A framework for advanced Information Communication Technologies integration within Higher Education Engineering Graphics and Design to improve spatial visualization

AC Kemp

orcid.org/0000-0002-5335-262X

Thesis accepted for the degree *Doctor of Philosophy* in *Curriculum Studies* at the North-West University

Promoter: Prof C Van Der Westhuizen

Graduation: May 2020

Student number: 25311697

DECLARATION

I the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature

Date: 25.11.19

ACKNOWLEDGMENTS

First and foremost, my thanks go to my heavenly Father for giving me the strength to complete this study.

I would furthermore, like to express my sincere appreciation to the following people:

- Francelle, my wife, thank you for your love, prayers, patience and continuous support.
- Prof Christo van der Westhuizen, who undertook to act as my supervisor despite his many other academic, managerial and professional commitments and who encouraged and supported me throughout the study.
- Dr Adri du Toit and Dr Coenraad Jurgens, who acted as critical readers, many thanks for your responses during this study. Mr Johan Coetzee, who acted as a co-coder in our niche Engineering Graphics and Design field.
- Prof Suria Ellis, for helping and assisting me in the quantitative data analysis and Dr Nicole Claasen for helping and assisting me with the qualitative data analysis in ATLAS.ti.
- Mom and Dad, for your never-ending love, prayers, phone calls, messages and encouragement.
- GP, my brother, for your moral support and phone calls.
- All my students and student assistants, for your interest and continuous support.

ABSTRACT

The purpose of the study was to discover and define the impact of subject-specific advanced information communication technologies as a medium for the teaching and learning of Engineering Graphics and Design in higher education in order to enhance students' understanding of sectioned mechanical assembly drawings while improving spatial visualization. Furthermore, students' self-directed learning skills were determined and advanced information communication technologies were implemented to improve students' self-directed learning skills while using information communication technologies.

Taking into consideration the different needs of Engineering Graphics and Design student teachers during the facilitation of teaching and learning, the primary aim is to describe a suitable framework to foster spatial visualization skills, self-directed learning skills and information communication technology skills with the integration of advanced information communication technologies in Engineering Graphics and Design within higher education.

A mixed-methods action research methodology, based on Norton's five action research steps, aligned with Whitehead and McNiff's action plan, was employed in the study. A combined qualitative and quantitative research methodology was followed to explore and describe how to improve the teaching and learning of Engineering Graphics and Design by means of action research. The study was guided by the interpretivist/constructivist paradigm to improve student teachers' understanding of sectioned mechanical assembly drawings while using information communication technology and improving their spatial visualization skills, self-directed learning skills and information communication technology skills as the foundation of the study.

Key terms: Engineering Graphics and Design (EGD); information communication technology (ICT); sectioned mechanical assembly drawings; self-directed learning skills; spatial visualization skills.

OPSOMMING

Die doel van die studie was om die impak van vakspesifieke gevorderde inligtingskommunikasietegnologieë as ŉ medium vir die onderrig en leer van Ingenieursgrafika en -ontwerp in hoër onderwys te ontdek en te definieer ten einde studente se begrip van meganiese snittekeninge te verhoog deur die verbetering van ruimtelike visualisering. Verder is studente se selfgerigte leervaardighede bepaal en gevorderde inligtingskommunikasietegnologieë is geïmplementeer om studente se selfgerigte leervaardighede te verbeter deur die gebruik van inligtingskommunikasietegnologieë.

Met inagneming van die verskillende behoeftes van Ingenieursgrafika en Ontwerp-studenteonderwysers tydens die fasilitering van onderrig en leer, is die hoofdoel om ŉ geskikte raamwerk te voorsien om ruimtelike visualiseringsvaardighede, selfgerigte leervaardighede en vaardighede met betrekking tot inligtingskommunikasietegnologie deur die integrasie van gevorderde inligtingskommunikasietegnologieë in Ingenieursgrafika en -ontwerp binne hoër onderwys te verbeter.

ŉ Gemengde-metode-aksienavorsingsmetodologie, gebaseer op Norton se vyf aksienavorsingstappe wat in lyn is met Whitehead en McNiff se aksieplan, is in die studie aangewend. ŉ Gekombineerde kwalitatiewe en kwantitatiewe navorsingsmetodologie is gevolg om die onderrig en leer van Ingenieursgrafika en -ontwerp deur middel van aksienavorsing te ondersoek en te beskryf. Die interpretivistiese of konstruktivistiese paradigma het die navorsing gerig om studenteonderwysers se begrip van meganiese snittekeninge te verbeter deur die gebruik van inligtingskommunikasietegnologie en die verbetering van hul ruimtelike visualiseringsvaardighede, selfgerigte leervaardighede en vaardighede met betrekking tot inligtingskommunikasietegnologie as die basis van die studie.

Sleutelterme: Ingenieursgrafika en -ontwerp; inligtingskommunikasietegnologie; meganiese snittekeninge; ruimtelike visualiseringsvaardighede; selfgerigte leervaardighede.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

2D:	Two Dimensional
3D:	Three Dimensional
CAD:	Computer-Aided Design
CAM:	Computer-Aided Manufacturing
CAPS:	Curriculum Assessment Policy Standards
EGD:	Engineering Graphics and Design
FET:	Further Education and Training
ICT:	Information Communication Technology
ICTs:	Information Communication Technologies
LMS:	Learning Management Systems
PAT:	Practical Assessment Task
SANS:	South African National Standard
SDL:	Self-Directed Learning

CHAPTER 1: ORIENTATION AND OVERVIEW OF THE STUDY

1.1 Introduction to the research problem

In engineering circles, Engineering Graphics and Design (EGD) is a means of communicating graphically (Khoza, 2017; Rust, 2017). EGD focuses on the correct use of drawing tools and drawing equipment, drafting media, freehand sketching, lettering, different categories of lines, geometric constructions, computer-aided drawing and multiview drawings (Carey, 2017; Shariffudin, Lee & Othman, 2006). The subject EGD furthermore educates internationally recognised principles that have both academic and technological applications (Davies & Yarwood, 1986; Lieu & Sorby, 2015; Rust, 2017; van As, 2018). It is important in EGD to teach specific knowledge, various drawing techniques and skills to provide the EGD student teacher with the ability to interpret, understand and produce different drawings within the contexts of Mechanical Technology, Civil Technology and Electrical Technology (Department of Basic Education, 2011). In order to effectively teach the subject EGD in South African schools, student teachers therefore need to be prepared in a similar manner.

Student teachers who wish to teach EGD can obtain a qualification for this in the form of a BEd degree at several universities across South Africa such as the University of the North West, University of the Free State and the University of Pretoria. Student teachers who enrol for EGD as a major subject in the BEd degree should not only have the specific knowledge and drawing skills to produce the required drawings but also need spatial visualization skills to create, interpret and understand different drawings, which improve critical thinking skills, modelling and the ability to solve problems (Carey, 2017; Constantine, 2017; Ottway; Serdar & Harm de Vries, 2015). They also need to develop the ability to visualize how parts fit together, how to draw a component that is sectioned and how to change a drawing from a two-dimensional (2D) view to a three-dimensional (3D) view.

As a lecturer of EGD in higher education for the past 14 years, I identified a specific type of drawing student teachers struggle with most, namely sectioned mechanical assembly drawings. While talking to EGD colleagues with years of experience in the field, having open discussions with student teachers in the EGD classroom during contact sessions and reading literature on the topic (Branoff & Dobelis, 2012; Khoza, 2013; Wang, Chang & Li, 2006), the problem of student teachers struggling with sectioned mechanical assembly drawings repeatedly surfaced. Student teachers struggle with multiview drawings, specifically mechanical assembly drawings, where they have to draw different machine components together and section this fully combined drawing. The reason for this is mainly because of students' poor understanding of spatial visualization and spatial perception (Khoza, 2013; Sharma & Dumpala, 2015). My study aimed to identify the challenges student teachers experience with 2D and 3D assembly drawings as well as the sectioning of these drawings.

Open discussions with student teachers and EGD colleagues furthermore led me to the conclusion that student teachers struggle with these drawings because of the complexity of the drawings. The reason why these drawings are seen as complex is because student teachers have to use critical thinking and problem-solving techniques, such as integrated design communication, to create a set of working drawings to solve the problem (Adams & Turner, 2008; Bertoline, Wiebe, Hartman & Ross, 2010). I am of the opinion that EGD on secondary and tertiary education level focuses only on the drawing part and not the practical application of how the drawings relate to the industries where these items are made. It is easy to tell a student to draw the fully assembled drawing of a crane hook assembly (see Figure 1-1), trailer wheel assembly or crank assembly; however, most students have never seen these machine components or worked with them before. Figure 1-1 displays three different views, namely an exploded view in 3D, an assembled 3D view and an assembled 2D view.

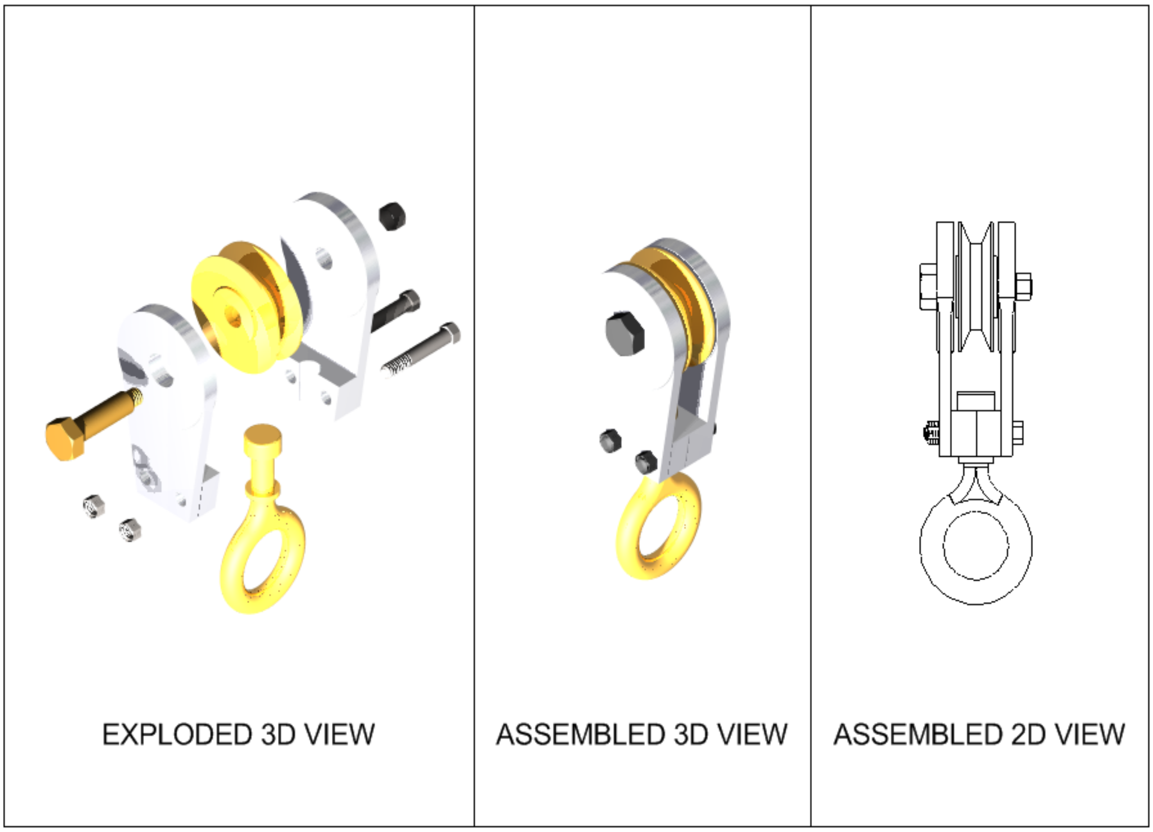


Figure 1-1: Exploded 3D view, assembled 3D view and assembled 2D view of a crane hook assembly (Author).

Figure 1-1 displays different 3D and 2D views of a crane hook assembly. An EGD lecturer can teach student teachers the theoretical part of the crane hook, for example, that there should be a bearing or a bush around the shaft. Furthermore, the EGD lecturer can teach the student teachers how to read or analyse a drawing to determine which radius or diameter corresponds with which component in order to fit onto each other. It is, however, still difficult for students to understand how the components fit together without seeing the actual machine part or having the opportunity to try and fit all the components together using trial and error. Not all tertiary institutions offering EGD have real examples for the student teachers to actually see how the components fit together (Sharma & Dumpala, 2015). A textbook is limited in helping student teachers to understand the complexity of mechanical assembly drawings, which implies that students need a 3D model to help them understand these drawings (Khoza, 2013). Spatial visualization has been shown to be important in the engineering fields and Technology classes (Alqahtani, Daghestani & Ibrahim, 2017). The use of

3D printed models with guidance from the lecturer during the session is an effective method for improving students' spatial visualization skills (Alqahtani *et al.*, 2017; LeBow, Bernhardt-Barry & Datta, 2018).

According to Fleisig, Robertson and Spence (2004), Khoza (2017); Singh-Pillay and Sotsaka (2017), there are different methods of improving spatial visualization skills in EGD, namely sketching, physical models and computer graphics. In addition to these methods, the theoretical component of improving spatial visualization is important too and determines that EGD consists of the technical rules, drawing conventions and visual skills to understand and create a drawing (Makgato, 2015; Olkun, 2003). In South Africa, these are prescribed for educators and students, as well as trained draughtsmen, in the form of the South African National Standard (SANS) (2011) for EDG principles (SANS 10111-1). According to these technical rules and drawing conventions, student teachers' spatial visualization needs to be developed. Mohler and Miller (2009) found that sketching and drawing activities improved spatial visualization in a positive way. This is supported by studies done on the importance of sketching to improve spatial visualization (Alias, Black & Gray, 2002; Contero, Naya, Company, Saorín & Conesa, 2005; Gorska, Leopold, Sorby & Shiina, 1998; Leopold, Gorska & Sorby, 2001; Lieu & Sorby, 2015; Orde, 1996; Rodriguez & Rodriguez-Velazquez, 2017). Katsioloudis and Jovanovic (2014) found that physical models, such as a 3D printed model, have the ability to improve spatial visualization, since a 3D printed model gives the student teacher a better understanding of the drawing that is taught. Newton, Alemdar, Hilton, Linsey and Fu (2018); Sharma and Dumpala (2015) state that computer graphics software such as CAD is used intensively for drawing, designing and developing different machine components. Using computer graphics in EGD brings precision in understanding the difficult theories in the engineering fields accurately and correctly because of the ease it offers in the development of spatial visualization among students. In fact, 2D and 3D CAD play a fundamental and essential role in supporting students gaining an in-depth understanding of EGD (Brown & Jayaram, 2013; Constantine, 2017).

Therefore, the lecturer needs to lead student teachers to use all four of the above-mentioned methods (i.e. sketching, physical models, computer graphics and the theoretical component) to improve their spatial visualization. However, as there is a time limit to complete the EGD teacher training module, it is important that EGD student teachers become self-directed learners in using their own initiative and taking responsibility for their own learning (Carey, 2017; James-Gordon & Bal, 2003; Newton *et al.*, 2018; Tolmay, 2017) while concurrently developing their self-visualization skills.

During the past years of using advanced information communication technology (ICT), specifically 2D and 3D CAD, I realised that it was easier to draw all of the different components of a machine assembly drawing and then fit them together like puzzle pieces. Thus, using ICT might help student teachers to better understand mechanical assembly drawings. ICT include various technological instruments and essential resources that improve not only communication but also disseminating, storing and managing information (Blurton, 2002; Carey, 2017; Carmona & Marin, 2013; Newton *et al.*, 2018). In addition, Beyers (2009) and (Tolmay, 2017) declare that there is a need to transform education from an educator-centred to a student-centred model, which they believe can be attained by empowering educators to encourage students through the integration of modern ICTs into all aspects of the learning process. Similarly, but along an expanded line, UNESCO (2011:7) and Kelentrić, Helland and Arstorp (2018) have identified three levels of ICT competencies that should be implemented specifically in teacher education:

- Understanding the technologies and integrating technological competencies in the curriculum (first level: technology literacy).
- Using these competencies in order to apply knowledge to solve complex and real problems (second level: knowledge deepening).
- Producing and subsequent leveraging of new knowledge (third level: knowledge creation).

Considering these levels of ICT competencies, student teachers' technological literacy should be expanded, their knowledge should be deepened and enhanced and their knowledge creation should improve in the study because of the implementation of ICT in the EGD module. Using advanced ICTs should improve the teaching of EGD as well as the student teachers' understanding of mechanical assembly drawings and their drawing skills, ICT skills, spatial visualization skills and SDL skills. The different advanced ICTs commonly used in EGD are CAD technologies, which are divided into

2D and 3D CAD software, and additive manufacturing technologies such as 3D printing and 3D animation (Hidayat, Hadi, Basith & Suwandi, 2018; Katsioloudis & Jovanovic, 2014; Kubheka, 2018; Kuna, Hašková, Skačan & Záhorec, 2018; Ottway; Webster, 2017). When this CAD software is used, it ultimately improves student teachers' spatial visualization skills (Fleisig *et al.*, 2004; Newton *et al.*, 2018; Rodriguez & Rodriguez-Velazquez, 2017).

The students currently in my class, studying to be EGD teachers, are all categorised as belonging to the so-called Generation Z. Generation Z consists of people born after 1995, who have never had a day without the use of the Internet, computers and cellular phones (Elston-Jackson, 2011; Ivanova & Smrikarov, 2009). Therefore, these student teachers enrolled for EGD are the Z-generationers who are more dependent on ICT than their predecessors, as they need the use of computers and other ICT means in all the different areas of their lives (Kumpikaite-Valiuniene, 2016). Taking into consideration that Generation Z students are dependent on ICT, they should probably connect better to benefit from advanced ICTs such as 2D or 3D CAD, 3D animation and 3D printing while learning. In an effort to foster the effective teaching of EGD through the utilisation of suitable advanced ICTs to promote and improve students' spatial visualization of sectioned mechanical assembly drawings, it would be important to develop a framework to structure and guide this process.

1.2 Keywords and clarifications

1.2.1.1 Engineering Graphics and Design

Engineering Graphics and Design (EGD) is a graphical language being used universally by engineers, educators and draughters to comprehend different technical concepts and ideas, such as the form and size of structures and mechanical objects. Furthermore, EGD is a subject that educates internationally recognised principles that have academic and technological applications. The emphasis in EGD is on teaching and learning subject-specific knowledge and different methods of drawing and sketching. Furthermore, skills should be obtained so that the EGD student teacher will be able to interpret, understand and produce drawings within the contexts of Mechanical Technology, Civil Technology and Electrical Technology (Department of Basic Education, 2011; Khoza, 2017; Niemann, 1976).

1.2.1.2 Computer-aided design

Computer-aided design (CAD) is the use of computer technology during the process of design and the recording of designs. Architects, draughters, engineers, artists and educators use CAD programs to do different drawings and designs. CAD can be divided into 2D and 3D CAD, where 2D CAD is used to draw 2D drawings and is primarily used for orthographic drawings, while 3D CAD is used to draw a model where all the planes are visible when the model is rotated (Allen & Kouppas, 2012; Lieu & Sorby, 2015; Rust, 2017; Viljoen, 2014).

1.2.1.3 Information and communication technology

Information and communication technology (ICT) is an umbrella term that refers to a diverse set of technological tools and resources used to communicate, create, disseminate, manage and store information through the use of different technologies, such as computers, the Internet and electronic delivery systems, such as radios, televisions, phones and projectors. These technologies are currently used to enhance learning opportunities and allow access to educational resources (Blurton, 2002; Geiler, 2014; Malan, 2014; Mbam, 2017; Rambrij, 2018; Victor & Bolanle, 2017). Advanced ICT in this study refers to 2D or 3D CAD, 3D animation and 3D printing.

1.2.1.4 Constructivism

Constructivism accentuates that students construct knowledge and meaning with their own activities during teaching and learning, which is not a matter of communicating but of engaging students in active learning. Furthermore, it builds upon their knowledge in terms of what they already understand (prior knowledge) and the connection to the new knowledge they still have to obtain (Biggs & Tang, 2011; Reuter, Hauser, Gold-Veerkamp, Mottok & Abke, 2017; Srivastava & Dangwal, 2017; Van der Poll, Van der Poll & Andrew, 2018; Wilson, 2017).

1.2.1.5 Spatial visualization

Spatial visualization is the ability to visualize, manipulate, rotate, twist or invert images in three dimensions (Hendroanto, Van Galen, Van Eerde, Prahmana, Setyawan & Istiandaru, 2017; Huang and Lin, 2017; Lieu and Sorby, 2015; Patanasakpinyo, Batinov, Whitney, Sulaiman & Miller, 2019; Serdar and Harm de Vries, 2015). It is seen as a cognitive skill that can be associated with success in technical education. Spatial visualization skills are important to enhance an EGD student's ability to create and understand technical drawings, which is essential in higher cognitive thinking, designing and problem solving. The ability to understand important topics in EGD, such as first- and third-angle orthographic projection drawings, axonometric drawings, sectional drawings and mechanical assembly drawings, is critical, as it represents the fundamentals of EGD education.

1.2.1.6 Self-directed learning

Knowles (1975:18) describes self-directed learning as a process "in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes".

1.3 Review of existing scholarship

Technology is rapidly changing in the classroom and technology is furthermore changing the way educators apply teaching in the classroom (Gilakjani, Lai-Mei, Ismail & Science, 2013; Kubheka, 2018; Victor & Bolanle, 2017). Grasso and Burkins (2010) state that educators nowadays attempt to educate 21st-century students with a 20th-century curriculum taught in a 19th-century institution. From their statement and considering the particular need of Generation Z students currently in our classrooms, it is evident that this situation requires being addressed. Four topics formed the foundation for the research reviewed in the study. The first topic aims to determine the correlation between constructivism and ICT in the EGD classroom (see Section 3.6). The second topic aims to determine the general advantages of ICT integration within EGD (see Section 2.6.1 and 6.2.2). Thirdly, the educational challenges and barriers for teaching and learning EGD while using ICT are discussed (see Section 2.6.2). Lastly, the South African secondary and tertiary curriculums of offering EGD are discussed (see Section 2.3.2).

1.3.1 Constructivism and ICT in the EGD classroom

According to Chaudhary and Nagar (2018); Coupal (2004); Lubis (2018); Van der Poll *et al.* (2018), ICT education is profoundly influenced by constructivism, since it promotes positive interaction skills among students and improves the self-facilitation of their own knowledge and skills in a more meaningful way which correlates with the Self-directed learning where a student is responsible for directing his or her own learning (Davis, Bailey, Nypaver, Rees & Brockett, 2010). The basic concept of constructivism is that knowledge must be structured and constructed by the student teacher and cannot only be delivered by the lecturer (Dang, 2018; Holzer, 1994; Kosnik, Menna, Dharamshi & Beck, 2018; Valls, Black & Lee, 2019). The construction of knowledge and skills is an active process that requires continuous commitment from student teachers who will be responsible for their own learning while the educator only creates an effective teaching and learning environment (Buwono & Ciptaningrum, 2019; Kharade & Thakkar, 2012; Matluba, Gulruh & Yuldasheva, 2019; Melovitz-Vasan, Gentile, Huff & Vasan, 2018; Naade, Alamina & Okwelle, 2018; Ranjan; Sujanem, Poedjiastuti & Jatmiko, 2018). Constructivism as a learning theory describes the student as an individual who actively composes his or her own ways of reasoning as a result of his or her own knowledge, understanding, skills and learning experiences (Buwono & Ciptaningrum, 2019; Killen, 2009; Matluba *et al.*, 2019; Spady, 2001). The integration of ICT in the EGD classroom should enhance the student teacher to construct his or her own knowledge, skills and understanding of sectioned mechanical assembly drawings, while the educator's role is to create an effective learning environment.

1.3.1.1 The educator's role in a constructivist class environment

Many educators (e.g. Brooks and Brooks (2001); Liu and Zhang (2018); Olakunle (2018); Tambaoan and Gaylo (2019) suggest that five norms are evident in the constructive classroom. These are as follows:

- The educator should seek, value and encourage the student teachers' point of view.
- Classroom activities should challenge student teachers' knowledge, skills and understanding.

- The educator should engage student teachers in experiences that would enhance their problem-solving skills.
- The educator should build a lesson around primary concepts and lead student teachers to distinguish for themselves which parts require more research.
- The educator should assess student teachers' learning continuously on a day-to-day basis instead of a once-off assessment.

The above-mentioned norms should be integrated (see Chapter 5) into the ICT or EGD classroom to enhance constructivism in the classroom in order to improve the spatial visualization of the students.

1.3.1.2 General advantages of ICT integration within EGD to improve spatial visualization

The advantages of ICT integration in education are recognised worldwide (Abdalla, 2018; Halili & Sulaiman, 2018; Kostikova, 2018; Ramadan, Chen & Hudson, 2018; UNESCO, 2011). ICT contributes to higher levels of student participation, the globalisation of the 21st-century education, enhancing the teaching and learning process, promoting higher-order thinking and improving problem-solving skills (Abdalla, 2018; Dhakal, 2018; Mazana, Montero & Oyelere, 2019; Olowookere & Iyiola, 2018; Oviawe, 2016; Rabah, 2015). Feng, Ahmed and Mahdjoubi (2003); Onana and Ancha ; Sampaio (2019) describe four distinct advantages when integrating ICT and EGD to improve spatial visualization:

- The World Wide Web search engines allow student teachers to access information at any time or place.
- Virtual presentations of EGD models promote the motivation of student teachers to enhance spatial visualization skills.
- Virtual models with machine connections offer a more applicable representation of real physical models.
- New technology, such as 3D models and 2D drawings, provides considerable flexibility to systemise and modify drawings.

According to the literature, the integration of ICT and EGD is important in enhancing spatial visualization among EGD students.

1.3.2 Educational challenges and barriers in teaching and learning EGD while using ICT

The new era of the Internet and the rapid changes and advancement in computer technology are forcing the education environment to change as well (Feng *et al.* (2003); Khomo (2018); Kruger (2018); Muslem, Yusuf and Juliana (2018). To ensure the improvement of spatial visualization skills among CAD students in the education fields, the main change required is the use of advanced ICTs in education that may influence spatial visualization skills. Thus it is important to promote educational tools to improve spatial abilities.

Using ICT as a medium of teaching and learning brings forth some challenges and barriers, which should be overcome to implement ICT in EGD properly. Ghavifekr *et al.* (2016); Kruger (2018); Oviawe (2016) describe different challenges when implementing ICT:

- A lack of support from educational institutions.
- Inconsistent investments in equipment, infrastructure and resources.
- A lack of funding.
- The need to integrate technology into the curriculum.

According to the Department of education (2004), every South African student in the General, Further and Higher Education and Training bands should be ICT-efficient. Students should be able to use ICT with confidence and creativity. This would help students to develop the essential skills and knowledge they need to succeed in their personal goals and gains. Furthermore, they should have been participating in the global ICT community by 2013 (Department of Education, 2004). In informal group discussions with the EGD first-year students in 2018, it was ascertained that only five of the 70 students had done CAD in EGD in the FET Phase. So, unfortunately, it seems that the Department of Basic Education has failed to implement the use of ICT in the General and the Further Education and Training bands in all school subjects. These challenges and barriers contribute to the current shortage of ICT integration in EGD education.

1.3.3 The South African EGD curriculum context

According to the Department of Basic Education (2011), the subject EGD as part of the FET Phase provides the fundamental knowledge and drawing skills required for learners to prepare them for a wide selection of potential career opportunities. These are listed in Table 1-1, as stated in the EGD Curriculum Assessment Plan.

Table 1-1: Career opportunities for EGD practitioners.

Mechanical fields	Civil fields	Electrical fields	Designing fields
Mechanical engineering	Civil engineering	Electrical engineering	Industrial designer
Draughtsperson	Architecture	Draughtsperson	Interior designer
Educator	Landscape architect	Educator	Graphic illustrator
CAD system operator	Quantity surveyor	CAD system operator	Jewellery designer
Boilermakers	Building management		Educator
Welders	City planner		CAD system operator
	Land surveyor		
	Draughtsperson		
	Educator		
	CAD system operator		

Table 1-1 shows that all of the above-mentioned careers would benefit from learners and students with improved ICT skills and spatial visualization skills, specifically CAD, 3D printing and 3D animation. Table 1-2 shows the career opportunities student teachers may obtain when studying in the field of technology on tertiary level.

Table 1-2: Career opportunities for Technology teachers studying towards a BEd degree.

Technology teachers in the FET Phase			
Engineering Graphics and Design	Mechanical Technology	Civil Technology	Electrical Technology

It is evident from Table 1-2 that the Technology student teacher who registers for a BEd degree in the FET phase has the choice to become an EGD, Mechanical Technology, Civil Technology and Electrical Technology teacher. If the student teacher wants to specialise in Mechanical, Civil or Electrical Technology, it is a prerequisite for the student teacher to take EGD as a four-year module as well (North-West University, 2019). In all four FET Technology subjects, the student teacher would benefit from this study by improving his or her ICT skills and spatial visualization skills, specifically CAD, 3D printing and 3D animation, and implementing these on secondary education level.

1.4 Statement of the problem and research questions

The purpose of the study was to discover and define the impact of subject-specific advanced ICTs as a medium for the teaching and learning of EGD in higher education in order to improve students' understanding of sectioned mechanical assembly drawings while improving ICT skills, spatial visualization skills and SDL skills. The following primary research question and secondary research questions guided the investigation to enhance students' ability to understand sectioned mechanical assembly drawings while using advanced ICTs.

1.4.1 Primary research question

Taking into consideration the different needs of EGD student teachers during the facilitation of teaching and learning, the study was guided by the following primary research question (see Table 1-4 in Section 1.14):

How can the implementation of advanced information and communication technologies, such as 2D or 3D CAD, 3D animation and 3D printing, improve spatial visualization and promote SDL in Engineering Graphics and Design in higher education environments?

1.4.2 Secondary research questions

In order to fully explore the primary research question, the following secondary research questions were addressed (see Table 1-4 in Section 1.14):

- What are the main advantages and barriers of using ICT in EGD education globally and in South Africa?
- To what extent are ICTs being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education?
- To what extent do advanced ICTs enhance the spatial visualization and SDL skills of students?
- How can ICT and spatial visualization skills be further developed to enhance EGD in higher education?
- What contributing suggestions made by student teachers, EGD lecturers and the researcher can assist in the development of a framework for advanced ICT integration in EGD to foster spatial visualization and SDL?

1.5 Research aim and objectives

The primary aim of the study was to describe a suitable framework to foster ICT skills, spatial visualization skills and SDL skills with the integration of advanced ICTs in EGD within higher education.

The research objectives were:

- to determine the main advantages and barriers of using ICT in EGD education globally and in South Africa;
- to determine to what extent ICTs are being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education;

- to discover to what extent advanced ICTs enhance spatial visualization and SDL skills;
- to discover how ICT and spatial visualization skills can be further developed to enhance EGD within higher education; and
- to propose a suitable framework for the implementation of advanced ICT integration in EGD to foster spatial visualization skills and SDL skills.

1.6 Research design, methodology and methods

1.6.1 Research design

A mixed method action research design based on Norton's five action research steps, aligned with Whitehead and McNiff's (2006a, 2006b) action plan as the focus of the study, was used. Furthermore, the study will be reported in the first person in order to focus on my personal reflection on improving my own teaching and learning, which is an integral part of the action research process (Taylor, Wilkie & Baser, 2006).

The five action research steps, as identified by Norton (2018:70), entail the following:

- Step 1: Identifying the problem
- Students struggle with sectioned mechanical assembly drawings.
- Step 2: Thinking of ways to take on the problem
- Improving student teachers' spatial visualization skills using ICTs in EGD.
- Step 3: Implementing ICT using the following technologies:
    - Animation
    - 2D CAD or 3D CAD
    - LMSs

      Software
    - 3D printing

      Hardware
- Step 4: Evaluating the research findings
- Step 5: Modifying my future practice in teaching EGD

Whitehead and McNiff's action plan entails answering the following questions, as set out in McNiff McNiff (2017:5):

- What issue am I interested in researching?
- Why do I want to research this issue?
- What kind of evidence can I gather to show why I am interested in this issue?
- What can I do? What will I do?
- What evidence can I gather that I am having an influence?
- How can I explain this educational influence?
- How can I ensure that any judgments I might make are reasonably fair and accurate?
- How will I change my practice with regard to my evaluation?

The answers to Norton's steps and Whitehead and McNiff's action plan will help a student teacher to obtain ICT skills, spatial visualization skills and SDL skills while using ICTs in EGD (see Table 1-4 in Section 1.14). Before each chapter a logic was added to show which research question was answered by which chapter and which of Norton's steps or McNiff's questions were used to answer the research question.

1.6.2 Methodology

1.6.2.1 Mixed-methods action research

I used a mixed-method action research methodology (QUAL-quan) to explore and describe how the teaching and learning of EGD can be improved by means of action research (Creswell, 2008a). I employed the interpretivist/constructivist paradigm to enhance the student teachers' understanding of sectioned mechanical assembly drawings while using ICT and improving their spatial visualization skills as the foundation of the study (Mackenzie & Knipe, 2006; Plano Clark & Creswell, 2011). In doing so, I collected data by means of the following methods. Firstly, I did a conceptual study from the relevant literature (see Chapters 2 and 3). Unstructured interviews were conducted to explore existing problems and to identify whether the intervention had improved the students' understanding of sectioned mechanical drawings (see Section 6.2 and 6.3). The participants wrote pre-tests and post-tests so that their SDL technology skills could be explored and to ascertain whether any improvement in their spatial visualization abilities had been made after the intervention (see Section 6.3). Responses of the student teachers' perceptions of the use of ICT as well as my own observations during the intervention will add to the credibility, transferability, dependability and conformability of the study (see Section 6.2).

1.6.2.2 Qualitative techniques

Focus groups are group interviews that are used as a means of obtaining a better understanding of how individuals experience or contemplate different issues or problems (Johnson and Christensen (2017); Monette, Sullivan and DeJong (2005). Participants are selected according to their specific characteristics and features that relate to the issue at stake. Focus group interviews with EGD student teachers were used to substantiate the research problem. According to Maree (2016), an interview is a two-way communication method between the researcher and the participants to collect data and learn about their ideas, beliefs, views and attitudes. In the study, I furthermore focused on open-ended interviews with EGD drawing lecturers on tertiary level with at least five years of experience. An open-ended interview takes place in the form of a discussion with the intention of exploring the participant's views, ideas, beliefs and opinions about a particular phenomenon (Leedy, Ormrod & Johnson, 2019; Ormrod & Leedy, 2005). The participating EGD lecturers and student teachers might substantiate the research problem and propose solutions or provide insight into the problem of student teachers struggling with sectioned mechanical drawings.

Throughout the study, I kept written records of the action research cycle, reflection and evaluation, using an observation journal (McNiff, 2017; Whitehead & McNiff, 2006b). In my research journal (Addendum J), I documented the progress of the research, what was done and what I was doing during each lesson, as well as my opinions and views of and reflections on my teaching and learning in EGD. I also documented my progress in enhancing the student teachers' spatial visualization skills with the integration of advanced ICTs and EGD.

1.6.2.3 Quantitative techniques

Babbie (2010; 2016) describes a questionnaire as a set of documents containing questions or other kinds of items designed to request information appropriate for data analysis. According to De Vos, Delport, Fouché and Strydom (2011:186), the essential purpose of a questionnaire is to "obtain facts and opinions about a phenomenon from people who are informed on the particular issue". Different questionnaires can be used in research. In the study, I used self-administrated questionnaires. A colleague handed out the questionnaires to the students during classes and was available if they experienced any problems (De Vos *et al.*, 2011:188). The questionnaires were used to substantiate the research problem under study.

According to Maree (2016:215), pre- and post-testing as an instrument involves administering the instrument to the subjects on two (or more) occasions. "The first set of scores is then compared with the second set by calculating a correlation" (Maree (2016:215). In the study, the student teachers wrote a pre-test about mechanical assembly drawings, using only hand drawing equipment, which was regarded as the pre-test. Subsequently, the students used advanced ICTs with similar drawings, which were treated as the post-tests and compared to the pre-test drawings. Furthermore, the students created mechanical assembly drawings with sectioned views during the pre-test (Addendum G) and the post-test (Addendum H) to determine the students' understanding of these drawings and whether there was any improvement after the intervention (Chapter 5). I furthermore adapted and used the Self-Directed Learning with Technology Scale (SDLTS) (Timothy, Chee, Beng, Sing, Ling, Li & Mun, 2010). A self-directed learning questionnaire was used as a pre-test (Addendum E) to determine the students' SDL skills while using ICT and to establish whether these skills had improved during the intervention by using an SDL post-test (Addendum F).

1.7 Philosophical orientation

1.7.1 Research paradigm

In the study, an interpretivist/constructivist paradigm with a mixed-methods action research approach was followed (Mackenzie & Knipe, 2006; Plano Clark & Creswell, 2011). According to Creswell and Creswell (2018), the interpretive researcher relies on the participants’ viewpoint of what is being studied as well as the researcher’s own interpretation, background and experiences of the study.

According to (King, Horrocks & Brooks*,* 2018) and Guba and Lincoln (1994:108), ontology raises the following question: What is the nature of reality? In my study, the nature of reality was interpretivist/constructivist, as I discovered the reality through the participants’ views, my own background and experiences (Thanh & Thanh, 2015:24). As the educator, observer and researcher, I was part of the EGD milieu where the research was conducted. Since I wanted to change my teaching and learning practice in such a way that I might adopt the student teachers’ perception of the difficulty of sectioned mechanical assembly drawings, I was part of the study, and it was not possible to isolate myself from the student teachers’ environment. I, therefore, had to adopt a participatory approach in the study (Creswell, 2003; Creswell & Creswell, 2018).

(King *et al.*, 2018) and Guba and Lincoln (1994:108) build upon the epistemology by means of the following question: What is the nature of knowledge and the relationship between the knower and the would-be knower? The focus of epistemology can be described by the following questions: How do students interpret and recognise new knowledge? What knowledge is known to the students? And, importantly, how does the new knowledge become known by the students? As the researcher and educator, I was part of the study and therefore played an important role in supporting the student teachers in attaining and understanding new knowledge about EGD, ICT and spatial visualization. Furthermore, as the researcher, educator and observer, I had to construct my own knowledge of the EGD environment while reflecting on my teaching and learning in EGD. Thus, the interpretivist/constructivist ontology of the study would be influenced by the epistemology of the study.

The methodology of the research refers to the following question: How can the knower go about obtaining the desired knowledge and understanding? (Guba & Lincoln, 1994:108; Mertens, 1998:6). The methodology, furthermore, refers to how things are done during the research (Chapter 4). Consequently, the research methodology followed is influenced by the ontology and the epistemology (Mackenzie & Knipe, 2006). My experiences and understanding as an educator, researcher and observer would assist and support me in interacting with the EGD students while reflecting on the research having been done, which would assist in understanding the research design and methodology followed.

1.7.2 The role of the researcher

The role assigned to me as the researcher in the study entailed specific activities. Firstly, I carried out an in-depth literature review on the orientation of the study (see Chapters 1-3), the nature of EGD (see Section 2.2) and the challenges and barriers involved in teaching EGD using advanced ICTs (see Section 2.6.2) while improving spatial visualization skills between the EGD students and myself. While adhering to these activities, the anticipated outcome was to adapt EGD teaching as a possible best practice in the EGD education environment (see Figure 7.2 in section 7.2). Furthermore, I facilitated all of the EGD sessions during the research process. In these sessions, I made use of interviews and pre- and post-testing to collect data. I then examined and transcribed all of the interviews. Lastly, I analysed the qualitative data with ATLAS.ti, while the quantitative data were analysed by statistical services with the Statistical Package for Social Sciences (SPSS) version 24.

1.8 Sampling strategy

By choosing a mixed-methods action research methodology, the participants were included in the research as equal in status and worth, while I was included as an active participant in the research as part of the study throughout all stages of the research (Creswell, 2008a; Kemmis & McTaggart, 1988). The participants were selected according to predetermined criteria relevant to the research questions (Hays & Singh, 2011:170). The two types of sampling relevant to the research are convenience sampling and purposive sampling (Ormrod & Leedy, 2005). Cohen, Manion & Morrison (2011:155) define convenience sampling as “choosing the nearest individuals to serve as respondents and continuing that process until the required sample size has been obtained or those who happen to be available and accessible at the time”.

In the study, current fourth-year student teachers and previous EGD lecturers were the individuals who happened to be available and accessible during the time when the research was done. Cohen *et al.* (2011:156) describe purposive sampling as where researchers “hand-pick the cases to be included in the sample on the basis of their judgement of their typicality or possession of the particular characteristic(s) being sought". The EGD lecturers who were used in the study, were selected because of their specific knowledge of the subject EGD and their years of experience in the technical fields. Homogenous groups were needed for the following perspectives:

- EGD student teachers currently registered and grouped according to their year of study (convenience sampling).
- EGD lecturers on tertiary level with at least five years' experience (convenience sampling).
- Two educators in the technology field who would act as critical readers to ensure validity and reliability (purposive sampling).
- The following two modules would be used: EGDD411 (n=+/-48) and EGDD421 (n=+/-48).

1.9 Methods of data collection

In line with choosing a mixed-methods action research methodology, I had to monitor my practice and method of gathering data about what I was doing and whether I had influence in my practice to improve my teaching and learning while using ICTs in EGD. Various data collection methods were used, with each method correlating with the research aims (see Section 1.5) of the study, as indicated in Table 1-3.

Table 1-3: Data collection methods.

Data collection methods	Aims				
	A1	**A2**	**A3**	**A4**	**A5**
Qualitative data collection methods					
Obtaining information from participants regarding their experiences and perceptions by means of focus group discussions	X	X	X	X	X
Keeping a reflection journal while documenting all my experiences and observations during the entire research cycle	X	X	X	X	X
Studying literature relevant to the issue at stake	X	X	X	X	X
Obtaining feedback from all of the research participants about the use of ICT to improve spatial visualization and SDL skills	X	X	X	X	X

Quantitative data collection methods					
Obtaining information from the student teachers regarding their experiences and perceptions by means of questionnaires			X		X
Making use of pre- and post-tests using sectioned mechanical assembly drawings			X	X	
Making use of pre- and post-tests using an adapted SDLTS (Timothy *et al.,* 2010)			X	X	

It is evident from Table 1-3 that for the collection of qualitative data, I recorded the progress of the research, what was being done and what I intended to do during each session as well as my thoughts, observations and reflection on my teaching and learning of EGD in a research journal. Throughout the data-gathering process, I was able to monitor and document my cycles of planning, observing and reflecting (Chapter 5) (Cohen, Manion & Morrison, 2009; McNiff, 2002; Ormrod & Leedy, 2005; Weinberg & Tomal, 2005).

1.9.1 Variables

The independent variables include the student teacher's age, academic year and the module (EGDD411/EGDD421) for which he or she has been registered. According to Leedy *et al.* (2019), the independent variables will have some effect on the dependent variables. The dependent variables consist of the student teacher's knowledge of EGD content and ICT skills, which amounts to the student teacher's cognitive development (Piaget & Inhelder, 1971). Furthermore, the variables include the gender of the student, which may have an influence on the student's spatial visualization (Alias *et al.*, 2002; Jordan, Wüstenberg, Heinze, Peters & Jäncke, 2002).

1.9.2 Measuring instruments

I obtained information from the student teacher participants regarding their experiences and perceptions of sectioned mechanical assembly drawings by means of focus group discussions (see addendum B and D) to determine the barriers in EGD as well as fellow EGD lecturers feedback from individual interviews (see Addendum C). The pre- and post-tests of the SDLTS (Timothy *et al.,* 2010) were administered to determine the students' self-directedness before and after the integration of ICT and

EGD (see Addendum E and F). Pre-and post-tests of mechanical assembly drawings were written to determine students spatial visualization skills (see Addendum G and H). The validity and reliability of the quantitative data were determined by the Statistical Consultation Services of the North-West University.

Furthermore, I obtained information from the lecturer participants regarding their experiences and perceptions of sectioned mechanical assembly drawings by means of individual interviews to determine the barriers in EGD. I kept a reflection journal and documented all my experiences during the research (see Addendum J). In addition, I obtained feedback from all of the research participants about the integration of ICT and EGD to improve spatial visualization. The validity and reliability of the qualitative data were ensured by multiple coding, triangulation and respondent validation (Leung, 2015).

1.10 Methods of data analysis

The ATLAS.ti 8.4 software was used to code, analyse and interpret the qualitative data of this study. The Statistical Package for Social Sciences (SPSS) version 24 was used to analyse the quantitative data of the study. The paired t-test was used to determine if there was an increase in the student teachers' EGD marks and SDL skills after the integration of advanced ICTs in EGD to improve spatial visualization.

The Statistical Consulting Services of the North-West University assisted in merging the data and performing the triangulation of the quantitative data.

1.11 Quality criteria

In order to convince my readers, as well as myself, that the study is trustworthy, I have to prove that the findings of the study are worth paying attention to and worth taking into account.

1.11.1 Trustworthiness of qualitative research

The trustworthiness of a qualitative study relies on the credibility, transferability, dependability and conformability of a study (Creswell & Creswell, 2018); Guba and Lincoln (1985); (Leedy *et al.*, 2019).

Credibility suggests the certainty in the truth of the research data in addition to the analyses of the data. Member checks, participant reviews and the use of triangulation should be used to authenticate the truth of the data. To ensure credibility, these methods should be used throughout the study. Transferability concentrates on the degree to which the findings and results of a research study can be generalised to other situations in similar studies done; consequently, I did an in-depth literature review to examine other research done in education. The dependability of a study refers to the stability of the qualitative data; that means when applied in similar settings, the result should be practically the same. Conformability applies to comparable concerns with objectivity in mind. To ensure that the judgments made in the study were minimised, truthful and not just figments of my imagination, critical readers read and gave feedback on the findings (Babbie, 2016; Creswell & Creswell, 2018; Guba & Lincoln, 1985; Shenton, 2004).

