sometimes...sometimes you present a thing then not having a deeper understanding on that, then some students will raise a question saying what is this…then maybe you could not have think about that. So it helps to know what you know and to know what you don't know.
	Student 2:	Yes, yes.
	Student 3:	Yes, it did. Because when I have asked question, someone tell me about it more than what I have asked.
	Student 4:	Yes, Sir, it…it made me understand the topics.
	Student 5:	Yes.
	Student 6:	Yes, Sir.
	Student 7:	Yes, Sir, it help me.
Negative Response	N/A	

Q 5. Did GEBL sessions help you to recall the topics learned?

	Q 5a. Explain how GEBL sessions helped you to recall the topics.	
	Student 1:	I think when you are discussing things... it becomes more easier like when you are taking notes, learning or I think it becomes very easy to understand and recall when you are discussing.
	Student 2:	GEBL sessions helped me to recall sessions which has been learned. As I have said in GEBL sessions we are researching, we are not spoon fed. So when we are researching something , I understand it as well as I go and ask questions to my group members. So understanding it better than framing a part and writing it. So sometimes as we are doing industrial, we are not only doing industrial. So I have some subjects like digits. So sometime I will not have enough time to read for tests sometime just because I'm busy with other subjects. So as I have learned, so as I am researching I understand the topic and I'm asking in the class where I'm not something clear to me. So when it comes to tests if I didn't get enough time to read I can be able to manage to write the test because I recall what I did.
	Student 3:	It helped me because when I study the topic, then it connects to the other topics I have learnt before.
Positive Response	Student 4:	Sir, if …if you are… if you are analysing something alone and then you leave it and then you meet a new topic, uh, most of the things in Electrical Engineering are related, but not be related. So if you…you are done something you just recall something from… from other subject. I can put it like that.
	Student 5:	Like in GEBL session, as we are most of the time as a student are the one who are working, the lecturer is there to assist. So it is… sometimes the question can come and maybe you were the one who was doing that question so it becomes easier for you to recall.
	Student 6:	For exampling… depletion MOSFET…I didn't know very well in the lower level. We just given the diagram of a depletion MOSFET and we didn't go through how it works and how depletion MOSFET… how the channel is formed and what happens when the channel is full of ions or electrons, or positive ions or electrons… how to get the break over voltage.
	Student 7:	Because when you… when you go to your house and you read what you are told to read and then come back to discuss with other members of your group, you will become more clear about the topic. So it help me.

	Q 5b. Did having a good understanding about the topic help to recall the topics?	
	Student 1:	Yes. Even when we are writing the tests it is a thing of going there; just check, check, check, because all those topics that are covered…we try to discuss them in depth so it's easy to recall. Yes, so I can say GEBL is doing a very good job there.
	Student 2:	Yes, it did.
	Student 3:	Yes, it did, Sir.
	Student 4:	Yes, Sir.
	Student 5:	Yes.
	Student 6:	Yes, Sir.
	Student 7:	Yes.
Negative Response	N/A	

Q 6. Did GEBL sessions help you to analyse the problems effectively?

	Q 6a. Explain how the group sessions helped you in analysing the problems.	
Positive Response	Student 1:	Okay… let me say like in our session we working in groups like if sir has given us a topic to prepare for so I will go and research about that topic, then we sit with the other students and discuss that. I think it helped our analysing skill in a better way of analysing things.
	Student 2:	The group sessions help me to analyse the…problems. Like I have said we are given topics. So if we have something to derive, like they are not being derived by our Lecturer. So we derive with our own, using uh…our techniques with our group members. So where there is a problem we have to share it with others so they go clarify for me as well by sharing information not like listening to our lecturer.
	Student 3:	It help me because when I think when I ask the question I am not just answering I try to think about it and analyse it more about what I have learnt in the class than about what I have researched.
	Student 4:	As I have said, Sir, we… we are…we were researching about the topic, then if you…if you get something you can get something but you cannot get the 100% information, but when you get to the class, you get more than… you can get more information that you were researching. So it… it help us to analyse the problem. When you have to research something you know what you do not know and

		you know what you know. So you can just confirm that in front of your members so they can correct you or they can…uh get you wrong.
	Student 5:	Like in GEBL, like I have said we are the one that is presenting the topics and we are having enough time I can say, to answer the questions to our class. If the question is a bit difficult for us, our lecturer is there to assist us. Even we can pick maybe a difficult point where our lecturer will even say that in normal class there were no one like we used to… like the way I used to lecture, there were no student who picked that question.
	Student 6:	It helps, because for you to be able to answer or to work on the problem you must first know what is given and what are you going to do to in order to get to solve the problem.
	Student 7:	Sir, because we were given the problems on the board and when we are discussing it that's where you get more information and get more knowledge about… about that problem.
	Q 6b. What exactly about the GEBL sessions helped you to analyse the problems?	
	Student 1:	I think it's the part that…that you must go and prepare...that is the part.
	Student 2:	I can say what hit me a lot is that GEBL session required me to bring what I have learned before I've been told new things? So that gave me the time to think and research about something clearly how did it go and how did it work before I come to the class. So when I told something to the class is what I have already said. So where I have noticed something not very clear so I get to clarify it with the class.
	Student 3:	It help me about how to face the question and I don't feel that way that I cannot write when the question is asked to me. So each and every question I try by all means to analyse it then I have something to write.
	Student 4:	It… It help us by researching and come with information and then we just discuss with both different information we come with them.
	Student 5:	That given time for you to go and research about the topic.
	Student 6:	I can say, to first analyse a part of the problem first, then after you are done this part then you move to the other one.
	Student 7:	It has helped me by giving me the time to think, because when we are thinking about the problems where we can easily analyse it, not only waiting for others to discuss. But if you give yourself the time to think about the problem that is given it is easy for you to analyse the problem.

	Q 6c. Did GEBL sessions help you to interpret the problems effectively?	
	Student 1:	Uh….to understand, yes, yes. I can say that.
	Student 2:	Yes, it did.
	Student 3:	Yes. I try to interpret the problems because of the knowledge I get when I am doing some research.
	Student 4:	Yes, Sir, to interpret.
	Student 5:	Yes.
	Student 6:	Yes, it helps.
	Student 7:	Yes, Sir.
Negative Response	N/A	

Q 7. Did GEBL sessions help you to think critically when a problem was given?

	Q 7a. Explain.	
Positive Response	Student 1:	As a GEBL student it's always uh...like an oblique to think critically. So if you are thinking surely you will understand the... what was asked in the problem.
	Student 2:	I can say that GEBL session requires like some critical thinking not to cram and pass. So I think it can help to having better understanding to other concept.
	Student 3:	GEBL sessions helped you to find the parameters in the problem and I have to think the next step to solve the problem.
	Student 4:	It did help us to think critically since…since we are researching something. So if you find a… a circuit, you can just think about how this circuit operates although you haven't been teached about it, but you can try to find it and then you have to think critically because your lecturer is not in front of you during that time you are doing your research, but after that you… you know that you will meet the group so that you will get the correct answer.
	Student 5:	I can say, uh, if I can quote for this question, in our test-that was test 1- I also was when had… during class when we were deriving a formulas for VDC, he touched based on the issue of efficiency and in the test brought the question about the efficiency itself. So it was easier for me to… to differen…distinguish between the two because in VDC it was just touch basing because of the value that we have…we have had and in the efficiency overall percentage that we have calculated.

	Student 6:	It helps because when you are given the problem, you have to think about the problem and how to solve it and strategies to work on the problem.
	Student 7:	Sir, as I have said we are given problems there and we were also given the chance to think about the problem and analyse it. So GEBL sessions… it helped me to critically to solve the problem that is given.
	Q 7b. Did group sessions help you in improving your thinking skills?	
	Student 1:	Yes, indeed.
	Student 2:	Yes, it did, Sir.
	Student 3:	Yes, it is improved because now I know before I answer the question I must think what is being questioned to me.
	Student 4:	Yes, Sir, as I have said, Sir, as I have said, it makes me improve the… the thinking skills because if I came with something and then I found out I was… I was correct when I was interpreting something and then I come to class and ask my members then they correct me so that I can confirm that that answer I was thinking, it was correct.
	Student 5:	Yes, Sir.
	Student 6:	Yes it helps, because in…in other normal classes when maybe you are given a question… you just let others think for you and then just sit there and not think because others will think and give the answer. But in this session we have to think, and also we have to contribute on the session to help other members.
	Student 7:	Yes, Sir.
	Q 7c. Did group sessions help you in comprehending a problem?	
	Student 1:	Yes, yes, indeed, Sir.
	Student 2:	Yes, it did.
	Student 3:	Yes, it did.
	Student 4:	Yes, it help me to comprehending a problem because there is…we are sharing information.
	Student 5:	Yes, Sir.
	Student 6:	Yes, it has.
	Student 7:	Yes, it helps sir because we are given time when the problem is there on the board. We are given the time to discuss about it and ask question where we don't understand, so it helps them.