I based my research on the issue at stake, namely teaching and learning EGD while using ICTs to improve spatial visualization and SDL skills among student teachers. Method triangulation and participant reviews were used to give trustworthiness to the study (Shenton, 2004). According to (Creswell & Creswell, 2018; Leedy *et al.*, 2019), the following strategies to support trustworthiness should be used in a study:

- Extensive time in the field: (Leedy *et al.*, 2019:104) describe the strategy of extensive time in the field as follows: "The researcher may spend several months, perhaps even a year or more, studying a particular phenomenon, forming tentative hypotheses, and continually looking for evidence that either supports or disconfirms those hypotheses." In the study, I spent two years in the research field (EGD classroom) searching for evidence. My prolonged engagement in the research field authenticates the credibility and dependability of the research.

- Feedback from others: According (Leedy *et al.*, 2019:104), the researcher should seek "the opinion of colleagues in the field to determine whether they agree or disagree that the researcher has made appropriate interpretations and drawn valid conclusions from the data". Focus group and individual interviews, along with feedback from critical readers, in this case fellow EGD educators, were used to confirm the credibility, dependability and reliability of the study.

- Respondent validation or member checks: (Creswell, 2008b:267) describes member checks as "a process in which the researcher asks one or more participants in the study to check the accuracy of the account". I discussed the conclusions made with the participants and questioned them to determine whether they agreed with the conclusions. The participant reviews substantiated the credibility, dependability and reliability of the study.

- Method triangulation: According to Creswell (2008b:267), method triangulation is the "process of corroborating evidence from different individuals (e.g., a principal and a student), types of data (e.g., observational field notes and interviews), or methods of data collection (e.g., documents and interviews) in descriptions and themes, in qualitative research". Therefore, the process of triangulation implemented supports the credibility of the study (Merriam & Tisdell, 2015).

The wide variety of approaches used in the study supported the trustworthiness of the research findings. An important factor connected to the trustworthiness of the study is my being part of the study and the fact that I reflected on what I did as well as on what the student teachers did. As I was involved with the various participants from the beginning to the end of the study, I was a participant observer (Bullard, Weekes, Cordle, Fox, Wares, Heffner, Howley & Navedo, 2019).

1.11.2 Trustworthiness of quantitative research

The trustworthiness of quantitative research is largely determined by the validity and reliability thereof; therefore it is important to pay particular attention to these aspects. Killen (2009:332) states that "[v]alidity is often considered as the extent to which a test (or test item) measures what it is intended to measure". Trochim (2006:1) remarks that validity is "the best available approximation to the truth of a given proposition, inference or conclusion". The conclusion is made that the research has to be tested against the idea that it is governed, determined and measured only by the relevant data.

Burke (2017:336) regards reliability as dealing with the quality of measurement, where "reliability is the 'consistency' or 'repeatability' of your measures". Killen (2009:322) expands on this by saying that reliability is "the degree to which test scores are free from errors of measurement". Therefore, reliability deals with the consistency and trustworthiness of the research. Thus, my research can only be considered valid and reliable if it would convey the same results under the same circumstances when repeated.

1.12 Ethical considerations

I obtained written informed consent from all EGD student teachers and EGD lecturers involved. The necessary ethical clearance (NWU-00532-17-A2) was obtained from the Faculty of Education Ethical Board and Committee (see Addendum I) and the Registrar of the University. As the researcher, I accepted the responsibility to ensure confidentiality during the research process and the data collection. All of the participants were informed that they had a choice as to whether they wanted to participate and had the right to withdraw from the research at any time. I further informed the participants that the data collected would only be used with their permission (De Vos *et al.*, 2014; McNiff, 2017; Whitehead, 2009).

1.13 Chapter division

Chapter 1: Introduction

In the first chapter, I explained the research problem, research questions and purpose of the research, and gave an orientation and general overview of the study.

Chapter 2: Conceptual framework

In Chapter 2, I shall outline the conceptual framework for the study by doing an in-depth literature investigation with regard to information on teaching and learning, ICTs and the history of EGD.

Chapter 3: Conceptual framework

In this chapter, I shall outline the conceptual framework for the study by doing an in-depth literature investigation with regard to information on teaching and learning, spatial visualization and EGD skills and learning theories.

Chapter 4: Research methodology

In Chapter 4, the research methodology will be discussed in depth by rationalising the research design and the data collection methods.

Chapter 5: Intervention

In the fifth chapter, I shall explain the development and theoretical evaluation of the integration of ICT in EGD to improve spatial visualization and SDL skills.

Chapter 6: Research results and triangulation

In the sixth chapter, I shall present the raw data, analyses and a discussion on the findings of the study, along with how I adapted my teaching and learning in EGD.

Chapter 7: A proposed framework to foster spatial visualization among EGD student teachers

In Chapter 7, feedback on the main findings and guidelines for improving the academic performance in sectioned mechanical assembly drawings will be provided. Furthermore, I shall propose a framework for successful teaching and learning in EGD while using ICTs, which could be applied to assist student teachers and educators in doing mechanical drawings. In addition, I shall present the recommendations and conclusions of the study. Possible areas for further research will be identified as well.

1.14 Summary

The importance of the study is twofold, being of importance to the student as well as the educator of EGD. For the EGD student teacher, the study proposes the integration of EGD and ICT to improve spatial visualization. Furthermore, it could improve the student teacher's ability to understand mechanical assembly drawings and how the different components fit together, while also improving the student teacher's ability to understand the sectioning of mechanical drawings. For the educator, the study could improve the educator's understanding of sectioned mechanical assembly drawings and how to integrate EGD and ICT to improve students' spatial visualization. It could, furthermore, advance the educator's teaching and learning of EGD.

The study adds to the body of knowledge to improve the integration of ICT and EGD on secondary and tertiary level.

Table 1-4: Matrix for the integration of ICT in EGD to improve spatial visualization

A framework for advanced ICT integration within higher education EGD to improve spatial visualization				
Primary question	**Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)**	**McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)**	**Chapter layout**	**Research method**
How can the implementation of advanced information and communication technologies, such as 2D or 3D CAD, 3D animation and 3D printing, improve spatial visualization and promote SDL in Engineering Graphics and Design in higher education environments?	Identifying the problem	What issue am I interested in researching? Why do I want to research this issue? What kind of evidence can I gather to show why I am interested in this issue? What can I do? What will I do? What evidence can I gather that I am having an influence? How can I explain this educational influence? How can I ensure that any judgments I might make are reasonably fair and accurate? How will I change my practice with regard to my evaluation?	**Chapter 1 Introduction and orientation**	**Literature**

Secondary questions	Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)	McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)	Chapter layout	Research method
What are the main advantages and barriers of using ICT in EGD education globally and in South Africa?	Thinking of ways to take on the problem	What issue am I interested in researching? Why do I want to research this issue? What kind of evidence can I gather to show why I am interested in this issue? What can I do? What will I do?	**Chapter 2**	**Literature**
To what extent are ICTs being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education?	Thinking of ways to take on the problem	What issue am I interested in researching? Why do I want to research this issue? What kind of evidence can I gather to show why I am interested in this issue? What can I do? What will I do?	**Chapter 2**	**Literature**
To what extent do advanced ICTs enhance the spatial visualization and SDL skills of students?	Thinking of ways to take on the problem	What issue am I interested in researching? Why do I want to research this issue? What kind of evidence can I gather to show why I am	**Chapter 3**	**Literature**

		interested in this issue? What can I do? What will I do?		
	Thinking of ways to take on the problem	What can I do? What will I do? What kind of evidence can I gather to show that I am having an influence?	**Chapter 4** The research design and methodology	**Research plan**
How can ICT and spatial visualization skills be further developed to enhance EGD in higher education?	Implementin g innovative teaching practices	What evidence can I gather that I am having an influence? How can I explain this educational influence? How can I ensure that any judgments I might make are reasonably fair and accurate?	**Chapter 5**	**Interventio n**
What contributing suggestions made by student teachers, EGD lecturers and the researcher can assist in the development of a framework for advanced ICT integration in EGD to foster spatial visualization and SDL?	Evaluating the actual research findings Modifying my future practice in the teaching of EGD	What evidence can I gather that I am having an influence? How can I explain this educational influence? How can I ensure that any judgments I might make are reasonably fair and accurate? How will I change my practice with regard to my evaluation?	**Chapter 6** **Chapter 7**	**Comprehen sive summary and integration**

CHAPTER 2: THE HISTORY OF ENGINEERING GRAPHICS AND DESIGN THROUGH THE AGES

LOGIC

Question	Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)	McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)	Chapter layout	Research method
What are the main advantages and barriers of using ICT in EGD education globally and in South Africa? To what extent are ICTs being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education?	Thinking of ways to take on the problem	What issue am I interested in researching? Why do I want to research this issue? What kind of evidence can I gather to show why I am interested in this issue? What can I do? What will I do?	The history of EGD through the ages	Literature

2.1 Introduction

In the previous chapter, I investigated the research problem by scrutinising the background of the implementation of advanced ICTs in EGD to improve spatial visualization, which led to the statement of the problem and the formulation of the primary research question and the secondary research questions of the study. The theoretical framework of the study was clarified and the relevant terminology used in the study was explained and defined within the context of the study.

In this chapter, I shall outline the conceptual framework for the study by doing an in-depth literature investigation with regard to information on EGD and advanced ICTs.

2.2 Engineering Graphics and Design

2.2.1 Definition of Engineering Graphics and Design

For years, man has been communicating ideas to express himself and presenting information with the use of pictures and drawings. However, different cultures used different ideas and pictures to communicate; therefore, a generic method was needed to communicate with drawings worldwide (Engelbrecht, 2015). Terms used for this method of communicating with drawings are “technical drawing”, “engineering drawing” and “engineering design” (Goetsch, Rickman & Chalk, 2016; Morling, 2010). In South Africa, it is more commonly known as “Engineering Graphics and Design” (Department of Basic Education, 2011).

“Technical drawings” can be seen as an umbrella term for graphical communication that is used across the world by engineers, educators, draughters and designers to communicate all of the relevant information necessary to convert different technological concepts and ideas into reality, such as the form and size of civil structures, electrical legends and mechanical objects (Goetsch *et al.*, 2016; Kemp, 2012; Niemann, 1976).

Reddy (2008:1) defines “engineering drawing” as follows:

> Engineering drawing is a two dimensional representation of three dimensional objects. In general, it provides necessary information about the shape, size, surface quality, material, manufacturing process, etc., of the object. It is the graphic language from which a trained person can visualise objects.

The Department of education (2005:9) describes the subject “Engineering Graphics and Design” as follows:

> Engineering Graphics and Design integrates the cognitive and manipulative skills that are used to design and communicate graphically. The subject combines lines and symbols to render services and design processes and systems that contribute to economic growth and enhanced quality of life.

If we look at the essence of the above-mentioned definitions, the main theme is to communicate on a graphical level. Thus the assumption can be made that in the engineering world, drawings are used as a means of communication on a universal level, where, without speaking a word, we can communicate crucial information through the use of drawings.

For many decades, the draughtsperson has relied on the drawing board, T-square, triangles, compasses, rulers, pencils and so forth to communicate on a graphical level (Joelson, 2011). Nowadays, our world has become one where computers are used to solve many problems quickly and accurately. The process of drawing has also largely been accelerated and computerised through the use of computer-aided design (CAD) software (Goetsch *et al.,* 2016; Morling, 2010). In the engineering world, CAD plays an integral role to communicate ideas and designs through CAD drawings. CAD furthermore relates to advanced ICTs, such as 3D CAD, 3D animation, 3D printing and 3D animation. These advanced ICTs are used to create prototypes during the design process to see whether the design will work (Berman, 2012). EGD in South Africa on the secondary and tertiary level should also be moving towards the worldwide trend to incorporate CAD and advanced ICTs into EGD.

The Department of Basic Education (2011) declares that CAD plays an integral role in EGD. "The PAT [Practical Assessment Task] for EGD requires that some of the presentation drawings have to be generated by a CAD system. CAD is therefore a mandatory part of EGD" (Department of Basic Education, Department of Basic Education (2011:29). Therefore, if it is mandatory for learners on secondary school level to be able to use CAD, teaching students on tertiary level should be able to use CAD and advanced ICTs, as these are being used worldwide. Drawings done on paper in EGD are no longer recognised in the drawing societies because of the ICT era in which we currently live. However, secondary schools still use the obsolete pencil-on-paper drawing method, which should be changed to deliver drawing students for the public sector (Abraham & Otuaga, 2017).

2.2.2 The origin and history of EGD

There has always been a need for the human race to capture historical occurrences and events on a visual level (Booker, 1963; Kemp, 2012). On 18 December 1994, a French speleologist and his two assistants located a cave in the area of Ardeche, France, which contained preserved rock-drawings from the Ice Age, approximately 30

000 to 32 000 years ago. The true-to-life drawings of horses, bison, cave lions and extinct rhinoceroses show the drawing skills of the human race in that period (Bocherens, Drucker, Billiou, Geneste & Van der Plicht, 2006; Fritz, 1995). Drawings used for more practical purposes are commonly found in architecture in Ancient Egypt. Drawings that used a grid of straight lines made on papyrus with a string dipped in ink pigment as well as carvings on wooden planks and tablets of rock were used by ancient Egyptian stonemasons to illustrate the drawings of pyramids and other structures by Egyptian architects (Harris & Meyers, 2007). A preserved floorplan in the form of a rock tablet of a temple in Ningirsu (Figure 2-1) is kept in the Louvre Museum in Paris, France. One of the most interesting phenomena of this floor plan in terms of EGD is that the Egyptian architects provided a scale for the drawing, which in current EGD terms would put this tablet in the category of an orthographic drawing (see Figure 2-6) in EGD (French & Svensen, 1966).

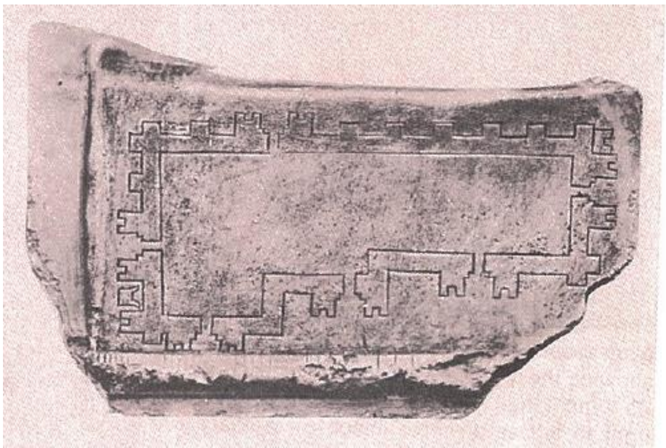


Figure 2-1: Floor plan of a temple in Ningirsu carved on a rock tablet.

The first written record conferring drafting representation was given by the Roman architect and builder Marcus Vitruvius Pollio (80-15 BC) in the *Ten books on architecture,* where he described the fundamental principles of architecture and showed different drawings of dwellings (Figure 2-2) of the time period (Barr, 2012; Vitruvius, 1914).

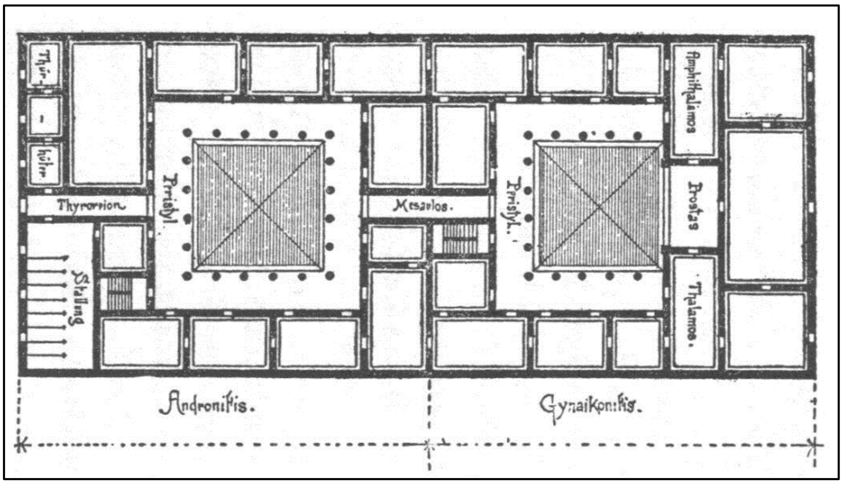


Figure 2-2: Floor plan of a Greek house.

The first record of linear perspective was captured in a painting by the Florentine architect Fillipo Brunelleschi (1377-1446). The painting was painted in 1413, portraying the Baptistery in Florence from the front access of the uncompleted cathedral (Camerota, 2006). Documentation capturing precisely what Brunelleschi did, is scarce (Raynaud (2016). Brunelleschi stood at a distance of three arms' lengths from the main access of the cathedral, facing the Baptistery while holding a mirror in one hand and a painting of the octagonal-shaped building portrayed on a wooden panel in the other hand. Through a small hole drilled in the wooden panel, Brunelleschi observed the image of the painting reflected in the mirror in his other hand. From this position, he could see the image and the actual building simultaneously; therefore, the linear perspective system projected the impression of depth onto a 2D plane. Brunelleschi made use of vanishing points, which were connected to all lines united, at eye level, on the level of the horizon (Figure 2-3). Not long after Brunelleschi's painting, the perspective drawing theory caught on and many Italian artists started to use linear perspective methods in their paintings (Camerota, 2006; Kemp, 1978; Raynaud, 2016).

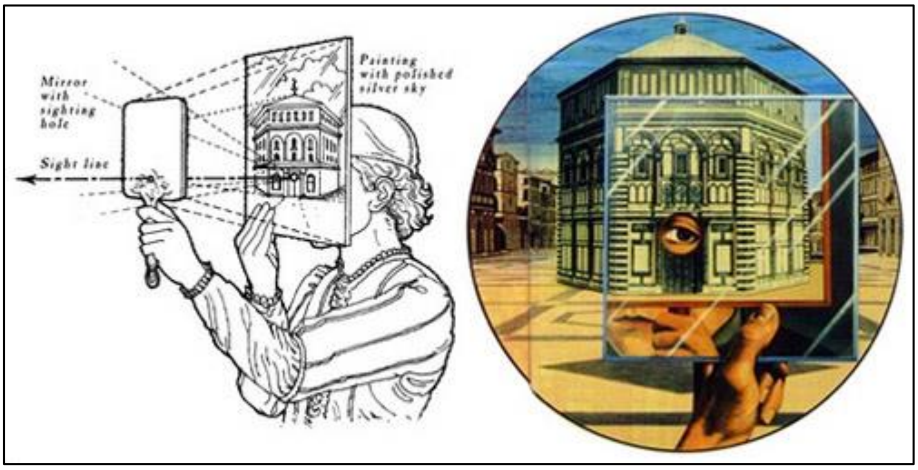


Figure 2-3: Linear perspective using a mirror.

The first record of multiview drawings was by Leonardo da Vinci (1452-1519) (Barr, 2012). He studied the art of drawings, illustrations, sketches, pictures and paintings, and improved on these by adding his own impression on them; he furthermore was extremely skilled in creating drawings in 3D views (Barr, 2012). Leonardo da Vinci not only tried his hand at sketching 3D drawings but also explored orthographical drawings that included multiple views of an object or model. What is most interesting and significant of Da Vinci's drawings is that the orthographic drawings he created had a component of 3D drawing that could be more specifically explained with oblique drawings (Figure 2-4) (Booker, 1963; Kemp, 2012). Figure 2-4 displays the shift from the 3D oblique drawings Da Vinci normally did, to a more practical orthographic drawing, where the front view and the top view of the rolling mill for forming lead and copper strips are portrayed. Da Vinci's artistic sketches and ideas are still being taught today in axonometric drawings (Barr, 2012).

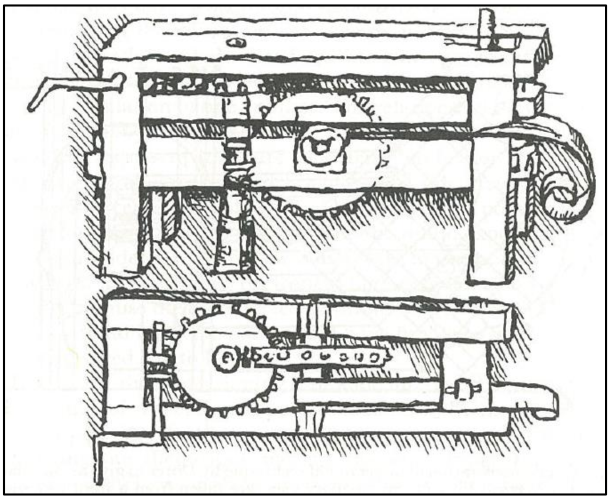


Figure 2-4: Da Vinci's orthographic drawings with an element of 3D oblique drawings.

Albrecht Durer (1471-1525) was a painter and an engraver who published *Four books on human proportion* in 1525, containing the different drawings of the human body. These drawings were done according to the orthographic principles that are used today in orthographic projection drawings. Durer studied the proportions of the human body (Figure 2-5), which were important for the life-like paintings seen in cathedrals across Europe. The full-scale measurements used by Durer in his drawings are seen as a possible shortcoming, as the drawings are big and not easily controllable (Booker, 1963; Lefèvre & Baldasso, 2005; Muller, 1993).

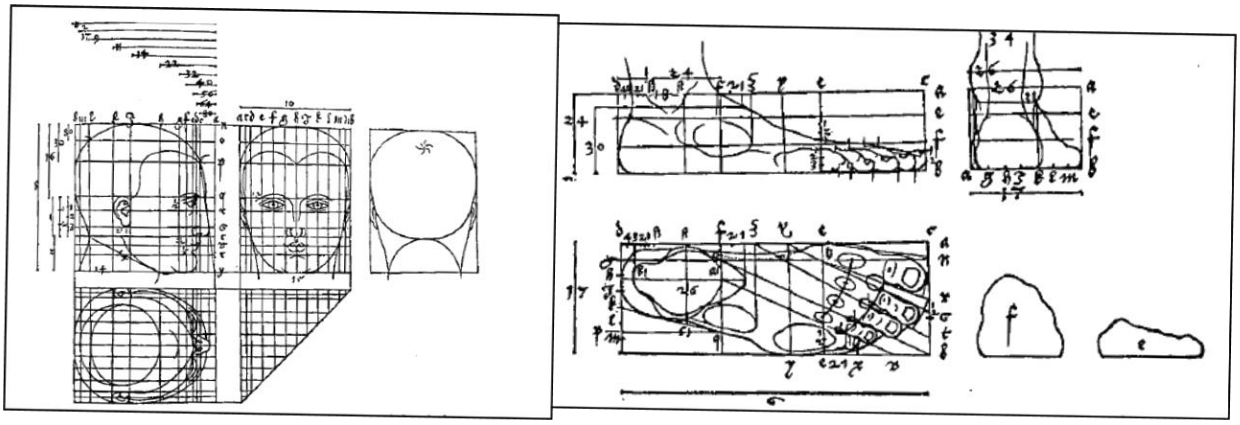


Figure 2-5: Orthographic drawings of a human head and foot.

Gaspard Monge (1746-1818) published *Géométrie descriptive* in 1795, one of the most intriguing books in the history of engineering drawing. An educator recognised the young Monge's talent for science and mathematics, and he was sent to the military school in Mezieres. While working as a military engineer, Monge discovered the principles of descriptive geometry while designing fortifications. These fortifications were made of accurately cut stones that fit onto one another so that a wall or tower could be constructed to be strong and self-supporting enough to withstand bombardment during the war (Booker, 1963; Sakarovitch, 2009). The descriptive geometry system invented by Monge was declared a classified military secret, and it was not until many years later, in 1795, that it became a part of French engineering and architectural education. Monge's descriptive geometry system was later adopted universally as a scientific foundation to EGD that is still being taught today (Barr, 2012; Barr *et al.,* 1994; Booker, 1963).

The above-mentioned artists, architects and engineers are seen as some of the forefathers of EGD as we know it today. They played a vital role in how drawings on secondary and tertiary education levels are created. According to Pahl, Giesecke, Hasselbring (2009), drawing projections can be divided into two main components, namely perspective or central projection and parallel projection (Figure 2-6). I added the forefathers to emphasise which type of drawings they unknowingly started or improved on. Figure 2-6 displays the classification of projections in EGD.

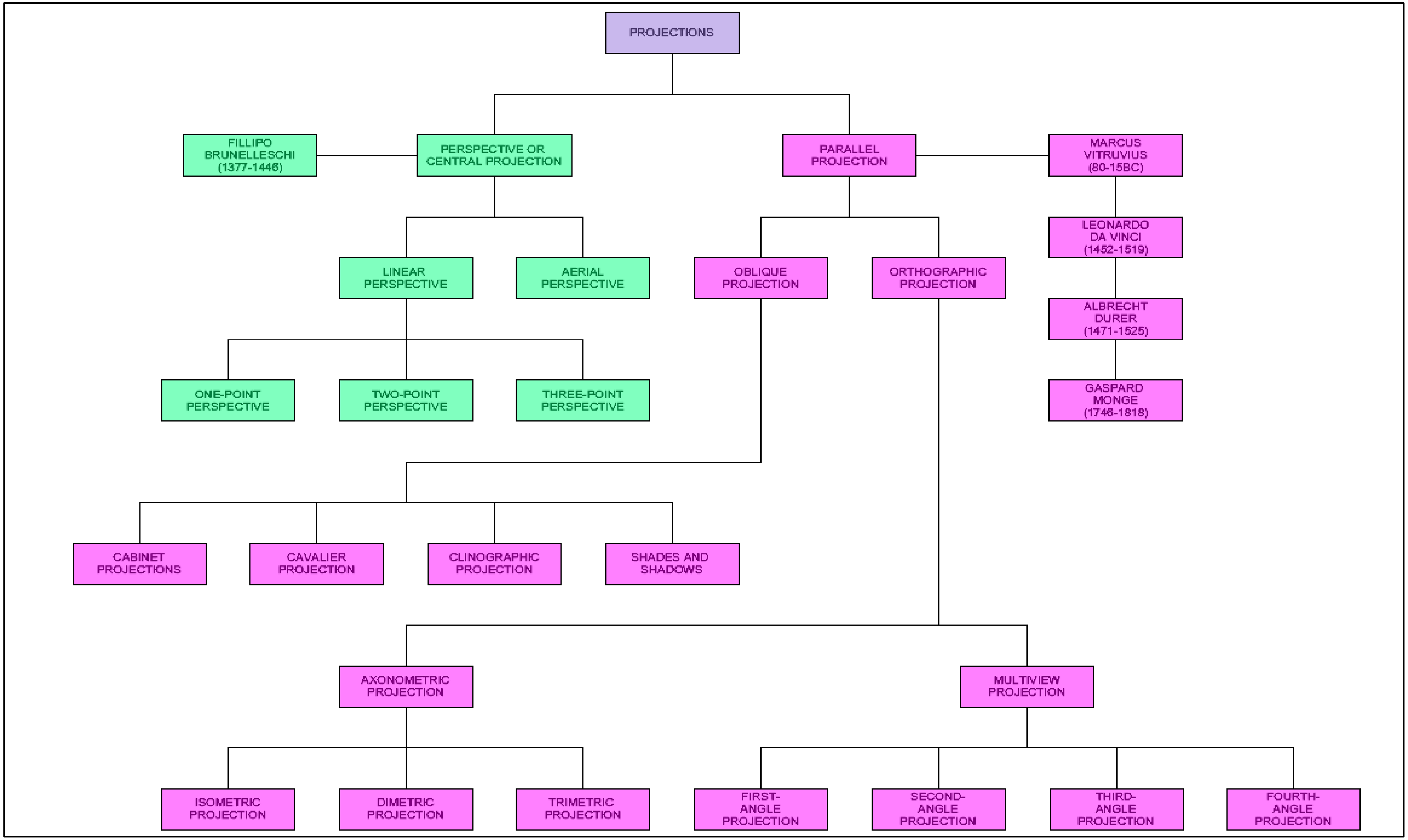


Figure 2-6: Classification of projections.

Figure 2-6 shows the different types of projections in EGD, to clearly understand and have a full picture of the drawings with which students struggle in EGD, we have to take a look at each drawing in the classification of projections table. To differentiate between types of drawings done in CAD, they can be divided into two types, namely 2D and 3D drawings. Brusic, Fales, Kuetemeyer and Thompson (2004) define a two-dimensional (2D) drawing or multiview drawing as a drawing that "shows two or more different views of an object drawn at right angles, or perpendicular, to one another". Multiview projections accordingly fall in the category of 2D drawings. Bertoline *et al.* (2010) differentiate as follows between a multiview or 2D drawing and an axonometric or 3D drawing:

> The difference between a multiview drawing and axonometric drawing are[*sic*] that in a multiview, only two dimensions of an object are visible in each view and more than one view is required to define the object; whereas in an axonometric drawing, the object is rotated about an axis to display all three dimensions, and only one view is required.

Axonometric, isometric, perspective and oblique drawings accordingly fall in the category of 3D drawings in EGD. Figure 2-7 shows an example of a simple 2D drawing (multiview), and Figure 2-8 shows an example of a simple 3D drawing (isometric) drawn in 2D CAD.

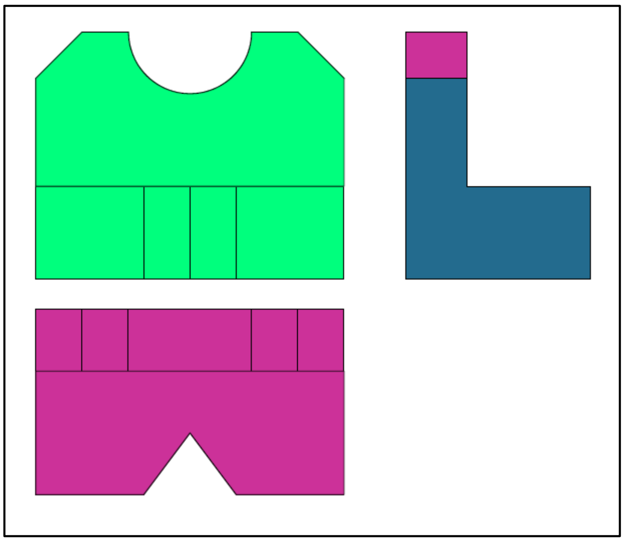


Figure 2-7: 2D drawing (Author).

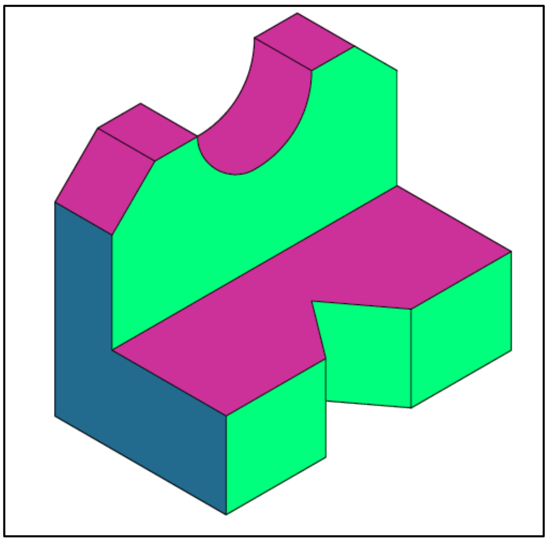


Figure 2-8: 3D drawing (Author).

The research done in the study (see Section 6.2.1) shows that EGD students normally do not struggle with these simple types of drawings. They typically struggle when drawings get more complex, such as assembly drawings, and when sectional views are added to assembly drawings. Sectional views are a significant aspect of design that communicate on a graphical level and convey more information about objects, with complicated internal characteristics of parts than the standard multiview drawing can with hidden detail; sectional views furthermore improve the understanding and visualization of the internal features of parts (Goetsch *et al.,* 2016; Lockhart, Goodman & Johnson, 2018). A sectional view can further be described as a view of the surface that would be seen if an object were cut open and is used to improve clarity and reveal interior features of parts (Bertoline *et al.,* 2010). The sectioned view is commonly referred to as a “cross-section” or simply a “section” (Bertoline *et al.,* 2010). Figure 2-9 shows an example of an orthographical drawing with the following multiviews: a sectional front view, a top view and a left view drawn in 2D CAD.

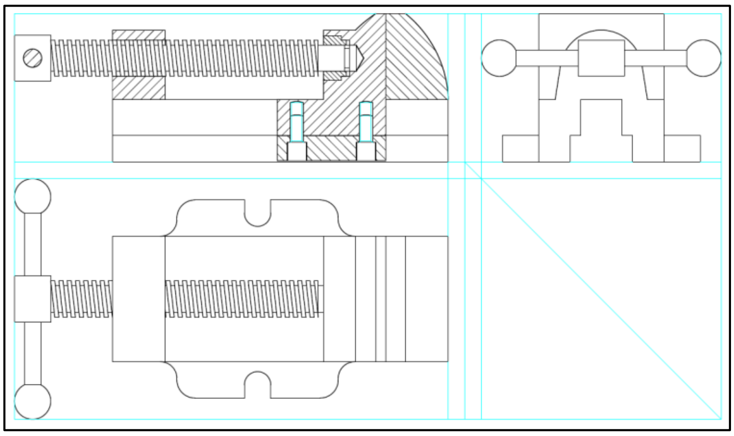


Figure 2-9: Sectional multiview drawing (Author).

Figure 2-9 displays the front view, top view and left view of a bench vice drawing in first angle orthographic projection.

2.3 EGD and the curriculum

Any educational institution follows a set of guidelines that determines what is taught, how it is taught and what students must learn. This is normally described as the curriculum. In the history of South Africa, various curricula have been used to teach students on primary, secondary and tertiary levels. At this moment in South Africa, the national curriculum followed by educational institutions is called the "Curriculum Assessment Policy Statement", better known as the "CAPS" (Department of Basic Education, 2011).

2.3.1 The Curriculum Assessment Policy Statement and EGD

According to Jacobs (2017), a curriculum is an important policy document within the educational framework, which can also be described as knowledge- or subject-specific content that has to be transferred to the student. It further states the achievement of particular goals and outcomes at the end of a learning cycle and can be seen as the process through which knowledge, skills and values are transferred (Jacobs, 2017). The CAPS adheres to the above-mentioned descriptors and is the curriculum followed on primary and secondary school level.

Educators do not have to create their own curriculum; each subject has a CAPS document that guides the educator in the why, what, when, where and how they should teach their subjects; teachers are therefore seen as implementers of the curriculum (Jacobs, 2017).

The Department of Basic Education (2011:1) divides EGD into four sections, namely:

Section 1: "Introduction to the Curriculum and Assessment Policy Statements"

This section consists of the general information about the background of the National Curriculum, an overview of the curriculum followed in South African schools from Grade R to 12, all of the important policy documents relevant to the curriculum, the general aims of the South African curriculum and the various time allocations per subject.

Section 2: "Introduction to Engineering Graphics and Design"

This section focuses on the main topics taught in EGD (see Table 2-2 and section 2.3.2), the subject-specific aims learners should achieve at the end of the learning cycle, the requirements to offer EGD in any school in South Africa and the different career opportunities (see Section 2.4) available to learners after they have obtained their Grade 12 certificate.

Section 3: "Overview of topics per term and annual teaching plans"

This section shows the educator precisely what he or she should do on each day during each term with an annual teaching plan. The main topics of EGD are shown in depth in the examinable content, and the Practical Assessment Tasks (PATs) are discussed for each grade (see Section 2.2.1).

Section 4: "Assessment in Engineering Graphics and Design"

This section focuses entirely on the assessment of EGD, the difference between informal and formal assessment, the assessment of projects and PAT assignments, the recording and reporting of marks and the different rubrics to assist in the marking process.

2.3.2 How does the EGD curriculum compare worldwide?

Various educational curricula are followed worldwide on secondary school level. The curricula nearest to the one followed in South Africa are those of the Republic of Ghana, the Caribbean and the island of Malta in the Mediterranean Sea as shown in Table 2-1 (Caribbean Examinations Council, 2006; Department of Basic Education, 2011; Ministry of Education, 2010; Ministry of Education and Employment, 2012).

Table 2-1: Comparison between EGD curricula.

	South Africa secondary education	Republic of Ghana secondary education	Caribbean secondary education	Malta secondary education
	Main topics of Engineering Graphics and Design	**Main topics of Technical Drawing**	**Main topics of Technical Drawing**	**Main topics of Graphics Communication**
1	General drawing principles for all technological drawings	General drawing principles for all technological drawings	General drawing principles for all technological drawings	General drawing principles for all technological drawings
2	Free-hand drawings	Free-hand drawings	Free-hand drawings	Free-hand drawings
3	Instrument drawings	Instrument drawings	Instrument drawings	Instrument drawings
4	First- and third-angle orthographic projections	First- and third-angle orthographic projections	First- and third-angle orthographic projections	First- and third-angle orthographic projections
5	Descriptive and solid geometry	Descriptive and solid geometry	Descriptive and solid geometry	Descriptive and solid geometry
6	Mechanical working drawing	Mechanical working drawing	Mechanical working drawing	Mechanical working drawing
7	Civil working drawing	Civil working drawing	Civil working drawing	Civil working drawing
8	Isometric drawing	Isometric drawing	Isometric drawing	Isometric drawing
9	Perspective drawings	Perspective drawings	Perspective drawings	Perspective drawings
10	Electrical diagrams	Electrical diagrams	Electrical diagrams	Electrical diagrams
11	Interpenetrations and developments	Interpenetrations and developments	Interpenetrations and developments	Interpenetrations and developments
12	Loci of helixes, cams and mechanisms	Loci of helixes, cams and mechanisms	Loci of helixes, cams and mechanisms	Loci of helixes, cams and mechanisms
13	The design process	The design process	The design process	The design process
14	CAD (computer-aided design)	CAD (computer-aided design)	CAD (computer-aided design)	CAD (computer-aided design)

Table 2-1 shows Ghana and the Caribbean Technical Drawing curricula have the same main topics as EGD in South Africa, except for the topic Design Process. Before EGD was implemented in South Africa, the subject was called “Technical Drawing”, which had the same main topics as Ghana and the Caribbean, but when Technical Drawing was changed to EGD in the South African curriculum, Design Process was added as a topic. The Malta secondary school curriculum differs from EGD with only one topic not being taught, namely Civil Working Drawing. In 2005, the topic Civil Working Drawing was added to the South African school curriculum when Technical Drawing was phased out and EGD was introduced into the school curriculum (Department of Education, 2007).

2.3.3 How does the South African school curriculum on secondary level compare with the tertiary curriculum followed on tertiary level?

If the EGD school curriculum (Department of Basic Education, 2011) is compared to what is taught in EGD on tertiary level where school educators are trained in the BEd degree in EGD (North-West University, 2019), the EGD CAPS document is followed as a guideline to prepare students with the same topics introduced on secondary school level. The topics on tertiary level are on a higher-order thinking level and with more advanced drawings being done. The higher-order thinking level is stated by the South African Qualifications Authority, which determines the National Qualifications Framework (NQF) that sets the requirements for all qualifications from basic education to doctoral studies (Jacobs *et al.,* 2016) as shown in Table 2-2.

Table 2-2: NQF levels.

The National Qualifications Framework		
School grade	University year level	NQF level
	EGD 4th year	7
	EGD 3rd year	6
	EGD 2nd year	6
	EGD 1st year	5/6
EGD Gr 12		4

EGD Gr 11		3
EGD Gr 10		2

Table 2-2 shows the relevant NQF levels to which any tertiary institution should abide by when designing modules for any degree in South Africa.

2.3.4 EGD skills

According to Bloom, as quoted in Killen (2009), it is common practice for educators to group learning outcomes or specific aims into three learning domains. According to Bloom (1956) and his colleagues, these domains are:

- the cognitive domain, which is related to mental processes that help process existing and new knowledge;
- the psychomotor domain, which is involved with the fine motor skills that control body movements and physical actions; and
- the affective domain, which is concerned with growth in feelings or emotional areas that relate to attitudes and values.

Taking Bloom's three domains into consideration, the main purpose of teaching and learning should be to increase and improve student teachers' cognitive, psychomotor and affective skills. The Department of Basic Education (2011:4) clearly states, "The National Curriculum Statement Grades R-12 gives expression to the knowledge, skills and values worth learning in South African schools." The Department of Basic Education (2011:4) furthermore describes that "knowledge, skills and values are necessary for self-fulfilment, and meaningful participation in society as citizens of a free country". Therefore, the three domains of learning are methodically applied in EGD, since the three domains of Bloom are applied during the EGD curriculum with regard to knowledge, skills and values to adhere to the regulations of the Department of Basic Education. Forterre (2015) explains that an interrelationship exists between Bloom's three domains. Figure 2-10 shows a visual representation of how the three domains are intertwined. All three domains must be stimulated equally for a student teacher to achieve the specific aims at the end of the curriculum (Kemp, 2012).

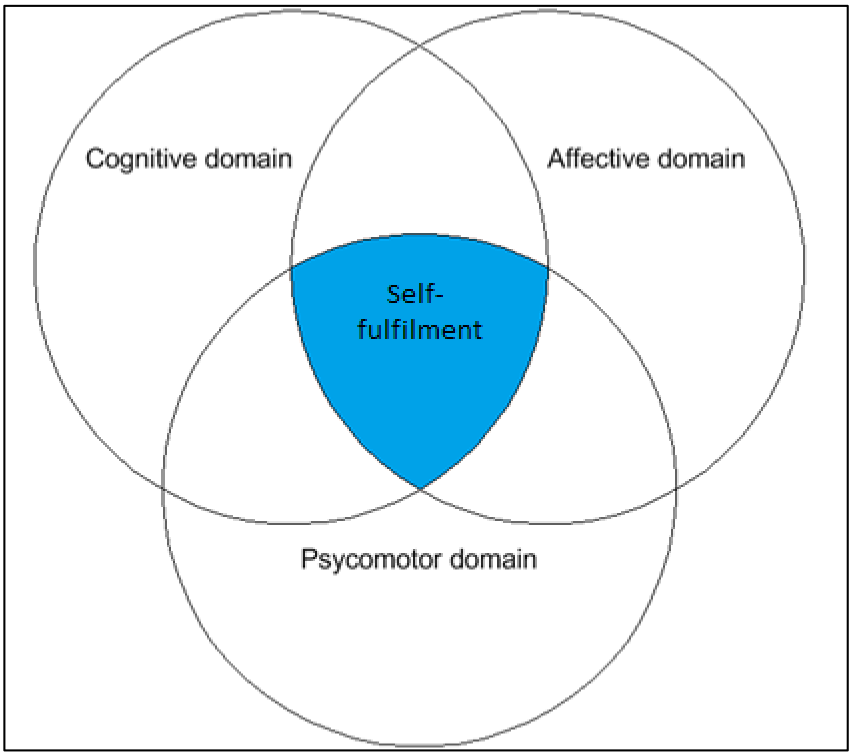


Figure 2-10: Bloom's domains (Author).

Figure 2-10 shows the importance of the interrelationship between the three learning domains to achieve self-fulfilment. The EGD student teacher should have fine motor skills that relate to small muscle coordination to make the required hand movements with drawing tools (psychomotor) to sketch or create a drawing. The EGD student teacher should furthermore have the cognitive ability to learn and understand the theory, phases and steps to create a drawing. Lastly, the EGD student teacher should want to perform and repeat these movements enough times, with neatness in mind, to proficiently develop the affective domain through practice.

2.4 Career opportunities in EGD

Considering global career development and opportunities, one question arises: Why do students study EGD on secondary and tertiary levels? The Department of Education gives learners the opportunity to decide on a profession for their future in the FET Phase. A learner should choose EGD if they want to follow particular careers. In the EGD CAPS document (Department of Basic Education (2011), some career pathways are linked to EGD, as listed in Table 2-3.

Table 2-3: Career opportunities for EGD practitioners.

Mechanical fields	Civil fields	Electrical fields	Designing fields
Mechanical engineering	Civil engineering	Electrical Engineering	Industrial designer
Draughtsperson	Architecture	Draughtsperson	Interior designer
Educator	Landscape architect	Educator	Graphic illustrator
CAD system operator	Quantity surveyor	CAD system operator	Jewellery designer
Boilermakers	Building management		Educator
Welders	City planner		CAD system operator
	Land surveyor		
	Draughtsperson		
	Educator		
	CAD system operator		

Table 2-3 shows the different career opportunities for EGD learners. Critique towards the Department of Basic Education, the Department of Higher Education and tertiary institutions is that EGD is not a prerequisite to study the above-mentioned careers. EGD would benefit the student who follows one of these careers, compared to a student who has not taken EGD as subject on secondary level. EGD is divided into two components, Engineering Drawing and Design. The first component, Engineering Drawing, involves the informal and formal drawings done by anyone with a background in draughting, CAD, civil drawings, electrical drawings and mechanical drawings. To ensure accurate and precise communication of Engineering Drawing, the South African National Standard (SANS) has specifications which should be adhered to. In EGD, the two most used are the SANS for building practice (SANS 10143) and for engineering drawing (SANS 10111-1). The second component of EGD is Design, and the design process is used to adhere to this component of EGD. According to Goetsch *et al.* (2016), the design process may be used cyclically or linearly to describe the different phases of design best. The Design Process followed in EGD contains the following steps, according to the EGD CAPS document (Department of Basic Education, 2011:11):

- Problem **identification** and the formulation of a **design brief** with a list of **specifications** and/or **constraints**.
- Conducting research and generating graphical **ideas/concepts**.
- **Selecting** the best solution within the context of the design brief.
- Presenting the final solution as **working and 3D drawings**.
- **Evaluation** of the entire process.

An integral part of the design process is freehand, working and 3D drawings; therefore Engineering Drawing and the design process are entwining, thus the name "Engineering Graphics and Design". Furthermore, there is integration among the following subjects on secondary and tertiary level in education: EGD, Civil, Mechanical, Electrical and Technology. In all these subjects, students should be able to do drawings and apply the design process in each of these fields (Department of Basic Education, 2011; Department of Basic Education, 2014a; Department of Basic Education, 2014b; Department of Basic Education, 2014c). The importance of advanced ICTs in the design process is that one could draw the final prototype on 3D CAD or print it with a 3D printer to see whether the design is flawless and ready to be marketed (Section 2.5.2.6).

2.5 EGD in the 21st century

2.5.1 The influence of ICT on EGD

ICT has profoundly changed the way we live and work. It has converted our ability to deal with information and data on a daily basis; engineering teaching, therefore, has to enhance value beyond just teaching skills (Apelian, 2007). Thus, ICT has to be incorporated into teaching and, furthermore, in EGD teaching. According to (Jian, 2011), the traditional education of EGD was based on Mechanical or Machine Drawings, specifically the national drawing standards with regard to technical specifications, technical requirements and the assembly of mechanical drawings. The drawings were done manually with drawing boards. Now, with the development of advanced ICTs, there is an urgent demand to add these technologies gradually into the EGD courses and remove the original teaching content that can be substituted by ICT, such as the use of drawing equipment (Martín-Erro, Domínguez & Espinosa, 2016). Harris and Meyers (2009:2) furthermore state that “nothing has had more of an impact on the ability to transform visual spatial perceptions and the evolution of graphical plans for construction of machinery and architecture than the computer and the Internet”. In addition, it is affirmed that EGD students are expected not only to understand engineering drawings but also to be skilled in the use of CAD software (Martín-Erro *et al*., 2016).

Taking the above-mentioned statements into consideration, it is evident that ICT should play a more integral part in the teaching of EGD to improve spatial visualization. South African schools and universities have formulated the importance of ICT in teaching in their outcomes, but not all of these institutions incorporate it as yet (Isaacs, 2007; Mdlongwa, 2012). To clearly understand ICT in EGD, it is necessary to differentiate between the relevant advanced ICTs that can be used in EGD.

2.5.2 The history of CAD

Sharma and Dumpala (2015) describe CAD software as comprehensively used software for drawing, drafting, designing, developing and manufacturing various components in the mechanical, electrical and civil engineering fields. While CAD seems like a relatively new technology to some, many of the CAD software programs used today have been around for more than 50 years. According to Harris and Meyers (2009), the first graphic system was developed in the mid-1950s by the Massachusetts Institute of Technology for the use of the United

States Air Force. In 1957, the first commercial and industrial computer-aided manufacturing (CAM) software was designed and developed by Dr PJ Hanratty, who is seen as the father of CAD or CAM in the CAD fields (Waurzyniak, 2010).

In the early 1960s, the CAD system Sketchpad was developed by a doctoral student, Ivan Sutherland, as part of his PhD dissertation at the Massachusetts Institute of Technology (Sutherland, 2012). Sketchpad is regarded as the world's first CAD program (Sutherland, 2012). The earliest CAD software started with simple algorithms showing different patterns of lines in 2D CAD, which were later converted into 3D images. In 1968, simple 2D drawing software was available, using mainframe computers in the industries (Harris & Meyers, 2009). Doing further research that same year, D Welbourne envisioned the possibility of solving the modelling of complicated 3D forms with 3D software, using computers (Harris & Meyers, 2009).

In the 1970s, M Riddle devised the first micro-based computer CAD software, which was available for purchase by large companies by the end of the 1970s (Weisberg, 2008). In the 1980s, technology hit a big milestone with the introduction of more effective small computers in the market. Normally, the target market for CAD was industries, universities and engineering fields, but because of the more affordable hardware, household CAD software could also be launched (Pan, Polden, Larkin, Van Duin & Norrish, 2012; Weisberg, 2008). During the 1990s, advanced CAD systems were developed, which introduced more innovative and creative applications for engineering, educational and domestic design (Bonnardel & Zenasni, 2010).

Chedi (2015) states that the advantages of CAD systems are numerous: it is estimated that a good CAD system saves as much as 90% in conceptual design and drawing time. In the 21st century, more tertiary institutions are decreasing and some of them are eliminating the use of manual graphics using drawing equipment and relying more on CAD software for teaching engineering drawings. The use of drawing equipment is slower than using CAD; so it is disappearing in many curricula (Harris & Meyers, 2009). In South Africa, this is not entirely the case, as the curriculum on secondary school level still uses manual graphics in

Grades 10, 11 and 12 (Department of Basic Education, 2011). CAD is only included in the Practical Assessment Task (PAT) for those schools that have the facilities to use CAD, while other schools should complete the PAT manually (Department of Basic Education, 2011). The curriculum on tertiary level, training educators in EGD, is more on par with using CAD and manual graphics as an instruction medium, but it could be further improved and adapted to international standards.

2.5.2.1 2D CAD

Sharma and Dumpala (2015:182) describe 2D orthographic drawings as the “universal language of engineers”. Such 2D drawings support three dimensions – length, height and width – but only two dimensions are expressed per orthographic view (see Section 2.2.2, Figure 2-7), such as the length and height in the front view, the height and width in the left and right view and the length and width in the top view. Because of the two dimensions per view in 2D CAD, the area can be determined in cm^2 (Carter, 2015a; István & László, 2012). CAD software has three axes on which a drawing is done, namely the X-axis, the Y-axis and the Z-axis (Carter, 2015a). In 2D CAD, the drawing is done on only two of the three axes – either X and Y, Y and Z or Z and X – therefore it must consist of two axes to be classified as a 2D drawing (Carter, 2015a). (Spear, 2019), 2D CAD drawings help one generate and create a 2D view of an object or product. Software programs such as AutoCAD and TurboCAD are leading software in 2D drawings (Spear, 2019). The designer of the product has to understand how the final product may look, which may be difficult for someone with a non-technical background (see Figure 2-11) (Spear, 2019).

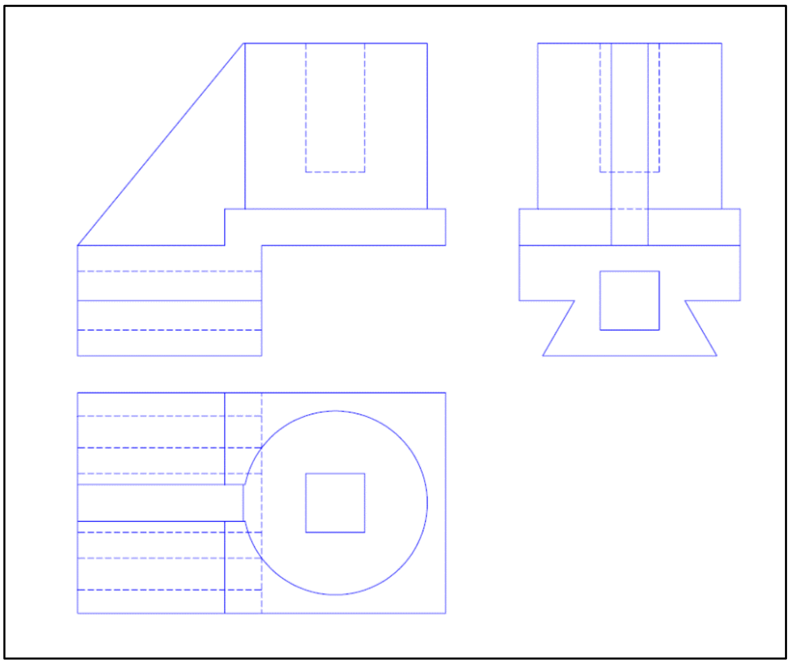


Figure 2-11: 2D drawing of cross slide.

Figure 2-11 displays a 2D drawing in first angle orthographic projection with a front view, top view and a left view.

2.5.2.2 3D CAD

Normally, 3D drawings or models are axonometric drawings (see Section 2.2.2, Figure 2-8), which show the length, height and width in one drawing (Sharma & Dumpala, 2015). In 3D CAD, the X-axis, Y-axis and Z-axis are still used, but it is important to notice that all three axes are used in one drawing – the XYZ-axes, YZX-axes or ZXY-axes. Because of the three dimensions used in 3D CAD, the volume of the model can be determined in cm^3 (Carter, 2015b; István & László, 2012). Therefore, a 3D drawing must consist of three axes to be classified as a 3D drawing. Using 3D CAD, the precise and accurate output of the final product can be observed as it will be after manufacturing. It furthermore supports the actual manufacturing process. As nothing is left for the imagination of the designer, everybody can read and understand the design. Thus, 3D modelling makes it easier to explain and understand an object or product in presentations to the consumer (see Figure 2-12) (Adler, 2008; Anon, 2018).

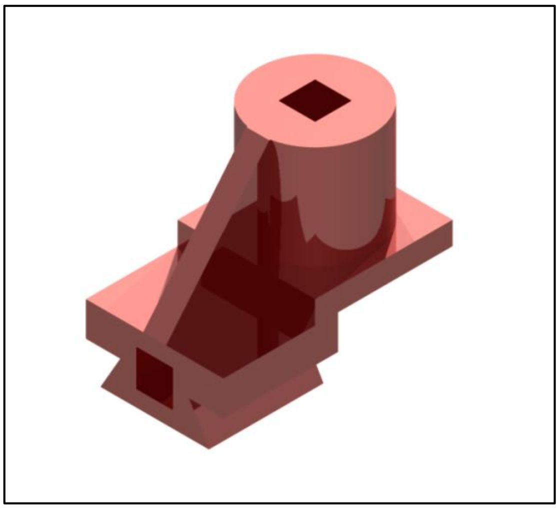


Figure 2-12: 3D drawing of cross slide.

Figure 2-12 shows the same drawing done in Figure 2-11; the difference is that Figure 2-12 is an isometric drawing done in 3D CAD.

2.5.2.3 3D simulation and animation

Tajvidi and Fang (2015) claim that the use of computer simulation and animation in the higher education field is growing at a fast-moving rate and has become a major trend in undergraduate engineering education. Rutten, Van Joolingen and Van der Veen (2012) claim that research in science education shows that computer software improves the learning process through simulation and animation, improves the representation of the topic being taught, fosters student involvement and decreases the lecturer's workload. Software is used to supply movement to 3D CAD drawings. The movement and animation provide the designer with the opportunity to test the moving parts before manufacturing the final product. It gives the designer the opportunity to experiment with different materials and forces working in on the materials (SolidWorks, 2018). Thus 3D simulation and animation can be used to show students what happens when different machine components are sectioned and what the inside of these components look like (Bobylev, 2017).

2.5.2.4 Learning management systems

Balderas, De-La-Fuente-Valentin, Ortega-Gomez, Dodero and Burgos*.* (2018) describe a learning management system (LMS) as a software application on an e-learning platform that is used for tracking, reporting, administration and facilitating education courses. An LMS is seen as beneficial for students as it is a system where module content is organised, to which the student has access any time and anywhere as the system is online and on which students and educators can easily track their progress. Furthermore, there is a link between students' usage of LMSs and the grades they achieve (Arenas-Gaitán*,* Rondán-Cataluña & Ramírez-Correa, 2018; Balderas *et al.*, 2018; Cheng & Yuen, 2018; Kvon, Vaks, Masalimova, Kryukova, Rod, Shagieva & Khudzhatov, 2018). During the intervention, the following LMSs will be used to make content available for EGD students: eFundi™ and the Depot™.

2.5.2.5 3D scanning

Kus, Unver and Taylor (2009) state that, while the use of 3D scanning is increasing in many industries, it is not as well-known in education fields. The ability to incorporate 3D scanned data and 3D software can lead to constructing different complex shapes and models with high accuracy. These models and shapes can be scanned at different locations and then be brought to the EGD classroom for students to observe and improve visualization (Urdarevik, 2013). Figure 2-13 shows a 3D scanner used in the EGD classroom.

Figure 2-13: 3D scanner in the EGD classroom.

Figure 2-13 shows a small object being scanned by the 3D scanner during an EGD contact session in the EGD classroom.

2.5.2.6 3D printing

According to Wohlers and Gornet (2014), there is a fast-growing field in digital production technologies; a new industry grounded on additive manufacturing (AM) technologies is developing throughout the world. AM, which is also referred to as “3D printing”, is described by theASTM (2012) as technologies that are capable of joining material layer by layer, through a series of cross-sectional layers, to create a 3D object or model. The 3D printer operates in a similar way as commonly known conventional laser and inkjet printers. While laser and inkjet printers use different colours of toner or liquid inks, the 3D printer uses powder or filament that slowly builds into an object when printing on a layer-by-layer basis (Berman, 2012). The 3D printer dispenses a thin layer of liquid resin or plastic when filament is used (Berman, 2012). According to Xiao, Wan and Wang (2016), 3D printing is a fast-growing AM technology that uses different powder materials, such as plastic, nylon, wood, metal, sandstone and magnetic iron, to construct a 3D object based in a digital model file.

A 3D printer makes use of 3D CAD software that calculates thousands of cross-sections of each object drawn in 3D CAD to establish precisely how each layer of the object should be constructed and which part must be supported with structures (Baumers, Dickens, Tuck & Hague 2015; Berman, 2012). These printers can range from desktop printers to industrial printers that can print large parts of several meters; therefore it is important to determine which printer is needed in one’s specific situation. In the study, the focus is on commercially built desktop printers for educational purposes (Figure 2-14).

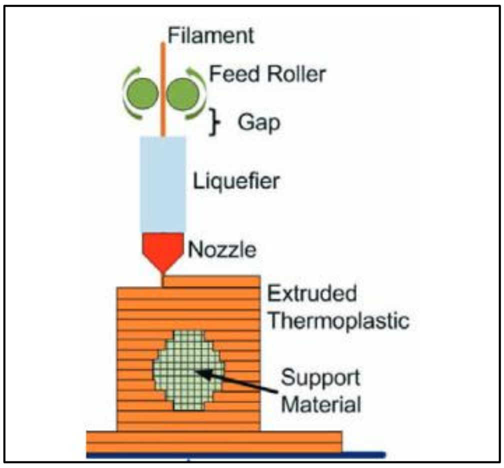


Figure 2-14: 3D printer using filament to print layer by layer.

Figure 2-14 illustrates the basic method of how a 3D printer works. The feed roller feeds the filament in the heated printer nozzle, which then prints the model layer by layer using G-codes.

2.6 The role of integrating ICT in education

Meyer and Gent (2016) describe the role of ICT in education as a method to do the following: equip educators and students with 21st-century skills; give access to online communities of practice and online content; make learning more student-focused, new, innovative and enjoyable; enable self-learning and discovery; promote critical thinking; and reduce administrative burdens. According to the Department of Basic Education (as cited by Padayachee (2017), the integration of ICT in education has not advanced as expected and there is an urgent need for universities and the government to integrate ICT in education to train aspiring educators effectively. It is therefore of the utmost importance for me as a lecturer at a university to adapt my EGD curriculum to train students to use ICT as a medium to improve SDL and spatial visualization, specifically with the use of advanced ICTs.

2.6.1 The importance and advantages of the use of advanced ICTs in EGD

Due to rapid technological developments worldwide and the demanding change in society, it is essential to change the way EGD is taught. Chedi (2015) supports the idea of changing the way EGD is taught by saying that overcoming the challenges in technology education, and EGD in particular, is only possible through sound pedagogy and the use of ICT in EGD.

Sharma and Dumpala (2015) state that advanced ICTs is an important factor in academic institutions and the most recent LMSs and CAD technologies should be utilised for the improvement of spatial visualization skills among EGD students. Advanced ICTs have gained substantial interest in the academic and industry fields due to the ability thereof to generate complicated geometries with custom material properties that improve spatial visualization abilities (Gao, Zhang, Ramanujan, Ramani, Chen, Williams, Wang, Shin, Zhang & Zavattieri, 2015). Abraham and Otuaga (2017) state that the use of advanced ICTs has the following benefits: it ensures precision, standardisation in drawings and measuring accuracy; it saves time, and erasing mistakes is a simple "undo" function; complex drawings can be done with ease in 2D CAD and it provides a method of fitting various components; CAD software allows virtual simulations of drawings and designs; and 3D CAD allows different components to be assembled to present a final product. Also, 3D objects or models convey clarity in understanding the complicated engineering drawings and design concepts in a precise and accurate way. Because of the ease in visualization, 3D models can be obtained by drawing it in 3D CAD, printing the model with a 3D printer and seeing it after a model has been scanned with a 3D scanner or animated in 3D animation (Sharma & Dumpala, 2015).

Advanced ICTs have the capacity to improve students' spatial visualization to see and understand the assembling of different components in mechanical drawings (see Figures 2-15 and 2-16).

Figure 2-15: Disassembled components.

Figure 2-16: Assembled components.

Figure 2-15 shows the four different components of a block bearing. Figure 2-16 shows all four components assembled.

2.6.2 Challenges and barriers in the use of advanced ICTs in EGD

The use of advanced ICTs in the EGD learning environment is very important for presenting opportunities for students to learn, understand and function in an era of digital information and technology. Studying the challenges and barriers in the use of advanced ICT education may assist EGD educators to overcome these challenges and barriers and become successful ICT adapters in future (Bingimlas, 2009). Several studies (e.g. Abraham & Otuaga, 2017; Bingimlas, 2009; Fakeye, 2010; Hennessy, Harrison & Wamakote, 2010; Yuming, 2010) show that ICT is essential in education. They furthermore state different challenges that must be overcome for ensuring quality teaching with ICT. These studies (Abraham & Otuaga, 2017; Bingimlas, 2009; Fakeye, 2010; Hennessy *et al*., 2010; Yuming, 2010) corroborate the same findings concerning the different challenges. The challenges relevant to EGD on secondary and tertiary level are summarised below.

Ogbomo (2011) states that inadequate funding and the lack of availability and accessibility of ICT software and hardware are problematic in the integration of education and ICT. Okafor (2015) mentions the shortcoming of educator-acquired skills; hence resources can only be utilised in teaching and learning if the educator has the required skills. Resistance to change and the confidence to teach ICT are other barriers educators have to overcome to improve the use of ICT in education (Abraham & Otuaga, 2017). A lack of time is seen as a huge challenge among educators because of their educational workload and the various administration tasks they are expected to carry out (Ghavifekr *et al*., 2016). The last challenge in the use of ICT is the lack of technical support; educators are not information technology specialists, and if there is a problem with the ICT software and hardware, it cannot be expected from them to have an experienced information technology solution for the problem (Bingimlas, 2009). According to theBecta (2004), the challenges in the integration of ICT and education can be divided into educator-level barriers, institution-level barriers and student-level barriers. Table 2-4 gives a summary of these challenges and ways to overcome them.

Table 2-4: Integration of ICT and EGD.

Overcoming barriers in the integration of ICT and EGD education			
Barriers	**Institutions**	**Educators**	**Students**
Lack of access and funding	Institution should provide the necessary ICT hardware and software	Take advantage of ICT resources available at institution	Take advantage of ICT resources available at institution
Lack of acquired skills	Institution should provide the necessary training for the use of ICT	Prepare themselves by self-training and attending any training offered by institution	As Generation Z students, students should encourage educators to use ICT EGD
Resistance to change	Institution should provide the necessary didactical skills to use ICT in education	Be open-minded towards change in EGD education	As Generation Z students, students should encourage educators to use ICT in EGD
Lack of time	Provide sufficient time	Acquire self-organisation and time management skills	Self-organisation and time management skills of should be taught
Lack of technical support	Provide technical support on a continual basis	Acquire basic technical skills to solve smaller problems	Basic technical skills to solve smaller problems should be taught

(Abraham & Otuaga, 2017; Becta, 2004; Bingimlas, 2009; Fakeye, 2010; Ghavifekr *et al.*, 2016; Hennessy *et al.*, 2010; Mdlongwa, 2012; Yuming, 2010)

From Table 2-4, it is evident that there are various challenges that should be overcome before ICT integration in education would be sufficient. Higher education institutions and the Department of Basic Education should adhere to these challenges to overcome them in South Africa.

2.6.3 Advanced ICT and the EGD student

According to Abraham and Otuaga (2017), EGD students would benefit from using advanced ICT tools for delivering content in EGD. The benefits are as follows: the use of ICT ensures precision and standard in drawings; it saves time when doing a drawing on 2D CAD; it allows the student to do more complex drawings with ease in 2D CAD; virtual simulations help students to see and understand the end product better; assembling individual parts to represent a final product in 3D CAD is faster and easier; the degree of accuracy improves when using CAD instead of a hand instrument drawing; CAD improves measuring accuracy compared to hand drawings; and the data communicated in CAD are clearer then in drawings done by hand.

2.6.4 Advanced ICT and the EGD educator

According to Chedi (2015), the use of ICT can bring changes in how teaching and learning will happen in the EGD classroom. The application of ICT in EGD allows for more interactive learning and student participation in class activities, improves students' skills in the application of CAD, develops students' skills in EGD drawing and improves students' understanding of basic concepts (Yasin, Halim & Ishar, 2012). It furthermore helps students to solve problems related to subject matter better (Yasin *et al*., 2012).

2.7 Conclusion

In this chapter, I attempted to combine a theoretical framework that explains the origin of EGD. I compared the South African EGD curriculum to curricula of other countries worldwide and saw that some countries still followed the same curriculum as the one in South Africa. The EGD secondary school curriculum is the starting point for EGD on tertiary level, where the same main topics are followed, but on a higher cognitive level. Different career opportunities in EGD were discussed and the importance of the design process was emphasised and linked to ICT. I described the significance of EGD and ICT and discussed the relevant advanced ICTs. Barriers in the integration of ICT and education were identified and it was determined how these barriers could be overcome. In the next chapter, the theoretical framework that explains the interrelationship between learning theories, spatial visualization skills and self-directed skills will be discussed.

CHAPTER 3: ENGINEERING GRAPHICS AND DESIGN SKILLS AND LEARNING THEORIES

LOGIC

Question	Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)	McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)	Chapter layout	Research method
To what extent do advanced ICTs enhance the spatial visualization and SDL skills of students?	Thinking of ways to take on the problem	What issue am I interested in researching? Why do I want to research this issue? What kind of evidence can I gather to show why I am interested in this issue? What can I do? What will I do?	EGD skills and learning theories	**Literature**

3.1 Introduction

In the previous chapter, I investigated the history of EGD, the EGD curriculum and the importance of ICT in education, inspecting the background of the implementation of advanced ICTs in EGD. In this chapter, I shall outline the conceptual framework for the study by doing an in-depth literature investigation with regard to information on learning theories in EGD, spatial visualization and SDL by choosing the learning theory for EGD that will best adhere to implementing important EGD skills, spatial visualization skills and SDL in order to improve spatial visualization in EGD while using ICT.

3.2 Learning theories in teaching and learning

Academics describe learning as an active process. A learning theory explains how human beings learn and understand concepts. In other words, learning theories are attempts to describe how people learn, thereby helping one understand the complex process of learning (Bada & Olusegun, 2015). Masethe, Masethe and Odunaike (2017) describe traditional educational philosophies, such as behaviourism, cognitivism and constructivism, as the basis of teaching and learning. Selivanova and Tagunova (2016) express that traditional educational philosophies are modernised to comply to the needs of a 21st-century student in education, which are supported by the views Masethe *et al.* (2017) propose on learning theories of the 21st century. Trnova and Trna (2015) suggest that there is a need to scrutinise learning theories and adapt these theories to the new approach to teaching and learning while using ICT. The younger generation is seen as the "Net generation" or, as referred to in this study, Generation Z. Generation Z students spend hours using technology such as smart phones and computers. It is therefore important to adapt learning theories in education to the 21st century. Table 3-1 shows, in short, research done on the traditional educational learning theories according to each factor of a learning theory, based on publications and pedagogical benefits.

Table 3-1: Learning theories.

Learning theory	Description of learning theory
Behaviourist theory	Behaviourism is the interest in looking at behavioural and observable changes in humans. The theory explains why humans behave the way they do. It is the concernment with observable behaviours that can be measured. In teaching and learning, behaviourism concentrates on stimuli such as positive and negative reinforcement that creates a specific response in humans (Kaplan, 2018; Lee, 2016).
Cognitive theory	Students are encouraged to explore instructional materials and become active creators of their own knowledge during the four stages of cognitive development (Goldie, 2016a; Louw & Louw, 2007):

Learning theory	Description of learning theory
	• Sensorimotor (0-2 years): understanding of the world is obtained through senses and movement. • Preoperational (2-4 years): starting to use language and symbols. • Concrete operations (7-11 years): logical thinking starts to develop while abstract thinking is, to a large extent, still absent. • Formal operations (12 years and older): adolescents and adults think abstractly and are capable of speculating and reasoning. Developing cognitive skills during the formal operational stage allows students to build upon previous knowledge and ideas. As students enter the formal operational stage, they obtain the ability to think and reason in an abstract manner by manipulating ideas in their head, without any dependence on concrete manipulation.
Constructivist theory	Students solve problems and develop solutions, with minimal intervention from the educator. Constructivism emphasises students' construction of new knowledge through self-guided discovery, self-reflection, self-assessment, self-improvement, self-actualisation, self-realisation and personal experience. The theory furthermore focuses on understanding the information rather than memorising and reproducing the information (Bada & Olusegun, 2015; Goldie, 2016b).

Taking Table 3-1 into consideration the descriptions of the three learning theories given above, the constructivist learning theory leans towards SDL and the improvement of spatial visualization. Noordin and Ahmad (2010) argue that the constructivist learning theory supports SDL and experiential learning, which are important in my study to improve students' SDL skills while using ICT and improving spatial visualization.

3.3 Constructivism in EGD teaching and learning

Constructivism is an approach to teaching and learning based on the premise that learning is the result of cognitive formation; students therefore acquire information by adding new knowledge to prior knowledge (Bada & Olusegun, 2015; Bada *et al.*, 2015). Academics in constructivism furthermore believe the process of learning is affected by the perspective in which ideas are educated as well as the different beliefs and attitudes of students towards learning; therefore constructivism may be seen as a learning theory found in psychology that explains how students acquire knowledge and how they learn (Kaplan, 2018). Al-Huneidi and Schreurs (2011) describe that the constructivism theory has an impact on the educational learning cycle in three different approaches. First of all, the curriculum followed should support the enhancement of students' experiences, integration of prior knowledge and new knowledge obtained as well as promoting problem-solving skills. Secondly, the method of instruction should promote teaching methods that encourage students to investigate, do research, interpret and analyse information. It furthermore should promote teamwork among students, with students learning from their peers. Thirdly, assessment should be adapted to improve the role students play during assessment; thus self-assessment and peer assessment should be part of the curriculum. According to the Department of Basic Education (2011), the South African school curriculum lends itself towards these three different approaches in the EGD curriculum. The EGD CAPS document (Department of Basic Education (2011) states that the curriculum aims to produce students that are able to:

- identify and solve problems and make decisions using critical and creative thinking;
- work effectively as individuals and with others as members of a team;
- organise and manage themselves and their activities responsibly and effectively;
- collect, analyse, organise and critically evaluate information;
- communicate effectively using visual, symbolic and/or language skills in various modes;
- use science and technology effectively and critically showing responsibility towards the environment and the health of others; and

- demonstrate an understanding of the world as a set of related systems by recognising that problem solving contexts do not exist in isolation.

As the school curriculum is followed as guideline on tertiary level when training EGD educators (see Section 2.3.3), higher education institutions also adhere to the three approaches of constructivism. The importance of constructivism is discussed in Section 3.6 and in Figure 3-1.

3.4 Spatial visualization in EGD

Spatial visualization is a fundamental skill in EGD and, according to Mohler and Miller (2009), is a critical cognitive skill or ability for many technology disciplines in order to ensure students' understanding of drawings in EGD. Spatial visualization skills involve the ability needed to mentally process, rotate, manipulate and visualize 3D images of objects and see spatial relation in 2D images, such as isometric, oblique, pictorial or multiview drawings. Students furthermore are envisaged to be able to mentally construct and draw these ideas through the computer (with CAD) or the drawing board (Fleisig *et al*., 2004). "Strong spatial visualization skills particularly the ability to visualize in three dimensions, are cognitive skills that are linked to success in science, technology, engineering and mathematics (STEM) fields" (Metz, Donohue & Moore, 2012). Based on the above definitions, it is evident that spatial visualization entails the ability to visualize, and for this study, it entails the visualization of sectioned mechanical assembly drawings.

3.4.1 Spatial visualization and the EGD student

Spatial visualization is important for students to improve visualization, sketching, spatial abilities, mental manipulation of objects and machine parts, construct spatial relations and communicate these via computer or paper (Ali *et a*l., 2012; Fleisig *et al*., 2004; Wang *et al*., 2006; Yue, 2006). Brudigam and Crawford (2012) furthermore believe that students perform better in drawing tests when their spatial visualization abilities are improved. When students perform better in tests and understand the work, they tend to be more motivated for the specific subject;

thus, better marks may improve their intrinsic motivation to perform and excel in EGD (Felder & Brent, 2016; Kusurkar, Croiset & Ten Cate, 2011). Students obtain particular skills using computers, drawing software, 3D printers and 3D animation, which will prepare them for the industry after their studies (McGill, Koppi & Armarego, 2015). If students obtain all of the above-mentioned skills, it will additionally improve EGD students' design process skills (see Section 2.4) when applying these skills in their PAT assignments (Department of Basic Education, 2011)

3.4.2 Spatial visualization and the EGD educator

According to Mohler and Miller (2009), EGD is important for an educator for the following reasons: to teach the graphical language; to develop students' capability to visualize; and to improve students' problem-solving skills in three dimensions. Sorby (2009) states that it is important for the educator to help students improve their spatial visualization in order to ensure success during the curriculum followed. As a facilitator of the EGD curriculum, it is of the utmost importance that the facilitator of any drawing or engineering course should promote spatial visualization skills to improve students' understanding of rotated views of drawings, sectioning of solids and assembly machine drawings. If the facilitator is part of the process teaching spatial visualization skills to students, it will encourage the students to attend lectures and allow the educator to do mass mentoring of proper drawing techniques (Mohler & Miller, 2009). When students overcome the barriers of spatial visualization, their motivation to perform well in EGD will improve. Furthermore, the EGD educator should ensure that he or she is up to date on the newest developments in the EGD field and make use of the newest technologies or developments to improve student participation, enhance learning engagement, improve problem-solving skills and improve cognitive ability for mental rotation, which will enhance students' visualization and interpreting skills of sectioned mechanical assembly drawings (Katsioloudis, Jovanovic & Jones 2014; Kusurkar *et al.*, 2011; Mohler & Miller, 2009; Olkun, 2003).

3.4.3 How are spatial visualization skills enhanced?

Zhu, Ferguson and DeMarco (2008) are of the opinion that there is no clear consensus on which methods or combination of methods are best for improving spatial visualization. According to Bishop (1978, as quoted by Fleisig *et al.* (2004), sketching, using physical models and objects, using computer graphics and employing descriptive geometry are four methods regarded as having an influence on spatial visualization. Katsioloudis *et al.* (2014) claim that spatial visualization skills should be enhanced when using 3D computer-based visualization, instructional designs being taught and sketching and drawing. Cho and Kwon (2003); Kim and Kwon (2003) believe that 3D visualization should be adequate to provide students with the ability to develop spatial visualization skills. To improve students' ability to understand and create sectional mechanical drawings, the course objectives of EGDD411 and EGDD421 are summed up as follows:

- Reading mechanical drawings
- Giving analytical descriptions of mechanical drawings
- Creating 2D mechanical drawings to understand the CAD program
- Creating 3D mechanical drawings to improve spatial visualization
- Doing 3D printing of mechanical components to understand how parts fit together

The above-mentioned objectives and how they are applied in the study will be discussed and explained in Chapter 5 (intervention).

3.4.4 Spatial visualization and the use of advanced ICTs

Gorska *et al*. (1998) are of the opinion that solid modelling (3D CAD) alone does not improve spatial visualization; it should be supported by other methods (see Section 3.4.3). During research at a later stage, Sorby and Wysocki (2003) came to the conclusion that the use of ICT with a workbook has shown positive levels in enhancing spatial visualization among students. Katsioloudis *et al*. (2014) suggest that more research should be done on the implementation of ICT in EGD, more specifically the effects of 2D drawings versus 3D drawings on CAD, to determine the influence 2D and 3D CAD have on spatial visualization. To clearly determine the benefits of advanced ICTs (see Section 2.5) in EGD, 3D printing and 3D animation will be added to explore the impact they have on spatial visualization skills in EGD.

3.5 Self-directed learning

Candy (2009) suggests that self-directed learning (SDL) was and still is the way in which most individuals learnt what they wanted or needed to know prior to the appearance of formal school systems years ago. Davis *et al.* (2010) define SDL as “an approach to knowledge relying on an individual being able to and responsible for directing his or her own learning”.

> SDL is a continuous engagement in acquiring, applying and creating knowledge and skills in the context of an individual student’s unique problems. SDL capabilities are critical in the ever-changing knowledge economy where the only constant is change. Instilling a lifelong learning perspective implies that schools and universities need to prepare learners to engage in SDL processes. (Stewart (2007)

Academics undertook the task to discover different methods to develop a better understanding of the implementation of SDL in the educational system by creating different models for SDL. These models are as follows:

- The Self-Directed Learning Readiness Scale (SDLRS) (Guglielmino, 1977)
- The Oddi Continuing Learning Inventory (OCLI) (Oddi, Ellis & Roberson, 1990)
- The Self-Directed Learning Readiness Scale for Nursing Education (SDLRS) (Fisher, King & Tague, 2001)
- The Self-Rating Scale of Self-Directed Learning (SRSSDL) (Williamson, 2007)

- The Self-Directed Learning with Technology Scale (SDLTS) (Timothy *et al*., 2010)

If students solve their own problems for their own sake and try to actively acquire the required knowledge and skills, they are active, motivated students. Active learning happens when students are self-directed to learn for themselves through their demands to solve authentic or personally meaningful problems (Fischer & Sugimoto, 2006; Guglielmino, 1977; Heikkilä & Lonka, 2006). As the focus in my study is to determine the students' SDL skills while using ICT and improving their spatial visualization skills, the SDLTS of Timothy *et al.* (2010) will be adapted and used to determine fourth-year EGD students' self-directedness while using ICT (see Section 4.6.4.2, Table 4-4).

3.5.1 SDL and the student

A self-directed student is able to identify what needs to be learnt and what is required to introduce learning by identifying different learning objectives and choosing different learning strategies to acquire these objectives while evaluating his or her learning processes (Guglielmino, 1977). Robertson (2010) believes that the self-directed student should take responsibility for his or her own learning and obtain a comprehensive assortment of higher cognitive skills while learning.

Merriam-Webster (2018) describes a student as someone who acquires knowledge, skills or behavioural tendency by taking part in learning, which is the process of gaining knowledge or skills by means of studying, instruction or experience.

Knowles (1975) identified the following competencies that are required by an SDL and EGD student: The SDL and EGD student should relate to peers in group work, see their peers as resources for identifying different needs and plan to provide in these needs. They should, furthermore, help one another and be able to receive help from peers (peer learning). The students should translate their learning needs into learning objectives and diagnose their own learning needs in a realistic way with the help of the lecturer and peers. In addition, they should relate to the educator as an educator and be creative in making use of their own resources. SDL and EGD students should select efficient methods for making use of the learning resources available. The students should, furthermore, be able to collect, demonstrate and validate these learning resources with the different learning objectives in mind.

What is most needed by EGD students is best summarised by Dweck (2008), who expresses that a student's viewpoint and approach to learning is significantly influenced by personality characteristics that can enhance his or her learning skills by adopting a way to change his or her own principles. Cazan and Schiopca (2014) further state that SDL characteristics are not pre-set, but can be developed with different exercises. SDL skills are seen as the foundation of lifelong learning; therefore it is important to focus on these skills as soon as possible to help students reach a level of life-long learning. Dynan, Cate and Rhee (2008) describe the following skills as important to engage in SDL and most applicable to EGD students: making use of real-world problems and determining different solutions for these problems; and identifying and being able to explain underlying statements. Furthermore, to be a self-directed student is seen as a normal way to learn. Self-direct learning is a characteristic that can be reduced, restored and further developed (Guglielmino, 1977). The use of SDL skills in teaching and learning is seen as a method to enhance the way in which individuals learn (Guglielmino, 1977).

3.5.2 SDL and the educator

The key role of an educator should be to act as an educator instead of the main source of knowledge for students. They should no longer only dispense knowledge, but should rather teach students by observing their progress in the classroom and inspiring them to challenge themselves to adapt their learning in such a way that students learn without knowing it (Gillies, 2007; Knowles, 1975).

The role that educators play can be described as vital, as educators' method of teaching and learning and their interaction with students influence the way SDL is developed in the classroom. Through giving support, guidance and assistance, educators can develop skills among students, which will lead them to be successful, self-directed students. While promoting the effective use of SDL, it is advised to remember that methodological concerns and cognitive preparation are of the utmost importance (Gillies, 2007; Knowles, 1975; Thornton, 2010). Oswald (2003) sees the most important step in fostering self-directedness as preparing the student for SDL, since it not only presents students to direct their own learning but also explains to students what is expected from them from the educator's side.

Another important role an educator plays in effectively promoting SDL is facilitating teaching pedagogies and teaching strategies by engaging students in SDL. Furthermore, the educator should be aware of students' attitudes and behaviours in the SDL setting. Educators should also be aware of the role that the classroom atmosphere can play in enhancing SD skills and should lead students in regulating their own learning (Liu Hodgson & Lord, 2010; Robertson, 2010).

3.5.3 How can SDL skills be improved?

Different authors and researchers have different ideas about how to improve SDL skills among students. A reason for this could be that SDL is not yet a coherent theory, as it is relatively new as a theory (Hiemstra, 1994; Titmus, 2014). During the literature study, I found different methods to improve SDL skills among students. The adapted guidelines for developing SDL skills (Table 3-2) of Buthelezi and Phahamane (in Buthelezi, De Beer, Du Toit, Golightly, Gravett, Havenga, Lubbe, Makonye, Petersen & Phahamane, 2016) were the skills best suited for utilising in EGD.

Table 3-2: Adapted guidelines for developing SDL skills.

No.	Action step
1	Introduce problem-based learning, project-based learning and field-based learning and build the skills to analyse and address problems
2	Problem identification
3	Planning
4	Resource identification
5	Evaluation of strategies and results
6	Identification of new questions
7	Provide support systems
8	Other appropriate sources – human or material

(Buthelezi & Phahamane in Buthelezi *et al.* (2016)

The action steps mentioned in Table 3-2 were applied in the intervention phase (see Chapter 5) of the study. The students were introduced to a relevant problem or scenario in the engineering field with regard to the sectioning of assembly drawings. The students then had to use their basic EGD and CAD skills to identify the problem. Then they had to plan and research the problem and identify a possible solution for the problem. After following steps 1 to 4, the students had to evaluate the end result, which was printed by a 3D printer. When the prototype was evaluated, different new problems might appear, which would be addressed in another problem or scenario in class. Steps 7 to 8 are the different support systems in place to assist the students during the design process.

3.5.4 SDL with advanced ICTs in EGD

According to Timothy *et al*. (2010), there is a relationship between SDL and ICT; ICT may have direct impact on SDL because it has greatly facilitated access to both information resources and online expertise. For students, being able to access a wide and unlimited range of information to serve their learning needs and interests is important to SDL. This includes capturing, storing, manipulating and displaying information as well as making contact with fellow students and experts around the globe without layers of formality and at the press of a button (Timothy *et al.* (2010).

Similarly, Lin (2008) found that the 92 online learners in their study, in their pursuit of achieving expert knowledge, had followed three kinds of learning approaches: independent inquiry; collaborative inquiry; and formative inquiry. The two learning approaches of direct relevance to SDL are independent inquiry and formative inquiry. Independent inquiry is characterised by the learner’s desire and action to work through online communication channels and technologies that enable him or her to think out loud, reflect, explore, search and express him- or herself independently. Formative inquiry combines aspects of both independent and collaborative inquiries that help learners to build and help one another to build expert knowledge in online environments.

3.6 Integration of constructivism, SDL and spatial visualization

For the optimal application of constructivism as a learning theory, the improvement of SDL skills and the enhancement of spatial visualization skills, the three above-mentioned theories (constructivism, spatial visualization and SDL) should be integrated and be interdependent of one another. Boylan, Micarelli, Pirrottina and Sciarrone (2000) state that while constructivism is a recognised and well-documented theory, SDL is less so; therefore it is important to integrate SDL with a recognised theory to substantiate and support my research findings. In Figure 3-1, the benefits of constructivism are linked to the three main dimensions of SDL. To furthermore strengthen the importance of SDL dimensions, the principles of spatial visualization are linked to the SDL dimensions. Garrison (1997) and Timothy *et al.* (2010) believe that there is an interdependent, overlapping of the dimensions in SDL.

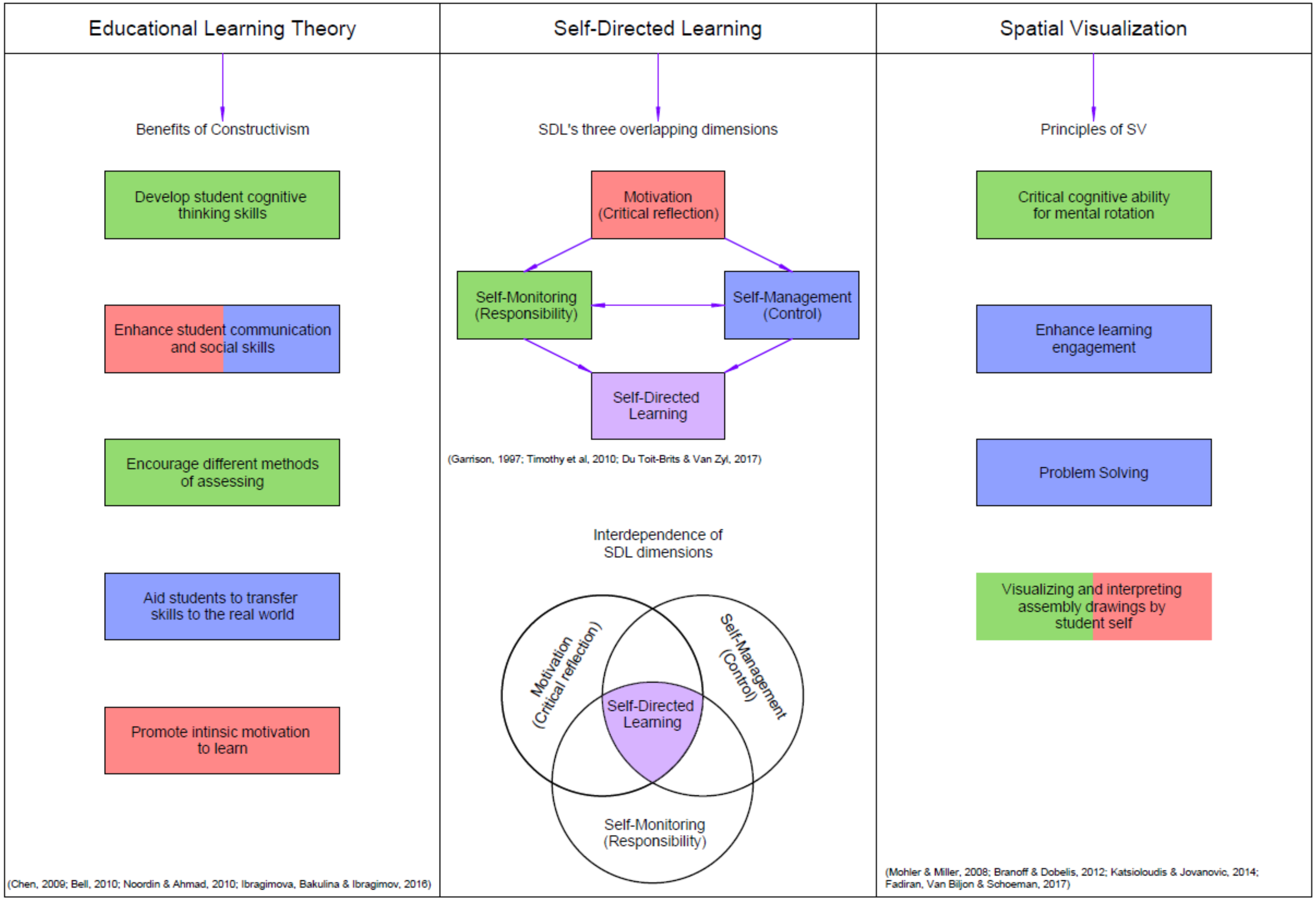


Figure 3-1: Integration of constructivism, spatial visualization and SDL.

Figure 3-1 shows by means of the colour coding the integration of constructivism, spatial visualization and SDL which shows the **Interdependence of SDL dimensions** to accentuate that SDL skills will be difficult to obtain if motivation, self-management and self-monitoring are not present.

Motivation as a dimension of SDL is enhanced by constructivism when students are motivated to enhance their communication and social skills and the intrinsic motivation to learn and excel is promoted. The principle of spatial visualization that supports the SDL motivation dimension is when students are intrinsically motivated to visualize and interpret assembly drawings themselves (drawings are a means of communication in EGD) and reflect on what was done during the class activity.

Self-monitoring as a dimension of SDL is enhanced by constructivism when students develop cognitive thinking skills and are encouraged to assess and evaluate problems with different methods, such as problem-based learning. Principles of spatial visualization that verify this SDL dimension is when students use their critical cognitive abilities to visualize, interpret and mentally rotate objects in EGD.

Self-management or intentional learning as a dimension of SDL is improved by constructivism when students are guided to transfer and communicate different skills to the real world. This is strengthened by spatial visualization principles where students' learning engagement and problem-solving skills towards the real world are enhanced.

The integration of constructivism, SDL and spatial visualization should assist in improving students' understanding of sectioned mechanical assembly drawings while using advanced ICTs (see Chapter 6).

3.7 Conclusion

In this chapter, I attempted to combine a theoretical framework that explains the importance of SDL for the student and the educator, as well as the importance of spatial visualization for the student and the educator. Furthermore, an educational learning theory was chosen to support SDL and spatial visualization. This was followed by a discussion of the integration of constructivism, SDL and spatial visualization, which are necessary to prove that students’ skills with regard to SDL and spatial visualization will be improved by using advanced ICTs in EGD. In the next chapter, I shall expound on the research methodology, research design and paradigm followed in the study.