	Q 7d. Did group sessions help in determining the key parameters in a problem?	
	Student 1:	Yes, to understand what is given to us. What is that the examiner wants, you must just check. It encourages us to do that. Like we always in class is a thing of, like in a normal class if the test is given you will just take the question and you will write. But as a GEBL student you have to think, you have to think. Each time you are given a thing you just look what has been asked so that you answer accordingly to what is being asked. So it helps to understand the problem.
	Student 2:	Yes, it did.
	Student 3:	Ya… because when the question is asked I have to think about what is actually needed to that parameter.
	Student 4:	Yes, Sir.
	Student 5:	Yes, Sir.
	Student 6:	Yes. You must first know what is given in order to get what you want.
	Student 7:	Yes.
Negative Response	N/A	

Q 8. Did GEBL approach motivate you to come to class?

	Q 8a. Explain.	
Positive Response	Student 1:	As I have already said, yes, yes.
	Student 2:	GEBL sessions give me positive attitude towards the class. Like I have said, I have to come prepared. So I have to give something to the class. So I am not sitting there being quiet, so just because I feel like now I can talk as they are presenting what they did. So I have to come prepared to the class like with that positive attitude so that I can stand in front of other people, either my classmates or group members.
	Student 3:	Yes, it is more motivating me because I always expecting some questions when to something that I have learned so that I will understand it better.
	Student 4:	Sir, it motivates me to come to class, as I said before, if I know something I want to share it with my colleagues. So… so to get the chance to go to classes, it… it encourages me because I will share information I know to my colleagues. That’s why I am encouraged by that.

	Student 5:	GEBL did motivated me to come in class because there we have… there are couple of questions that we have been asked to in the class and they are… uh, each student come with his way to tackle the problem so that's how I've became motivated.
	Student 6:	It motivates me because when you were given topics you have to first prepare yourself, then if you are prepared well then you will have that confidence to go to the class because there's something that you know about the topic, then we, in the lesson… then we discuss it more.
	Student 7:	It motivate me because there we were given chance to go and read about the topics. It's not normally like you wait for the lecturer to come and teach something that is new. So the GEBL help me because I come to the class with some little knowledge and when we discuss it, it becomes more clear. So it helps.
	Q 8b. Did group sessions give you a positive attitude towards the course?	
	Student 1:	Yes.
	Student 2:	Yes, it did.
	Student 3:	Yes, it did.
	Student 4:	Yes, Sir, because I… from now onwards I know what I'm going to do in future.
	Student 5:	Yes.
	Student 6:	Yes, because in GEBL class we are forced more thinking and strategies how to work on a problem.
	Student 7:	Yes, we are given chance to go and say.
Negative Response	N/A	

Q 9.Did GEBL approach assist you to have a positive attitude?

Positive Response	Q 9a. Explain why GEBL approach gave you a positive attitude towards the course.	
	Student 1:	Uh…okay, I can say like, this question is little bit repeating but I will say it again. In GEBL session we are given a task to go and prepare. Then when we are preparing that, you are so willing to come back to the class and present that information within the class so that you know what you prepared is wrong, right or wrong. So if it is wrong you will learn more than you will learn in a normal class. So you will be able to get that information.

	Student 2:	I can say that GEBL give me positive attitude just because as I have said as we know as students we used to compete. So GEBL session gave me that time to…time to analyse the problem so that it's like researching so that I can come to the class with something so that now I can share, not always listen. So I can share something.
	Student 3:	It is because now I get more information by understanding to my group members because we always preparing it before we come to the class then something I don't know I ask to them.
	Student 4:	I… I can say that because if you are… if I research about something, I will come to the group. If the group doesn't know that something I come with it, the lecturer can…can just explain for me deep down so that I can get detailed information from… from my lecturer.
	Student 5:	Like, as I have said in past questions that, our lecturer gave us that chance that we have to feel free to stand in front of your classmate because they are no one except my classmate. So that gave me a positive attitude towards the subject.
	Student 6:	Because with this GEBL approach even there in… let's say… other subjects there are topics that I didn't understand, then I will go to the internet and do more research like I did in GEBL session.
	Student 7:	As I have said, we are given that chance to read out the topic before we go into the class. That's what it gave me a positive attitude towards the class.
	Q 9b. Did interaction with other group members make the course more enjoyable?	
	Student 1:	Yes, yes, yes, I can say.
	Student 2:	Yes, it did.
	Student 3:	Yes, it did because working in group it develops some knowledge to me.
	Student 4:	Yes, Sir, since we are being judged… arguing with questions and then we answer each other. All those things.
	Student 5:	Yes.
	Student 6:	Yes, because we are… we are free to discuss and ask questions if we have and when I don't understand some other topic.
	Student 7:	Yes, because we were not laughing at each other, we were assisting one another.