CHAPTER 4: THE RESEARCH DESIGN AND METHODOLOGY

Logic

Question	Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)	McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)	Chapter layout	Research method
How can the implementation of advanced information and communication technologies, such as 2D or 3D CAD, 3D animation and 3D printing, improve spatial visualization and promote SDL in Engineering Graphics and Design in higher education environments?	Thinking of ways to take on the problem	What can I do? What will I do? What kind of evidence can I gather to show that I am having an influence?	**Chapter 4** The research design and methodology	**Research plan**

4.1 Introduction

In this chapter, I shall attempt to expand upon the research design and methodology that I have briefly introduced in Chapter 1. De Vos, Strydom, Fouche, Poggenpoel, Schurink and Schurink (2001) describe the research design as a "blueprint according to which a study will be implemented". It furthermore entails the planning and the structuring of the study while addressing the research questions, and it indicates the caution with which I approached issues such as ethical considerations and trustworthiness, sampling, data collection and the data analysis of the study. The research done was designed to answer the primary research question: How can the implementation of advanced information and communication technologies, such as 2D or 3D CAD, 3D animation and 3D printing, improve spatial visualization and promote SDL in Engineering Graphics and Design in higher education environments?

In order to clearly understand why, how and what I intended to do in the study, I have to discuss my research design and methodology to outline the different qualitative and quantitative approaches I followed. The primary research question lends itself to the specific research design and methodology followed in this chapter. The methodology followed is discussed under the following headings:

- Research problem and research questions
- Research aims and objectives
- Research design and methodology
- The trustworthiness of the research

4.2 Research problem and research questions

The study proposes a framework to improve students' spatial visualization skills while using advanced ICTs and attempts to enhance their SDL skills as well. In order to do this, the following primary research question was identified:

How can the implementation of advanced information and communication technologies, such as 2D or 3D CAD, 3D animation and 3D printing, improve spatial visualization and promote SDL in Engineering Graphics and Design in higher education environments?

To respond to the primary research question, the following five secondary research questions were addressed:

- What are the main advantages and barriers of using ICT in EGD education globally and in South Africa?
- To what extent are ICTs being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education?

- To what extent do advanced ICTs enhance the spatial visualization and SDL skills of students?
- How can ICT and spatial visualization skills be further developed to enhance EGD in higher education?
- What contributing suggestions made by student teachers, EGD lecturers and the researcher can assist in the development of a framework for advanced ICT integration in EGD to foster spatial visualization and SDL?

4.3 Research aims and objectives

The study was aimed at increasing students' spatial visualization skills while using advanced ICTs and, furthermore, determining fourth-year students' SDL abilities when using ICTs. At the same time, the teaching and learning of EGD may improve because of the new methods introduced in the EGD class. The result will be to design a framework that may serve as a possible guideline for future implementation in EGD to improve spatial visualization. My research objectives were:

- to determine the main advantages and barriers of using ICT in EGD education globally and in South Africa;
- to determine to what extent ICTs are being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education;
- to discover to what extent advanced ICTs enhance spatial visualization and SDL skills;
- to discover how ICT and spatial visualization skills can be further developed to enhance EGD within higher education; and
- to propose a suitable framework for the implementation of advanced ICT integration in EGD to foster spatial visualization and SDL.

4.4 Philosophical grounding of the study

A paradigm is a shared worldview based on different theories Johnson(2012); Koshy (2010); Whitehead and McNiff (2006a). Ontology, epistemology and methodology are key aspects in educational research that supported the philosophical or theoretical grounding of my study.

Ontology as a theory raises the question: What is the nature of reality? In my study, the nature of reality is interpretivist/constructivist as I am constructing my own meanings and understanding through the research cycle (Koshy, 2010). Since I was facilitating the EGD classes as the lecturer and researcher, I was part of the EGD environment where the research was done to improve students' spatial visualization and SDL skills while using advanced ICTs. Since I was part of the study, it would not have been possible to separate myself from the students' environment; therefore I adopted a participatory action research approach in the study (Creswell & Creswell, 2018; Maree, 2016).

Epistemology as a theory is built upon the ontology theory and raises the following question: What is the nature of knowledge and the relationship between the knower and the would-be knower? (Whitehead & McNiff, 2006a). The main principle of the epistemology theory entails how the students understand EGD knowledge and skills, what is known to them and how EGD knowledge and skills become known by the students. As the researcher and educator, I would play a very important part in facilitating and assisting the EGD students to obtain and understand the knowledge and skills required to improve spatial visualizing. As the researcher, I had to construct and improve my own EGD knowledge and skills while reflecting on my teaching practice during the action research cycle (Hinchey, 2016; Koshy, 2010; McNiff, 2010).

The **methodology** theory is influenced by the ontological and epistemological theories and refers to the following question: How can the knower go about obtaining the desired knowledge and understanding? (Mackenzie & Knipe, 2006; McNiff, 2014). It is further explained as knowing how things are done. In the context of the study, it involves how my experiences as an educator and researcher have influenced the interaction with my students and how the process of reflecting in EGD has assisted me to understand the research design and methodology I followed (Koshy, 2010).

Taking the above-mentioned theories into consideration, it is evident that the three theories are interdependent of each other (see Figure 4-1) and would influence the research of my study in a real-life situation and the accumulation of knowledge based on my personal values, experiences and interaction with the participants (Johnson, 2012). Figure 4-1 displays the interdependence of ontology, epistemology and methodology.

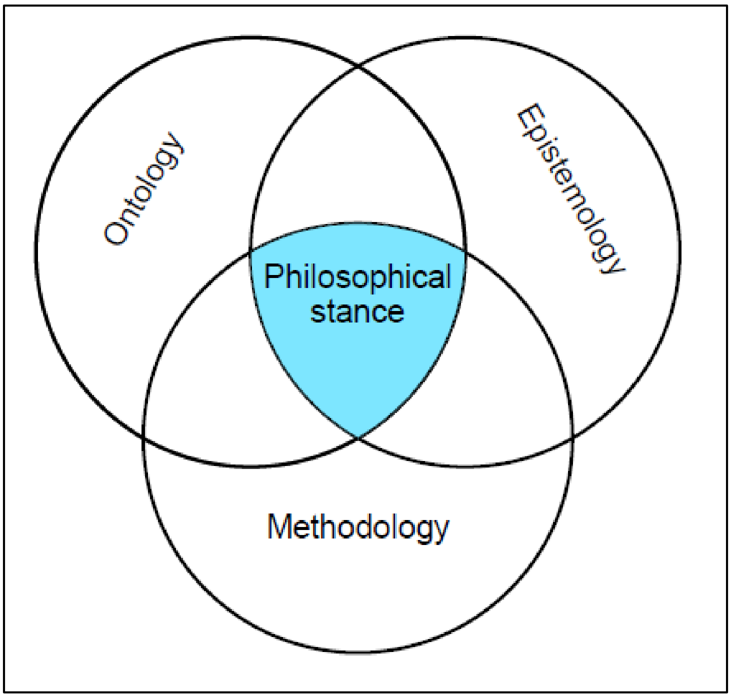


Figure 4-1: Interdependence of philosophical theories (Author).

Figure 4-1 shows that to have a philosophical stance, it is important to make use of ontology, epistemology and methodology. Kuhn (1962) describes a paradigm as a philosophical way of thinking. Throughout the years in educational research, the term "paradigm" has often been used to describe the researcher's worldview. The worldview is the perspective that shapes how the researcher sees the world and how research is interpreted (Kivunja & Kuyini, 2017). According to Bassey (1990), as quoted by Sullivan, Glenn, Roche and McDonagh (2016), research paradigms are "a network of coherent ideas about the nature of the world and the functions of researchers which are adhered to by a group of researchers, conditions the patterns of their thinking and underpins their research actions". It is therefore important to identify through which worldview lens one approaches one's research, as it will influence the research design and methodology one follows during research (Kivunja & Kuyini, 2017; Mackenzie & Knipe, 2006).

After an in-depth self-analysis and having read the literature about different paradigms, I realised that the interpretivist/constructivist paradigm fitted my research best. Interpretivism is also referred to as constructivism, therefore I shall use the term "interpretivist/constructivist paradigm" when referring to the paradigm (Kivunja & Kuyini, 2017; Maree, 2016). Researchers who use the interpretivist/constructivist paradigm believe that there is no single method or means to gain knowledge and there are no correct or incorrect theories; it should rather be judged according to how interesting the research is for the researcher, and the findings should be derived from the research field by means of an in-depth analysis of the phenomenon of interest (De Vos, 2011; Maree, 2016). It is furthermore stated that the interpretivist/constructivist paradigm has a vital purpose for researchers, namely to gain insight into and in-depth information of the issue at stake (Thanh & Thanh, 2015). The issue at stake in my study is the phenomenon that students struggle to assemble sectioned mechanical drawings. Therefore I, as the researcher, should gain insight into and in-depth information on how to improve students' spatial visualization and SDL skills while using advanced ICTs. The study is situated in the interpretivist/constructivist paradigm. Table 4-1 shows the characteristics of interpretivism/constructivism, as used in the study.

Table 4-1: Characteristics of interpretivism/constructivism.

Characteristic	Description
Purpose of research	How can the implementation of advanced ICTs, such as 2D or 3D CAD, LMSs and 3D printing, improve spatial visualization and SDL skills in EGD in higher education environments?
Ontology	The research in this study may have multiple realities, which can be investigated and reconstructed to give meaning through human collaboration between the researcher and research participants.
Epistemology	As the researcher, I shall make meaning of the data through my own thinking and cognitive processing of data by means of interacting with research participants.
Methodology	Data are gathered by means of interviews, keeping a journal, focus group discussions and self-reflection.

It is evident from Table 4-1 that the key aspects of using the interpretivist/constructivist paradigm in the ontology and epistemology phase are participation, collaboration and engagement with the participants; therefore the researcher is seen as a participant observer who participates in the activities and determines the meaning of action taken during the research within specific social contexts (Henning, Van Rensburg & Smit, 2004; Koshy, 2010; McNiff, 2014). The methodology followed relies on the method of data collection, which was, in this instance, by means of focus group interviews and observations.

4.5 Research design

A research design is described as a detailed plan, procedure and actions followed in research that extend the findings from broad statements or assumptions to detailed methods of data collection and analysis (Creswell, 2008a). The three types of research design are the qualitative, quantitative and mixed-methods designs (Creswell, 2008a; Creswell & Creswell, 2018; McMillan & Schumacher, 2010). Johnson and Christensen (2016) state that a research design is the plan or strategy followed to investigate the research questions of a study. The focus of my research question was to improve spatial visualization skills and SDL skills among EGD students while using advanced ICTs (see Section 1.4.1 and 1.4.2).

A qualitative research design incorporates different approaches into research. While some aspects are quite different from one another within these approaches, all of these approaches have two distinctive features in common. Firstly, there is a focus on a phenomenon that occurs in a natural setting or in the real world; secondly, these approaches involve the phenomenon to be studied in its entire complexity (Leedy & Ormrod, 2013; Leedy *et al*., 2019). Qualitative researchers furthermore believe that there is not a single outcome to the phenomenon being studied and different researchers may have different outcomes with equal validity and truth (Creswell & Creswell, 2018; Guba & Lincoln, 1994).

The quantitative research design is used for testing theories by examining the relationship between variables with the final objective, that is, to determine, describe, predict and control the phenomenon (De Vos *et al*., 2014). Quantitative researchers regard this approach as a process that is systematic, methodical, logical and objective when using numerical data from the population to generalise the findings and results to the phenomenon that is being studied (Maree, 2016). Thus the three important elements in quantitative research are objectivity, numerical data and generalisability (Maree, 2016; McMillan & Schumacher, 2010).

According to Ivankova (2015), mixed-methods research is increasing among researchers in order to overcome the separation of quantitative and qualitative research methods. Mixed-methods research has gained popularity due to the ability of this research method to deal with the research problem more comprehensively (Creswell, 2008b; Plano Clark & Creswell, 2011). Nastasi and Hitchcock (2016) furthermore claim that mixed-methods research may provide the most instructive, complete, balanced and useful research results, as the approach balances qualitative and quantitative research by drawing on the advantages of the one approach and compensating for the disadvantages of the other. It is therefore evident that the mixed-methods research approach will support a profound combination of qualitative and quantitative methods in a study to produce more credible, more persuasive and more dependable conclusions to the research problem (Ivankova, 2015; Mills, 2018; Wisniewska, 2011). Creswell (2008a); Creswell (2008b); Plano Clark and Creswell (2011) further state that by employing the mixed-methods research approach, utilising both qualitative and quantitative research, as a combination, provides a better understanding of the research problem or issue at stake than either research approach alone.

McMillan and Schumacher (2010) divide mixed-methods research into two designs, namely the sequential explanatory design and the sequential exploratory design. The sequential explanatory design implements quantitative and qualitative data collection: while the primary emphasis is on the quantitative method, the qualitative data further elaborate on the quantitative findings (QUAN-qual). The sequential exploratory design implements qualitative and quantitative data collection: with the primary emphasis on the qualitative method, the quantitative data further elaborate on the qualitative findings (QUAL-quan). In the study, using the mixed-methods research approach, I followed a QUAL-quan approach, where the quantitative data would support the qualitative data to solve the problem at stake. The research design and methodology in which I have engaged in the study are illustrated by means of a schematic representation in Figure 4-2.

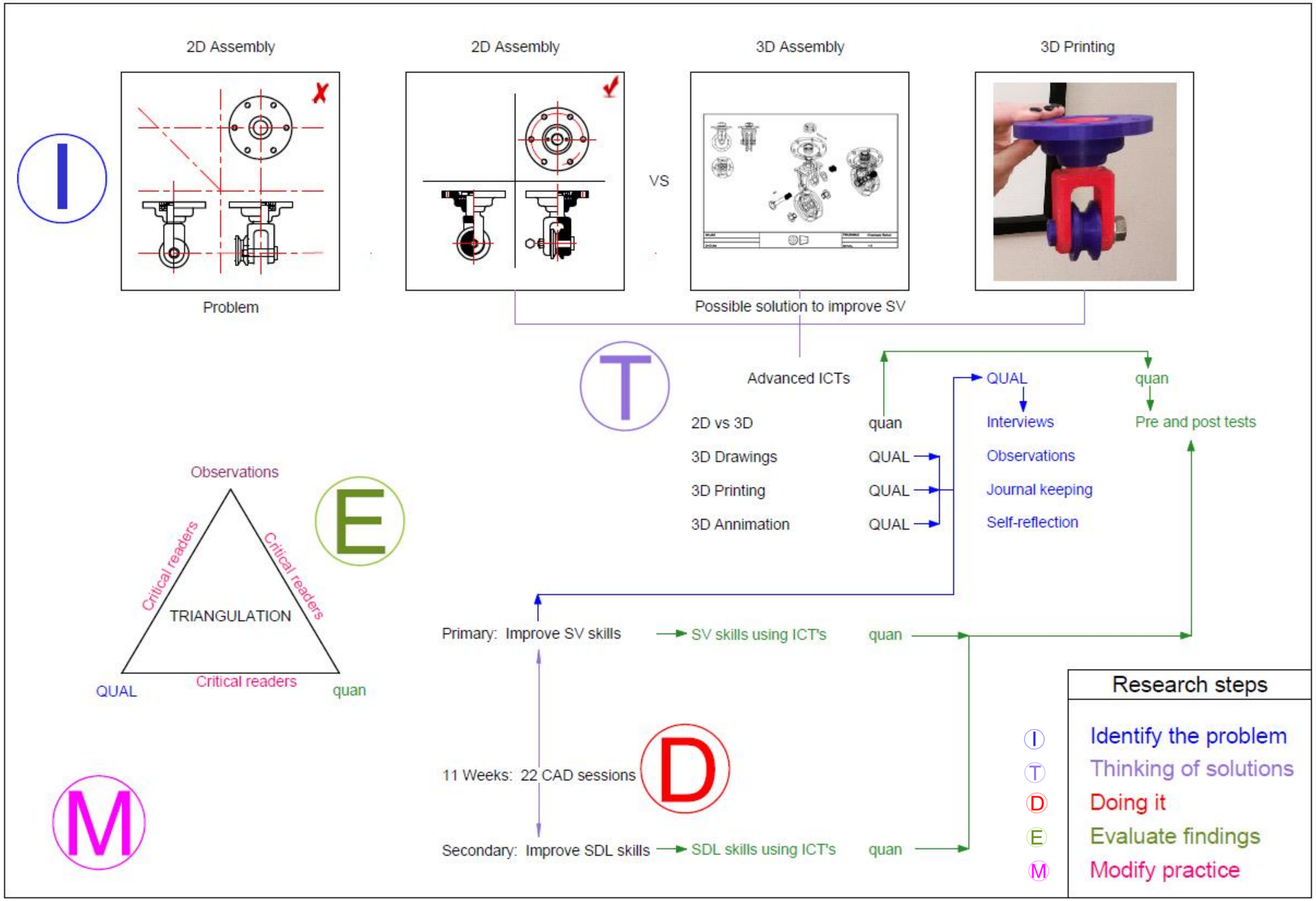


Figure 4-2: **Research methodology.**

Figure 4-2 describes the steps followed during the research. Initially, it was decided that mixed-method action research would be used as methodology and research design. During the literature review, Norton's five phases were identified (see Section 4.6.1.1). The phases followed are as follows:

- Phase1: I *Identifying the problem*
- Phase 2: T *Thinking of ways to take on the problem*
- Phase 3: D *Doing it*
- Phase 4: E *Evaluating the actual research findings*
- Phase 5: M *Modifying my future practice*

During phase one, the research problem was established: students struggle with mechanical sectioned assembly drawings. This was done by means of focus group interviews (see Section 6.2.1) and in the literature review (see Section 1.1). Phase two focused on the different ways of improving on the research problem, which in this case, was the use of advanced ICTs, namely 2D, 3D CAD, 3D printing and 3D animation (see Figure 6-6). During phase three (see Chapter 5), the intervention was implemented in the EGDD421 class. In Chapter 6, phase four was expounded on to determine whether the use of advanced ICTs improved the students' spatial visualization skills and SDL skills. Phase five was done in Chapter 7 in Figure 7-2.

4.6 Methodology and methods

In following a mixed-methods research approach that focuses more on qualitative than quantitative research, a suitable research methodology that could be applied to mixed-methods research should be used. The research methodology that fitted the study best was mixed-methods action research (Ivankova, 2015).

4.6.1 Action research as methodology

4.6.1.1 Action researched defined

Action research is seen as a research method that focuses on finding a solution to current problems or issues in a local setting (Coghlan, 2019; Flick, 2018). The problem identified in the study was students struggling with the concept of assembling mechanical drawings. The solution derived from the literature was to incorporate ICT into EGD to improve students' spatial visualization and enhance their understanding of assembly drawings. Action research is an inquiry that is transformative, with the end goal being to change the setting in which the research is done for the better; it furthermore aims to combine action and reflection along with the combination of theory and practice within the research setting (Bradbury, Waddell, O'Brien, Apgar, Teehankee & Fazey, 2019; Chevalier & Buckles, 2019). Action research within education normally focuses on three different stages: research done by the individual educator; research done by a single school or entity; or research done on a school-wide level (Hagevik, Aydeniz & Rowell, 2012). During the research, I have focused on individual educator research. According to (Mintrop, 2019), the focus of action research is to find solutions to everyday problems in the classroom setting. This may lead to the localisation of action research, which in principle, does not need demanding research control, and therefore both quantitative and qualitative research may be used to strengthen the research done (Mintrop, 2019; Oosthuizen, Du Toit, Lubbe & Klopper, 2012).

"Action inquiry" is an umbrella term for any kind of action research done in the field (Dosemagen & Schwalbach, 2019; Tripp, 2003). To understand action research or inquiry, it is necessary to look at how various researchers define action research in the literature.

"Action research is a practical form of enquiry that enables anyone in every job and walk of life to investigate and evaluate their work" (McNiff, 2017:9). McNiff (2017:9) furthermore states that action research is for all people to "take action in their personal and social situations with a view to improving them". "Action research draws on all forms of knowing with a view to generating practical knowing in addressing those issues" (Coghlan, 2019). "Action research is the process of using research principles to provide information that educational professionals use to improve aspects of day-to-day practice" (McMillan & Schumacher, 2010).

In essence, the above-mentioned definitions and statements express that action research is a form of research in which one investigates an obstacle in one's workplace and makes use of action research to find a solution to address the issue at stake.

Therefore it is evident that I would use action research as a method to conduct my research in the EGD classroom to improve ICT skills, spatial visualization skills and SD skills among EGD students.

In addition, Koshy (2010) is of the opinion that there are different advantages to using action research as a methodology when doing research. Research can be done within a particular situation, which in this case would be the improvement of EGD and SDL skills while using ICTs. In such research, the researcher is not detached from the research: I was part of the study, while being a participant as well. Continuous assessing can be done and the result of that is that continuous changes can be made to arrive at the best solution for the problem. New theories may arise from research as it is not necessary to follow an exactly formulated theory. The finding may lead to open-ended outcomes that can be researched again within a new action research cycle. Lastly, during action research, the researcher may bring a story to life, as he or she is continuously part of the study.

Cohen, Manion & Morrison (2018) recognise seven different areas within action research that can be improved on while using action research: teaching or learning activities; learning strategies; evaluative procedures; attitude and values; continuing professional development of educators; management; and control and administration. In the study, I focused on all seven these stages to ensure optimal learning experiences in my study. In the first stage, where teaching or learning activities are used, I substituted traditional teaching or learning activities of doing EGD drawings on the drawing board with new methods and activities while using advanced ICTs, such as 2D CAD, 3D CAD, 3D printing, 3D scanning and learning management systems (see Section 2.5), to improve spatial visualization skills. Furthermore, different techniques were used to improve students' SDL skills. The second stage involved various learning strategies. In Chapter 3, behaviourism, cognitivism and constructivism were discussed, and the conclusion made was that constructivism was the most appropriate strategy to improve SDL skills and enhance spatial visualization skills among students (see Section 3.2). The third stage, which was most important to me, was the evaluative procedure, where I had to evaluate my own teaching to discover my own shortcomings with regard to SDL, EGD and spatial visualization to expound upon these shortcomings and improve on them to be a master in my niche area of EGD. Furthermore, if I could improve my own teaching and learning, it might help students to understand EGD better. The fourth stage, focusing on attitudes and values, involved inspiring students to focus on SDL skills, which would lead to a more positive attitude towards their own work and value systems with regard to some aspects of life; the value intended for them to acquire was internal motivation to succeed using SDL. The fifth stage was the continuing professional development of educators, which was important for me to improve on my own teaching practices by attending seminars, congresses concerning EGD, spatial visualization and SDL. Further professional research development will be to do research in my field to improve my own knowledge, values and skills in EGD and SDL. Stages six and seven can be combined, as it is important to use the relevant data obtained during the study to manage, control and administrate all the findings and incorporate them in the framework (see Chapter 7).

4.6.1.2 Action research cycle

Reading through the literature, it has become evident that action research is based on linear steps or cyclical cycles one can follow to determine a solution to a specific problem (Coghlan, 2019; Koshy, 2010; McNiff, 2017; Norton, 2018). To adhere to the different phases and cycles in action research, I combined Norton (2018:70) five linear phases of action research with (McNiff, 2017:5) linear phases of action research and put my action plan in a cycle (see Figure 4-3). According to Norton (2018:70), there are five linear action research phases that can be followed in action research:

- Phase 1: ***I****dentifying the problem*
- Phase 2: ***T****hinking of ways to take on the problem*
- Phase 3*:* ***D****oing it*
- Phase 4: ***E****valuating the actual research findings*
- Phase 5*:* ***M****odifying my future practice*

Whitehead and McNiff's action plan entails the following questions as a guide for doing action research (McNiff, 2017:5):

- What issue am I interested in researching?
- Why do I want to research this issue?
- What kind of evidence can I gather to show why I am interested in this issue?
- What can I do? What will I do?
- What kind of evidence can I gather to show that I am having an influence?
- How can I explain this educational influence?
- How can I ensure that any judgments I might make are reasonably fair and accurate?
- How will I change my practice with regard to my evaluation?

Looking at Norton's five stages or steps, they can be compared with the steps used in problem solving in EGD (Department of Basic Education, 2011). The main idea during phase 1 is to determine the specific problem, which in this study is that students struggle to understand sectioned mechanical assembly drawings. Secondly, as the researcher, I should generate different ideas to get a solution to the problem at stake. In this instance, the solution is to enhance students' spatial visualization skills while using advanced ICTs and to improve students' SDL skills to strengthen their own intrinsic motivation to improve. Third is the application of the research done in the field (see Chapter 5). Fourth is the data analysis to see whether there is any improvement in the students' perception of sectioned mechanical assembly drawings and their SDL skills (see Chapter 6). Lastly, I would adapt my EGD classes in such a way that I would improve students' spatial visualization and SDL skills (see the EGD-ICT-SDL integration framework, Figure 7-2, in Chapter 7).

The reason for adding McNiff's action research questions to Norton's stages (as illustrated in Figure 4-3) was to investigate the problem more in-depth and make sure that all necessary steps were taken to determine a solution to the issue at stake. Figure 4-3 displays the combination of McNiff's and Norton's research stages and questions.

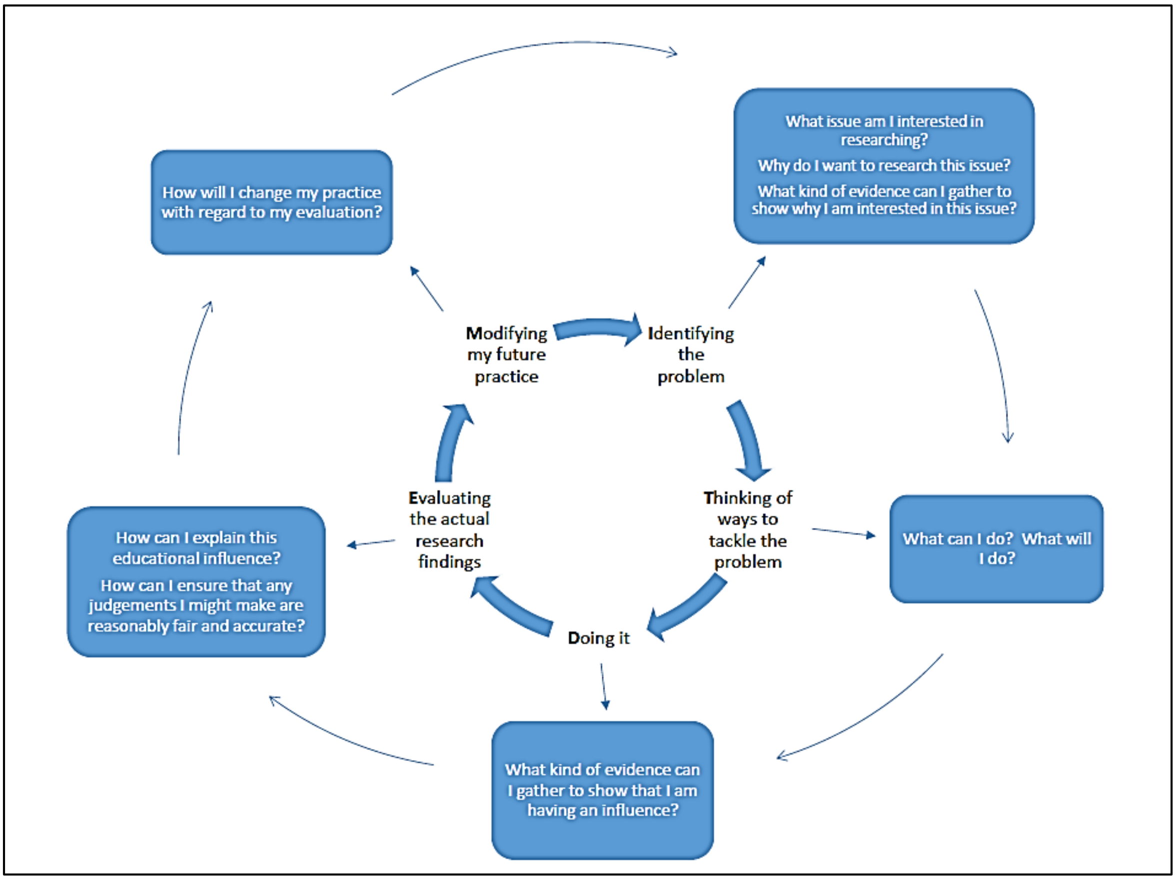


Figure 4-3: Combination of Norton's action research stages and McNiff's action research questions (Author).

From Figure 4-3 it is evident that the answers to the above-mentioned cycle will assist in creating an action plan to implement spatial visualization skills and SDL skills in the EGD classroom while using ICT as a method and an aid during teaching. Phase one, where the problem is identified, is supported by the following questions of McNiff: What issue am I interested in researching. Why do I want to research this issue? What kind of evidence can I gather to show why I am interested in this issue? Phase two focuses on the methods used to improve the problem at stake and is supported by the following questions of McNiff: What can I do and what will I do? Phase three, which shows what needs to be done to improve upon the research at stake, is supported by the following questions of McNiff: What kind of evidence can I gather to show that I am having an influence? Phase four, where the actual research findings are evaluated, is supported by these questions of McNiff: How can I explain this educational influence? How can I ensure that any judgments I might make are reasonably fair and accurate? The last and final phase on how to modify future practices is underlined by McNiff's question:

How will I change my practice with regard to my evaluation? The combination of Norton's phases and McNiff's questions will lead to the framework done in Chapter 7 (see Figure 7.2).

4.6.2 Target population and sampling

Research participants are seen as the individuals that are affected most by the research issue (Efron, 2013; Reid, Hart & Peters, 2014). The EGD students and I, as the lecturer, as well as fellow EGD lecturers were the participants of the study. The participants were selected according to predetermined criteria relevant to my research questions (see Section 1.8) (Creswell, 2008a; Creswell & Creswell, 2018). Two types of sampling that were relevant to the research were identified in Section 1.8, namely convenience sampling and purposive sampling. (Efron, 2013) and Etikan, Musa and Alkassim (2016) see convenience sampling as participants being selected because they are easily accessible, physically near and available at a given time. They are furthermore willing to participate in finding a solution to the problem. Purposive sampling, on the other hand, is seen as a deliberate choice of a participant because of the qualities the participant possesses; it is normally seen as a non-random method that is underlined with different theories or a specific number of participants. Putting it simply, the researcher decides on and selects the participants due to the researcher's knowledge or experience (Efron, 2013; Schreier, 2018). Homogeneous groups were needed for the following perceptions: firstly, the EGDD411 and EGDD421 students (n=48) registered and grouped according to their year of study (convenience sampling); secondly, two previous EGD and Technical Drawing lecturers (convenience sampling); and thirdly, two educators who acted as critical readers, were selected because of their specific knowledge of the subject as well as their years of experience to ensure validity and reliability (purposive sampling).

4.6.3 Data collection

According to Johnson and Christensen (2017), it is an excellent technique to mix research methods, which will lead researchers to conduct high-quality research, and specifically in a way that the research provides multiple and complementary strengths. As a mixed-methods action research design was followed, the data collection was divided into qualitative data collection methods and quantitative data collection methods (see Section 4.6.3.1 and 4.6.3.2).

4.6.3.1 Qualitative data collection methods

4.6.3.1.1 Focus group interviews

Conducting a focus group interview is based on the assumption that the interaction with the participants in a group will produce a widening range of feedback. Students may feel more confident to respond to questions in front of their peers than on an individual interview level with only the researcher present (Efron, 2013; Johnson and Christensen, 2017; Maree, 2016). Before I started with the 3D CAD course, I facilitated focus group interviews with the EGDD students. I made use of open-ended questions to determine what the students perceived to be the most difficult types of drawing in EGD, why they thought these drawings were the most difficult and how they thought these obstacles could be overcome in EGD (see Addendum B). After the 3D course had been completed, I again facilitated focus group interviews to determine once again what they perceived as being the most difficult drawings in EGD, why they thought so and how these obstacles could be overcome (see Chapter 6).

4.6.3.1.2 Individual interviews

I conducted individual interviews (Addendum C) with two colleagues who have some years of experience in the EGD field. The same open-ended questions that were used during the focus group interviews were used to determine which types of drawings were seen as the most difficult to teach and whether the students struggled more with these drawings. Furthermore, I wanted to know how these specialists would try to improve on these types of drawings in their subject (see Chapter 6).

4.6.3.1.3 Observation

When doing action research, the researcher is seen as a participant observer with two purposes in mind. Firstly, the researcher should observe the various activities, participants and the different aspects of the problem and solution. Secondly, the researcher should engage in the activities applicable to the research done that will offer useful information and may lead to the solution of the issue at stake (Ivankova, 2015; Kumar, 2019; Mills, 2018). During my observation of the various activities done (see Chapter 5), I made field notes in my journal (see Addendum J) to read and investigate later on, which might lead me to conclusions to determine whether what had been done in class was worthwhile.

4.6.3.1.4 Research journal

Many researchers in education find keeping a journal a very useful method of doing research. Patterns may be revealed in the classroom or in different activities done in class, and the researcher can monitor what is being done throughout the study and if he or she is subjective and mindful of the different roles that have been undertaken in the study (Koshy, 2010). Journals may vary from a structured to an unstructured design. A structured journal design may consist of lists of events, daily events and student behaviour, which are normally noted in the journal with date and time. An unstructured journal design may vary from one's own perspective and whatever happened in class that is relevant to the study (Koshy, 2010; Oliver, Wehby & Nelson, 2015; Wheeler, 2018). Initially, I started keeping a structured journal in the EGD classroom, but later on, I made use of an unstructured journal as well (see Addendum J).

4.6.3.1.5 Gathering documentary evidence

Documentary evidence research is the use of different sources and relevant documents which will support the assumptions made during the research. The following types of documents can be used to support one's research: government publications; non-governmental sources; and academic publications (Ahmed, 2010), these documents were used during the literature review in Chapter 2 and 3.. During the research, I used all three types of documents to support my research.

4.6.3.1.6 Visual material (photographs)

According to Merriam and Grenier (2019), the use of visual material, more specifically taking photographs during one's research cycle, has become a standard procedure in research. Making use of photographs in research gains insight into and understanding of the perspective of what was has been done in the research, and can assist readers in interpreting what has happened during the research by constructing their own opinion (Bignante, 2010; Glaw, Inder, Kable & Hazelton, 2017; Winton, 2016). I used photographs during the intervention (see Chapter 5) to be able to recall and remember what happened during the specific CAD session, and I added thorough descriptions of what happened when the photographs were taken. Photographs combined with the use of interviews, observations and keeping a journal would ensure a more deepened approach in the study (Byrne, Daykin & Coad, 2016). Photographs of all models built in class are presented in Section 5.6.

4.6.3.2 Quantitative data collection methods

4.6.3.2.1 Educator-made tests

According to Mills (2018), educator-made tests are a common quantitative data collection method to see if specific aims and outcomes are being mastered by the students. This can be done with formative and summative assessments. Formative assessments are done on a continuous basis to determine if students are ready to move on to the next learning unit. Summative assessments are normally done at the end of a course to determine if students have achieved all the outcomes of the specific learning units (Department of Basic Education, 2011). In the study, I made use of pre- and post-tests of sectioned mechanical assembly drawings. The pre-test was done after the completion of the following modules: EGDE322, which teaches the student the theoretical knowledge, applying this knowledge to the drawing board; and EGDD411, where the knowledge of EGDE322 is applied with 2D CAD onto the computer (see Addendum G). The post-test was done after the students had completed EGDD421, which dealt with 3D CAD, 3D printing and 3D animation to improve students' understanding of mechanical assembly drawings (see Addendum H). These tests were then compared to see whether there was a difference in the understanding of sectioned mechanical assembly drawings, which would mean that the students' spatial ability skills had been improved.

4.6.3.2.2 Standardised tests

Standardised tests are seen as tests that, if written under the same circumstances, would give relatively the same results. These tests are the same with each use and, therefore, can be compared to see if students have improved on what was taught, adapted or changed in the classroom (Mills, 2018). In the study, I made use of an adapted Self-directed Learning in Technology test (see Addendum E and F) to determine, with the pre-test, if students (Generation Z) possessed SDL skills when it came to the use of ICT. The post-test would determine whether the students' SDL skills had been improved after the intervention (see Chapter 5).

4.6.4 Data analysis and interpretation

Following a mixed-methods research design, the design was guided by the research aims (see Section 1.5). The data I collected are reported on in Chapter 6 by means of detailed descriptions of the focus group interviews with the participants, the lecturer interviews and my own observations recorded in my research journal. The qualitative data were thoroughly investigated and analysed with ATLAS.ti version 8. The quantitative data, sectional mechanical pre-tests and post-tests, as well as the Self-directed Learning in Technology pre-test and post-test, were analysed with the help of statistical services. In the analysis of the qualitative and quantitative data, relevant data were identified from the various data reports; thereafter, the relevant data were compared and interpreted to conclude the research findings.

4.6.4.1 Qualitative data analysis

In the qualitative data analysis, I, as the action researcher, should be able to use the results, the initial data collection and the analysis to change my teaching practice. Subsequently, the analysed data would produce new research questions that would then be followed by new data collection and analysis procedures for further studies (Flick, 2018; McMillan & Schumacher, 2010; Merriam & Grenier, 2019). McMillan and Schumacher (2010) recommend a cyclical research process (as illustrated in Figure 4-4). Therefore, it seems that data analysis during qualitative research tends to be an on-going and non-linear process. This indicates that my data analysis and interpretation are interconnected, and not merely a number of successive steps (Coghlan, 2019; McKenney & Reeves, 2018; Norton, 2018; Seidel, 1998).

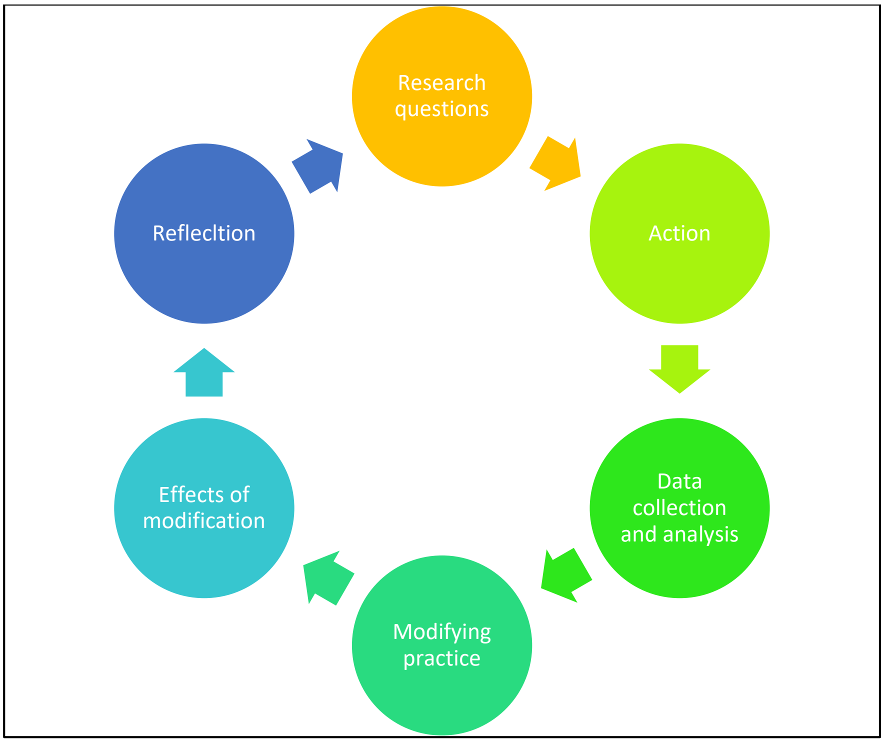


Figure 4-4: The on-going cycle of research (Author)

Figure 4-4 shows the cyclical process of analysing the qualitative data. After the research questions were determined, the action taken was implementing advanced ICTs to improve students' spatial visualization skills and SDL skills. The data were then collected and analysed. The EGD practice was modified during the intervention and in the final framework and reflected upon to determine whether any changes appeared after the intervention. During the qualitative data analysis, it was important that the data analysis was interconnected with the research design followed. Therefore, my findings after the qualitative data analysis and interpretation had to conclude that the use of advanced ICTs in EGD would enhance spatial visualization skills among the EGDD fourth year students.

Throughout the analysis of the qualitative data, ATLAS.ti.™ version 8 was used. It is a software platform that enables qualitative researchers to organise text and visual and audio files, along with the coding, memos and findings of the data (Creswell & Creswell, 2018; Creswell & Poth, 2017). The semi-structured interviews with the students and lecturers were transcribed and assigned to a hermeneutic unit (*cf.* (Archer, Herman, Van Vuuren & Hugo, 2017; Friese, 2019).

The qualitative data of the semi-structured interviews were analysed according to Creswell's six steps of data analysis (*cf*. (Creswell & Creswell, 2018). Firstly, the researcher should organise and prepare the data for analysis. During this step, the interviews were transcribed and the data were sorted and arranged in such a way that these would improve the process of analysis that would follow at a later stage (Flick, 2018; Gibbs, 2018). The interviews were recorded as MP3 files and then transcribed and organised for the data analysis process.

Secondly, the researcher should read through all the data. Creswell and Creswell (2018) state that it is of the utmost importance to read through all the data to obtain an overall essence of the information to reflect on the general meaning of the information before starting the coding process. I read through the transcribed data to get an overall notion of the data.

Thirdly, the researcher should commence detailed analysis with a coding process. Both a deductive and an inductive process of data analysis were used during this study. Deductive content analysis is done when the aim is to test a theory on existing research (Elo & Kyngäs, 2008; Khaldi, 2017). The existing theory that was tested is the use of CAD to improve spatial visualization among students. Inductive content analysis is done when a new theory emerges from the qualitative data (Assarroudi, Heshmati Nabavi, Armat, Ebadi & Vaismoradi, 2018; Miles, Huberman & Saldaña, 2014). The new theory tested was that advanced ICTs enhance students' spatial visualization skills and abilities in sectioned mechanical assembly drawings. The codes used during the coding process were selected according to these aspects, aimed at the conceptions from the qualitative semi-structured interviews. The data collected from these interviews were coded in ATLAS.ti™ according to specific categories. Figure 4-5 shows how the data have been analysed according to codes, categories and themes.

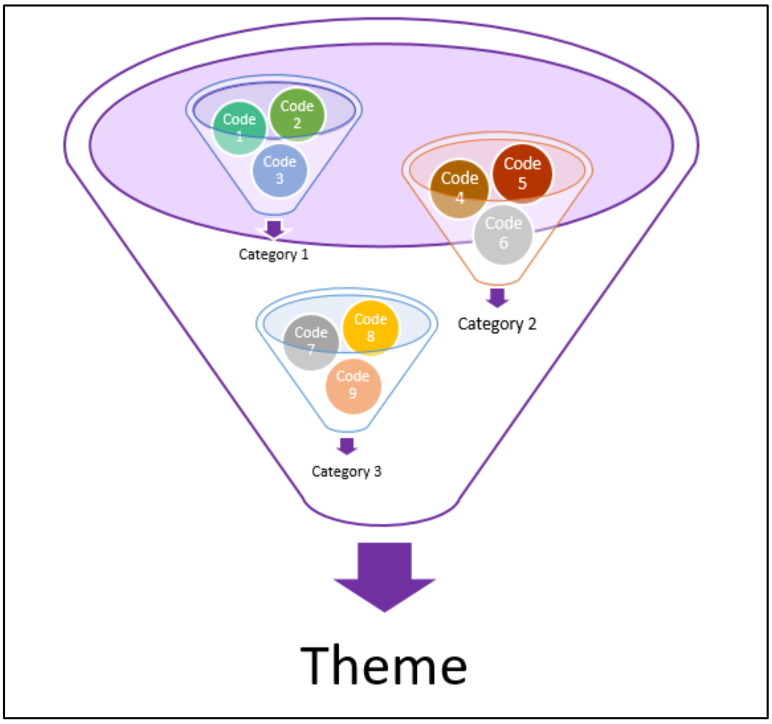


Figure 4-5: Identifying themes in qualitative data (Author).

Figure 4-5 describes the difference between codes, categories and themes. A code is seen as a highlighted section of data that is of interest to one's research objectives; a category is a smaller collection of organised coded data with the same fundamental or corresponding data; and a theme is an abstract entity that produces meaning, significance and understanding to a group of categories (Friese, 2019; Miles *et al.*, 2014; Saldaña, 2015).

Fourthly, the researcher should use the coding process to generate categories or themes for analysis. After completing the coding process in ATLAS.ti™, the different codes were clustered into categories, and then the categories were clustered into themes. The codes identified were grouped into categories to reduce the number of concepts (Friese, 2019). When categories are formulated, the researcher should decide, through interpretation, which codes should be in the same category. The main categories may be divided into subcategories to strengthen the data to correlate with the study aims (Krippendorff, 2018). There is a possibility that codes may not fit into the categories identified during the generating of categories process. Such a code should not be forced into a category where it does not fit; instead, the code should be kept as a concept that still may be a relevant and important finding (Maree, 2016). The different themes identified in the study are presented in Table 4-2.

Table 4-2: Theme and category names for qualitative analysis.

Animation reasons (see section 6.2.4)	Theme
A – Animation easier	Category
A – Animation visualize	Category
3D Printer (see section 6.2.4)	Theme
3 – 3D printer understand	Category
3 – 3D printer visualize	Category
Advantages ICT (see section 6.2.2, 6.2.3)	Theme
A – Advantages easier	Category
A – Advantages respond	Category
A – Advantages spatial ability	Category
A – Advantages Z Generation	Category
Barriers ICT (see section 6.2.2, 6.2.3)	Theme
B – Barriers maintenance	Category
B – Barriers electricity	Category
B – Barriers finance	Category
B – Barriers theft	Category
B – Barriers time	Category
B – Barriers training	Category
CAD reasons (see section 6.2.4)	Theme
C – CAD easier	Category
C – CAD fit	Category
C – CAD knowledge	Category
C – CAD saves time	Category
Drawings difficult (see section 6.2.1)	Theme
D – Drawing interpenetration	Category
D – Drawing isometric	Category
D – Drawings civil	Category

D – Drawing descriptive Geometry	Category
D – Drawing machine drawings	Category
D – Drawing mechanisms	Category
D – Drawing solids	Category
Higher education ICT (see section 6.2.3)	Theme
H – HE 3D printer	Category
H – HE CAD	Category
H – HE data projector	Category
H – HE interactive whiteboard	Category
H – HE YouTube	Category
H – HE LMS	Category
Spatial visualization (SV) improvement (see section 6.2.4)	Theme
S – SV exploded view	Category
S – SV 3D model	Category
S – SV animation	Category
Yes (see section 6.2.4)	Theme
Yes 3D printer	Category
Yes animation	Category
Yes CAD	Category

Table 4.2 shows the categories identified during the interviews with the participants. These categories were then analysed and structured in themes, which was important to answer the research questions in Chapter 6 (see Section 6.2).

Lastly, steps 5 and 6 are combined: the data should be analysed and interpreted. During these steps, the researcher should present the themes to communicate the findings of the data analysis along with the interpretation of the findings; these findings should be reported in a narrative format (Flick, 2018; Kumar, 2019).

The above-mentioned steps guided me to prepare the data, code the data, categorise the data and establish themes within the data (see Figure 4-4), structure the analysed data and afterwards interpret the data to make conclusions about the effect of advanced ICTs in enhancing students' spatial visualization abilities in mechanical drawings (Friese, 2019; Gibbs, 2018; Maree, 2016).

4.6.4.2 Quantitative data analysis

When dealing with quantitative data analysis, statistics are seen as a tool that can assist me, the researcher, to understand the relations in the quantitative data. Statistics furthermore aid the researcher to communicate the results proficiently (Ivankova, 2015; Kumar, 2019). In addition, statistics are a group of techniques for describing, synthesising, analysing and interpreting quantitative data (Creswell & Creswell, 2018). In the study, two methods of data analysis were used, namely a paired t-test and descriptive statistics. The Statistical Package for Social Sciences (SPSS) version 24 was used for the quantitative data analysis.

4.6.4.2.1 Descriptive statistics

Descriptive statistics are a summary of quantitative data that are intended to provide, summarise and describe information about the distributions of the variables (McCarthy, McCarthy, Ceccucci & Halawi, 2019). Quantitative data was descriptively analysed through the location, centrality and dispersion of the data (Maree,2016). During this study the paired t-tests were analysed to determine the effect sizes using Cohen's d-value (see Section 4.6.2.2). Reliability should be established throughout all the quantitative data analysis and the Cronbach's alpha formula was used to ensure reliability (see Section 4.6.2.3).

4.6.4.2.2 Paired t-test

To analyse the quantitative data, the different statistical tools should be determined. Paired t-tests were used in the study to compare the pre-tests with the post-tests. First, there was a pre-test to determine the students' understanding of mechanical drawings, and after the intervention, a post-test was completed. The means of the pre-test and the post-test were compared to calculate the effect size to determine if there was a practically significant difference between the results of the tests. Secondly, the participants had to complete a questionnaire on SDL as a pre-test to determine their SDL skills, and they completed a post-test after the intervention to determine whether there were any significant changes in their SDL skills. The effect size, Cohen's d-value, is calculated with the following formula:

$$d = \frac{\bar{X}_1 - \bar{X}_2}{\mathrm{SD}}$$

- X1 is the mean of pre-test 1
- X2 is the mean of post-test 2
- SD is the standard deviation of pre-test 1

The formula calculates Cohen's d-value or effect size; the effect sizes are shown in Table 4-3.

Table 4-3 Effect sizes.

Effect sizes		
d = 0,2	Small effect	No practically significant difference
d = 0,5	Medium effect	Practically visible difference
d = 0,8	Large effect	Practically significant difference

The effect sizes in Table 4-3 shows if the quantitative data after analysis had a small effect, medium or large effect. A paired t-test compares means from the same group at different times in the study and evaluates whether there is a significant difference between the means of the two variables (Kim, 2015; Maree, 2016). In the study, paired t-tests were done twice.

In 2018, a paired t-test was done on the pre-tests and post-tests of the student teachers to determine if there were any differences between their SDL technology skills at the beginning of the course and their SDL technology skills at the end of the course, before and after an intervention shown in Table 4-4.

Table 4-4: The SDLTS.

Self-Directed learning with Technology Scale (SDLTS) for Engineering Graphics and Design (EGD 421) students.

Directions: Please read each statement and circle the number that best describes your thoughts and feelings about your own learning. There is no right or wrong answer.

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree

1	I go online to ask my lecturer questions on my EGD lessons when I am not in class.	1	2	3	4	5
2	I use the computer to share my thoughts and ideas about my EGD classwork (e.g., through multimedia, The Depot, eFundi)	1	2	3	4	5
3	I found out more information on the internet to help me understand my EGD lessons better.	1	2	3	4	5
4	I use the computer to work with information for my EGD learning.	1	2	3	4	5
5	I practice skills that I learnt in class through drawing on CAD.	1	2	3	4	5
6	I use the computer to become better at a skill that I am interested in (e.g., drawing skills)	1	2	3	4	5
7	I use the computer to get ideas from different websites and people to learn more about a topic.	1	2	3	4	5

(Timothy et al: 2010)

Table 4.4 shows the seven questions the students had to answer to determine their self-monitoring and intentional learning SDL skills. Questions 1 and 2 were used to verify the students' self-monitoring SDL skills, while questions 3 to 7 determined their intentional learning SDL skills. These tests were compared to determine whether the students' SDL skills had improved when advanced ICTs had been introduced in EGD.

In 2018, a paired t-test was done on the pre-tests and post-tests of the student teachers to determine if there were any differences between their spatial visualization skills at the beginning of the course and those skills at the end of the course, before and after an intervention shown in Figure 4-6.

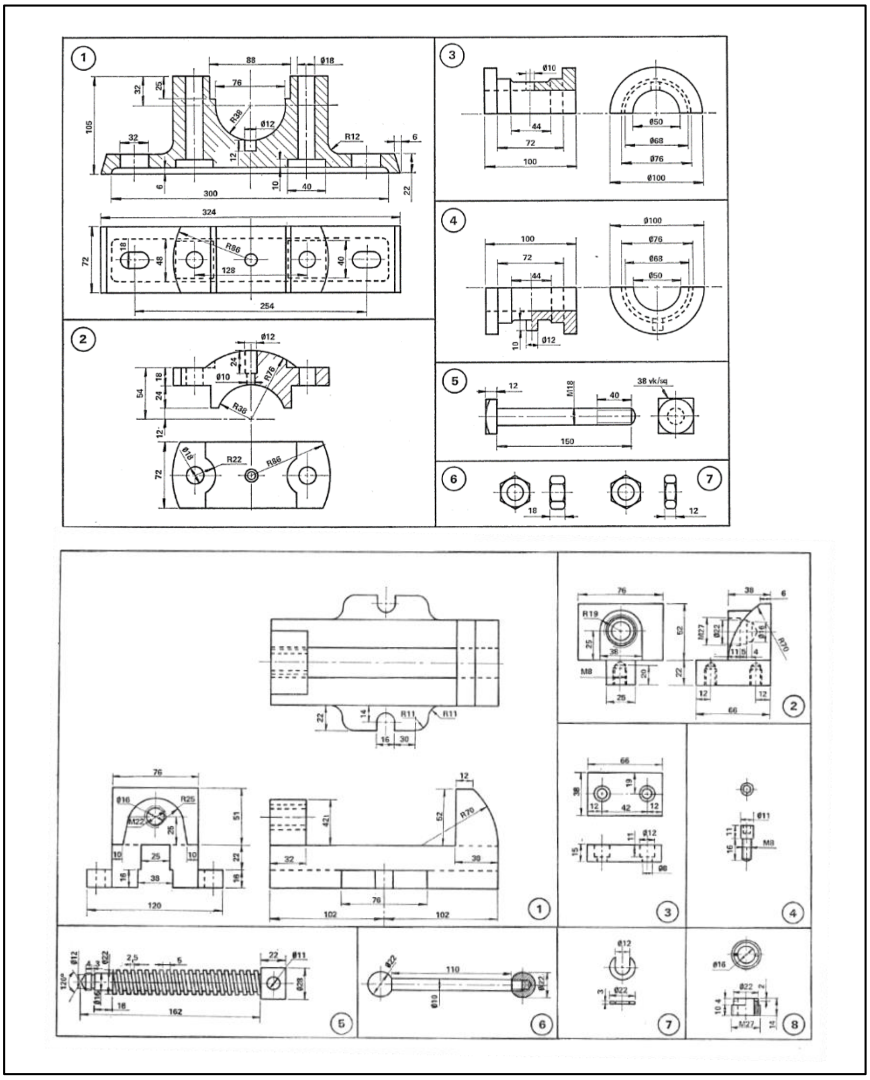


Figure 4-6: Sectioned mechanical assembly drawings.

Figure 4-6 shows the two tests the students have written on sectioned mechanical assembly drawings. The pre-test on top shows the details of a block bearing. All the measurements of the parts were given in millimetres. The students had to draw a full-size, first-angle orthographic projection drawing of the following views of the assembled block bearing:

- A half-sectional front view, showing the right-hand half in section through the centre of the bolt and along the centre of the bearing.
- A left view.
- A top view, showing no hidden detail.

The post-test on the bottom shows the details of a machine vice. All the measurements of the parts were given in millimetres. The students had to draw a full-size, first-angle orthographic projection drawing of the following views of the assembled machine vice:

- A front view, showing a full section through the centre of the clamping screw.
- A left view.
- A top view, showing no hidden detail.

The students' marks were compared to determine whether there was a change in their spatial visualization skills after introducing advanced ICTs in EGD. This data was discussed and analysed in section 6.4.1.1.

4.6.4.2.3 Reliability

Reliability should be established throughout all the quantitative data analysis, to ensure reliability the Cronbach's alpha formula was used.

$$\alpha = \left(\frac{K}{K-1}\right)\left(\frac{s_x^2 - \Sigma s_i^2}{s_x^2}\right)$$

K = number of items on the test

Σs_i^2 = sum of variances of the item scores

s_x^2 = variance of the test scores (all K items)

A negative number indicates that something is wrong with the data. The universal rule is that a Cronbach's alpha of 0,7 or above is good, while 0,8 or above is better and 0,9 or above is the best.

Therefore, Cohen's d-value and Cronbach's alpha were used in the statistical analysis. The paired t-tests have been used to calculate the p-value for completeness, which reduces generalisation in quantitative data, which determines the statistical significance of the research data. Furthermore, the effect sizes of the differences have been calculated to determine and understand the practical significance of the research data.

4.7 Trustworthiness of the research

The trustworthiness of any study can be described as the credibility towards the reader that strives towards the neutrality of the research findings (Maree, 2016). In qualitative research, trustworthiness is established through credibility, transferability, dependability and confirmability throughout the study (Korstjens & Moser, 2018). Credibility refers to the researcher being confident in finding the truth of the data as well as being believable in the interpretations thereof (Guba & Lincoln, 1985; Ivankova, 2015; Maree, 2016). Transferability focuses on the extent to which the findings of a study can be applied to other situations in comparison to other studies done; it furthermore intends to portray the comparisons based on the descriptions of the research situation (Dustman, Kohan & Stringer, 2014; Mills, 2018). Dependability refers to the stability of the research findings to the extent that the findings are dependable and could be repeated with similar results (Babbie, 2016; Mills, 2018). Confirmability indicates to what extent the study findings are affected by the participants' views and not the researcher's own view; it helps to assess the neutrality and objectivity and to avoid bias when collecting the data (Ivankova, 2015; Shenton, 2004).

In quantitative research, trustworthiness is determined by the validity and reliability of a study (Babbie & Mouton, 2001; Babbie, 2016). Validity is regarded as the extent to which a test measures what it has been intended to measure; it is the available approximation to the truth of a given conclusion (Maree, 2016; Merriam & Grenier, 2019). Reliability is seen as dealing with the quality of measurement; it is where the test measures on a consistent and repeating level to achieve the same results under the same circumstances (Maree, 2016; Nardi, 2018). Therefore, it is important during quantitative research to recognise that validity deals with the importance of a test that measures what it intends to measure. Accordingly, reliability deals with the consistency of the test to achieve more or less the same results under the same conditions. Research findings are regarded as valid and reliable if the same results could be conveyed under the same conditions if repeated.

Throughout the study, I strove to establish trustworthiness. In answering the research questions, planning was needed to be valid, reliable, credible, transferable, dependable and confirmable. Table 4-5 shows the strategies followed to confirm the trustworthiness of the study.

Table 4-5: Criteria and strategies for assessing trustworthiness in mixed-methods action research.

Qualitative findings	
Criteria	**Strategies**
Credibility	Triangulation Spending prolonged time in the field Persistent observation Member checks Peer debriefing (critical readers)
Transferability	Collecting detailed descriptive data Detailed description of the study (Intervention Chapter 5)
Dependability	Triangulation Keeping audit trail (own journal) External audit (critical readers)
Confirmability	Triangulation External audit (critical readers)
Validity	Expert panel: Research Committee Ethics Committee Registrar of the North-West University Statistical Services Critical readers

Qualitative findings	
Criteria	**Strategies**
Reliability	Test and retest reliability, compare scores. Pre-tests compared with post-tests.

From Table 4-5 it is clear that it is important to have strategies in place to establish trustworthiness. Ivankova (2015), Creswell and Creswell (2018); Mills (2018); Plano Clark and Creswell (2011) describe particular strategies to support the trustworthiness of the research findings. Based on my research on the issue at stake, namely enhancing students' spatial visualization skills and SDL skills in EGD, the following strategies were followed to ensure trustworthiness in the study:

- Triangulation can be done. In the study, triangulation was done by supporting evidence from different individuals (student teachers and lecturers), types of data (QUAL-quan) and methods of data collection (interviews, questionnaires and pre- and post-tests) in descriptions and themes in attaining converging evidence in qualitative research and quantitative research (see Section 6.6).

- The researcher may spend extensive time in the research field. It may vary for several months, even a year or more, studying a particular phenomenon while constructing hypotheses and continually searching for evidence that either promotes or disconfirms these hypotheses. In the study, I spent one year in the EGD classroom seeking for evidence that advanced ICTs enhance spatial visualization skills and SDL skills.

- The researcher should engage in persistent observation during the time in the research field to determine patterns, consistencies and new knowledge, which, in my study, concerned implementing advanced ICTs in the EGD classroom.

- Member checking is an important process. I asked the participants to check the accuracy of what was done in the research.

- Peer debriefing from individuals not involved in the study can be used to ensure the accuracy of the research account. Two critical readers in the EGD field were used to ensure that the findings and procedures were accurate in making interpretations and drawing valid conclusions from the research data.

- A detailed description of the study should be collected and kept. Chapter 5 gives a descriptive analysis of what was done during the intervention or action plan.

- An audit trail of what was done in the study should be kept to provide evidence of the data collection, analysis and interpretation. To keep an audit trail of what happened in the classroom, I kept a reflective journal.

- Making use of an expert panel enhances the validity of what was done throughout the study. The Research Committee approved the study with all the questionnaires and interview questions. The Ethics Committee approved that all the necessary steps were taken to make sure that the study was ethical. Furthermore, the registrar of the North-West University approved the study. The Statistical Services of the North-West University made sure that all quantitative data were valid. Lastly, a co-coder made sure that all of the codes, categories and themes were determined to reveal underlying assumptions and biases.

I thus made use of a wide variety of strategies to ensure the trustworthiness of the study.

4.8 Ethical considerations

The research was conducted according to the ethical codes as stipulated by the Ethics Committee of the Faculty of Education and the feedback of the registrar of the North-West University. The factors that were considered are described below.

4.8.1 Informed consent

Written informed consent was obtained from all of the EGDD students and lecturers involved (see Addendum A). I informed the participants that they had a choice in participating in the study. They were furthermore informed that the collected data would only be used with their permission (King *et al.*, 2018; Leedy *et al.*, 2019). During the research study, different ethical standards needed to be considered. The participants were informed about the type of research taking place as well as their involvement in the research study. Furthermore, the participants needed to agree to the conditions of the research study as laid out by me as the researcher. Leedy *et al.* (2019); McMillan and Schumacher (2010) and Maree (2016) give specific guidelines that need to be followed prior to involving participants in a research study. Participants should be notified:

- of the aims, methods and probable benefits of the study;
- of their right to refrain from taking part in the study, in addition to their right to stop participation at any given moment;
- of the importance and the nature of their feedback;
- that no participant will unknowingly become part of the research study without having the above-mentioned information; and
- that anonymity is agreed upon by the researcher and the participants; hence any identifying information will be destroyed once the research is concluded.

All of the participants agreed to the above-mentioned guidelines, which were intended to protect their privacy and dignity during the research.

4.8.2 Ethics

I completed the required ethical clearance application form and submitted it to the Ethics Committee of the Faculty of Education and the registrar of the North-West University. Permission from the relevant deans, heads of schools, lecturers and students to conduct the research was also obtained. The necessary ethical clearance (NWU-00532-17-A2) was obtained from the Ethical Board and Committee of the Faculty of Education (see Addendum I).

4.8.3 Participant confidentiality

I accepted the responsibility to ensure confidentiality during the research process and the process of data collection. The participants' confidentiality and privacy were respected at all times. The students were expected to include their student numbers when they completed the questionnaires, because it was necessary in order to pair the pre-tests and post-tests; however, the data were only used by the Statistical Services of the university and were not made available to anyone else

4.9 Conclusion

In this chapter, the research design and methodology were investigated in order to conduct and justify the research. The study was guided by a constructivist paradigm. A sequential exploratory mixed-methods action research design (QUAL-quan) was utilised. The qualitative and quantitative elements were focused on separately. The aim of this chapter was to justify the use of mixed-methods action research and to expand on the design and methodology implemented in order to answer the research questions of the study. The qualitative element of the study focused on the data collected with semi-structured interviews. Furthermore, during the quantitative element of the study, pre-tests and post-tests were written to determine the students' SDL skills and their understanding of sectioned mechanical assembly drawings.

In the next chapter, I shall focus on the intervention implemented in the study to enhance students' spatial visualization and SDL skills while using advanced ICTs in the EGD classroom.

CHAPTER 5: THE IMPLEMENTATION OF ICT IN EGD TO IMPROVE SPATIAL VISUALIZATION

LOGIC

Question	Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)	McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)	Chapter layout	
How can ICT and spatial visualization skills be further developed to enhance EGD in higher education?	Implementing innovative teaching practices	What evidence can I gather that I am having an influence? How can I explain this educational influence? How can I ensure that any judgments I might make are reasonably fair and accurate?	**Chapter 5**	**Intervention**

5.1 Introduction

Chapter 2 and 3 focused on EGD, advanced ICTs, spatial visualization and SDL, while in Chapter 4, the methodology and research design were discussed with regards to the action research phases (see Figure 4-3). In addition, the solution to the issues at stake was discussed to start planning the intervention. The advanced ICTs that might enhance spatial visualization were discussed as well as how to integrate constructivism, SDL and spatial visualization skills to enhance students' understanding of sectioned mechanical assembly drawings.

The main purpose of Chapter 5 is to indicate how the above-mentioned factors were integrated and implemented during the intervention in the module EGDD421. The background and module information are given. The way the current EGDD421 module was adapted, is categorised according to the following phases: planning and designing the intervention; and implementing the intervention.

5.2 Background of the modules

EGDD411 is a compulsory fourth-year module for all EGD students in the first semester. The module focuses on the implementation of drawings done by hand in 2D CAD. Students have to pass EGDD411 before they can move on to EGDD421. EGDD421 is also a compulsory fourth-year module for EGD students in the second semester. This module focuses on the application of hand drawings in 3D CAD. During the intervention, advanced ICTs have been introduced in the EGDD421 module. 48 students registered for these modules per semester per year in 2017. Both modules are taught by the same lecturer, me.

5.3 The intervention

When I first started as a lecturer in this specific subject group at the North-West University in 2015, CAD was the only advanced technology used in EGDD411 and EGDD421. Students normally only copied hand drawings in 2D CAD (EGDD411). In 3D CAD (EGDD421), the first real application of drawings was done. eFundi™ as an online tool was used only to upload drawings that should be done in class. The use of in-depth 2D/3D CAD training, hardware such as 3D printers and LMS software such as the Depot™ to improve students' spatial visualization skills and SDL skills was lacking. While planning the intervention, I had to rethink and restructure the entire module in terms of advanced ICT integration to improve spatial visualization among students. Furthermore, the students' self-directedness towards technology was to be tested with the self-directed learning with technology scale (see Section 4.6.4.2.1, Table 4.4), and I had to combine the improvement of spatial visualization skills (see Section 3.4.3) and SDL skills (see Section 3.5.3 and Table 3-2) in the intervention.

I implemented the intervention; the EGDD411 module was used as the control group, while EGDD421 was used as the experimental group. The same students were used in both the modules. When planning the implementation of the intervention, a constructive alignment plan, based on Biggs and Tang (2011) findings with regard to constructive alignment combined with the model of curriculum design proposed by (Jacobs *et al.*, 2016), was used as guideline, as illustrated in Figure 5-1.

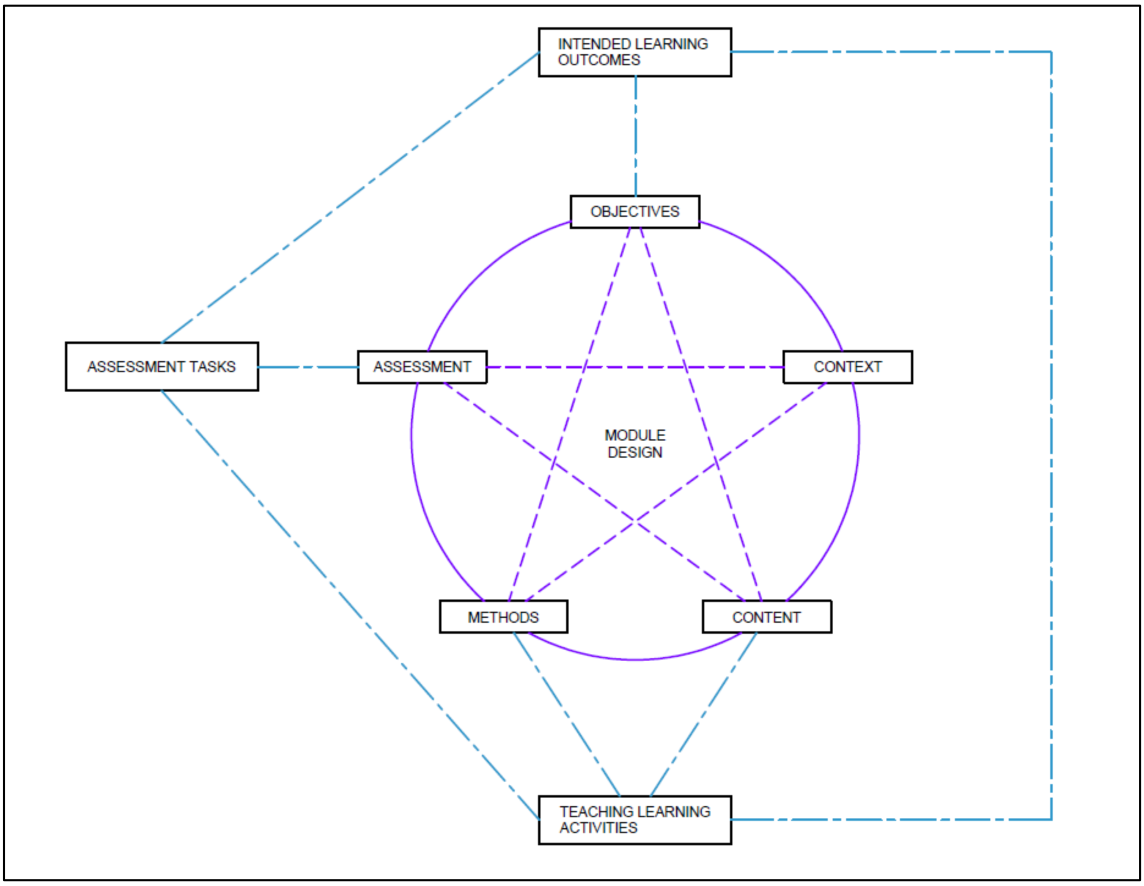


Figure 5-1: Combination of the designs of Biggs and Tang (2011) and Jacobs *et al.* (2016).

It is evident from the combination of the models (see Figure 5-1) of Biggs and Tang (2011) and Jacobs *et al.* (2016) that, when a module is changed, modified or constructively aligned, the focus should be on changing the intended learning outcomes (ILOs), teaching-learning activities (TLAs) and assessment tasks. Therefore, I had to create ILOs, TLAs, assessment tasks and methods of grading for each EGDD421 contact session. The contact sessions were divided according to specific criteria, as shown in Table 5-1. The facilitator of learning and the different learning activities are structured to possibly improve ICT, spatial visualization and SDL skills among the EGD students.

Table 5-1: Contact session divisions.

Facilitator of learning	TLAs	ICT, SDL and spatial visualization skills
3D CAD session facilitated by lecturer	3D CAD drawings with online tutorial	ICT and SDL
3D CAD session facilitated by students self	3D CAD drawings with online tutorial and animation	ICT, SDL and spatial visualization skills
3D CAD sessions facilitated by peers	3D CAD drawings with 3D printed models as guideline	ICT, spatial and visualization skills
	3D CAD drawings with 3D scanned models as guideline	ICT, spatial visualization skills
	3D CAD drawings	Spatial visualization skills

It is evident from Table 5-1 that in order to improve and enhance the students' ability to clearly understand sectioned mechanical assembly drawings, improve their ICT skills, spatial visualization skills and SDL skills, I had to make an interconnection between these skills in the EGD classroom. To utilise the different skills, the facilitation of each session was divided into three groups. Firstly, as the lecturer, I was part of all the sessions; however, in some sessions, I was in control of only a part of the session to lead the students to understand 3D CAD while improving their ICT, SDL and spatial visualization skills. In other sessions, the students themselves facilitated the session with the help of online tutorials, animations and 3D models to more specifically enhance their SDL skills (Brockett & Hiemstra, 2018; Du Toit-Brits, 2017; Guglielmino, 2013) as well as ICT and spatial visualization skills. Peer teaching is seen as teaching with which students can feel more comfortable and open when interacting with their peers. Peer teaching allows for greater understanding as students share a similar discourse (Farias, Mesquita, Hastie & O'Donovan, 2018; Ferris, 2019; Guglielmino, 2013). Students might feel more comfortable when interacting with one another than interacting with me as the lecturer. Therefore peer teaching was used in groups for students to help one another to understand 3D CAD while improving their ICT, SDL and spatial visualization skills.

5.3.1 The contact sessions

Each contact session was carefully planned to improve the students' ICT skills, spatial visualization skills and SDL skills. Table 5-2 shows each week of the intervention and who was responsible for learning during each session. It furthermore shows which skills might be improved during each session. In each contact session, I as the facilitator made use of various advanced ICTs and teaching methods to facilitate the classes. When peer teaching was done, the students were allowed to choose their own partners. In Session 1 to 10, the TurboCAD 3D Training Guide was used to teach students the relevant 3D CAD skills. Isometric 1 to 3 were used to recap Session 1 to 10 and lead students to draw machine components on their own. Machine assembly drawings 1 and 2 were done to practise the different methods to assemble different machine components in the assembly machine drawings. Sectioned machine assembly drawings 1 to 5 were done to apply all the different functions and operations learnt and practised during Session 1 to 10, Isometric 1 to 3 and Machine assembly 1 and 2 with the help of different advanced ICTs to draw different sectional machine assembly drawings. Whilst using advanced ICTs, students improved on their ICT skills as well therefore during each session students enhanced their ICT skills.

5.3.2 Facilitation

As the lecturer, I facilitated all of the lessons, but my role varied in the lessons. I was the main role player in some sessions where I made use of demonstrations and lecturing. In other lessons, the students helped and taught one another during collaborative group work. Lastly, in some lessons, the students had the opportunity to facilitate the lessons on their own or had to prepare lessons during role play.

Table 5-2: Intervention.

Week	Teaching learning activities	Facilitator	Advanced ICTs	SDL skills	Spatial visualization (SV) skills
	Pre-test sectioned machine assembly 2D (current knowledge)		2D CAD		SV skills
	Pre-test SDLTS	Lecturer		SDL skills	
1	Session 1	Lecturer	3D CAD 3D printed model		SV skills
	Session 2	Lecturer	3D CAD 3D printed model		SV skills
2	Session 3	Lecturer	3D CAD 3D printed model		SV skills
	Session 4	Peer/Group	3D CAD Animation		SV skills
3	Session 5	Peer/Group	3D CAD Animation		SV skills
	Session 6	Self	3D CAD Animation	SDL skills	SV skills
4	Session 7	Self	3D CAD Animation	SDL skills	SV skills
	Session 8	Self	3D CAD Animation	SDL skills	SV skills
5	Session 9	Self	3D CAD Animation	SDL skills	SV skills
	Session 10	Self	3D CAD Animation	SDL skills	SV skills
6	Isometric 1	Lecturer	3D CAD 3D printed model		SV skills
	Isometric 2	Self	3D CAD 3D printed model	SDL skills	SV skills
7	Isometric 3	Self	3D CAD	SDL skills	SV skills
	Machine assembly 1	Lecturer	3D CAD 3D printed model		SV skills
8	Machine assembly 2	Peer/group	3D CAD 3D printed model		SV skills
	Machine assembly (sectioned) 1	Lecturer	3D CAD 3D printed model		SV skills
9	Machine assembly (sectioned) 2	Self	3D CAD 3D printed model	SDL skills	SV skills
	Machine assembly (sectioned) 3	Self	3D CAD 3D printed model	SDL skills	SV skills
10	Machine assembly (sectioned) 4	Self	3D CAD	SDL skills	SV skills
	Machine assembly (sectioned) 5	Self	3D CAD	SDL skills	SV skills
	Post-test sectioned machine assembly 3D (new knowledge)		3D CAD		SV skills
11	Post-test SDLTS	Lecturer		SDL skills	

5.4 Classification of advanced ICTs

Planning the ICT-SV-SDL model, I had to integrate a number of ICTs and online tools that would be able to assist in reaching the outcomes of the study and the ILOs of each lesson. As seen in Section 2.5.2.1 to 2.5.2.6, I chose advanced technologies to ensure spatial visualization among students. These advanced ICTs were established during focus group interviews with the EGDD411 students in the first semester before the intervention done with the EGDD421 students in the second semester (see Chapter 6). The advanced ICTs used in the intervention were 2D/3D CAD, 3D printing, animation and LMSs, specifically eFundi™ and The Depot™. The advantages of these technologies were carefully investigated to ensure that they would deepen the students' learning experience (see Section 2.6.1). Furthermore, I had to make sure that the challenges and barriers that might occur during ICT integration were mitigated (see Section 2.6.2). During the intervention, the students also made use of the LMS eFundi™ platform, powered by SAKAI™, to receive information and feedback on drawings. In addition, the students had to submit their work on eFundi™ for assessment. The LMS-relevant functionalities used in eFundi™ are shown in Table 5-3. As students are introduced to the eFundi™ platform in their first year and make use of it up to their fourth year, no additional training in eFundi™ was needed. Besides eFundi™, the students had to use the LMS The Depot™, powered by Tri-CAD Technologies™, to submit their drawings of sessions 1 to 10. Table 5-3 displays the relevant functions used in eFundi™.

Table 5-3: LMS-relevant functionalities used in eFundi™.

Functions	Explanation
Home	Viewing recent announcements
Announcements	Posting urgent information
Assignments	Submitting of drawings, posting of feedback
Messages	Messages to and from users on the eFundi™ site
Resources	Posting relevant information, such as the CAD Training Guide and Study Guides
Statistics	Site statistics, online attendance
Tests and quizzes	Create online tests for students

Table 5-3 shows the relevant functions used in eFundi™. As there are many different functions in this LMS, I chose functions that would benefit the study. On the homepage function, the students were able to see the announcements I posted before each session, so that they could prepare in advance for their class. The assignment function was used to post the drawings they had to do in class or for homework; this function also let the students submit their drawings for assessment on eFundi™. The messages function could be used as a method of conveying important information to all students via e-mail or to communicate with students on an individual level when something was needed from only one student. The resource function was used to provide students with the relevant study material, their EGDD421 Study Guide, the 2D/3D CAD manual, the EGDD421 module overview document (MOD) and animated videos to complete drawings in 3D CAD. The statistics tool was more relevant for me as lecturer. With this tool I could determine which students did not visit the eFundi™ site on a regular basis. The test and quizzes function was used to test the students' theoretical knowledge of 3D CAD. The marks were used to determine if I could move on to the next session.

The LMS-relevant functionalities used in The Depot™ are shown in Table 5-4. The students wrote an online theoretical test to obtain their internationally acknowledged 2D or 3D certificate in the use of CAD. Table 5-4 displays the relevant functions used in The Depot™.

Table 5-4: LMS-relevant functionalities used in The Depot™.

Functions	Explanation
Home	Viewing recent announcements
Announcements	Posting urgent information
Messages	Messages to and from users on The Depot™ site
Lesson information	Information for each lesson
Content	Content of the module done
User statistics	Site statistics, online attendance
Lesson reports	See overall progress of students

Table 5-4 shows the different functions that were used in The Depot™. The home page was used by students to see any important announcements posted by me or TriCAD Technologies regarding updates and new tools on CAD. The announcement function in The Depot™ was used minimally, as I did not want to confuse the students with two different LMS sites. The messages function was used only by the students to correspond with TriCAD Technologies when they had any problems with the CAD software. The lesson information tool was used more often by the students, as it contained animations of what was done in each session. This helped those students who did not attend class for some reason because they could do the session on their own to prepare for the next session. In the content section, there was an online e-book the students could use if there was still any tools or functions in CAD they did not understand. The statistics tool was more relevant for me as lecturer. With this tool, I could determine which students did not visit The Depot™ site on a regular basis. The lesson report function was used by me to determine if students had completed the theoretical test and practical drawing to obtain their internationally acknowledged certificate in CAD.

5.5 Planning and design of intervention

During the first phase of restructuring the EGDD module, in-depth planning was necessary. The difficult part was combining the ICT skills, spatial visualization skills and SDL skills during the planning of the intervention (see Table 5.2). The discussions in Chapter 2 and Chapter 3 are summarised in Table 5-2. Table 5-6 was used to plan and design the intervention. Table 5-2 shows how the intervention was planned according to the time allocated by the university in the second semester. The semester consisted of 11 weeks, with two contact sessions per week, which added up to 22 sessions. These session were planned and designed with the combination of the models (see Figure 5-1) of Biggs and Tang (2011) and Jacobs *et al.* (2016). Table 5-7 shows how these models were used to constructively align the EGDD421 module to improve ICT skills, spatial visualization skills and SDL skills. The ILOs of each session were written to adhere to the teaching method used, whether ICT skills or spatial visualization skills or SDL skills should be obtained in the session. Furthermore, it was important to determine which advanced ICT should be used by the facilitator during the session.

5.5.1 Aims and objectives

According to Jacobs *et al.* (2016), module aims state the full purpose of a module, that is, what students should be able to do by the end of the module or series of lessons (see Figure 5.3). These aims furthermore state a long-term goal that demands many lessons before the goal is reached. The objectives are what a student should be able to do at the end of a teaching period or lesson and are seen as a short-term goal derived from an aim.

5.5.1.1 Module alignment

Assessment tasks and teaching strategies were developed so that students would be able to reach the module aims as well as the objectives of each lesson. The module aims are referred to as “module outcomes”, in accordance with the regulations of the tertiary institution. The module outcomes used in the study in EGDD421, which had been approved by the Senate’s Committee for Academic Standards, are shown in Figure 5-2. The learning outcomes for study unit one of the EGDD421 module are shown in Figure 5-3. These learning outcomes were also incorporated when designing and planning the intervention.

5.5.1.2 Communication of module information

The module aims or outcomes, as seen in Figure 5-2, were made available on eFundi™ and in the EGDD421 Study Guide that the students received at the beginning of the second semester.

MODULE OUTCOMES

You will have attained these outcomes if you

- demonstrate knowledge and understanding regarding the basic principles of computer-aided drawing and more specifically the TurboCAD drawing program;
- demonstrate skills with respect to CAD and make suggestions regarding the techniques thereof;
- are able to create isometric drawings;
- are able to create mechanical assembly drawings;
- can work independently and creatively to solve various applicable problems by means of CAD;
- can solve relevant problems independently and creatively;
- teach school learners the knowledge and skills of CAD accountable manner.

Figure 5-2: Module aims or outcomes in the EGDD421 Study Guide.

Figure 5-2 displays the outcomes for EGDD421 approved by the Senate's Committee for Academic Standards. The outcomes show that the module aims to prepare an EGD educator in the use of CAD software. They should demonstrate skills regarding the use of the CAD software, obtain skills to create isometric and mechanical assembly drawings, obtain the ability to solve applicable drawing problems (sectioning of mechanical assembly drawings) by means of CAD software and, lastly, be able to teach school learners the relevant knowledge and skills of CAD in an accountable manner.

The learning objectives or outcomes were made available for each study unit in the Study Guide and were also available on eFundi™, as seen in Figure 5-3.

Upon completion of study unit 1 you will be able to

1. execute the 3d and ACIS setup, prepare model mode and add the applicable tool bars.
2. activate and use the world coordinate system.
3. activate and use the user coordinate system.
4. select and manipulate work planes i.e. *Show/hide work plane, Plane by active view, Plane by world, Plane by entity, Plane by 3-points, Edit current work plane, Work plane origin, Work plane by facet, Show/hide work plane intersection, Saving, recalling and changing work planes.*
5. use 3D selector properties including: r*eference point, rotator handles*, *selector handles* and *toggle 2D/3D*.
6. to convert 2D profiles to 3D objects using the 3D thickness option.
7. create solids using the following functions: *3D box, sphere, hemisphere, cone, prism, torus, wedge, cylinder, polygonal prism.*
8. create first angle orthographic views.
9. create third angle orthographic views.
10. create isometric views.
11. activate the camera and change camera characteristics.
12. manipulate camera movements.

Figure 5-3: Learning aims or outcomes in EGDD421 Study Guide.

Figure 5-3 shows the specific learning outcomes portrayed in study unit one which students should be able to do after having completed the study unit.

5.5.2 Content of the module

According to Jacobs *et al.* (2016), content is an important part of any curriculum; it is what has to be taught and the skills that should be obtained in the learning cycle. To adhere to the different skills students had to obtain in the EGDD421 module, different resources had to be evaluated and the availability of the resources was determined,

5.5.2.1 Evaluate different resources

The main resource used was the CAD Training Guide (Figure 5-4), which was most applicable and appropriate for the focus and content of the CAD module. As an additional supporting document, the Study Guide with all the module outcomes and learning outcomes was used.

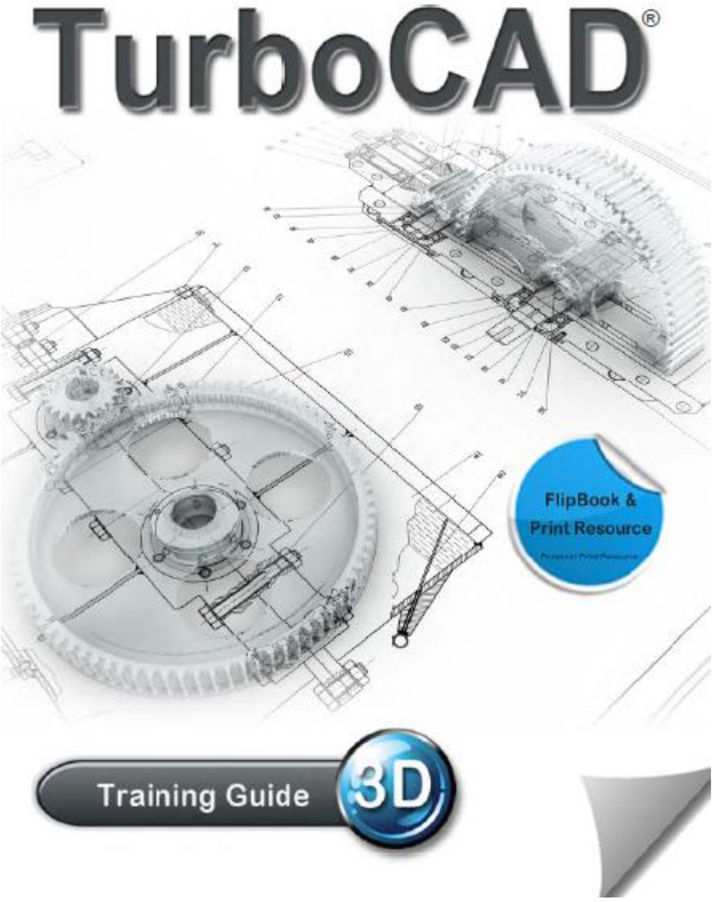


Figure 5-4: TurboCAD 3D Training Guide.

Figure 5-4 shows the front page of the TurboCAD 3D training guide that was used by students to get the theoretical knowledge in using CAD software with all the relevant functions and tools which had to be used to complete a 3D drawing in CAD.

Furthermore, eFundi™ (Figure 5-5) and The Depot™ (Figure 5-6) were used as online tools and learning management software to improve the students' experience in the online world. The learning management software furthermore helped in enhancing students SDL skills.

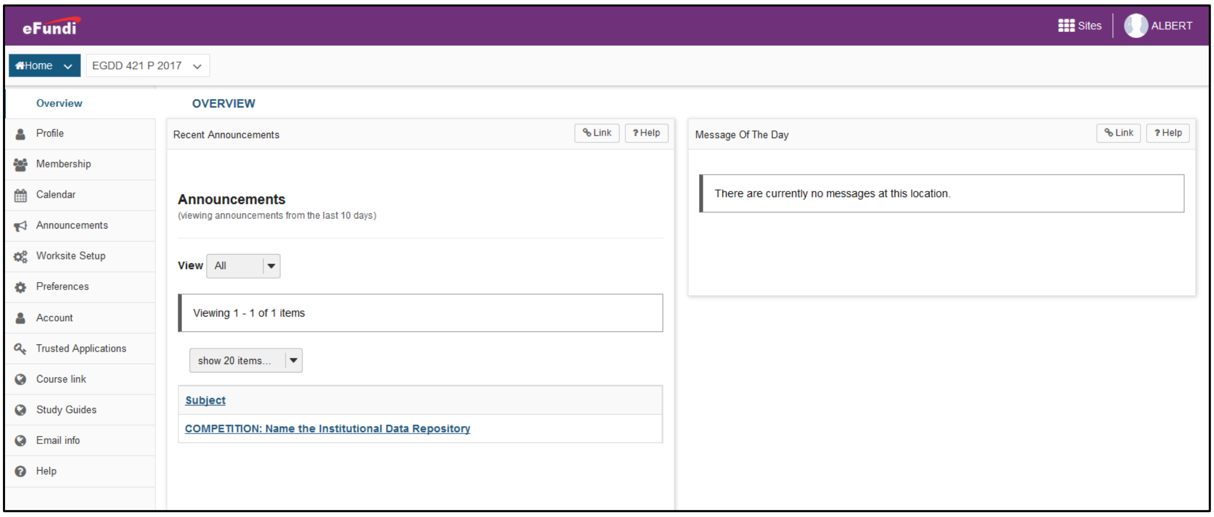


Figure 5-5: eFundi™ portal.

Figure 5-5 shows the home page of the eFundi™ site. This correlates with the functions explained in Table 5-3. The eFundi™ interface has more functions to offer, but during the EGDD421 intervention only the following functions were used: the home page that offers all the other functions and shows the recent announcement; the announcement function where important information can be read; the messages tool, used for communication between lecturer and student; the resources tool for uploading important documents such as study guides and videos; the statistic tool to determine students' online participation; and the test and quizzes function to determine students' knowledge of what was done during the session.

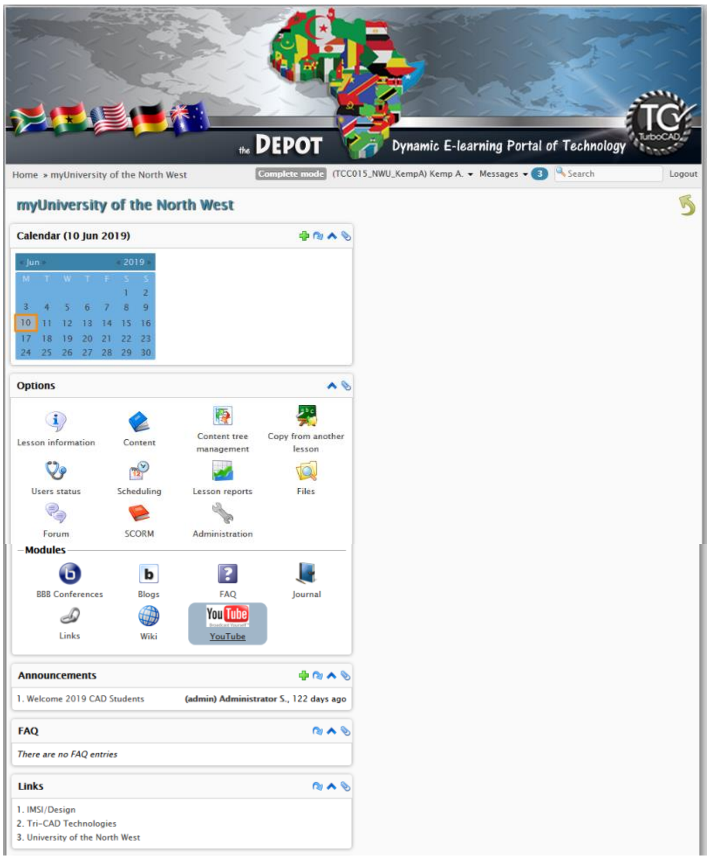


Figure 5-6: The Depot™ portal.

Figure 5-6 shows the home page of The Depot™ site. On this site, students had online tools to assist them in understanding the CAD software. These tools are explained in Table 5-4. In short, the important function used was the lesson information function, where students could recap on what was done during class with animated videos and an online e-book. Also, students could see their overall progress when completing the sessions by means of the lesson report tool.

5.5.2.2 Availability of resources

The different resources were made available on eFundi™ and The Depot™, as I moved to a paperless module when doing CAD. All assignments were done and feedback given on eFundi™ and The Depot™. All of the relevant resources and assignments could be downloaded onto the students' computers in class via free Wi-Fi to view offline during the stages where they did not have any access to the Internet. If students still struggled with assignments or different CAD functions, they were encouraged to find other online resources to complete assignments. This helped in attempting to improve technology SDL skills among the students.