	Q 9c.Did interation with other group members motivate you?	
	Student 1:	Yes, because I want to explain even there, because may be in a normal class you think that when you written notes you think you know everything but only to find out that this thing you have read other one has read it also but here is a different way of understanding. So it encourages to go in groups. I think it helped a lot.
	Student 2:	Yes, it did.
	Student 3:	Yes, I can say yes.
	Student 4:	Yes, Sir.
	Student 5:	Yes.
	Student 6:	Yes of course, if some or other group members… there is a topic he knows very well then I will go to him and ask how did he do to understand this very properly.
	Student 7:	Yes, Sir.
Negative Response	N/A	

Q 10. Did GEBL sessions improve your communication skills?

	Q 10a. Explain how it developed your communication skills.	
Positive Response	Student 1:	Okay, like in GEBL class we are encouraged to speak in English which is our second language. So it's a thing of going there in front, having to present your information, so I think it has assisted us a lot in terms of communicating.
	Student 2:	GEBL sessions did help me to develop communication skill like as you know that we are presenting it using English which is not our current language. So I have to come prepared so that I can stand in front of other people. So how does GEBL help is just because always when you are discussing we use English not Xhosa Language. That's how it helped me.
	Student 3:	It develop my communication because last time I was afraid to stand in front confidently because now I know how to stand in front of the class of my group members and present what I know and then they ask question to me that bring me more knowledge to me.
	Student 4:	Sir, I can say that Sir, because from now I am not afraid of talking in front of…of people. I was afraid of talking in front of people but now since we are just as a friends, we… we didn't know each other before, but now we know each other because we are sharing information; we are communicating each other; we are just presenting

		something on the board. Even when the lecturer is not there, but you are doing those things so we communicate each other. That's why I'm saying it give me communication skills.
	Student 5:	Since in class we are supposed to use in English, as it is supposed to be in English. In English, since it is not our mother tongue, so we are trained so that we can be frequently when we speaking English fluent for us.
	Student 6:	Because we have to talk in GEBL classes and think more and when you are given a topic, you have to go and prepare and you have to come and talk with other group members what you have researched.
	Student 7:	It develop my communication skills because in a GEBL, we are discussing there in English, so everyone was free to talk about the topic. So it improve my communication skill because firstly before that GEBL class, I was afraid to speak and communicate in English in front among others. So it really improve my communication.
	Q 10b. Did the sessions encourage you to talk more with other group members?	
	Student 1:	Yes, because if you don't know something you must go and ask to others.
	Student 2:	Yes, it did.
	Student 3:	Yes, it did.
	Student 4:	Yes, Sir.
	Student 5:	Yes.
	Student 6:	Yes, of course; we are free.
	Student 7:	Yes it did, because we are discussing it.
Negative Response	N/A	

Q 11. Did GEBL sessions improve your presentation skills?

Positive Response	Q11a. Explain how the group sessions developed your presentation skills.	
	Student 1:	Like, when we are given a topic we will come and sit there, one of us will go and present there. It was a thing of you must talk; you must answer questions so I think it did enhance our presentation skills.
	Student 2:	GEBL session did help me to develop my presentation skills, like I have said as we are…we always present things we have learnt not listening to what the lecturer is going to say. So I know that always when there is a class in GEBL I have to have to come in front of people to talk and looking to them, not being shy in front of them. So

		that's how it developed my presentation skills.
	Student 3:	Ya… it develops my presentation skills because when I understand, I am always willing to tell others what I understand. That's how it improves my presentation skills.
	Student 4:	Sir, it improve your presentation skills because now I can present something on the board and then I can see some…some members of my group, they ask question where they do not understand, but the question that they come they are few, which means I can present something clearly so that they can hear it.
	Student 5:	Like when I am, like I can say in first day when I was presenting the topic that I was given, I was a bit scared and afraid and that vibration. But as the GEBL sessions continues I feel bit comfortable when I was presenting topics.
	Student 6:	It did, but not that much because I think for more given time, it would improve.
	Student 7:	Because we were given chance to stand in front of our group mates to discuss about the topics. So it really improve my presentation skill because now also I have been confident to stand before others and discuss about the topics.
	Q 11b. Did presenting the topics to other group embers enhance your confidence level?	
	Student 1:	Yes, yes, Sir.
	Student 2:	Yes, it did.
	Student 3:	Yes, it did because when I understand something I always like to go forward and tell what I know.
	Student 4:	Yes, Sir, when they ask me a… when they ask me a question and then I answer it and then I find that he or she understand what I said to him or to her, I get that confidence.
	Student 5:	Yes.
	Student 6:	Yes.
	Student 7:	Yes, because for an example, even in Digital System 2, on the other day I was standing in front of students analysing the other problems. So it really helped me- the GEBL.
Negative Response	N/A	

Q 12. Do you prefer GEBL approach over the traditional teaching method?