5.5.3 Teaching strategies

Teaching strategies can be seen as the method of instruction during contact sessions with the help of a definite plan, such as lecturing, questions and answers or group work. Any educator needs an instruction method for each lesson, otherwise he or she may roam on without any direction (Jacobs *et al.*, 2016). During the research conducted in my master's degree in Higher Education Studies, I identified different teaching methods (see Table 5-5) in EGD that led students to a deep approach to learning (Kemp, 2012). SDL is linked to a deep approach to learning, as students who follow a deep approach to learning are more likely to be self-directed learners (Candy, 1991; Higgs & Boud, 1991; Kek & Huijser, 2009; Mentz & Oostuizen, 2016). Table 5-5 shows teaching strategies that may enhance a deep approach to learning.

Table 5-5: Teaching strategies to enhance a deep approach to learning and SDL.

Kemp (2012)	Mentz and Oosthuizen (2016)	Method of instruction (Section 5.5.3.1)
Video analysis, discussion and application	Using information technology effectively in teaching.	ICT
Problem solving	Problem-based learning	Problem solving
Group work	Participating in group discussions	Group work
Role play	Role play	Role play

In Chapter 3, Section 3.6, I discussed the interrelationship between constructivism as a learning theory, SDL and spatial visualization. A deep approach to learning can now be added as well; therefore it is possible that if the above-mentioned teaching strategies are followed (Table 5-5), spatial visualization skills and SDL skills can be enhanced. As a result of proposals by Mentz and Oostuizen (2016) and Kemp (2012), the teaching strategies that are used in the study are ICT, problem solving, group work and role play.

5.5.3.1 Methods of instruction

5.5.3.1.1 Information Communication Technologies

ICT as a method to support instruction is seen as a method that helps students with the visualization of images and graphics that could develop their understanding of difficult problems. It furthermore enhances students' ability to understand their learning outcomes appropriately. In addition, ICTs assist lecturers in offering students an effective and deep learning experience that enhances students' problem-solving skills, while at the same time building content knowledge efficiently (Erstad & Voogt, 2018; Mahmud, Nasri, Samsudin & Halim, 2018; Triana, Zubainur & Bahrun, 2019). The different advanced ICTs used in the study are discussed in Chapter 2, Section 2.5.

5.5.3.1.2 Problem solving

Problem solving is a method of posing significant real-world situations and providing resources, guidance and instruction to students as they develop content knowledge and problem-solving skills (Biggs & Tang, 2011; Wilson, 2018). It furthermore reflects on the method by which students learn in real life with whatever resources are available to them (Biggs & Tang, 2011; Wilson, 2018).

5.5.3.1.3 Collaborative group work

Collaborative group work is seen as a method that provides an environment in which students help one another, as they are exposed to different perspectives to solving a problem while working together, thus collaborative group work. During group work activities, students have the opportunity to think deeply about the problem or learning content and to compare their views to those of peers, the lecturer and other sources (Biggs & Tang, 2011; Jacobs *et al.*, 2016). In the study, the students had the opportunity to help their peers and learn from their peers during some of the lessons (see Table 5-2).

5.5.3.1.4 Role play

Role play requires students to put themselves in an imaginary situation in someone else's shoes, which would lead them to solve a problem. This method invokes students' existing knowledge and enhances deep and lasting learning (Berényi &

Deutsch, 2018; Jacobs *et al.*, 2016). During the role play teaching method, the students were assigned the role of a lecturer, draughtsperson and mechanical engineer and had to prepare the drawings by themselves.

All of these teaching methods were being incorporated during the intervention to make sure the students had the opportunity to enhance their spatial visualization skills and SDL skills.

5.5.4 Module development

The different activities and lessons were carefully planned beforehand to integrate specific teaching methods with the advanced ICTs that were to be used in each session. The students knew exactly what was expected from them during each session, as they all received a work schedule for EGDD421 on the eFundi™ platform (see Table 5-6). Table 5-7 shows the planning and design of the intervention. The different design principles I had to implement to constructively align the EGDD421 module were ILOs, TLAs and assessment tasks.

Table 5-6: EGDD421 work programme and time schedule.

WERKPROGRAM EN TYDSKEDULES

WORKPROGRAM AND TIME SCHEDULES

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

EGDD 421 – 2017

Week 1-16	Tema / *Theme*	Inhoud / *Content*	Kontaksessie / *Contact sessions*
1	**Inleiding / *Introduction***	Oriëntering / *Orientation* Voortoetse / *Pre-tests*	17.07.17
	Sessie 1 / Session 1	Seephouer / *Soap holder*	19.07.17
2 - 4		Praktiese onderwys / *Practical teaching*	24.07.17 -11.08.17
5	**Sessie 2 / Session 2**	Gietstuk / *Cast*	14.08.17
	Sessie 3 / Session 3	Muurlig / *Wall light*	16.08.17
6	**Sessie 4 / Session 4**	Flitslig / *Flash light*	21.08.17
	Sessie 5 / Session 5	Deurknop / *Door knob*	23.08.17
7	**Sessie 6 / Session 6**	Mikrometer / *Micro meter*	28.08.17
	Sessie 7 / Session 7	Haardroeër / *Hair dryer*	30.08.17
8	**Sessie 8 / Session 8**	Stoel / *Chair*	04.09.17
	Sessie 9 / Session 9	Ketel / *Kettle*	06.09.17
9	**Sessie 10 / Session 10**	Katroleenheid / *Pulley unit*	11.09.17
	Sessie 11 / Session 11	Isometries / *Isometric*	13.09.17
10	**Sessie 12 / Session 12**	Isometries / *Isometric*	18.09.17
	Sessie 13 / Session 13	Isometries / *Isometric*	20.09.17
11		Openbare vakansiedag / *Public holiday*	25.09.17
	Sessie 14 / Session 14	Samestelling / *Assembly*	27.09.17
12		Reses / *Recess*	30.09.17 – 08.10.17
	Sessie 15 / Session 15	Samestelling / *Assembly*	09.10.17
13	**Sessie 16/ Session 16**	Samestelling (Snit) / *Assembly (Sectioned*	11.10.17
	Sessie 17 / Session 17	Samestelling (Snit) / *Assembly (Sectioned*	16.10.17
14	**Semester toets / *test* 2**	Week 1-14	18.10.17
15	**Sessie 18 / Session 18**	Samestelling (Snit) / *Assembly (Sectioned*	23.10.17
15	**Sessie 19 / Session 19**	Samestelling (Snit) / *Assembly (Sectioned*	25.10.17
	Sessie 20 / Session 20	Samestelling (Snit) / *Assembly (Sectioned*	
16		Na-toetse / *Post-tests*	
		Eksamen / *Exam*	

Table 5-6 shows the outlay of the second semester for the module EGDD421. Each week had two contact sessions. The work programme and time schedule showed the students exactly what was expected from them during the intervention.

Table 5-7: Planning and design of intervention.

Intervention design		
Design principle		**Implementation guideline**
Constructive	To constructively align a module, Biggs and Tang (2011) describe that one should focus on the ILOs, TLAs, assessment tasks and grading	Following Biggs and Tang's (2011) guideline to constructively align a module
ILOs		ILOs guide students to know exactly what is expected from them after each lesson
TLAs	Administrative aspects	When designing TLAs for the intervention, the researcher should keep the following in mind: Teaching methods Facilitator Advanced ICTs Skills
	Teaching methods	ICT Problem solving Group work Role play
	Facilitator	Lecturer Student (self) Student (peer)
	Advanced ICTs	2D CAD 3D CAD 3D printing Animation
	Skills	ICT skills Spatial visualization skills SDL skills
Assessment tasks	Assessment outcomes	Students should know what is expected from them
	Assessment strategy	Feedback should be given as soon as possible after each task
	Submission of assessment	Students should know when to submit assignments
	Assessment criteria/grading	Students should know how their assignments will be assessed/graded

It is evident from Table 5-7 that the researcher or educator should do thorough research on the different components of Biggs and Tang (2011) module design to redesign the existing module. To constructively align the EGDD421 module, the ILOs for each lesson should be established first. During this phase, I focused on the aims of the study and made sure that the ILOs adhered to them. It was important that the students knew what they should achieve after each lesson with regard to the use of advanced ICTs, spatial visualization skills and SDL skills.

The second phase focused on the TLAs, which should be linked with the ILOs. The administrative aspects that are important to design the TLAs are as follows: the different teaching methods used in each lesson; who will facilitate the lesson (the educator, the student or the student's peers); and which advanced ICTs will be used in the lesson, namely 2D or 3D CAD, animation or 3D printing. These administrative aspects should be carefully chosen to improve the following skills: ICT skills, spatial visualization skills and SDL skills.

The third phase involved how the assessment tasks should be designed and planned according to the assessment outcomes, assessment strategies, assessment submission and criteria for grading. The assessment outcomes were supported by a grading rubric, which showed the students what was important for marks during the drawing task. The assessment strategy that should be followed, was to give feedback to the students as soon as possible so that they could improve on what they had done wrong in the drawing activity. The submission of the activities should be clear on when and on which platform (eFundi™ or The Depot™) the activities should be submitted.

Thus I had to adhere to all of the above-mentioned phases to constructively align the EGDD421 module to improve ICT skills, spatial visualization skills and SDL skills.

5.5.4.1 Different activities

The different activities involved in each session are shown in Tables 5-2 and 5-6.

5.5.4.2 Student participation

Because there were only 48 students, it was easy to monitor all the students' class participation, eFundi™ participation and participation on The Depot™. I also motivated the students to participate during contact sessions and made them aware of the importance of the activities done in each session regarding which type of drawing was done.

5.5.5 Feedback

In the study, different opportunities were provided to the participants to give feedback. At the beginning of the study, I had unstructured interviews with the participants to determine the qualitative data (Chapter 6). After the intervention, I again held unstructured interviews to get feedback from the students to determine whether the intervention had helped them to understand sectional mechanical assembly drawings. The students gave feedback to determine the quantitative data during the pre-tests that measured their understanding of mechanical drawings before the intervention. They gave feedback again during the post-test after the intervention. They also gave feedback before the intervention with a pre-test to determine their technology SDL skills and once again after the intervention to determine whether they had gained any technology SDL skills after the intervention.

5.5.6 Profile of students

5.5.6.1 Pre-knowledge of mechanical drawings

The students had theoretical knowledge of mechanical assembly drawings as they had already completed the EGDE321 module that had a component on mechanical drawings. As they still struggled with these drawings, the EGDD421 module should help them to gain a deeper understanding of sectioned mechanical assembly drawings if combined with advanced ICTs.

5.5.6.2 Pre-SDL skills

The students should have had experience with SDL, as it is a prerequisite of the North-West University when designing their modules. Normally, SDL is part of the hidden curriculum, and students might not know that they have learnt various SDL skills during their training as an educator. The SDL technology skills are new to the students, as not all modules make use of ICT during students' training.

5.6 Implementation of intervention

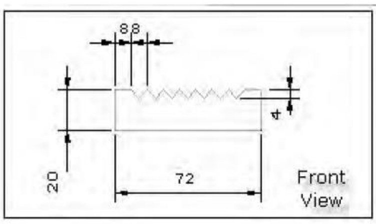
During the first lesson, the students draw a sectional mechanical assembly drawing test as a pre-test to determine on what level of understanding of mechanical drawing they were (Addendum G). They completed the SDL technology questionnaire (Addendum E) as a pre-test to determine their SDL skills when using technology in the EGD classroom.

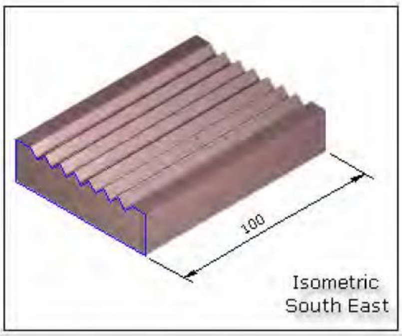
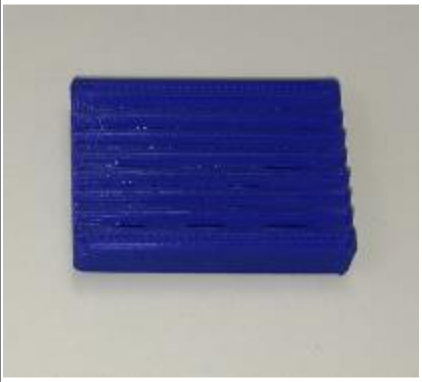
5.6.1 Week 1

5.6.1.1 Session 1

The first 3D CAD lesson was done with Session 1 in the 3D CAD Training Guide. The students had to draw a soap holder in CAD. Before we started drawing, I presented the following problem to the students; the problem was that we needed a place to put our soap in the shower; the solution was a soap holder. Before we started drawing, the 3D printed model of a soap holder was sent around the class to familiarise students with what they had to draw. As it was the first session, I demonstrated how to do the drawing in 3D CAD. The methods of instruction used were ICT and problem solving. The students may have obtained the following skills: spatial visualization skills as they saw what they had to draw; ICT skills because they used advanced ICTs; and critical thinking skills because they had to think of a solution for the problem. (See Table 5-8 for a summary of the session, the person or persons who facilitated the session, the method of instruction and which possible skills the students could obtain.)

Table 5-8: Session 1.

<table>
<tr><th>Session 1 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3">

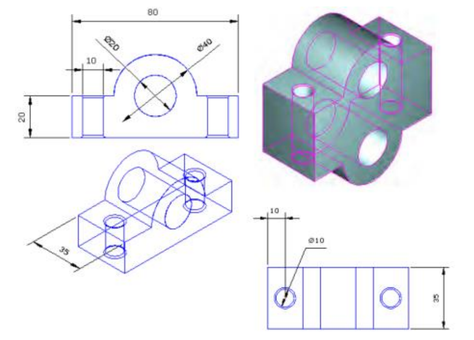
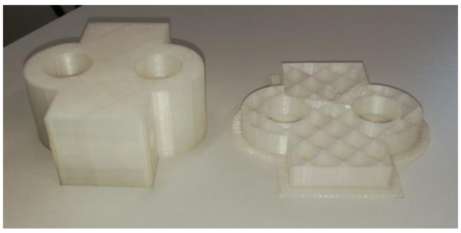

</td><td>Lecturer</td><td>ICT
Problem solving</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="3">Spatial visualization skills
ICT skills
Critical thinking skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer)</td></tr>
<tr><td></td></tr>
</table>

5.6.2 Week 2

5.6.2.1 Session 2

The second 3D CAD lesson was done with Session 2 in the 3D CAD Training Guide. The students had to draw a cast iron piece that was part of a thickness planer in CAD. Before we started drawing, I presented the following problem to the students: the problem was that we needed a new part to fix the thickness planer in the Civil Technology workshop. As not all of the students had Civil Technology, specifically Woodworking, I led them to the answer by showing them the broken part. The 3D-orientated model was sent around the class before we started drawing the 3D object. I demonstrated how to do the drawing in 3D CAD with new functions that built on their prior knowledge of Session 1. Table 5-9 shows the methods of instruction used were ICT and problem solving. The students may have obtained the following skills: ICT skills because the used advanced ICTs; spatial visualization skills as they saw what they had to draw; and critical thinking skills because they had to think of a solution for the problem.

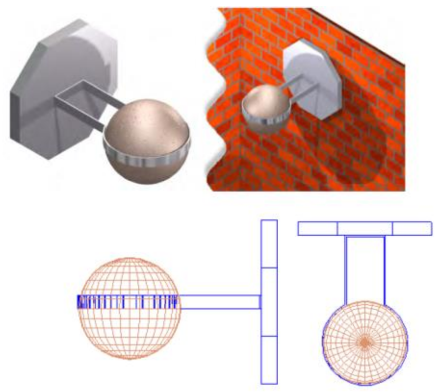
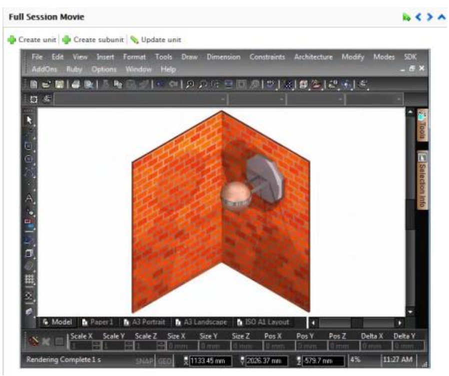
Table 5-9: Session 2.

Session 2 3D CAD	Facilitator	Method of instruction
	Lecturer	ICT Problem solving
	Possible skills attained:	
Advanced ICT used: 3D model (3D Printer)	Spatial visualization skills ICT skills Critical thinking skills	
		

5.6.2.2 Session 3

Table 5-10 shows the third 3D CAD lesson which was done with Session 3 in the 3D CAD Training Guide. The following scenario was presented to the students: there is a lot of burglary in your part of town; the police suggests that it is because there is not efficient lighting. The students came up with a few designs of different lights that could be put on the front porch. During this session, the students made use of the animation on The Depot™ to guide them in doing the drawing. They therefore had to build on their prior knowledge of Sessions 1 and 2 on their own. ICT and problem solving were used as teaching methods. The students may have obtained the following skills: ICT skills because they used advanced ICTs: spatial visualization skills as they saw what they had to draw; and critical thinking skills because they had to think of a solution for the problem.

Table 5-10: Session 3.

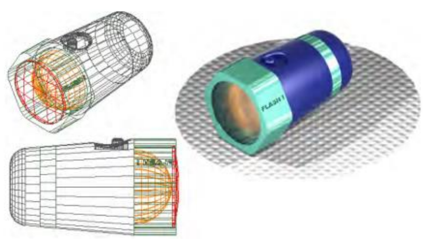
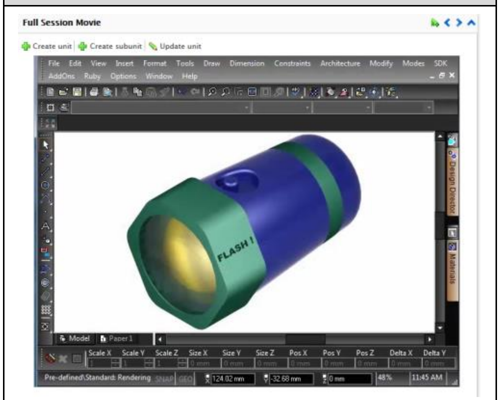
Session 3 3D CAD	Facilitator	Method of instruction
	Student	ICT Problem solving
	Possible skills attained:	
	Spatial visualization skills ICT skills Critical thinking skills	
Advanced ICT used: 3D model (3D printer)		
		

5.6.3 Week 3

5.6.3.1 Session 4

Table 5-11 shows the fourth 3D CAD lesson which was done with Session 4 in the 3D CAD Training Guide. We still made use of the scenario in Session 3 but added that one had to see in the house without switching on the lights. The students decided that a torch light would be efficient for lighting one's home. The students then worked in groups while making use of the animation on The Depot™ to guide them in doing the drawing. They built on their prior knowledge of Sessions 1, 2 and 3 on their own. ICT and problem solving were used as method of instruction. The students may have obtained the following skills: ICT skills because they used advanced ICTs; spatial visualization skills as they saw what they had to draw; and critical thinking skills because they had to think of a solution for the problem.

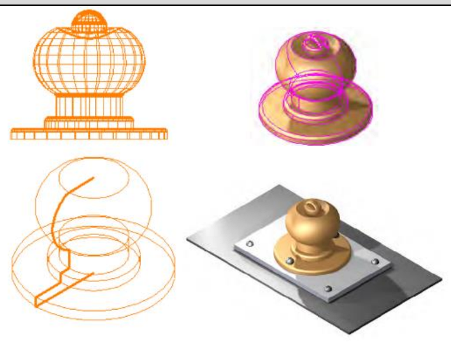
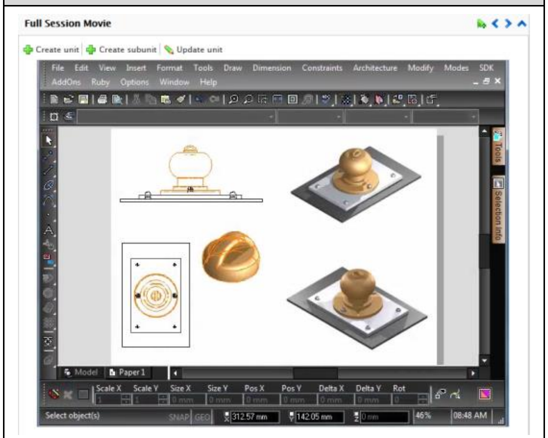
Table 5-11: Session 4.

<table>
<tr><th>Session 4 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="2"></td><td>Student</td><td>ICT
Problem solving
Group work</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td>Advanced ICT used:
3D animation (The Depot™)</td><td colspan="2" rowspan="2">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills
Communication skills</td></tr>
<tr><td></td></tr>
</table>

5.6.3.2 Session 5

The fifth 3D CAD lesson was done with Session 5 in the 3D CAD Training Guide (see Table 5-12). Still using the scenario in Session 3, the students then had to design a system where one could lock one's bedroom door on the inside of the room without searching for a key. The students had a lot of designs that all leaned towards the CAD drawing they had to do. During this session, I showed them functions that were not in the animation, and after showing them these functions, they used the animation on The Depot™ to guide them in doing the rest of the drawing in groups, helping one another. The students built on their prior knowledge of the previous sessions. ICT and problem solving were used as method of instruction. The students may have obtained the following skills: ICT skills because they used advanced ICTs; and spatial visualization skills as they saw what they had to draw.

Table 5-12: Session 5.

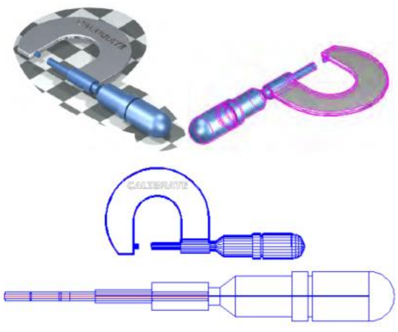
<table>
<tr><th>Session 5 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Lecturer
Student</td><td>ICT
Problem solving
Group work</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="3">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills
Communication skills</td></tr>
<tr><td>Advanced ICT used:
3D animation (The Depot™)</td></tr>
<tr><td>
</td></tr>
</table>

5.6.4 Week 4

5.6.4.1 Session 6

The sixth 3D CAD lesson was done with Session 6 in the 3D CAD Training Guide. During this session, the problem to solve was to determine which instrument should be used to do precision measuring in the fitting and turning classroom. Once again not all of the students had Mechanical Technology as a second subject. The Mechanical Technology students now had the opportunity to be the lecturer in the fitting and turning room and explain to the other students which tool to use and how to use it. After the role play, the 3D printed model of the micrometer was sent around the class. The students then did the drawing on their own, only following the 3D CAD Study Guide. The students built on their prior knowledge of the previous sessions. ICT and problem solving were used as teaching methods. The students may have obtained the following skills: ICT skills because they used advanced ICTs; and spatial visualization skills as they saw what they had to draw (See Table 5-13, which summarises what was done, which method of instruction was used and which skills could be obtained.)

Table 5-13: Session 6.

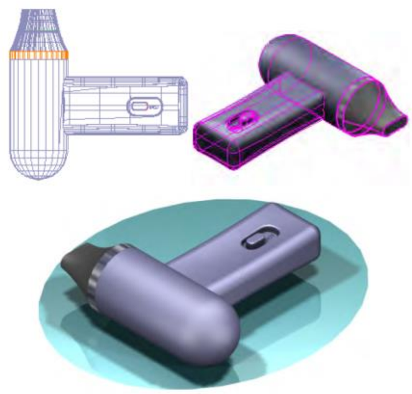
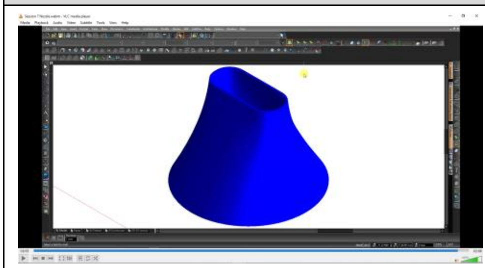
<table>
<tr><th>Session 6 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Student</td><td>ICT
Problem solving
Role play</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="2">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills
Communication skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer)</td></tr>
</table>

5.6.4.2 Session 7

Table 5-14 shows session 7, the students did not have to solve a problem. As this session was somewhat time-consuming, the students started with the drawing of the hairdryer on their own, using the 3D CAD Study Guide and the animation on the eFundi™ site. The students built on their prior knowledge of the previous sessions. ICT and problem solving were used as method of instruction. The students may have obtained the following skills: ICT skills because they used advanced ICTs; and spatial visualization skills as they saw what they had to draw.

Table 5-14: Session 7.

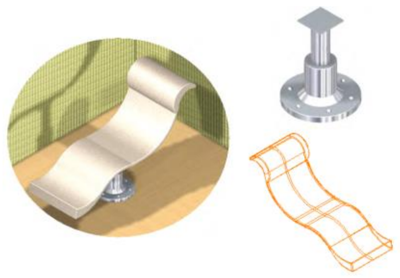
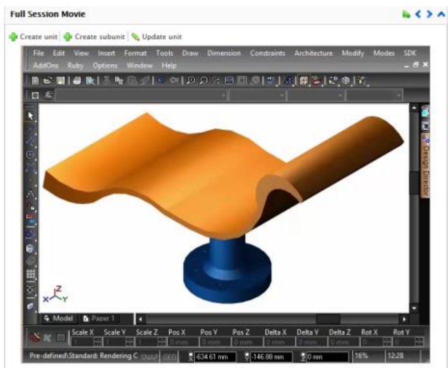
Session 7 3D CAD	**Facilitator**	**Method of instruction**
	Student	ICT
	Possible skills attained:	
	Spatial visualization skills ICT skills SDL skills	
Advanced ICT used: 3D animation (eFundi™)		
		

5.6.5 Week 5

5.6.5.1 Session 8

Table 5-15 shows the eighth 3D CAD lesson which was done with Session 8 in the 3D CAD Training Guide. The students had to design chairs that could be bolted onto the deck of a cruise ship. Many different designs were suggested, which they then showed to the rest of the class on the document camera as designers of a big company. Then they made use of the information in the Study Guide and the animation on The Depot™ to complete the drawing of the chair. The students built on their prior knowledge of the previous sessions. ICT and problem solving were used as teaching methods. The students may have obtained the following skills: ICT skills because they used advanced ICTs; and spatial visualization skills as they saw what they had to draw.

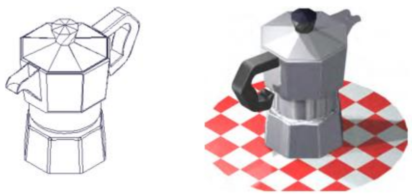
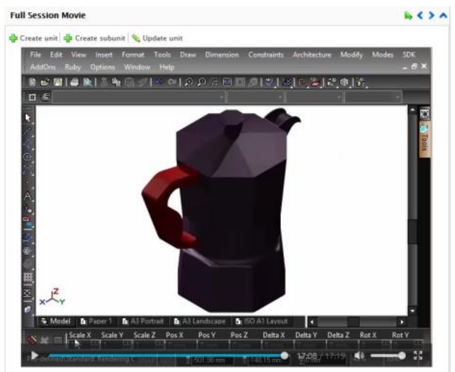
Table 5-15: Session 8.

<table>
<tr><th>Session 8 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="2"></td><td>Student</td><td>ICT
Problem solving
Role play</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td>Advanced ICT used:
3D animation (The Depot™)</td><td colspan="2" rowspan="2">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills
Communication skills</td></tr>
<tr><td>
</td></tr>
</table>

5.6.5.2 Session 9

The second to last lesson in the 3D CAD Training Guide was Session 9 (see Table 5-16). The students had to design a kettle that had a modern style and accounted for given specifications. They then had the opportunity to show their designs to the rest of the class as the designer of their stylish kettles. Then they used the information in the Study Guide and the animation on The Depot™ to complete the drawing of their kettles. The students built on their prior knowledge of the previous sessions. ICT and problem solving were used as teaching methods. The students may have obtained the following skills: ICT skills because they used advanced ICTs ; and spatial visualization skills as they saw what they had to draw.

Table 5-16: Session 9.

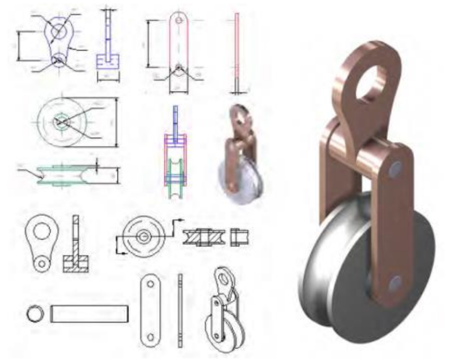
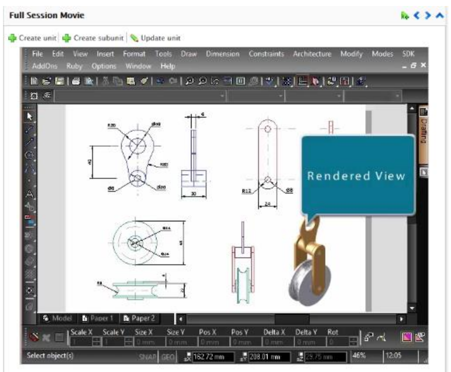
Session 9 3D CAD	**Facilitator**	**Method of instruction**
	Student	ICT Problem solving Role play
	Possible skills attained:	
Advanced ICT used: 3D animation (The Depot™)	Spatial visualization skills ICT skills SDL skills Critical thinking skills Communication skills	
		

5.6.6 Week 6

5.6.6.1 Session 10

Table 5-17 shows the last session of the 3D CAD Training Guide which was Session 10. Students had to draw a pulley unit in CAD and then section the different parts of the pulley unit. The students used the information in the Study Guide and the animation on The Depot™ to complete the drawing of the pulley unit and section the different components. They built on their prior knowledge of the previous sessions. ICT and problem solving were used as method of instruction. The students may have obtained the following skills: ICT skills because they used advanced ICTs; and spatial visualization skills as they saw what they had to draw.

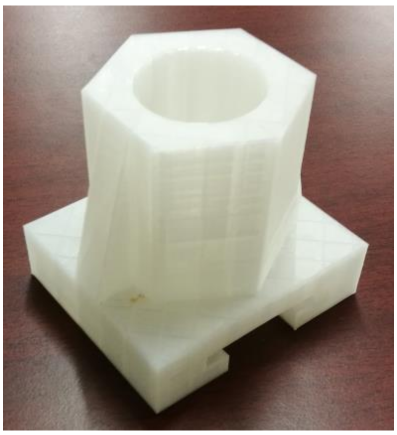
Table 5-17: Session 10.

<table>
<tr><th>Session 10 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Student</td><td>ICT
Problem solving</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="3">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills</td></tr>
<tr><td>Advanced ICT used:
3D animation (The Depot™)</td></tr>
<tr><td>
</td></tr>
</table>

5.6.6.2 Session 11

Table 5-18 shows how I facilitated session 11 to do a recap of the CAD knowledge and skills the students had attained during Session 1 to 10. This session was important: as the drawing difficulty would increase in the next sessions, I had to make sure that the students obtained enough knowledge and skills during sessions 1 to 10 to gradually move on to the next mechanical assembly drawings. I sent the 3D printed model around the class, so that the students could familiarise themselves with what they were drawing. We then drew the model step by step and I assessed all the students' drawings in class to ensure that they were all comfortable with the content done in sessions 1 to 10. The methods of instruction followed during this session were the use of ICT and problem solving. The students had the opportunity to obtain the following skills in this session: ICT, spatial visualization, SDL and critical thinking skills.

Table 5-18: Session 11.

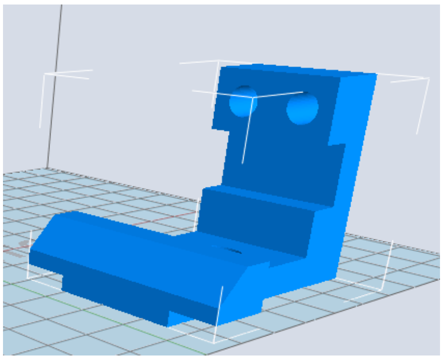
<table>
<tr><th>Session 11 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Lecturer</td><td>ICT</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="3">Spatial visualization skills
ICT skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer)</td></tr>
<tr><td></td></tr>
</table>

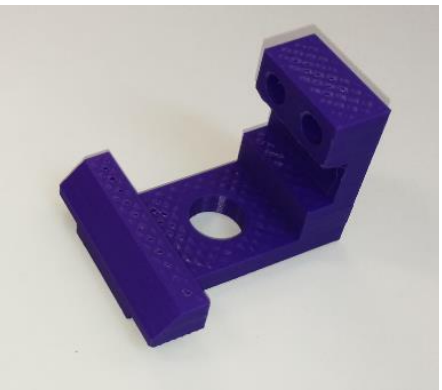
5.6.7 Week 7

5.6.7.1 Session 12

Table 5-19 shows Session 12 and summarises what I did in this session. In the EGDD421 classroom, I showed the students the 3D scanned model on the data projector and sent the 3D printed model around the classroom for the students to familiarise themselves with what they would be drawing in class. The students then had to do the drawing without any guidance from animation, from the Study Guide or from me as the lecturer. The method of instruction focused on ICT and problem solving. The students then had the opportunity to complete the 3D drawing on their own, using any functions they had learnt from sessions 1 to 11, thus using any problem-solving skills they had obtained throughout the intervention Therefore the students only had to complete the final product; how they got there was not important for the duration of the drawing. When all of the students had completed the drawing, we had a class discussion and the students had the opportunity to show their peers how they had gotten to the final drawing on their own. The students' ICT skills and spatial visualization skills may have improved during this session.

Table 5-19: Session 12.

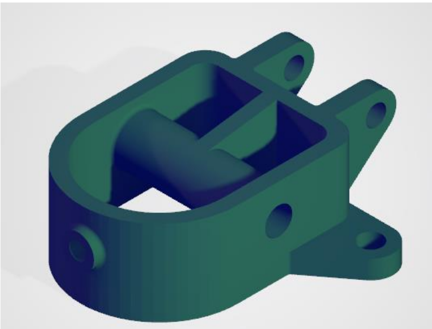
<table>
<tr><th>Session 12 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Student</td><td>ICT
Problem solving</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="2">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer and 3D scanner)</td></tr>
</table>

5.6.7.2 Session 13

In Table 5-20, during Session 13, I once again showed the students the 3D scanned model by means of the data projector. I then sent the 3D printed model around the classroom to familiarise the students with what they had to draw. The students then had to rely on the skills obtained during sessions 1 to 12 to do the drawing without any guidance from animation, from the Study Guide or from me as the lecturer. During this session, the method of instruction used was the combination of ICT and problem solving. During the session, the students gradually made use of the intentional learning SDL skill to complete the drawing without knowing that they were using this skill. The students furthermore had to rely on critical thinking skills as they were left alone to complete the drawing on their own.

Table 5-20: Session 13.

<table>
<tr><th>Session 13 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Student</td><td>ICT
Problem solving</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="2">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer)</td></tr>
</table>

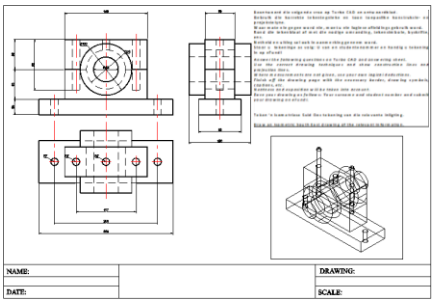
<table>
<tr><td></td><td></td></tr>
</table>

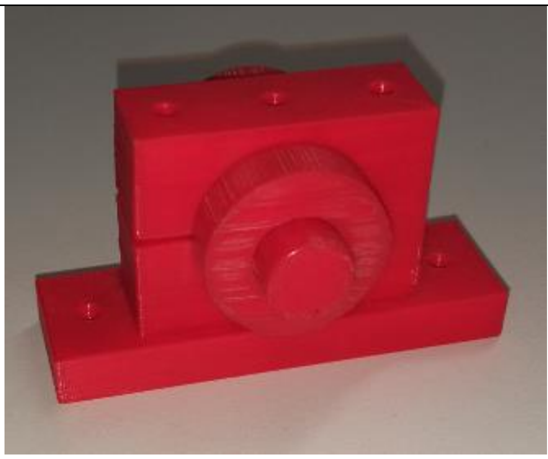
5.6.8 Week 8

5.6.8.1 Session 14

Table 5-21 shows what was done during week 8, Session 14. This session consisted of an assembly machine drawing without any sectioned parts. I facilitated the lesson and did a recap of Session 10. I then sent the different parts to the groups in the class and they had to assemble these parts with the basic knowledge they had of machine assembly drawings. After the group work was completed, I showed the students how to draw all the components and how to combine them in 3D CAD. The methods of instruction used were the use of ICT, problem solving and group work. The different skills the students could have obtained were as follows: spatial visualization skills, as they had the opportunity to see the 3D model beforehand; ICT skills, as they made use of 3D CAD; critical thinking skills, as they had to use prior knowledge and the 3D parts to assemble the model; and lastly, an SDL skill that could be obtained was the self-monitoring skill, as the students used problem-based learning to complete the drawing.

Table 5-21: Session 14.

<table>
<tr><th>Session 14 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3">
</td><td>Lecturer</td><td>ICT
Problem solving
Group work</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2">Spatial visualization skills
ICT skills</td></tr>
</table>

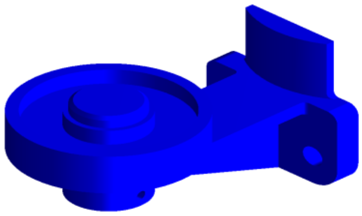
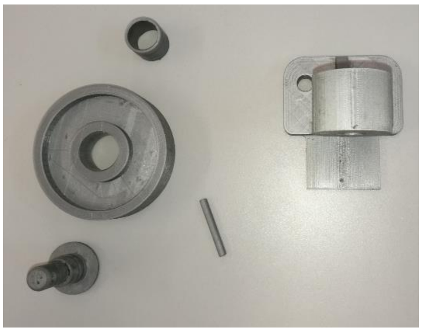
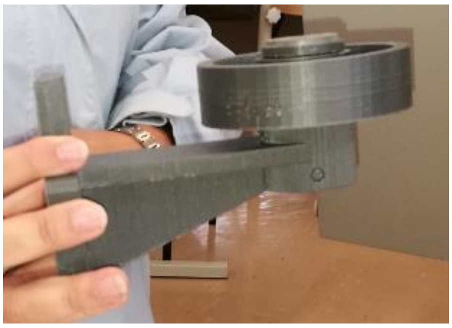
Advanced ICT used: 3D model (3D printer)	SDL skills Critical thinking skills Communication skills
	

5.6.8.2 Session 15

Table 5-22 shows what was done during Session 15. The students received the different components of the 3D printed model of the assembly drawing. In groups, they had to assemble the different components to create the final product. They then had to complete the drawing on CAD by themselves. The methods of instruction used were the use of ICT, problem solving and group work. The students obtained spatial visualization skills when assembling the parts. They also had to use critical thinking skills to decide which part fits where. They further made use of communication skills to communicate with one another in the group and decide which part would fit where. In using advanced ICTs, they obtained ICT skills. They furthermore obtained SDL skills such as self-monitoring and intentional learning skills by doing the rest of the drawing on their own while using problem solving to complete the drawing.

Table 5-22: Session 15.

Session 15 3D CAD	Facilitator	Method of instruction
	Student	ICT Problem solving Group work

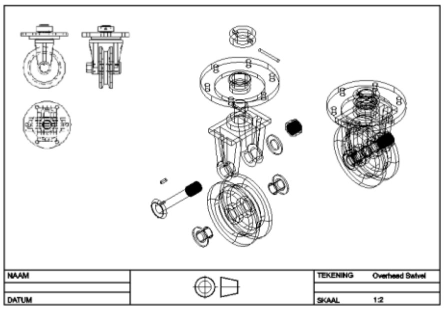
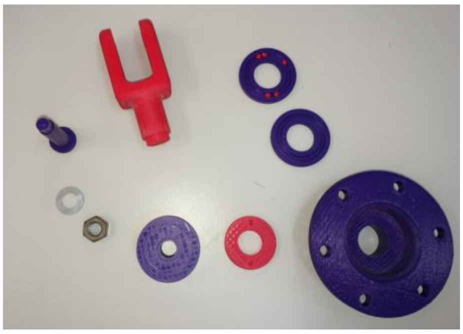
	Possible skills attained:
Advanced ICT used: 3D model (3D printer)	Spatial visualization skills ICT skills SDL skills Critical thinking skills Communication skills
	
	

5.6.9 Week 9

5.6.9.1 Session 16

Table 5-23 shows week 9, Session 16, where the students received the different components of the 3D printed model of the assembly drawing. In groups, they had to assemble the different components to create the final product. I then showed them how to combine all of the parts and section the final product in CAD. The students obtained spatial visualization skills when assembling the parts and sectioning the drawing. They had to use critical thinking skills to decide which part fits where. They made use of communication skills to communicate with one another in the group and to decide which part would fit where. Furthermore, by using advanced ICTs, they obtained ICT skills. The students furthermore obtained self-monitoring and intentional learning SDL skills while using problem-solving skills.

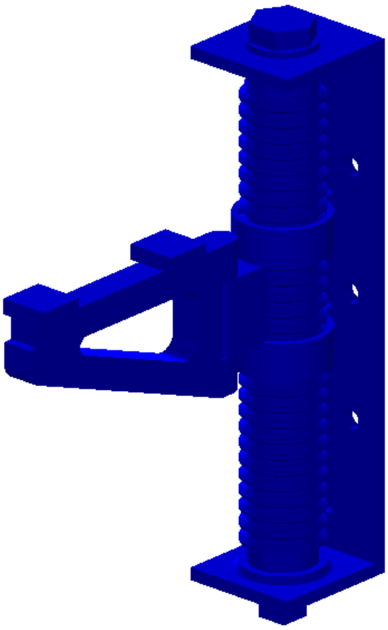
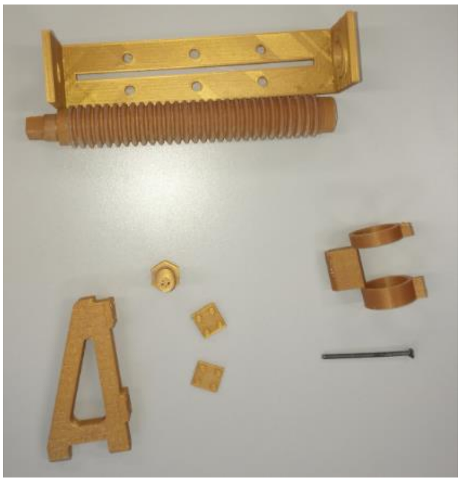
Table 5-23: Session 16.

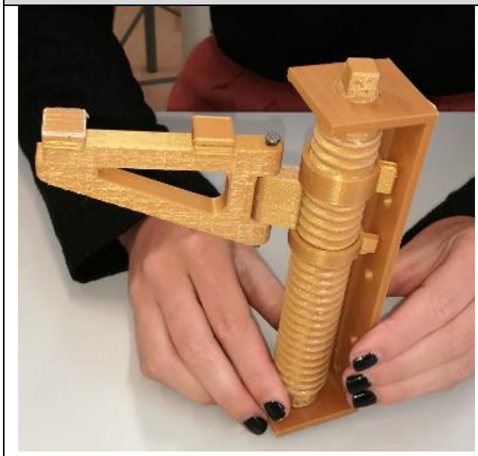
<table>
<tr><th>Session 16 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3">
</td><td>Lecturer</td><td>ICT
Problem solving
Group work</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="2">Spatial visualization skills
ICT skills
SDL skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer)</td></tr>
<tr><td></td><td colspan="2"></td></tr>
</table>

5.6.9.2 Session 17

During Session 17, the students received the different components of the 3D printed model of the assembly drawing (see Table 5-24). In groups, they had to assemble the different components to create the final product. They then had to complete the drawing on CAD by themselves and create a full sectional view of the drawing. The students obtained spatial visualization skills when assembling the parts and sectioning the model. They made use critical thinking skills to decide which part fits where and how to section the assembled drawing. They made use of communication skills to communicate with one another in the group and decide which part would fit where. In using advanced ICTs, they obtained ICT skills. They also obtained SDL skills, such as self-monitoring and intention learning skills, by doing the rest of the drawing on their own and using problem-solving skills.

Table 5-24: Session 17.

<table>
<tr><th>Session 17 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Student</td><td>ICT
Problem solving
Group work</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills
Communicating skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer)</td><td colspan="2" rowspan="2"></td></tr>
<tr><td></td></tr>
</table>

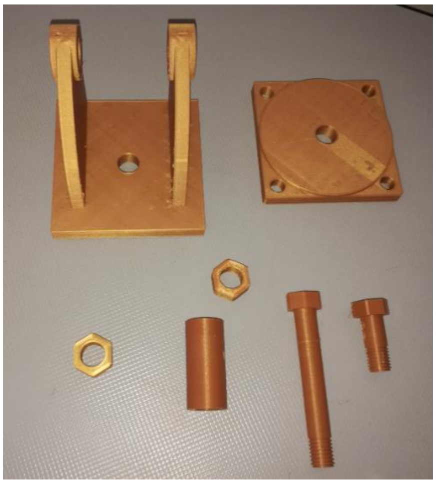
Session 17 3D CAD	Facilitator	Method of instruction
		

5.6.10 Week 10

5.6.10.1 Session 18

Table 5-25 shows what was done during Session 18, when the students received the different components of the 3D printed model of the assembly drawing. During group work, they had to assemble the different components to create the final product of the assembly drawing. They then had to complete the drawing on CAD by themselves and create a full sectional view of the drawing. The students obtained spatial visualization skills when they assembled the parts and sectioned the assembled model. Students furthermore had to use critical thinking skills to decide which part fits where and how to section the drawing according to drawing regulations. They made use of communication skills to communicate with one another in the group and decide which part would fit where. In using advanced ICTs they obtained ICT skills, and they obtained SDL skills such as self-monitoring and intentional learning skills by doing problem solving as a teaching method.

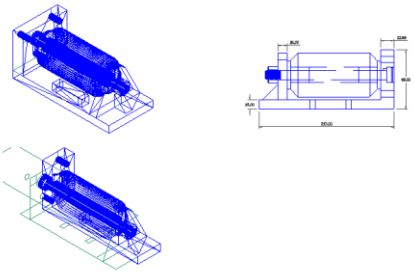
Table 5-25: Session 18.

<table>
<tr><th>Session 18 3D CAD</th><th>Facilitator</th><th>Method of instruction</th></tr>
<tr><td rowspan="3"></td><td>Student</td><td>ICT
Problem solving
Group work</td></tr>
<tr><td colspan="2">Possible skills attained:</td></tr>
<tr><td colspan="2" rowspan="2">Spatial visualization skills
ICT skills
SDL skills
Critical thinking skills
Communicating skills</td></tr>
<tr><td>Advanced ICT used:
3D model (3D printer)</td></tr>
<tr><td></td><td colspan="2"></td></tr>
</table>

5.6.10.2 Session 19

Table 5-26 shows what was done during Session 19, the EGDD421 students did not receive any 3D printed model of the assembly drawing. They had to complete the drawing on CAD by themselves and create a full sectional view of the drawing. During this session, the students obtained spatial visualization skills when they assembled the parts and sectioned the fully assembled model. The students had to use critical thinking skills to decide which part fits where and how to section the final product. The students furthermore made use of communication skills to communicate with one another in the group and decide which part would fit where. In using advanced ICTs they obtained ICT skills in using 3D CAD. In addition, they obtained self-monitoring and intentional learning SDL skills by doing the drawing on their own while solving the problem.

Table 5-26: Session 19.

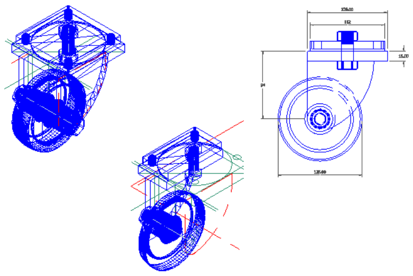
Session 19 3D CAD	Facilitator	Method of instruction
	Student	ICT Problem solving
	Possible skills attained:	
	Spatial visualization skills ICT skills SDL skills Critical thinking skills	

5.6.11 Week 11

5.6.11.1 Session 20

During Session 20, the students did not receive any 3D printed model of the assembly drawing (see Table 5-27). The students had to complete the drawing on CAD by themselves and create a full sectional view of the drawing. They obtained spatial visualization skills when they assembled the parts and sectioned the assembled model. They had to use critical thinking skills to decide which part fits where and how to section the drawing. They made use of communication skills to communicate with one another in the group and decide which part would fit where. In using advanced ICTs they obtained ICT skills, and they obtained self-monitoring and intentional learning SDL skills by doing the rest of the drawing on their own while solving the problem.

Table 5-27: Session 20.

Session 20 3D CAD	Facilitator	Method of instruction
	Student	ICT Problem solving
	Possible skills attained:	
	Spatial visualization skills ICT skills SDL skills Critical thinking skills	

5.6.11.2 Session 21

During the last lesson, the students draw a sectional mechanical assembly drawing as a post-test to determine whether there was any change in their understanding of mechanical sectional drawings (Addendum H). They also completed the SDL technology questionnaire (Addendum F) as a post-test to determine their SDL skills when using technology in the EGD classroom.

5.7 Conclusion

The purpose of this chapter was to describe how the intervention was planned, designed and implemented. During the design and planning phase, I focused on the different teaching methods, who facilitated the lessons, which advanced ICTs were implemented to enhance spatial visualization and what strategies were applied to enhance SDL skills. The implementation of the intervention was discussed for each session during the eleven weeks of the intervention. The next chapter will focus on the data analysis and interpretation of data.

CHAPTER 6: RESULTS AND ANALYSIS

LOGIC

Question	Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)	McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)	Chapter layout	Research method
What contributing suggestions made by student teachers, EGD lecturers and the researcher can assist in the development of a framework for advanced ICT integration in EGD to foster spatial visualization and SDL?	Evaluating the actual research findings. Modifying my future practice in the teaching of EGD.	What evidence can I gather that I am having an influence? How can I explain this educational influence? How can I ensure that any judgments I might make are reasonably fair and accurate? How will I change my practice with regard to my evaluation?	**Chapter 6**	**Comprehensive summary and integration**

6.1 Introduction

In the previous chapter, I discussed the planning, design and implementation of the intervention. The purpose of this chapter is to report on the findings on the qualitative and quantitative data. The research aims identified in Chapter 1 (Section 1.5) are compared to the data to determine whether these research aims and the secondary research questions were answered during the data analysis. Table 6-1 shows the different research aims and whether they were resolved during the qualitative or quantitative research, and which data collection method, data analysis method and instrument were used to analyse the data.

Table 6-1: Research aims.

Research aims of the study	Mixed-methods action research	Chapter layout	Data collection method	Data analysis method	Instru ment
The research aims are:					
to determine the main advantages and barriers of using ICT in EGD education globally and in South Africa;	Qualitative	Chapter 2 and 6	Focus group interviews Individual interviews Observation Research journal Gathering documentary evidence	Coding	ATLAS. ti
to determine to what extent ICTs are being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education;	Qualitative	Chapter 6	Focus group interviews Individual interviews Observation Research journal	Coding	ATLAS. ti
to discover to what extent advanced ICTs enhance spatial visualization and SDL skills;	Qualitative/ quantitative	Chapter 6	Questionnaires Focus group interviews Individual interviews Observation Research journal	Descriptive statistics Coding	SPSS ATLAS. ti
to discover how ICT and spatial visualization skills can be further developed to enhance EGD within	Qualitative/ quantitative	Chapter 5	Questionnaires Focus group interviews Individual interviews Observation	Descriptive statistics Coding	SPSS ATLAS. ti

higher education; and			Research journal Visual material		
to propose a suitable framework for the implementation of advanced ICT integration in EGD to foster spatial visualization skills and SDL skills.	Qualitative/ quantitative	Chapter 7	Questionnaires Focus group interviews Individual interviews Observation Research journal	Descriptive statistics Coding	SPSS ATLAS. ti

From Table 6-1 it is evident that to fully answer the research question and adhere to the research aims, each aim shows if the data were collected by means of qualitative or quantitative research. The data collection method was determined with the relevant analysis method and the instrument that was used to analyse the data.

6.2 Results from qualitative research

The qualitative research of the study consisted of focus group interviews with student teachers and individual interviews with fellow lecturers. I documented my own observations during the research in my research journal. In cases where participant narrative is in the Afrikaans language, verbatim English translation follows such quotations.

6.2.1 Determine the research problem

In Chapter 1, it was established that students normally struggle with their spatial ability to visualize how different models or components can be rotated or manipulated and how they will look if they are sectioned. The literature and research done worldwide show that there is a common problem among students who do EGD – they struggle with spatial visualization. In this research, the problem I identified was that my students in EGD struggled with sectional assembly drawings. To make sure my assumption was correct, I held interviews with students and fellow lecturers to determine if this was really a problem or only my own opinion. The first question I asked the participants during the focus group interviews and individual interviews was as follows:

As an Engineering Graphics and Design (EGD) student teacher, tell me which drawings are seen as the most difficult drawings?

Different types of drawings were identified, as illustrated in Figure 6-1. The participants believed that descriptive geometry, mechanisms, civil, isometric, interpenetration, solid geometry and machine drawings were seen as difficult.

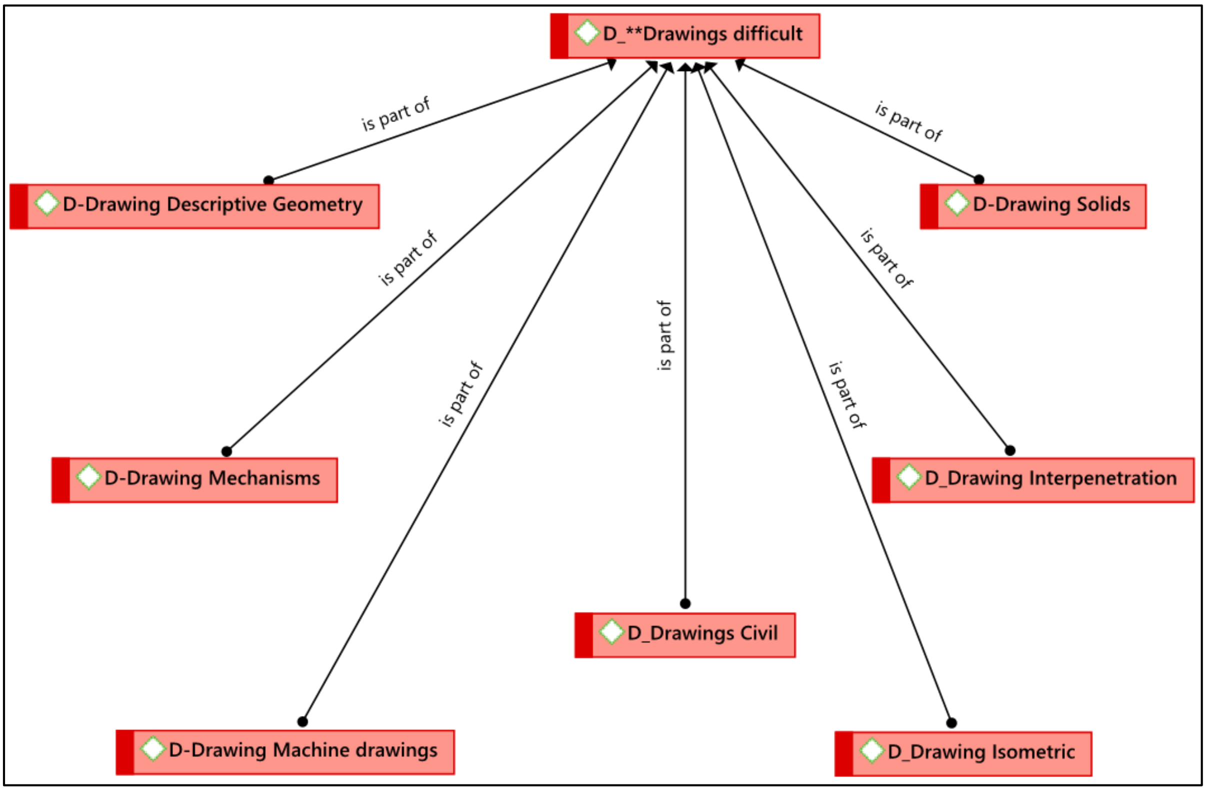


Figure 6-1: Difficult drawings.

It is evident from Figure 6-1 that there is various drawings students struggle with, but when the numbers of the focus groups are compared with their answers, mechanical assembly drawings were mentioned the most (see Figure 6-2).

Figure 6-2 shows that the mutual drawing with which students struggle is machine drawings. If we take a look at what the different focus groups perceived as the most difficult drawings, all of the focus groups mentioned machine drawings.

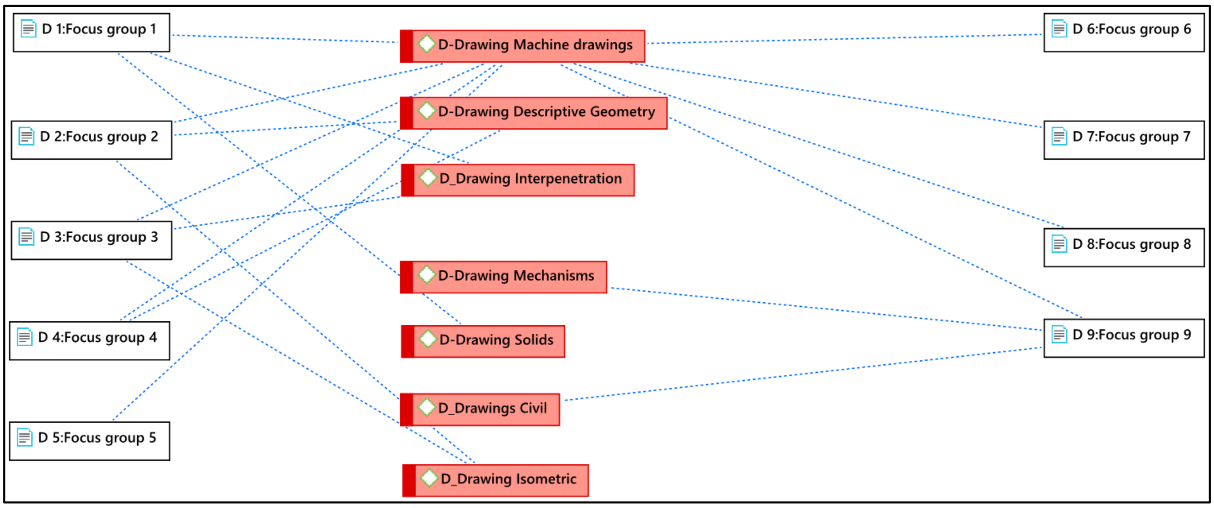


Figure 6-2: Research problem.

In Figure 6-2, the problem established in Chapter 1 was confirmed, namely that students struggle with sectional mechanical assembly drawings. This was furthermore confirmed by the students' responses during the focus group interviews with students and individual interviews with fellow lecturers (see Table 6-2). This was furthermore established when compared with my observations made during EGD classes and the interviews, which I documented in my research journal, the research problem was established with the literature, interviews and my own assumption as an EGD lecturer for the past 14 years. Table 6-2 displays some typical quotations supporting the network in Figure 6-2.

Table 6-2: Typical quotes as evidence of sectioned mechanical assembly drawings.

Category	Quotations (verbatim) gained from focus group interviews
Mechanical assembly drawings	P9, 1-2: *"Ek sal sê dit is tien teen een maar jou masjientekeninge; om te sien hoe om dit aanmekaar te sit. Sommige mense sit dit verkeerd aanmekaar, so dit is nie noodwendig, die tekening nie, maar die insig van die skets".* *[I'd say it's ten against one machine drawings; to see how to put it together. Some people put it together*

	incorrectly, so it's not necessarily, the drawing, but the insight of the sketch].
	P19, 13-14: *"Masjientekeninge, omdat mens nou verskillende parte het, wat in mekaar gepas word, moet jy nou bietjie meer dink daaroor, soos, is dit nou in die regte posisie, dan moet jy bietjie verder dink daaroor".* *[Machine drawings, because you now have different parts that fit together, you now have to think a little more about it, like, if it is in the right position, then you have think a little further about it].*
	P39, 12-14: *"…meganiese samestellings vir die leerders leer – hoe 'n bout gaan lyk of hoe 'n struktuur sal lyk as jy hom in die helfte deursny. Jy sal vir hulle 'n beter idee skep van hoe goed sal voorkom as dit 'n snit in het, soos 'n sny-aansig of net 'n kantaansig van 'n 3D-skets of 'n 2D-skets".* *[…mechanical assemblies will teach the learners - what a bolt will look like or what a structure will look like if you cut it in half. You will give them a better idea of how good it will look if it has a section in it, such as a sectioned view or just a side view of a 3D sketch or a 2D sketch].*
	Quotations (verbatim) gained from individual interviews with fellow lecturers
	P47, 3: I think students also lack the mechanical insight into how the different parts fit into each other.
	P48, 13-14: Any error from the draughtsperson may ultimately convey incorrect information regarding an individual part or even the entire mechanical assembly.

It is evident from Table 6-2 that sectioned mechanical assembly drawings are seen as the most difficult drawing because as it is difficult to mentally rotate and determine where the different components should fit to complete the assembled drawing. The sectioning of the drawing is further important to determine where different components should be in the assembled drawing. Lecturer feedback furthermore displays the mechanical assembly drawings as the most difficult drawings because students do not have the mechanical insight to fit the different components together, and if the components are not fitted together precisely, the entire mechanical assembly drawing may convey incorrect information. Therefore, the interviews with the students and fellow lectures concurred that sectioned mechanical assembly drawings are seen as the most difficult.

To furthermore understand why students struggle with these drawings, I asked the participants:

What challenges do you think students have in understanding sectional mechanical assembly drawings?

The common determining factor was that students felt they did not have the ability to mentally see how the different parts fit together. This was coded as the lack of spatial abilities and can be seen in Figure 6-3. This furthermore confirms that a method to improve students' spatial visualization skills was necessary. During my own observations in the EGD classes, I also established that students mentioned that they could not mentally see how the different components fit together if they did not know what they were drawing. This further complicated the process of sectioning as students struggled to assemble the drawing. If students are able to assemble the drawing, it would be easier to section it afterwards. Figure 6-3 shows that all focus groups mentioned mechanical assembly drawings as being difficult.

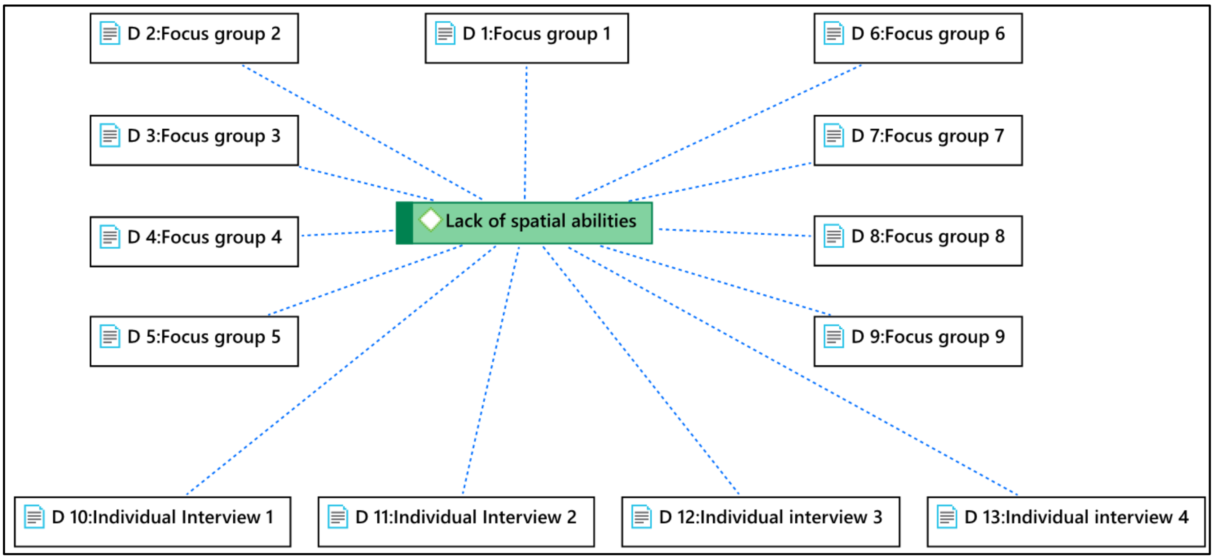


Figure 6-3: Lack of spatial abilities.

Therefore it is evident from Figure 6-3, within the focus group interviews, individual interviews and my own observations, the participants and I confirmed the research problem identified in Chapter 1. I therefore did not make the assumption that all students struggled with mechanical drawings and that the reason for that is that students do not have spatial visualization skills; the literature and the interviews led me to this conclusion. Table 6-3 displays some typical quotations supporting the network in Figure 6-3.

Table 6-3: Typical quotes as evidence of the lack of spatial abilities.

Category	Quotations (verbatim) gained from focus group interviews
Lack of spatial abilities	P9, 35-37: *"Ek kyk terug verder na waar ons sit met die vraag … dat mense sukkel met masjientekeninge, want hulle kan nie insien watter gedeelte pas by watter gedeelte in nie; ek sal sê abstrakte motoriese vaardighede wat hy nie in sy kop kan inkry nie".* *[I look back at where we are sitting with the question… that people are struggling with machine drawings, because they cannot see which part fits into what part; I will say abstract motor skills that he cannot get into his head].*
	P18, 18-19: *"Ek dink hulle verstaan nie altyd waar elke komponent inkom nie en dit pas nie so lekker in mekaar nie. So, dit is vir hulle moeilik om dit in te sien en dit dan so te teken".* *[I think they don't always understand where each component comes in and it doesn't fit together so well. So, it's hard for them to see it and then draw it that way].*
	P29, 19: *"Nie almal kan alle tekeninge in mekaar insien nie. Sekere mense kan tekeninge in mekaar sien, maar nie ander nie".* *[Not everyone can see all the drawings fitting together as one. Some people can see drawings fitting together, but not others].*
	Quotations (verbatim) gained from individual interviews with fellow lecturers
	P47, 7: They have difficulty envisioning how the parts fit together.
	P48, 20-22: Challenges are the understanding of how mechanical components fit and function together, which mainly results in students experiencing difficulty in visualizing the construction of different sectioned projections of an assembly.

From Table 6-3 it is evident that students struggle with sectioned mechanical assembly drawings as they struggle to see and mentally fit the parts together. This is the confirmation needed to determine that students' spatial visualization skills need to be improved in order for them to do sectional mechanical assembly drawings.

6.2.2 Determine the main advantages and barriers of using ICT in EGD education globally and in South Africa

As I wanted to determine whether advanced ICTs would have an impact on students' spatial visualization skills, I first had to determine if there would be any advantages and barriers in using advanced ICTs in EGD. In Chapter 2, I established different advantages and barriers in using ICT in education worldwide. Since most of these studies were done overseas, I needed to confirm if these advantages and barriers were the same in this study's context with regard to the EGD classroom. Firstly, I asked the participants during the interviews:

What do you think the main advantages are in implementing information communication technologies (ICTs) in EGD?

When coding the data, the following advantages were identified: spatial ability; respond easier; and Generation Z (Figure 6-4). The participants believed that the use of ICT would improve students' ability to mentally manipulate and rotate the different views of the drawings. They furthermore believed that the Z-generation students would respond better to ICTs in the EGD classroom as they are more used to using technology. Lastly, they assumed that advanced ICTs would help the student and the educator to understand and teach EGD easier as Generation Z is more comfortable with the use of different ICTs in education.

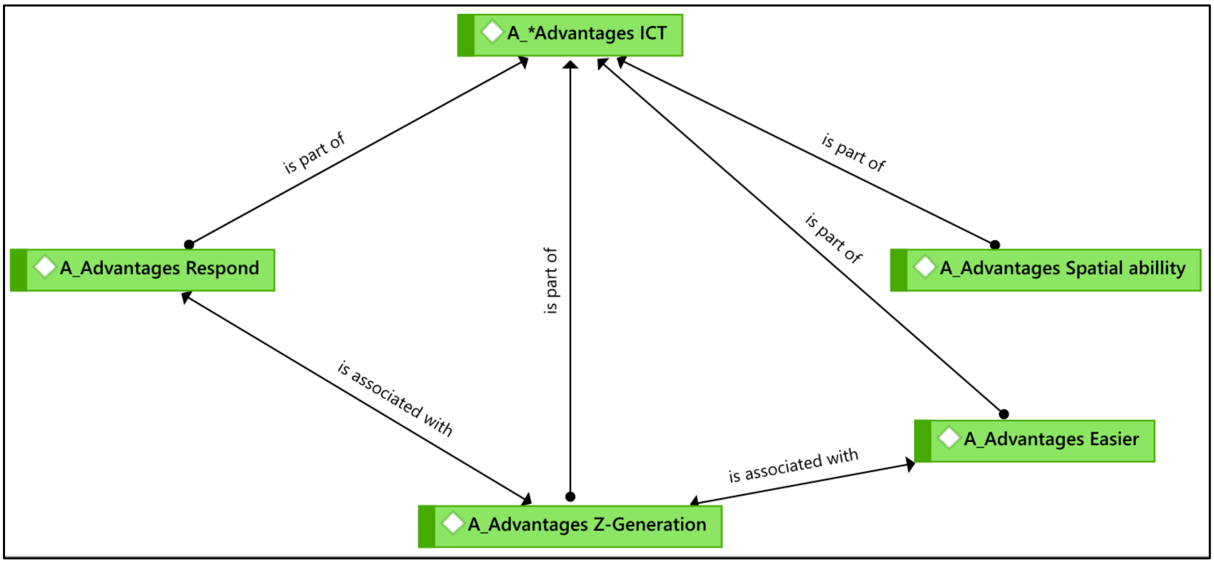


Figure 6-4: Advantages of ICTs.

Figure 6-4 shows the advantages of ICTs the participants discussed during the focus group interviews. Table 6-4 displays some typical quotations supporting the network in Figure 6-4.

Table 6-4 Typical quotes as evidence of the advantages of ICT.

Category	Quotations (verbatim) gained from focus group interviews
Z-Generation	P2, 31-36: "*Studente en leerders is baie meer tegnologies georiënteerd so jy kan nie net op 'n swartbord gaan teken met kryt en 'n liniaal nie, want dit is primitief. So jy kan eerder 'n SMART Board of TurboCAD op 'n rekenaar or projektor gebruik en te sê "wag hierdie is cool" of "ek sal dit ook kan doen op my rekenaar" en self laai jy 'n "app" af op jou foon. Sodra jy so iets doen met tegnologie sal jy hulle aandag prikkel".* *[Students and learners are much more technologically oriented so you can't just draw on a blackboard with chalk and a ruler, because it's primitive. So you could rather use a SMART Board or TurboCAD on a computer or projector and say "wait this is cool" or "I'll be able to do that on my computer" and download an app on your own phone. Once you do something like this with technology, you will keep their attention].*
Spatial ability	P3, 40-45: "*Met behulp van ICT soos 'n 3D-print sal die leerders dan kan sien. Dit wat hulle geteken het, kan hulle dan sien. Hulle kan dit vashou in hulle hande. Partykeer kan jy nie 'n leerder leer om iets in te sien nie.*

	Jy kan vir hulle 'n ortografiese skets gee en sê teken vir my 'n isometriese tekening", maar daai leerder kan nie sien hoe dit gaan lyk nie, waar as jy dit gaan print kan hy sien o dis hoe hy gaan lyk as hy klaar is". *[With the help of ICT like a 3D print, the learners will then be able to see. What they have drawn. They can hold it in their hands. Sometimes you can't teach a learner to see something. You can give them an orthographic sketch and say, draw me an isometric drawing, but that learner can't see what it's going to look like, where if you print it he can see, oh that's what he's going to look like when it's done].*
Respond	P8, 38-40: *"Die kinders is gewoond aan tegnologie en alles van tegnologie so ek dink dis 'n goeie idee om tegnologie by hulle onderrig ook in te bring, want dit is waaraan hulle gewoond is".* *[The learners are used to technology and everything about technology so I think it's a good idea to bring technology to their teaching as well, because that's what they're used to].*
Easier	P47,45-47: *"Dit is baie gerieflik. Soos as jy 'n fout maak, kan jy dit vinnig regmaak sonder om daar uit te vee en jou hele skets te belemmer".* *[It is very convenient. Like if you make a mistake, you can fix it quickly without deleting it and ruin your entire sketch].*

Table 6-4 shows the categories identified during the qualitative data analysis, students feel that their peers and learners on school level is more focussed on technology and ICT therefore they do respond better when using ICT in EGD. Students furthermore feel that when students can see the model or the different components that their spatial ability will be better and it will help them to understand the drawings better. Lastly students feel that it is easier to use CAD programs as they can only delete lines and don't have to use an eraser which may lessen the quality of the drawing.

To understand the advantages of ICTs in the context of the study compared to the advantages of ICTs worldwide, Table 6-5 shows the difference between advantages of ICTs in South Africa and the norm of first-world countries (see Sections 1.1 and 2.6.1). Comparing the students' responses about the advantages of the use of advanced ICTs in EGD, it is the same as the norm globally.

Table 6-5: Comparison of the advantages of ICTs in EGD between South Africa and the global norm.

Advantages of ICTs in the context of this study	Advantages of ICTs in the global context
Spatial abilities	Spatial abilities (Section 2.6.1)
Respond / Generation Z	Generation Z (Section 1.1)
Easier	Easier (Section 2.6.1)

Table 6-5 shows the difference between the advantages of using ICT in EGD in the context of this study and the worldwide norm. The data collected from Figure 6-4 confirm the same advantages mentioned in Section 2.6.2, Section 1.1 and Section 2.6.1.

The next question I asked the participants was to determine if they thought there were any barriers to implementing ICTs in the EGD classroom:

What do you think are the main barriers in implementing ICTs in EGD?

The barriers identified by the participants were as follows: finance; training; time; maintenance; electricity; and theft (Figure 6-5). The participants realised that finance was one of the most common barriers in the use of ICTs. Adequate training for educators is necessary to be able to use advanced ICTs in EGD. Implementing advanced ICTs in the classroom may be time-consuming as these are new technologies used in the EGD classroom; time is of the essence to complete the curriculum, and unnecessary time cannot be spent on implementing a new method of instruction. The maintenance of advanced ICTs may be seen as a barrier as the educator does not have the time or expertise to fix problems with advanced ICTs. In South Africa, the electricity provider is not reliable at all times, and without electricity advanced ICTs do not work (Gehringer *et al.*, 2018). Lastly, as the crime rate in South Africa is among the highest in the world, there is a possibility that advanced ICTs might be stolen (De Wet, Somefun & Rambau, 2018). Figure 6-5 illustrates the barriers determined during this study.

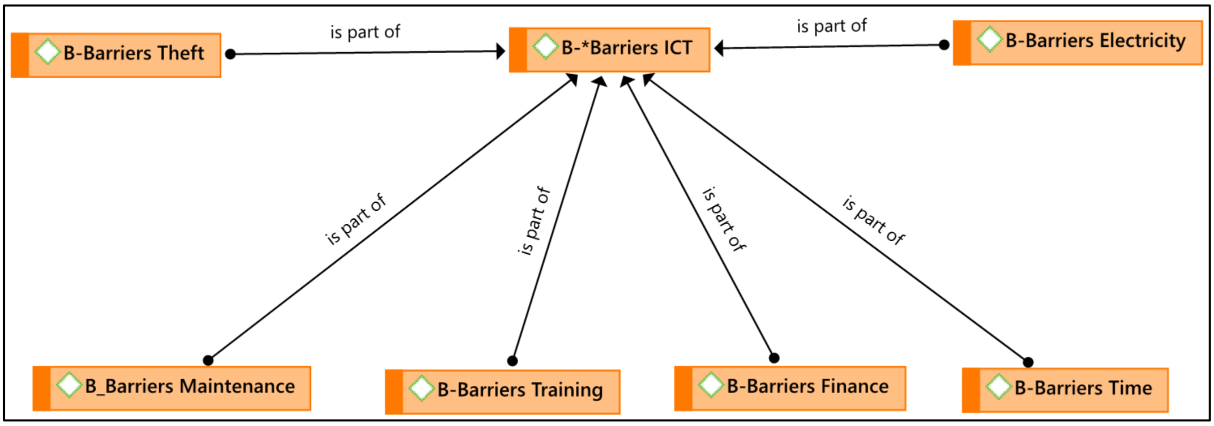


Figure 6-5: Barriers of ICTs.

To understand if these barriers relate to the barriers worldwide, Table 6-6 shows the comparison between this study's context and the worldwide standard (see Table 2-4). During the interviews, the same barriers were identified, except for resistance to change, which is seen as a worldwide norm. In this study's context, the lack of electricity due to load shedding and theft were added as barriers. Throughout my observation in the EGD theory and methodological classes, I also identified these barriers in informal discussions with the students.

Table 6-6: Comparison of the barriers of ICTs.

Barriers in using ICTs in this study's context	Barriers in using ICTs in the worldwide context
Lack of funding	Lack of access and funding
Lack of training	Lack of acquired skills
	Resistance to change
Lack of time	Lack of time
Maintenance	Lack of technical support
Lack of electricity due to load shedding	
Theft	

From Table 6-6 it is evident that there is a global problem when advanced ICTs are applied in education. When the barriers are identified, it is easier to overcome these barriers (see Table 2-4). The barriers are furthermore displayed in the quotations of the participants in Table 6-7, supporting the network in Figure 6-5..

Table 6-7: Typical quotes as evidence of the barriers of implementing ICT.

Category	Quotations (verbatim) gained from focus group interviews
Lack of funding	P2, 28-31: *"Die programme wat ons gebruik het, soos die TurboCAD en die 3D-printer, kos baie geld en nie alle skole kan dit bekostig nie. As jy soos 'n plattelandse skool vat wat net-net genoeg leerders vir IGO het, kan jy nie nog van hulle verwag om duisende rande op die tafel te sit vir iets soos 'n 3D-printer of genoeg rekenaars vir die TurboCAD-program nie. So jy kan nie die CAPS-stelsel so implementeer om te sê dit moet 'n vereiste wees nie, want nie alle skole kan dit bekostig nie. So jy limit die skole om dit aan te bied''.* *[The programs we used, such as TurboCAD and the 3D printer, cost a lot of money and not all schools can afford it. If you're at a rural school that has just enough EGD learners, you can't expect them to use thousands of Rands on the table for something like a 3D printer or to buy enough computers for the TurboCAD program . So you can't implement the CAPS system like this to be a requirement, because not all schools can afford it. So you limit the schools to offer it].*
Lack of training	P39, 41: "*Ek dink nie almal is opgelei om die program aan te bied nie en om dit aan te leer vat 'n rukkie".* *[I don't think everyone is trained to use the program for facilitation and to learn it takes a while].*
Lack of time	P8, 53-55: *"Dit neem tyd om video's te wys. Dit neem tyd om goed te print en dit vat tyd vir die onderwyser om goed op TurboCAD te teken voor die tyd en om goed op die interaktiewe bord te doen, vat baie voorbereiding".* *[It takes time to show videos. It takes time to print models and it takes time for the teacher to draw well on TurboCAD ahead of time and to do stuff on the interactive board, takes a lot of preparation].*
Maintenance	P31, 40: *"Die instandhouding van die goed raak baie keer ook baie moeilik".* *[The maintenance of the technologies is often very difficult].*
Lack of electricity due to load shedding	P43, 60: *"Elektrisiteit is ook 'n probleem. Ons is in Suid-Afrika. Ons het al load shedding ervaar. As die krag af is, kan jy niks gebruik nie".* *[Electricity is also a problem. We are in South Africa. We have already experienced load shedding. When the power is off, you can't use anything].*

Category	Quotations (verbatim) gained from focus group interviews
Theft	P11, 43-44: *“Meeste van die skole in plattelandse dorpe, die klein skole, is nie behoorlik veilig, as ek dit so kan stel, nie. Daar kan maklik ingebreek word en gesteel word. So, dit is een groot aspek wat ons het in Suid-Afrika; diefstal in skole”.* *[Most of the schools in rural towns, the smaller schools, are not quite safe, if I may say so. It can easily be broken into and equipment can be stolen. So, that's one big aspect we have in South Africa; theft in schools].*

Table 6-7 shows the barriers of implementing ICT in EGD; a lack of funding, a lack of training, a lack of time, maintenance, a lack of electricity and theft are seen as the main barriers when implementing ICT in EGD. From the focus group interviews, it is evident that the students felt that funding was one of the most important factors when implementing ICTs in public schools; the training of educators to use the ICTs and the maintenance of these ICTs are also a secondary part of funding. If the school does not have the funding, they cannot buy ICTs, send educators for training or maintain advanced ICTs. The lack of time in the already busy school curriculum is also problematic, but it would be possible for the educator to get time to implement ICTs in their teaching. Load shedding is another barrier that would be difficult to overcome in the school system. At present, however, when load shedding takes place in South Africa, the load shedding schedules are available beforehand and teachers should plan accordingly.

6.2.3 Determine to what extent ICTs are implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education

To understand which ICTs are known by the participants, the following questions were asked during the interviews:

What do you think the main advantages and barriers are in implementing ICTs in EGD?
Have you ever used advanced ICTs in EGD? Which ICTs were used?

Participants identified the following advanced ICTs; CAD, interactive whiteboard; 3D printer; data projector or camera; YouTube; and learning management software or system (LMS) as shown in Figure 6.6.

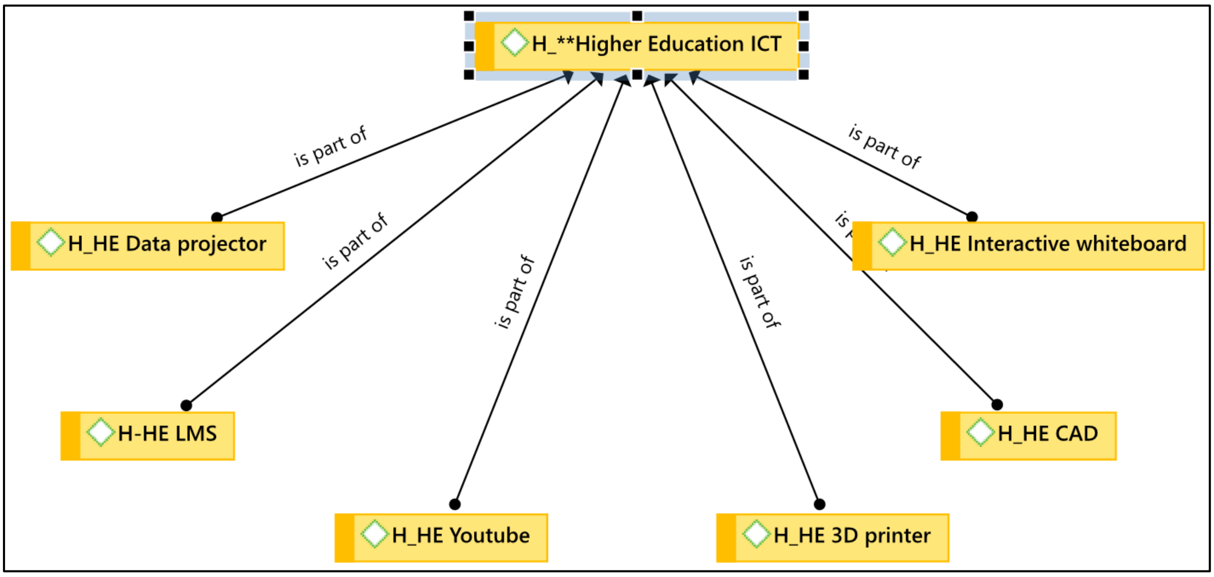


Figure 6-6: Implementation of advanced ICTs.

Figure 6-6 shows the different advanced ICTs students identified during the focus group interviews. During the students' BEd training, they made use of 2D CAD in the first semester of their fourth year in EGDD411. Throughout their first to their fourth year, the students used the interactive whiteboard and data projector or camera and saw the 3D printer during their subject methodology courses as they had to use it to facilitate classes as aspiring educators. YouTube was used during lessons and the students used it to facilitate classes during their practical teaching. For the purpose of this study, YouTube videos refer to animation that helped students to understand different types of drawings. The LMS was identified by a participant lecturer – students made use of an LMS when they used eFundi™ and The Depot™; however, they did not perceive it as an advanced ICT tool. These were the different advanced ICTs that are implemented at this specific university in the EGD classroom according to the participants. Thus they had an idea what advanced ICTs were. The advanced ICTs the participants identified were also the same I recorded in my research journal during EGD classes and the interviews. The two advanced ICTs I feel that should have arisen from the interviews as well should have been the 3D scanner and the document camera, which are normally used during the EGD classes. The reason why the document camera was not mentioned may be that the participants confused the document camera with the data projector. The reason why the 3D scanner was not mentioned may be that the participants mentioned 3D models and did not differentiate that one can get a physical 3D model one can touch as well as the representation of a 3D model, which can be drawn on CAD or scanned with a 3D scanner.

6.2.4 Discover to what extent advanced ICTs enhance spatial visualization skills

This research objective is divided into three different parts: which advanced ICTs were known by the participants (as discussed in Section 6.2.3, Figure 6-6); which advanced ICTs participants believed would improve spatial visualization (Figure 6-7); and which advanced ICTs did improve spatial visualization among students (Figure 6-8). The second part of this objective was to identify which advanced ICTs participants assumed would improve spatial visualization among EGD students. The question asked in the interview to determine the advanced ICTs was as follows:

To what extent do advanced ICTs enhance students' spatial visualization to improve the understanding of sectional mechanical assembly drawings?

The participants identified the following advanced ICTs as seen in Figure 6-7: 3D model; exploded views; and YouTube.

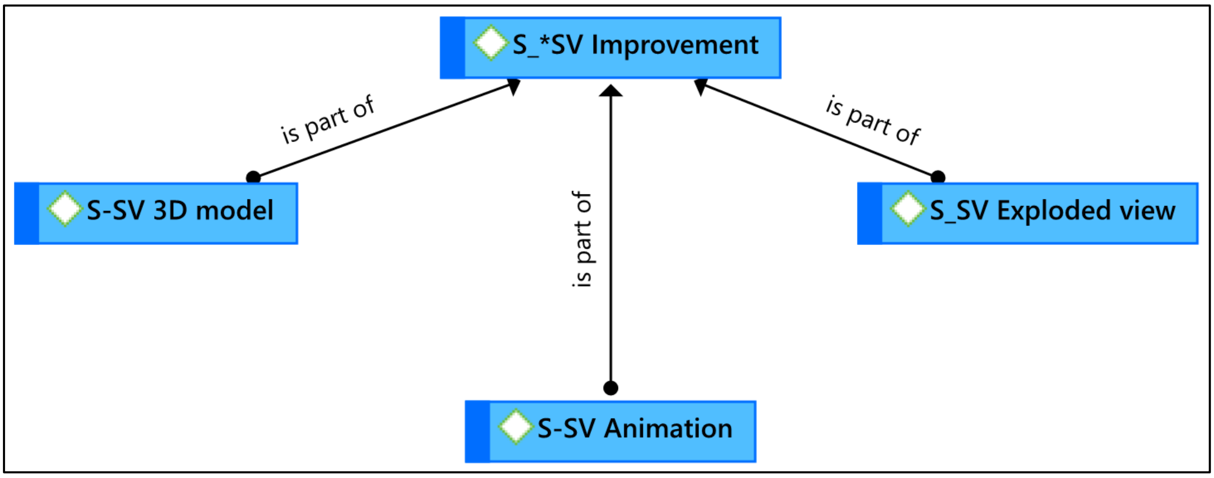


Figure 6-7: Advanced ICTs that may improve spatial visualization.

Figure 6-7 shows that the advanced ICT that creates 3D models is the 3D printer. The exploded view the participants identified is the different components drawn in 3D CAD; therefore the advanced ICT used is 3D CAD. As mentioned in Section 6.2.4, YouTube videos are seen as animation in 3D; the advanced ICT used was the LMSs The Depot™ and eFundi™, where students had the opportunity to watch animation on how to do the drawings. Table 6-8 portrays typical quotations by participants regarding the best advanced ICTs that may enhance spatial visualization supporting the network in Figure 6-7.

Table 6-8: Advanced ICTs that may improve spatial visualization.

Category	Quotations (verbatim) gained from focus group interviews
3D model	P44, 33-34: *“Ek dink ook, dit is belangrik om te weet hoe die isometriese tekening lyk. As jy die regte voorbeelde, soos modelle, daar het, kan isometriese tekeninge jou help om te wys hoe dit in mekaar inpas”.* *[I also think, that it is important to know how the isometric drawing looks like. If you have the right examples, such as models, the isometric drawings can help you show how they fit together].*
Exploded view	P19, 22-23: *“Exploded view kan ook help. As jy met ŉ exploded view met ŉ pyltjie kan sê: “hierdie part gaan in daai gat in”; sal dit help om die tekening te verstaan”.* *[Exploded view can also help. If you can use an arrow with an exploded view that shows that this part goes into that hole; it will help to understand the drawing].*
Animation	P30, 27-28: *“Ek sal sê, dalk net ŉ video as jy dalk nie modelle kan bekostig nie, net om ‘n idee te kry; YouTube het baie videos wat wys hoe komponente in mekaar inpas. Sodat kinders net kan besef hoe die dele by mekaar inkom”.* *[I would say, maybe just a video if you can't afford models, just to get an idea; YouTube has many videos that show how components fit together. So that learners can only realise how the parts fit together].*

Table 6-8 displays the three advanced ICTs that may influence students’ understanding of sectioned mechanical assembly drawings. The students believed if a 3D printed model of all the necessary components were available, they could figure out where each part fits in the model and understand the drawing better. The students furthermore believed that if they received a 2D or 3D sketch with an exploded view of where all the components should fit, it would help them to complete the sectioned mechanical assembly drawing. Lastly, the students believed that animation played a vital role in understanding how components fit together if they were able to watch an animated video of how components should fit together.

The last part of this objective was determined after the intervention to see if the advanced ICTs mentioned in Figure 6-7 had an effect on students' spatial visualization skills among the participants. The first question asked during the interview was to determine whether CAD had an effect on students' understanding of sectional assembly machine drawings:

As an EGD student teacher, tell me if the use of 3D CAD helped you to understand and enabled you to draw the assembly of sectional mechanical drawings? Motivate why.

All of the participants agreed that CAD helped them when doing mechanical drawings. They gave different reasons why CAD would help them when doing machine drawings (Figure 6-8). Firstly, the students were of the opinion that it was easier to do drawings in CAD. Secondly, they felt that when they drew the different components, it was easier to fit the components together to give them an understanding of where these components had to fit to complete the drawing. Thirdly, CAD helps students to obtain new knowledge when using the different functions in CAD that help them to section these drawings. Lastly, CAD saves time when drawing; therefore students have more time to figure out where the different components fit. The second question asked during the interviews was to determine if the use of animations would help students to visualize what they were drawing and whether they understood the drawing better with these teaching aids. Table 6-9 displays some typical quotations supporting the question if 3D CAD helped them to understand sectioned mechanical assembly drawings.

Table 6-9: 3D CAD helps the understanding of sectional mechanical assembly drawings.

Category	Quotations (verbatim) gained from focus group interviews
3D CAD	P17, 1-2: "*Ja, dit gee mens 'n beter idee van hoe die model as geheel moet lyk en dit versnel die tekenproses".* *[Yes, it gives you a better idea of what the model as a whole should look like and it speeds up the drawing process].*
	P27, 1-2: *"Ja, dit help baie; dit maak dat 'n mens maklik teken, want jy sien fisies die ding of voorwerp voor jou. Dis makliker om met dit te werk".* *[Yes, it helps a lot; it makes the drawing process easier, because you physically see the thing or object in front of you. It's easier to work with].*
	P39, 5: *"Dit het my baie gehelp; dit is vinniger en maklik om te gebruik as jy dit eers verstaan".* *[It helped me a lot; it is faster and easier to use once you understand it].*

Table 6-9 gives the students' responses that support that 3D CAD improves their understanding of sectioned mechanical assembly drawings. The students felt that 3D CAD helped them because after they had drawn the different components, they might use the CAD functions, which helped them to move the parts around in the program and fit them with trial and error. They also felt that CAD reduced the drawing time; therefore they had more time to determine where the components should fit.