	Q 12a. Explain why you prefer the GEBL approach over the traditional method.	
Positive Response	Student 2:	I can say that I prefer GEBL approach over other traditional methods just because GEBL sessions help us to understand like deep, deep in the concept not rather than being here to lay out of the problem, just because we used to cram and write and then we forget. In GEBL we used to think deep so that we can understand the whole concept so that we can be sometimes better in the field.
	Student 3:	It develop more knowledge because when you try to find some knowledge by yourself, you get more than when the teacher is in front of you teaching many things that you don't study.
	Student 4:	Sir, I prefer that GEBL can… can be on other courses because if you… if you came to class with something and then you just show your lecturer what you have read, and then he can just assist you where you are wrong because if… if you just come to class with nothing you will just see the thing for the first time and then you will be just lectured and then you want to know just now, but if you came with something at least the lecturer will be polishing where you… you didn't get something correctly.
	Student 5:	It is because in traditional method it's like we are being… in traditional method we are just given notes. The fact that the student, they are… when it comes to read our books, they are… they can't go further with portion. We are trying to note the given information, while in GEBL session we have to go and research about the given topic and know some couple of things.
	Student 6:	I prefer it because in GEBL session… if there is something or some topics that we don't understand, we talk with other group members that will help you to understand the topics.
	Student 7:	I can say so because it help the teacher and the learner to be more committed in everything that is happening in the class. That's the only reason, that I prefer because as I have said earlier, that we are given a chance as a student to go and analyse the problem on your own and then come into the class and discuss as whole. That is helping the lecturer and student to take part in the class because in the normal class the lecturer become in the class and present the lesson and go out not knowing that everyone is understanding the topics. But in a GEBL we are given a chance to present on our own and also ask the question where we don't know.

	Q 12b. What in GEBL sessions particularly helped you in learning the topics?	
	Student 2:	In GEBL what particularly helped me in learning the topic is that, first we have to research the topic so I have to use many techniques like listening to the YouTube's, analysing like picking some important points as well that my have to in class that I have to discuss and share information with my group members. So something that I didn't grasp, so maybe someone is going to ask or easy to ask from your group member rather than the lecturer. So that's how it helped me.
	Student 3:	It helps me to understand what I have prepared to do or it need to understand the topic that is given to me because I try to get some information in books or to get more information.
	Student 4:	It… it just helped me because even each and every topic that I…I am given in…in the course, I am researching about it. So it helped me about learning the topics, Sir.
	Student 5:	It was by coming in front of the class and presenting those topics we have given.
	Student 6:	I can say is to first research the topic, then we come to the class with some knowledge to discuss with other members.
	Student 7:	I can say yes because of the presentation and discussion we were doing.
Negative Response	Q12c.Explain why not.	
	Student 1:	For now I will say no, because GEBL requires commitment from both from students and lecturers. And for other subjects I'm still not sure, but for industrial electronics I'm very sure.
	Q12d.What part of the traditional teaching method do you like more than the GEBL approach?	
	Student 1:	I like the one, where student will go and prepare, come back in class like not in a group. I think in other subjects we are not ready to create groups to discuss things. So even in class in other subjects you don't understand, so you need to go and prepare more which will need much time which we don't have in some other subjects.
	Q12e.What part of GEBL approach did you not like when compared to the traditional approach?	
	Student 1:	I like everything about GEBL, I won't lie…everything.

Q 13. Should GEBL approach be introduced in other subjects?

Positive Response	Q 13a. Explain why GEBL approach should be introduced in other subjects.	
	Student 2:	GEBL approach I can say that must be introduced to other subjects. So that it can in the end of the day you have a better understanding of what you did just because GEBL require that time to work hard like understanding the main concept in deep details not like what we did cramming in the past. Like usually as I'm doing the S3, so I'm a senior doing S4. So something sometime we may not understand and go talk to him like, "Hey, I don't understand, I don't remember it now it was long time ago". And even me when I was through S1, when they ask something I say, "Hey, I don't understand". So I thinks that's how GEBL help me understand the main concept so you don't cram and forget.
	Student 4:	Sir, as I said Sir, I think it should be introduced, Sir, because it…it helped me because I am that kind of person who wish he can come with something in the class so that I can know what I do not know. If you just come to class and knowing nothing, you will just go out of the class without knowing something and then you will know it later and then it will be later for you to go to the lecturer and ask it again because you will be given another, uh, topics for you to finish the syllabus.
	Student 6:	Yes, but not all of them. I can say if you are introducing, you must start in lower levels, then, I can say we start lower level for example, S1, then in S2 then S3. It must not be seen S3 only, because when you… I can say, if you start in S1 then when you are in S2, then when you are in S3, it will be easier for you because you already know what is expected from you in GEBL classes.
	Student 7:	The GEBL session makes the subject to be easier to understand to a student, because the student is given the chance to go and prepare for the class. While you are in the normal class you are not… you come in the class without knowing what is going to be introduced if you are not told by your lecturer. So we always come without knowledge, everything is always new. But in a GEBL class we are given the chance to go and prepare and then when the lecturer is presenting the lesson there you become more clear about what you have read. So it's really helped me.
	Q 13b. How will the use of GEBL approach make other courses easier to understand?	
	Student 2:	As I can say that GEBL session requires like some critical thinking not to cram and pass. So I think it can help to having better understanding to other concept like understand the main concept of the course so that when you are going to write. Even if you didn't have enough time to read you can able to write something you understand

		rather than something you have to cram and look into the book always before you write.
	Student 4:	Sir,I have already answered that, Sir. It can help because if you… if you get in class knowing something and then the lecturer will polish where you do not know something.
	Student 6:	It must start from lower levels, and then when… then… it must be lower level- from S1 to S2, not in S3 only.
	Student 7:	The GEBL session makes the subject to be easier to understand to a student, because the student is given the chance to go and prepare for the class. While you are in the normal class you are not… you come in the class without knowing what is going to be introduced if you are not told by your lecturer. So we always come without knowledge, everything is always new. But in a GEBL class we are given the chance to go and prepare and then when the lecturer is presenting the lesson there you become more clear about what you have read. So it's really helped me.
Negative Response	Q13c. Explain why GEBL approach should not be introduced .	
	Student 1:	It needs commitments both from the lecturer and student uh...I think it must be just practised step by step easily; maybe we can get there where we introduce GEBL into other subjects as well. Because on other subjects, because I did Electronics, I can say things are not introduced properly, if I'm honest. So if you don't understand, if like you don't understand what is being introduced you can go and search and search but you won't understand as much as you would understand if things were introduced. So that's why I'm saying, if it can be introduced it must be taken step by step just a little bit.
	Student 3:	I can say no because it is right in this Power Electronics only because we know how to deal with the components that we are forced to do about it. Then in other subjects I think for now it is not good because I can say that they are not prepared to do such research like this one because it must first be introduced to them.
	Student 5:	Like in our department, some subjects… if we introduce the GEBL session it may be difficult because I may say that we are not fit enough for in this department- for our department - for GEBL because some subjects… they may have problem.
	Q13d. Do you think traditional teaching method will be better than a GEBL approach to understand other courses?	
	Student 1:	Even that traditional teaching method should be done

		correctly. It should be done correctly.
	Student 3:	Ya…I can say no because it is right in this Power Electronics only because we know how to deal with the components that we are forced to do about it. Then in other subjects I think for now it is not good because I can say that they are not prepared to do such research like this one because it must first be introduced to them.
	Student 5:	Yes, you are 100% correct. Our department is not ready and I am a bit concerned that students will not get enough support for GEBL sessions

APPENDIX I – MARKING KEY

FORMATIVE ASSESSMENT 1

Marking Key

c - Explanation completely correct

mie - Explanation contains minor errors

ce - Explanation contains considerable errors

mje - Explanation contains major errors

I - Explanation completely incorrect

The left hand column of the table shows the marks awarded to the student based on the answer given by the student. The right hand column shows the grading based on the mistakes made by the student. For example, the table for Q1a, shows that the full mark for question 1a is 1.5. If the student answers correctly with no mistakes, the student is given the code 'c' for that question and hence the marks awarded will be 1.5. If the students makes a major mistake in answering the question or if the students answers incorrectly then the student is given a code of mje or I respectively and the marks awarded is 0.

QUESTION 1

Q1 a	Marks out of - 1,5
1.5	C
1	mie
0,5	Ce
0	mje, i

Q1 b	Marks-1,5
1.5	c
1	mie
0,5	ce
0	mje, i

Q1 b	Marks-1,5
1.5	C
1	mie
0,5	ce
0	mje, i

QUESTION 2

Q2 a	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

Q2 b	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Q2 c	Marks-4
4	c
3 - 3,5	mie
2 - 2,5	ce
1 - 1,5	mje
0	i

QUESTION 3

Q 3	Marks-6
6	c
4 - 5	mie
2 - 3	ce
1 - 1,5	mje
0	i

QUESTION 4

Q 4 a	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

Q4 b	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

QUESTION 5

Q 5 a	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

Q 5 b	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

QUESTION 6

Q6 a	Marks-4
4	c
3 - 3,5	mie
2 - 2,5	ce
1 - 1,5	mje
0	i

Q 6 b	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

Q 6 c	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

QUESTION 7

Q 7 a	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

Q 7 b	Marks-1
1	c
0,5	ce
0	i

Q 7 c	Marks-1
1	c
0,5	ce
0	i

Marking Key: FORMATIVE ASSESSMENT – 2

Marking Key

c - Explanation completely correct

mie - Explanation contains minor errors

ce - Explanation contains considerable errors

mje - Explanation contains major errors

I - Explanation completely incorrect

QUESTION 1

Q1	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

QUESTION 2

Q 2	Marks-6
6	C
4 - 5	Mie
2 - 3	Ce
1 - 1,5	Mje
0	I

QUESTION 3

Q3	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

QUESTION 4

Q4.1	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q4.2	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

QUESTION 5

Q 5	Marks-3
3	C
2 - 2,5	Mie
1,5	Ce
0,5 - 1	Mje
0	I

QUESTION 6

Q6.1	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q6.2	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

QUESTION 7

Q7.1	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
0,5 - 1,5	Mje
0	I

Q7.2	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
0,5 - 1,5	Mje
0	I

QUESTION 8

Q 8	Marks-5
5	C
3 - 4	Mie
2 - 2,5	Ce
0,5 - 1,5	Mje
0	I

QUESTION 9

Q9	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
0,5 - 1,5	Mje
0	I

QUESTION 10

Q10 a	Marks-1
1	C
0,5	Ce
0	I

Q10 b	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Q10 c	Marks-1
1	C
0,5	Ce
0	I

Q10 d	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Marking Key: Summative Assessment

Marking Key

c - Explanation completely correct

mie - Explanation contains minor errors

ce - Explanation contains considerable errors

mje - Explanation contains major errors

I - Explanation completely incorrect

QUESTION 1

Q1.1 a	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q 1.1 b	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 – 1	mje
0	i

Q 1.1 c	Marks-1
1	c
0,5	ce
0	i

Q 1.1 d	Marks-3
3	C
2 - 2,5	Mie
1,5	Ce
0,5 – 1	Mje
0	I

Q 1.1 e	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Q 1.1 f	Marks-2
2	c
1,5	mie
1	ce
0,5	Mje
0	I

Q 1.1 g	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

QUESTION 2

Q 2.1 a	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q 2.1 b	Marks-4
4	c
3 - 3,5	mie
2 - 2,5	ce
1 - 1,5	mje
0	i

Q 2.1 c	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

Q 2.2.1	Marks-7
7	C
4 - 6	Mie
2,5 - 3,5	Ce
0,5 - 2	Mje
0	I

Q 2.2.2	Marks-1
1	c
0,5	ce
0	i

Q 2.2.3	Marks-1
1	C
0,5	Ce
0	I

Q 2.2.4	Marks-1
1	C
0,5	Ce
0	I

QUESTION 3

Q 3.1.1	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q 3.1.2	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Q 3.1.3	Marks-7
7	c
4 - 6	mie
2,5 - 3,5	ce
0,5 - 2	mje
0	i

Q 3.1.4	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q 3.1.5	Marks-1
1	c
0,5	ce
0	i

QUESTION 4

Q 4.1.1	Marks-1
1	C
0,5	Ce
0	I

Q 4.1.2	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

Q 4.1.3	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

Q 4.2	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

Q 4.3.1	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q 4.3.2	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Q 4.3.3	Marks-3
3	c
2 - 2,5	mie
1,5	ce
0,5 - 1	mje
0	i

Q 4.3.4	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

QUESTION 5

Q 5.1.1	Marks-4
4	C
3 - 3,5	Mie
2 - 2,5	Ce
1 - 1,5	Mje
0	I

Q 5.1.2	Marks-7
7	c
4 - 6	mie
2,5 - 3,5	ce
0,5 - 2	mje
0	i

Q 5.1.3	Marks-1
1	c
0,5	ce
0	i

Q 5.1.4	Marks-1
1	C
0,5	Ce
0	I

Q 5.2	Marks-3
3	C
2 - 2,5	Mie
1,5	Ce
0,5 - 1	Mje
0	I

Q 5.2.1	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Q 5.2.2	Marks-2
2	c
1,5	mie
1	ce
0,5	mje
0	i

Q 5.2.3	Marks-2
2	C
1,5	Mie
1	Ce
0,5	Mje
0	I

Q 5.3	Marks-9
9	C
6 - 8	Mie
3 - 5,5	Ce
0,5 - 2,5	Mje
0	I

APPENDIX J – ETHICS CONFIDENTIALITY AND INFORMED CONSENT FORM

IN LUMINE TUO VIDEBIMUS LUMEN

University of Fort Hare
Together in Excellence

Ethics Research Confidentiality and Informed Consent Form

Please note:

This form is to be completed by the researcher as well as by the interviewee before the commencement of the research. Copies of the signed form must be filed and kept on record

I (Mr V Kumar) request the students from your class in the department of Electrical Engineering to take part in a study using Guided Enquiry Based Learning (GEBL) as a method of teaching and learning for Power Electronics course. I will be assisted by a colleague who is qualified to carry out this study.

The research is to assess the impact of this teaching and learning method in the enhancement of critical thinking ability and the understanding of Power Electronics concepts.

Please understand that you are not being forced to take part in this study and the choice whether to participate or not is yours alone. However, we would really appreciate it if you do share your thoughts with us. If you choose not take part in answering these questions, you will not be affected in any way. If you agree to participate, you may stop me at any time and tell me that you don't want to go on with the interview. If you do this there will also be no penalties and you will NOT be prejudiced in ANY way. Confidentiality will be observed professionally.

I will not be recording your name anywhere on the questionnaire and no one will be able to link you to the answers you give. Only the researchers will have access to the unlinked information. The information will remain confidential and there will be no "come-backs" from the answers you give.

Once we have completed our study we shall inform you and your class of what the results are and discuss our findings and proposals around the research and how this study might assist other learners in the university.

INFORMED CONSENT

I hereby agree to participate in this research where GEBL will be used as a method of teaching and learning. I understand that I am participating freely and without being forced in any way to do so. I also understand that I can stop this interview at any point should I not want to continue and that this decision will not in any way affect me negatively.

I understand that this is a research project whose purpose is not necessarily to benefit me personally.

I have received the telephone number of a person to contact should I need to speak about any issues which may arise in this interview.

I understand that this consent form will not be linked to the questionnaire, and that my answers will remain confidential.

I understand that if at all possible, feedback will be given to my community on the results of the completed research.

Name of participant

…………………………………………………………..

……………………………..

Signature of participant **Date**:…………………..

……………………………..

Signature of Researcher **Date**:………………….

APPENDIX K – CERTIFICATE OF LANGUAGE EDITING

20 Neale Road

Berea

East London 5241

R Thomas

19 June 2018

TO WHOM IT MAY CONCERN

CERTIFICATE OF LANGUAGE EDITING

Title of thesis : The effect of a Guided Enquiry Based Learning Approach on Electrical Engineering students' conceptual understanding, problem solving skills and critical thinking ability in Power Electronics course

Student : Vinod Kumar

Student number : 201415921

Supervisor : Mammen KJ

Degree : Doctor of Philosophy(Education), Faculty of Education, University of Fort Hare

I confirm that the above thesis was checked for language and the suggestions for improvement have been implemented.

R Thomas

(MA- English)

APPENDIX L-a – AVERAGE PERCENTAGE SCORES OF FORMATIVE 1, FORMATIVE 2 AND SUMMATIVE ASSESSMENTS DURING 2016

Note: Under the 'column title' student number, 2016 refers to the year and S refers to student number-e.g, 2016-S1 refers to 2016 TTG student number 1.

Student Number	Formative 1 (%)	Formative 2 (%)	Summative (%)
2016-S1	52	18	22
2016-S2	66	64	38
2016-S3	68	68	34
2016-S4	52	60	35
2016-S5	60	74	51
2016-S6	46	54	52
2016-S7	52	44	32
2016-S8	82	78	51
2016-S9	66	42	40
2016-S10	76	64	51
2016-S11	54	44	52
2016-S12	62	66	57
2016-S13	62	66	37
2016-S14	72	40	56
2016-S15	76	50	53
2016-S16	60	62	50
2016-S17	60	68	41
2016-S18	68	76	63
2016-S19	58	78	53
2016-S20	50	58	40
Total	1242	1174	908
Average	**62,1**	**58,7**	**45,4**

APPENDIX L-b – AVERAGE PERCENTAGE SCORES OF FORMATIVE 1, FORMATIVE 2 AND SUMMATIVE ASSESSMENTS DURING 2017

Note: Under the 'column title' student number, 2017 refers to the year and S refers to student number-e.g, in the first table 2017-S1 refers to 2017 TTG student number 1. Similarly in the second table, 2017-S1 refers to GEBL student number 2017 GEBL student number 1.

Traditional Group			
Student Number	**Formative 1 (%)**	**Formative 2 (%)**	**Summative (%)**
2017-S1	60	45	58
2017-S2	29	50	52
2017-S3	47	62	37
2017-S4	35	26	40
2017-S5	53	32	13
2017-S6	83	51	62
2017-S7	37	33	47
Total	344	299	309
Average	**49.14**	**42.71**	**44.14**

GEBL Group			
Student Number	**Formative 1 (%)**	**Formative 2 (%)**	**Summative (%)**
2017-S1	52	53	54
2017-S2	67	58	44
2017-S3	51	39	31
2017-S4	77	39	32
2017-S5	76	76	60
2017-S6	80	59	57
2017-S7	85	49	58
Total	488	373	336
Average	**69.71**	**53.29**	**48**