As an EGD student teacher, tell me if the animations on The Depot™ and eFundi™ helped you to understand and be able to draw the assembly of sectional mechanical drawings? Motivate why.

All of the students in the focus groups agreed that animations helped them to visualize what they were drawing, and when they saw the final product, it helped them to understand these drawings (Figure 6-8). The students had two specific views as to why animation helped them when doing machine drawings. Firstly, it is easier to see what one is drawing when there is a video showing how all of the parts fit together;

and it is easy to follow the steps because it shows chronologically what one has to do in CAD to complete the drawing. Secondly, the students felt that they could visualize better what they were drawing and how these parts fit together. The final question during the interview was to determine if the students visualized and understood machine drawings better when 3D printed models are used as a teaching aid. Table 6-10 displays some typical quotations supporting the question that animations will help students in understanding sectional mechanical assembly drawings.

Table 6-10: Animation helps the understanding of sectional mechanical assembly drawings.

Category	Quotations (verbatim) gained from focus group interviews
Animation	P14, 9-10: *"Yes, it helped me to visualise and it saved time because I didn't need to figure everything out from scratch".*
	P26, 11-12: *"Ja, animasies het gehelp om te sien wat presies van jou verwag word deur stap-vir-stap-verduideliking".* *[Yes, animations have helped to see exactly what is expected of you through step-by-step explanation].*
	P40, 9: *"Yes it helps me to see how the components work and where it needs to be drawn".*

It is evident from Table 6-10 that the students felt that the animations helped them to visualise how to complete the drawing. Animations furthermore showed the students how to do the drawing step by step, and that helped them to understand the drawing better.

As an EGD student teacher, tell me if the 3D components (printed with a 3D printer) helped you to understand and be able to draw the assembly of sectional mechanical drawings? Motivate why.

All of the students agreed that 3D printed models should help when doing a machine assembly drawing (Figure 6-8). During the interviews, it became evident that all of the students felt that a 3D printed model improved their spatial visualization skills and their understanding of these drawings, since they could hold the parts in their hands and could build the final product as a puzzle. In doing this, the students understand better why these components fit where they should as they can test the functionality of the moving parts in the final product. Table 6-11 displays some typical quotations supporting the idea that 3D printed models will help students in understanding sectional mechanical assembly drawings better.

Table 6-11: 3D models help the understanding of sectional mechanical assembly drawings.

Category	Quotations (verbatim) gained from focus group interviews
3D Models	P9, 17: *"Yes, it help me see how everything fits together and makes it easier to envision the solution of the problem".*
	P14, 19-20: *"Yes, I am a visual learner and by taking the model apart and putting it back together, it help[s] me to understand the components better".*
	P26, 24: *"Ja, jy kan baie beter visualiseer wat gebeur en watter komponente waar inpas".* *[Yes, you can visualize much better what happens and what components fit where].*
	P36, 28-29: *"Ja, veral in meganiese samestellings. Ek sukkel gewoonlik met die insien en met 3D help dit om alles in te sien".* *[Yes, especially in mechanical assemblies. I usually struggle with to see and understand, with 3D it helps to see everything].*
	P38, 24-26: *"Ja, as mens gebruik maak van die 3D-drukker, dan kan mens in lewende lywe sien hoe die komponente in mekaar pas. Mens kan ook die werking van die verskillende komponente sien".* *[Yes, if you use the 3D printer, you can see how the components fit together. One can also see the operation of the various components].*

Table 6-11 displays relevant responses from the students and why they felt 3D printed models helped them to understand sectional mechanical assembly drawings better in EGD. The students emphasised the idea that when they had the components in hand, they could better visualise and understand how the components fitted together in a sectional mechanical assembly drawing.

Taking into consideration the interviews done after the intervention, it is evident that CAD, animation and 3D printed models improve on students' spatial visualization skills and their understanding of sectioned mechanical assembly drawings. Figure 6-8 shows how advanced ICTs improved the students' understanding of sectional mechanical assembly drawings.

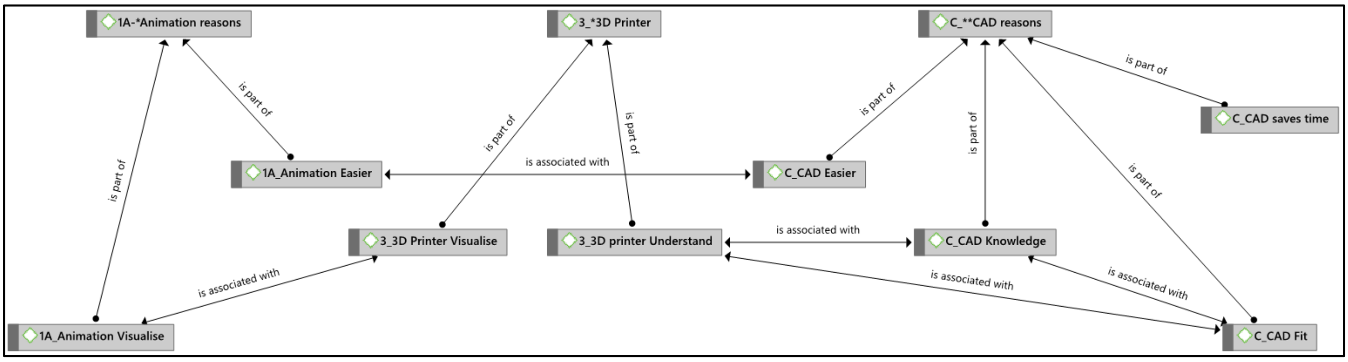


Figure 6-8: How advanced ICTs improve understanding of mechanical drawings.

Figure 6-8 illustrates how the three advanced ICTs support one another when all three are used. The three advanced ICTs used are CAD, 3D printing and animation. From the students' focus group interviews, the following were determined: the students believed that CAD and animations made the drawing element easier to understand sectional mechanical assembly drawings. All three advanced ICTs enhances the visualization and understanding of sectional mechanical assembly drawings.

6.3 Conclusion from the qualitative research

6.3.1 Research problem

As mentioned in Section 4.6.3.1, the qualitative research of this study consisted of focus group interviews and individual interviews before and after the intervention. From Figure 6-1 and 6-2 in section 6.2.1 it is evident that the research problem was accurate – students do struggle with sectioned mechanical assembly drawings. This confirmed the research problem with the qualitative data of the participants as well as the literature review in Chapter 1.

6.3.2 Advantages and barriers when using ICT in EGD

In Figure 6-4, the advantages of using advanced ICTs in EGD were identified and compared with the worldwide advantages of using advanced ICTs in EGD. From Table 6-4 it is evident that in terms of advantages in this study's context and globally, it is easier to use advanced ICTs as the students in classes today are Generation Z students who respond better to ICTs. In Figure 6-5, the barriers of using advanced ICTs in EGD were identified and compared with the global norm in Table 6-5. The barriers identified that were the same in this study's context and globally were a lack of funding, a lack of training, a lack of time and maintenance. Two barriers were added from this study, which are the lack of electricity due to load shedding and theft.

6.3.3 Advanced ICTs used at this specific institution

Figure 6-6 shows the advanced ICTs the participants used throughout their BEd degree and were known to them. The participants mentioned the data projector, LMSs such as eFundi™ and The Depot™, YouTube videos which are referred to as animation in the study, the 3D printer, CAD and the interactive whiteboard.

6.3.4 Advanced ICTs that may improve spatial visualization

The participants identified advanced ICTs that they felt might improve spatial visualization. The following three were chosen in Figure 6-7: 3D models (printed with a 3D printer); animation; and exploded view (drawn in 3D CAD).

6.3.5 Improvement of spatial visualization

After the intervention, the students had the opportunity to give feedback on the advanced ICTs used and whether they thought these helped them understand sectional mechanical assembly drawings. Figure 6-8 shows the three advanced ICTs used and the reasons why the participants felt the ICTs had improved their spatial visualization skills. During the interviews, it was evident that the participants felt that 3D models, animation and CAD played a vital role in their understanding of sectioned mechanical assembly drawings. In Figure 6-8, reasons are given for ICTs improving spatial visualization, such as that ICTs made the drawing process easier, helped them visualize the drawing and had improved their knowledge of mechanical drawings.

6.4 Results from quantitative research

6.4.1 Objective – discover to what extent advanced ICTs enhance spatial visualization and SDL skills

To analyse the quantitative data, the different statistical tools should be determined. Paired t-tests were used in the study to compare the pre-tests with the post-tests. First, there was a pre-test to determine the students' understanding of mechanical drawings, and after the intervention, a post-test was completed. The means of the pre-test and the post-test were compared to calculate the effect size to determine if there was a practically significant difference between the results of the tests. Secondly, the participants had to complete a questionnaire on SDL as a pre-test to determine their SDL skills, and they completed a post-test after the intervention to determine whether there were any significant changes in their SDL skills.

6.4.1.1 Spatial visualization skills

Before implementing the intervention, the EGDD421 students wrote a sectional assembly mechanical drawing pre-test (see Addendum G) to determine their understanding of these drawings. After the implementation of the intervention, the students wrote a post-test (see Addendum H) on sectional assembly mechanical drawing to determine if the intervention had an effect on the students' understanding of sectional assembly machine drawings to see whether their spatial visualization skills had improved during the intervention. During the statistical analysis, the mean and the standard deviation were established and compared to the mean and the standard deviation of the post-test. The comparison between the statistics is shown in Table 6-12.

Table 6-12: Paired sample statistics of pre-test and post-test of spatial visualization skills.

Paired samples statistics						
		Mean	N	Std. deviation	Std. error mean	Effect size
Pair 1	Pre	61,6250	48	20,78320	2,99980	0,42
	Post	70,4375	48	16,99175	2,45255	

It is evident from Table 6-12 that the result of the paired t-test had an effect size of 0,42. This effect size is seen as a medium effect, which shows that there was a practically visible difference in the improvement of the participants' understanding of sectional assembly mechanical drawings. Therefore, the participants' spatial visualization skills and their spatial abilities had improved during the intervention.

6.4.1.2 SDL skills

As mentioned in Chapter 3 (Figure 3-1), there is a correlation between students' spatial visualization skills and SDL skills. Therefore, the participants were subjected to a pre-test to determine their SDL technology skills before the intervention and a post-test to determine whether there was an improvement in their SDL technology skills after the intervention. The SDLTS was developed to determine if students had self-monitoring and intentional learning skills. Question 1 to question 2 should determine the students' self-monitoring skills and question 3 to question 7 should establish their intentional learning skills (see Table 4-4 in Chapter 4). In Table 6-13, the results of the pre-test and the post-test are compared to determine how the students completed the questionnaire before and after the intervention.

Table 6-13: Summary of results of the pre-test and the post-test of the SDLTS during this study.

Questionnaire		SDL skills	Pre-test						Post-test					
			Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total
Q1	I go online to ask my lecturer questions on my EGD lessons when I am not in class	Self-monitoring	20,8%	22,9%	29,2%	18,8%	8,3%	100%	10,4%	4,2%	31,3%	35,4%	18,8%	100%
Q2	I use the computer to share my thoughts and ideas about my EGD classwork (e.g. through multimedia, The Depot™, eFundi™)		10,4%	16,7%	29,2%	25,0%	18,8%	100%	0%	6,3%	18,8%	41,7%	33,3%	100%
Q3	I get more information on the Internet to help me understand my EGD lessons better	Intentional learning	4,2%	16,7%	22,9%	35,4%	20,8%	100%	4,2%	4,2%	14,6%	39,6%	37,5%	100%
Q4	I use the computer to work with information for my EGD learning		0%	6,3%	14,6%	39,6%	39,6%	100%	0%	0%	4,2%	33,3%	62,5%	100%
Q5	I practise skills that I learnt in class through drawing on CAD		0%	4,2%	16,7%	43,8%	35,4%	100%	0%	0%	6,3%	25,0%	68,8%	100%
Q6	I use the computer to become better at a skill that I		4,2%	0%	22,9%	47,9%	25,0%	100%	0%	2,1%	10,4%	16,7%	70,8%	100%

	Questionnaire	SDL skills	Pre-test Strongly disagree	Pre-test Disagree	Pre-test Neutral	Pre-test Agree	Pre-test Strongly agree	Pre-test Total	Post-test Strongly disagree	Post-test Disagree	Post-test Neutral	Post-test Agree	Post-test Strongly agree	Post-test Total
	am interested in (e.g. drawing skills)													
Q7	I use the computer to get ideas from different websites and people to learn more about a topic		4,2%	12,5%	27,1%	43,8%	12,5%	100%	0%	6,3%	14,6%	29,2%	50,0%	100%

To determine the reliability of the data analysis to establish the self-monitoring SDL skills and intentional learning SDL skills the students were supposed to have obtained after the intervention had been implemented, the Cronbach's alpha test was used. When the statistical data were compared, the self-monitoring SDL skill in question 1 and question 2 was not a reliable value. Table 6-14 shows the reliability of the self-monitoring SDL skill determined with Cronbach's alpha test.

Table 6-14: Reliability of self-monitoring SDL skill.

Reliability statistics		
Cronbach's alpha[a]	Cronbach's alpha based on standardised items[a]	N of items
-0,132	-0,132	2

From Table 6-14, the assumption can be made that the reason for the negative value may be that the participants did not understand the questions. For question 1 it may be because students normally attend class and do not need to go online to ask the lecturer any questions. For question 2 it may be that students do not really make use of The Depot™ and eFundi™ to share their thoughts and ideas about EGD, as they usually do this during class discussions. Taking into consideration that the self-monitoring skill in Table 6-13 was not reliable to render an effect size, the data of question 1 and question 2 still provided an effect size that is relevant to the study.

Table 6-15 shows that when Cronbach's alpha test was done on the data of question 3 to question 7, the data were positive and therefore are seen as reliable. Thus the intentional learning skills could render an effect size in Table 6-15.

Table 6-15: Reliability of intentional learning SDL skill.

Reliability statistics		
Cronbach's alpha	Cronbach's alpha based on standardised items	N of items
0,782	0,788	5

In Table 6-15, the data for questions 3 to 7, which determined the participants' intentional learning skills, were reliable. Table 6-16 shows the results from the paired t-tests for both the pre-test and the post-test for individual questions as well as for intentional learning skills.

Table 6-16: Paired sample statistics for pre-test and post-test of the SDLTS during this study.

Paired samples statistics						
			Mean	N	Std. deviation	Effect size
Pair 1	Q1	I go online to ask my lecturer questions on my EGD lessons when I am not in class	2,71	48	1,237	0,62
	P1		3,48	48	1,167	
Pair 2	Q2	I use the computer to share my thoughts and ideas about my EGD classwork (e.g. through multimedia, The Depot™, eFundi™)	3,25	48	1,246	0,62
	P2		4,02	48	0,887	
Pair 3	Q3	I get more information on the Internet to help me understand my EGD lessons better	3,52	48	1,13	0,44
	P3		4,02	48	1,041	
Pair 4	Q4	I use the computer to work with information for my EGD learning	4,13	48	0,89	0,51
	P4		4,58	48	0,577	
Pair 5	Q5	I practise skills that I learnt in class through drawing on CAD	4,1	48	0,831	0,63
	P5		4,63	48	0,606	
Pair 6	Q6	I use the computer to become better at a skill that I am interested in (e.g. drawing skills)	3,9	48	0,928	0,72
	P6		4,56	48	0,769	

Paired samples statistics						
			Mean	N	Std. deviation	Effect size
Pair 7	Q7	I use the computer to get ideas from different websites and people to learn more about a topic	3,48	48	1,01	0,74
	P7		4,23	48	0,928	
Pair 8	Intentional learning pre-test		3,825	48	0,70454	0,82
	Intentional learning post-test		4,4042	48	0,50947	

From Table 6-16 it is evident that questions 1 and 2 had an effect size of 0,62, which can be seen as a medium effect that had a practically visible difference. The participants therefore had improved their online usage to ask questions to the lecturer if they were not in class. They furthermore made use of ICTs to share their thoughts and ideas on LMS platforms such as The Depot™ and eFundi™. Question 3 had an effect size of 0,44 that still is seen as a medium practical significance and shows that there has been an improvement in the participants' view on using the Internet to do research to understand difficult EGD drawings better. Question 4 had an effect size of 0,51. This relates to a medium practical significance that shows that the students used computers to work with the different EGD information, such as CAD. For question 5, which shows that participants practised the CAD skills they learnt in class, the effect size was 0,63. This is a medium effect, which shows that there was a practically visible difference. Question 6, which determined whether the participants used the computer to improve their CAD skills because they were interested in CAD, had an effect size of 0,72; this can be seen as a large effect that was practically significant. Question 7, which determined whether the participants made use of the computer to do research on different websites to learn more about specific topics in EGD, had an effect size of 0,74; this can also be seen as a large effect and therefore there was a practically significant difference between the pre-test and the post-test. The most important effect size was the intentional learning of the students through question 3 to 7, which had an effect size of 0,82. This is a large effect that shows that there was a significant difference between the participants' intentional learning before and after the intervention.

6.5 Conclusion from the quantitative research

6.5.1 Spatial visualization skills

As seen in Table 6-12, which aimed to determine the secondary objective, namely the extent to which advanced ICTs enhance spatial visualization skills, there was an increase in the values of the pre-test and the post-test. Since the difference was a medium effect, it indicates that there was a practically visible difference. This indicates that there was an improvement in the students' understanding of sectional assembly mechanical drawings. It furthermore illustrates that the participants' spatial visualization skills had improved with the use of advanced ICTs in EGD during the intervention.

6.5.2 SDL skills

Table 6-13 shows the data that determined to what extent advanced ICTs enhance SDL skills. From the data, it is evident that there was an increase in all the elements in the questionnaire after the intervention was done when compared to the data in the questionnaire before the intervention was done. The effect sizes indicate a medium practically visible difference and a large effect, which indicate a practically significant difference between the pre-test and the post-test.

6.5.2.1 Self-monitoring skill

Table 6-14 shows the results from Cronbach's alpha test that estimate that the data for the self-monitoring skill were not reliable. The reason for this may be that the participants did not understand the questions or that the participants did not have the opportunity to apply what was expected from them in the study.

6.5.2.2 Intentional learning skills

Table 6-15 shows that the results from Cronbach's alpha test that estimate the intentional learning skills that the participants had to acquire throughout the intervention were reliable. The difference between the pre-test and the post-test is practically significant as it has a large effect. Thus, the intentional learning skills of participants was enhanced during the intervention. The conclusion can be made that the use of advanced ICTs had improved the participants' intentional learning SDL skill when they used advanced ICTs in EGD.

6.6 Triangulation

To establish trustworthiness (see Section 4.7) in a qualitative study, credibility, transferability, dependability and confirmability should be established, while ensuring trustworthiness in a quantitative study, the validity and reliability of the study should be determined. Table 4-5 shows the strategies used throughout the study to ensure trustworthiness. Triangulation is described as one of the important strategies to follow to support the trustworthiness of the research findings.

6.6.1 Triangulation of qualitative data

During the qualitative data analysis, the data obtained from the participants were organised and prepared according to different categories and themes. These categories and themes were thoroughly analysed and compared with the literature review and my own observations that were recorded in my research journal throughout the study, as shown in Figure 6-9. Figure 6-9 illustrates the process of triangulation followed during the qualitative data analysis.

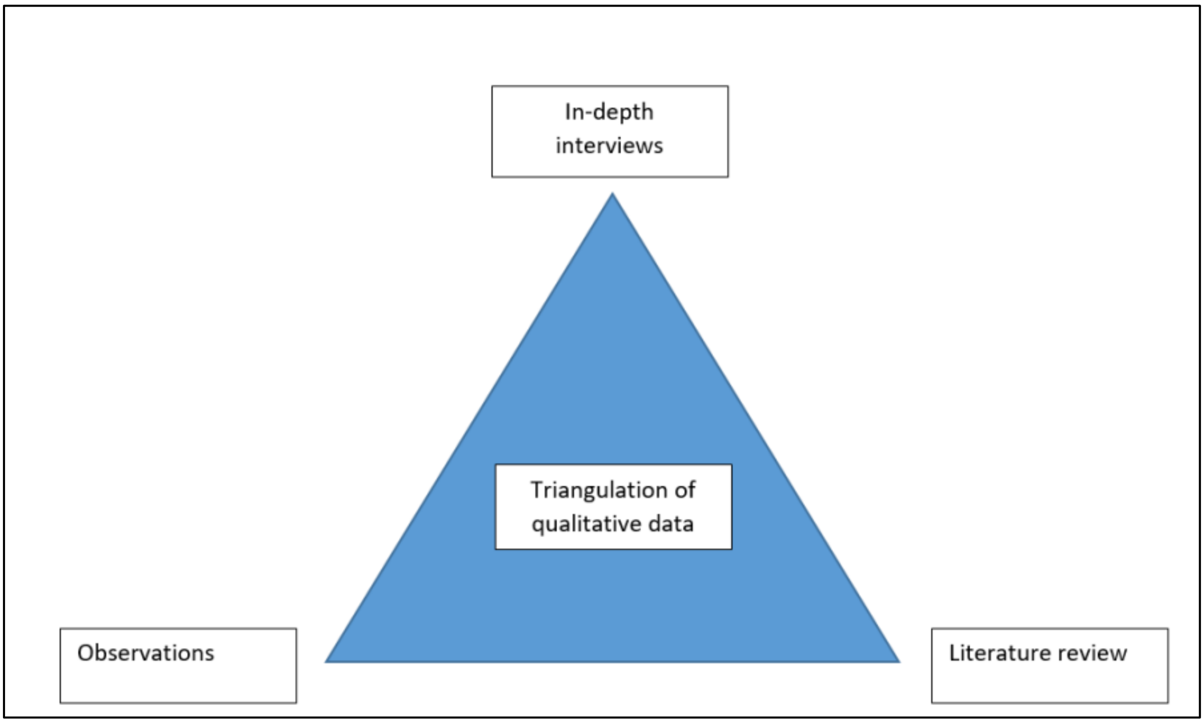


Figure 6-9: Triangulation of qualitative data.

Figure 6-9 shows the comparison of the in-depth interviews, the literature review and my own observations during the triangulation process. This was done to ensure that the assumptions made were fair and accurate. Furthermore, member checking was done to confirm that the information used was exactly portrayed as the students intended it to be from the beginning of the interviews. Critical readers and a co-coder were used to ensure that I made accurate interpretations and drew valid conclusions from the qualitative data. During the triangulation of the qualitative data, the following were confirmed: which drawings students find difficult (sectioned mechanical assembly drawings, Section 6.2.1); why students struggle with these drawings (spatial abilities, Figure 6-3); what can be done to improve students' understanding of these drawings (use of ICT, Section 6.2.2); the barriers and advantages of implementing advanced ICTs in EGD (Section 6.2.2); and lastly, did advanced ICTs improve spatial abilities among students (Section 6.2.4).

6.6.2 Triangulation quantitative data

During the quantitative data analysis, the data obtained from the pre-tests and post-tests were compared to determine if the students' spatial visualization skills and SDL skills had improved after the intervention. Figure 6-10 illustrates the process of triangulation followed during the quantitative data analysis.

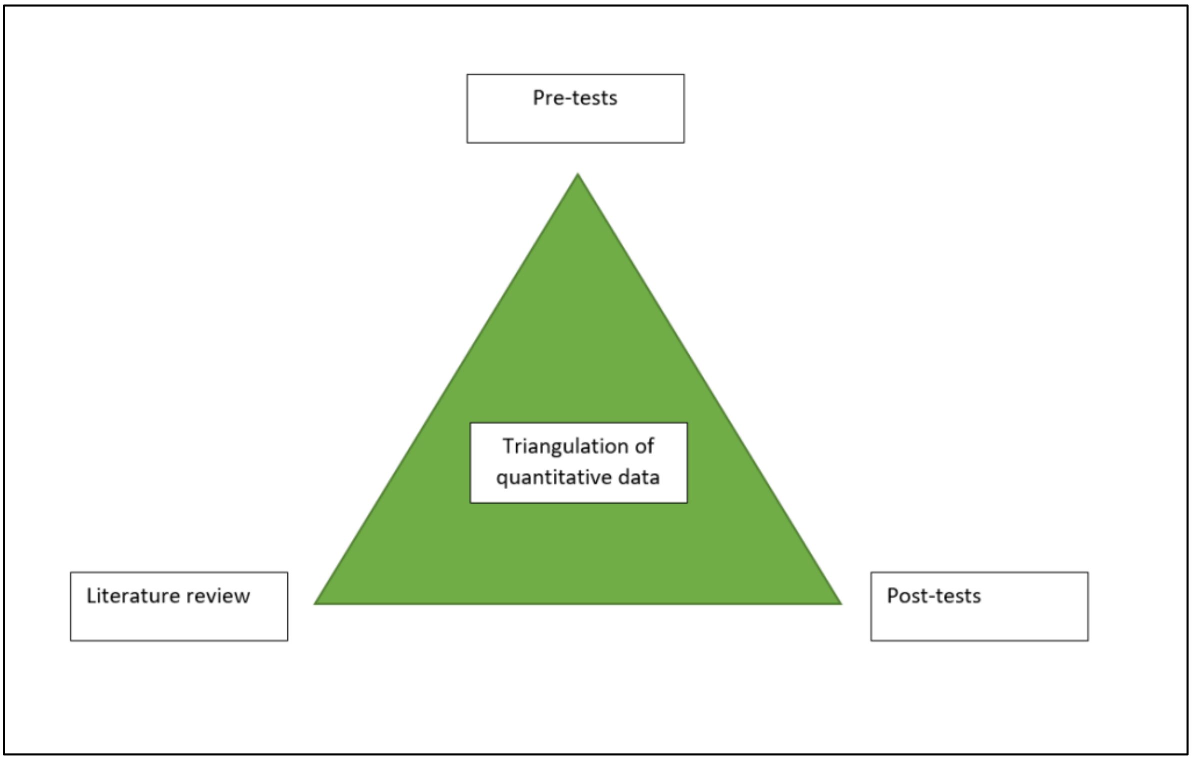


Figure 6-10: Triangulation of quantitative data.

Figure 6-10 shows how the statistical data from the pre-tests and post-tests and the information from the literature review were compared and triangulated to ensure reliability (see Table 4-5) throughout the process of quantitative data analysis. During the triangulation of the quantitative data, the following were determined: when the pre-test and post-test of the sectioned mechanical assembly drawings were compared, there was an effect size of 0,42, which confirms that there was a practically visible improvement in the students' spatial visualization skills. Furthermore, when the SDL pre-test and post-test were compared, there was a large effect in the students' intentional learning skills, and the Cronbach alpha showed that the data for the students' self-monitoring skills were not reliable (Table 6-13). The reason for this may be that the students did not understand the question.

6.6.3 Final triangulation

During the final triangulation, the data obtained from the qualitative research and the quantitative research were compared, integrated and interpreted (Figure 6-11). Figure 6-11 illustrates the process of triangulation followed during the qualitative data analysis and the quantitative data analysis.

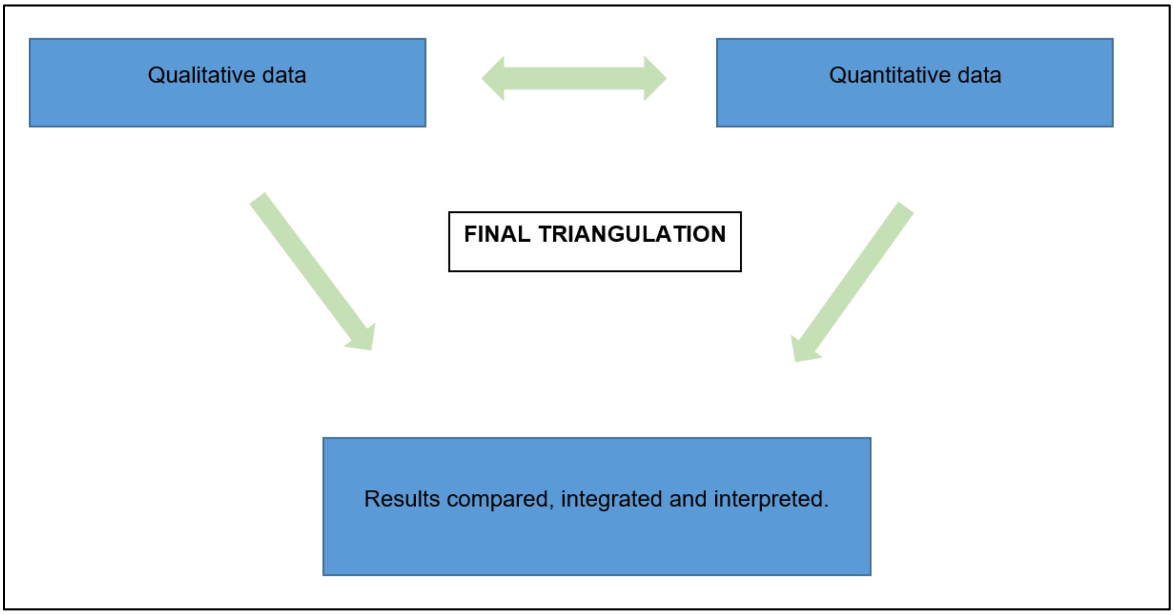


Figure 6-11: Final triangulation.

It is evident from Figure 6-11 that when the students' feedback on the interviews was compared with the results of the pre-test and post-test written about the students' understanding of sectioned mechanical assembly drawings, it became evident that students' spatial visualization skills could be improved for sectioned mechanical assembly drawings when using advanced ICTs in EGD (Sections 6.4.1.1 and 6.2.4).

6.7 Conclusion

In this chapter, the qualitative and quantitative findings were discussed and reported. The research objectives, which were identified in Chapter 1, were reported on with the qualitative and quantitative data. From the qualitative data, the research problem was confirmed, advanced ICTs which may improve spatial visualization were identified, advantages and barriers were identified when using advanced ICTs in EGD, advanced ICTs that improve spatial visualization skills were reported on and the reasons why ICTs improve spatial abilities were determined. From the quantitative data, the improvement of spatial visualization skills was identified with a pre-test before the intervention and a post-test after the intervention. SDL skills obtained in the study were identified with a pre-test before the intervention and a post-test after the intervention. In the next chapter, the primary research question and secondary research questions will be discussed and the framework for improving spatial visualization skills while using advanced ICTs will be set forth.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

LOGIC

Question	Norton's action research steps (Norton, 2018:70; Kemp, 2012:42)	McNiff's questions (McNiff, 2017:5; Kemp, 2012:43)	Chapter layout	Research method
What contributing suggestions made by student teachers, EGD lecturers and the researcher can assist in the development of a framework for advanced ICT integration in EGD to foster spatial visualization and SDL?	Modifying my future practice in the teaching of EGD	How will I change my practice with regard to my evaluation?	**Chapter 7**	**Comprehensive summary and integration**

7.1 Introduction

The study aimed to determine the influence of the use of advanced ICTs in EGD to improve spatial visualization skills among students when doing sectioned mechanical assembly drawings. Furthermore, students' SDL skills were identified, and the study aimed to determine if students' SDL skills regarding using advanced ICTs had improved throughout the intervention. In order to achieve these aims, particular research objectives were addressed. These objectives were:

- to determine the main advantages and barriers of using ICT in EGD education globally and in South Africa;

- to determine to what extent ICTs are being implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education;
- to discover to what extent advanced ICTs enhance spatial visualization and SDL skills;
- to discover how ICT and spatial visualization skills can be further developed to enhance EGD within higher education; and
- to propose a suitable framework for the implementation of advanced ICT integration in EGD to foster spatial visualization skills and SDL skills.

In this chapter, I shall expound on the conclusions regarding the literature study, the implementation of the intervention and the research done in terms of the above-mentioned research objectives of the study.

7.2 Conclusions

The conclusions based on the research objectives are discussed in the following sections, which will lead to the intended framework to improve spatial visualization and SDL skills while implementing advanced ICTs in the EGD classroom.

7.2.1 Determine the main advantages and barriers of using ICTs in EGD education globally and in South Africa

In Chapter 2 and 3 of the study, a literature review was conducted to discuss EGD in South Africa and how the drawing topics compare to those of other countries (see Table 2-1). In understanding what other counties do in EGD, I could determine if the same problems occurred worldwide in EGD. The use of advanced ICTs was discussed, and advantages (see Section 2.6.1) and barriers (see Section 2.6.2) were identified in the literature review and compared with qualitative data (see Section 6.2.2, Figure 6-4, Table 6-5, Figure 6-5 and Table 6-6). These were compared to the qualitative data obtained from the participants in the study, comprising EGD students and fellow EGD lecturers with years of experience in the field and my own observations made throughout the study. The findings of the main advantages and barriers of using advanced ICTs are discussed in terms of the following questions: What does EGD entail and what do advanced ICTs entail?

7.2.1.1 What does EGD entail?

Drawings as a means of communication can be dated back to 30 000 – 32 000 years ago when cave dwellers illustrated their drawing skills on cave walls (Bocherens *et al*., 2006). Throughout the years, drawing skills improved and were used for more practical reasons in the civil, mechanical and electrical fields. Therefore, EGD can be seen as a means of communicating ideas on paper and nowadays on CAD to solve a relevant problem (Goetsch *et al.*, 2016). EGD therefore consists of different skills, which students in the relevant fields should obtain to communicate graphically to adhere to worldwide drawing standards. As a subject that relies on critical thinking to solve problems, many students do struggle with EGD. Except for drawing skills that students should obtain, there are critical thinking skills and spatial visualization skills students need to excel in EGD. These skills should be the focus to improve in EGD, to provide the relevant personnel in the work sector, which will be able to communicate on a graphical level as well as personnel that will be able to solve problems. In this study, the lack of spatial visualization skills is seen as the reason for students struggling with sectioned mechanical assembly drawings (see Section 6.2.1 and 6.3.1).

7.2.1.2 What do advanced ICTs entail?

Research in education and the use of ICT can be seen as a teaching aid that will help educators and students to enhance the learning process, promote higher-order thinking, critical thinking and obtaining skills to solve problems. There is a worldwide trend to incorporate ICT into education as it has different advantages that will improve education and teach students 21st-century skills (Chedi, 2015). Different advantages were identified in the literature regarding the use of advanced ICTs in EGD. These advantages were corroborated in the qualitative data of the study when the students gave feedback on the use of ICT in EGD (see Section 6.2.2 and 6.3.2). Barriers were also identified in the literature, and these were supported by the participants' feedback as well. In comparing the barriers to the norm worldwide, new barriers were identified in this study (see Section 6.2.2).

CAD software, which consists of 2D CAD and 3D CAD, 3D printing, animation as well as LMSs such as The Depot™ and eFundi™, was used to improve spatial visualization and SDL skills as provided in Sections 6.2.4 and 6.4.

7.2.2 Determine to what extent ICTs are implemented in EGD in higher education at this specific tertiary institution in the Faculty of Education

As EGD as a module in the Faculty of Education is not offered by many tertiary institutions, it was difficult to obtain information on which advanced ICTs are used at other universities in EGD. The literature shows that in the engineering fields, advanced ICTs are more commonly used in engineering drawing, a subject commonly taken by Engineering students in the engineering fields at different universities worldwide, such as Harvard University and Stanford University in the United States of America, the University of Cambridge and the University of Oxford in the United Kingdom and the North-West University, Stellenbosch University and the University of Pretoria in South Africa, to name a few. Various advanced ICTs that students use throughout their four-year degree were identified at this specific institution in education, such as 3D printers, CAD software, learning management software and animation software (see Section 6.2.4). After determining the advanced ICTs that are known to students and are available for use in EGD, the ones which might improve spatial visualization skills were chosen and implemented in the intervention (see Table 5-7). The different advanced ICTs known to students are the data projector, eFundi™, animations, the 3D printer, CAD and the interactive whiteboard while the 3D printer, eFundi™,The Depot™, CAD and animations were used during the intervention (see Table 5-7).

7.2.3 Discover to what extent advanced ICTs enhance spatial visualization and SDL skills

7.2.3.1 Spatial visualization skills

Spatial visualization skills are seen as the ability to mentally manipulate, rotate and see how a drawing looks before one draws it. Spatial abilities are important for students to understand what and how they are drawing all the different types of drawings (see Section 2.2.2, Figure 2-6). During the research, it became evident that the use of advanced ICTs, specifically CAD, 3D printing and animations, help students to improve their spatial abilities to understand mechanical assembly drawings better (see Section 6.4). The participants wrote a sectional mechanical assembly pre-test and post-test after the intervention, and it was determined that there was an improvement after the intervention (see Section 6.4.1.1). The qualitative data showed that the participants also believed that the use of advanced ICTs in EGD helped them to understand sectional mechanical assembly drawings better (see Section 6.2.4).

7.2.3.2 SDL skills

SDL skills are seen as skills that students might obtain while learning in EGD that help them to be more self-directed when preparing and learning work (Davis *et al*., 2010). The aim is to lead students to a deep approach to learning where they are more reliant on themselves to learn and excel in their studies (Robertson, 2010). The quantitative data showed that the students' SDL skills had improved while using advanced ICTs, especially their intentional learning SDL skill (see Sections 6.4 and 6.5). The students completed the SDLTS before the intervention and again after the intervention. The data gathered were compared, and it was evident that the students' intentional learning skills had improved during the intervention with an effect size of 0,82. This is seen as a large effect that shows that there has been a significant difference between the students' intentional learning before and after the intervention (see Table 6-16).

7.2.3.3 Interrelationship between spatial visualization skills and SDL skills

In the literature review in Chapter 3, the interrelationship between spatial visualization skills and SDL skills was discussed and shown in Figure 3-1. During the final triangulation when the qualitative data and quantitative data were compared, integrated and interpreted, it was evident that the use of advanced ICTs has had an effect on both the students' spatial visualization skills and their SDL skills (see Sections 6.4, 6.5 and 6.6).

7.2.4 Discover how ICT and spatial visualization skills to be further developed to enhance EGD within higher education environments

Throughout the interviews and facilitation of EGDD421, I kept a research journal and wrote down my own observations. During the intervention, different advanced ICTs came up: a computer numerical control router that could machine wood to create different models for students to use during their EGD classes; different animation software that could help students understand how different components fit together, such as Blender™ and Animation Lab™. With funding, these advanced ICTs could be bought and tested in the EGD classroom.

7.2.5 Propose a suitable framework for the implementation of advanced ICT integration in EGD to foster spatial visualization skills and SDL skills.

The framework for implementing advanced ICTs to enhance students' spatial visualization skills and SDL skills will be discussed under the following headings.

7.2.5.1 Development of EGD-ICT-SDL integration framework

With the purpose of identifying and producing a framework to improve on students' ICT skills, spatial visualization skills and SDL skills, the research problem was identified by means of a literature review (see Sections 1.1 and 3.4), interviews with student teachers and EGD lecturers (see Section 6.2.1) and with a pre-test (see Section 6.4.1.1) which determined students' understanding and skills in sectioned mechanical assembly drawings. Furthermore, the possible advantages and barriers were determined and explained by means of a literature review (see Sections 2.6.1 and 2.6.2) and interviews with student teachers and fellow EGD lecturers (see Section 6.2.3). Different solutions were identified by means of a literature review (see Section 2.5) and interviews (see Section 6.2.4) with student teachers and fellow EGD lecturers. The data obtained played a vital role in developing, integrating and implementing the final framework to improve student teachers' ICT skills, spatial visualization skills and SDL skills in EGD.

Figure 7-1 shows the six phases used in the framework to improve spatial visualization skills among EGD student teachers while using ICT as an instruction method.

Phase 1
Analysis of teaching and learning needs in EGD
Phase 2
Identify possible solutions
Phase 3
Planning for integration
Phase 4
Implementation
Phase 5
Analysis and revisions
Phase 6
Adapt framework and repeat cycle

Figure 7-1: Development phases of the EGD-ICT-SDL framework.

Phases 1 to 3 were important in developing a framework for implementation during the intervention. In phase 1, the research problem was identified; phase 2 helped to determine the possible solutions to the research problem; and, lastly, phase 3 was important to plan and design the intervention (see Section 5.5.4). Phases 1 to 6 are discussed in depth in Section 7.2.5.2 with reference to the visual presentation of the framework in Figure 7-2.

7.2.5.2 EGD-ICT-SDL integration framework

From the quantitative and qualitative data it was evident that the use of advanced ICTs is advantageous for EGD. The student teachers of EGD had improved their understanding of sectioned mechanical assembly drawings and their spatial abilities to see what the drawing should look like before drawing it. It had furthermore enhanced students' SDL skills, particularly their intentional learning skills. To implement the framework, it is divided into six phases that should be followed to enhance spatial abilities and foster SDL skills. With the help of Figure 7-2, the proposed framework will be discussed in depth for other EGD educators to enhance ICT skills, spatial visualization skills and SDL skills among their students or learners.

7.2.5.2.1 Problem identification

1 First of all, it is important for lecturers and educators who might use the EGD-ICT-SDL framework to understand that they may use the framework for different drawings with which students struggle. The first step of the whole process is to identify the problem in the educator's classroom. In the study, the problem identified was that students struggled with sectioned mechanical assembly drawings (see Section 6.3.1). The methods used to determine the problem are firstly to observe one's classroom and see with which drawings the students are struggling (in this case, sectioned mechanical assembly drawings were identified as problematic). Secondly, the problem should be substantiated with relevant literature (see Section 1.1 and 3.4) to determine if there are other institutions in which the same problem is experienced and what they may have done to address the problem (see Section 6.3.1). Thirdly, interviews should be conducted with students and fellow lecturers to determine if this really is the problem. Interviews with the students are necessary to minimise bias and ensure that a problem is not determined according to the educator's own assumptions. Therefore, it is important to make sure that the true problem at stake is identified. The educator's role is thus to identify the problem with observation and doing a literature review. Furthermore, the educator should facilitate sessions to conduct the interviews with the students and fellow lecturers. The students' role is to take part in the discussions during the interviews.

7.2.5.2.2 Possible solutions

2 During phase 2, different advanced ICTs are identified. The advanced ICTs can be determined according to the literature (see Section 2.5), which states that advanced ICTs could have an effect on spatial visualization skills. Furthermore, it is important to determine which advanced ICTs are known to the students (see Section 6.3.3), as it is time-consuming to teach them how to use different advanced ICTs, which may lessen valuable teaching time. The educator should consult fellow lecturers or experts in the EGD field to understand their view on how to improve spatial visualization skills using advanced ICTs. In the study, CAD, 3D printing and animations were identified as advanced ICTs that would improve students' ability to mentally manipulate, rotate and section mechanical assembly drawings (see Section 6.3.4). The educator's role is of the utmost importance to decide which advanced ICTs should

be used to improve ICT skills, spatial visualization skills and SDL skills. In the study, 2D or 3D CAD, animation and 3D printing were identified and used. The students' role during phase 2 is to help determine which advanced ICTs may enhance ICT skills, spatial visualization skills and SDL skills. Furthermore, the data obtained from the students identified which advanced ICTs were known to them and what advanced ICTs were available at this specific institution.

7.2.5.2.3 Constructively align module

3 Phase 3 can be seen as the most important phase, as in this phase, the educator has to design and plan each lesson to adhere to the problems identified in phase 1. To design and plan the module, a combination of the module designs of Biggs and Tang (2011) and Jacobs *et al.* (2016) was used (see Figure 5-1). This phase is divided into three stages, namely intended learning outcomes (ILOs), teaching-learning activities (TLAs) and assessment (see Table 5-). In the ILO stage, each session should be designed so that students' spatial visualization skills, SDL skills and critical thinking skills would be improved to solve the drawing problems. The TLAs are important as to how the lesson would be facilitated to improve ICT skills, spatial visualization skills, and SDL skills. The TLAs (see Section 5.5.3) used were a combination of Kemp (2012) and Mentz and Oostuizen (2016) activities that would foster a deep approach to learning. These activities have the ability to lead students to higher-order thinking and critical skills, which are important for the improvement of spatial visualization skills and SDL skills. The TLAs used in this framework is problem solving, collaborative group work and role play (see Section 5.5.3). During this stage, advanced ICTs must also be incorporated into each lesson. The type of drawings students must draw should also be considered – there should be a progression in the drawings from simple to advanced. Therefore it is important to distribute the TLAs, the sequence of drawings and advanced ICTs to lead students to do the drawings on their own without any teaching aids. The assessment stage is vital in that the educator gives prompt feedback to students so that they have the opportunity to understand why they did not succeed in the drawing and have the opportunity to see the memorandum and improve on their mistakes. The educator's role during phase 3 may be seen as the most important part of the study. The educator should plan and design the new module that should consist of ILOs, TLAs and methods of assessment that would enhance

student teachers’ ICT skills, spatial visualization skills and SDL skills (see Table 5.7). During phase 3, the student teacher does not have any role when designing and planning the new module.

7.2.5.2.4 Implementation

In phase 4, the implementation of the framework takes place (see Section 5.6). Phases 2 and 3 played an important role during this phase as the planning and design of the redesigned module are vital to the outcomes of the problem at stake. During phase 4, the educator’s role consists of facilitating all the lessons, observing on a continuous basis to determine if the students are on track with what is expected from them and doing assessment of TLAs at the end of each lesson to give prompt feedback at the next lesson so that the students can understand what they did wrong and how they should improve on it. The educator further has to incorporate the different methods of instruction that will improve and enhance students’ ICT skills, spatial visualization skills and SDL skills (see Table 5-2). The students’ role during phase 4 is also very significant, as the students should be willing to participate in all the different TLAs (see Section 5.5.3). If students participate, there is a better chance that they will enhance their ICT skills, spatial visualization skills and SDL skills.

7.2.5.2.5 Evaluation

Phase 5 is the evaluation of the implementation of the framework. Students’ grades can be compared to see if there was any improvement in the students’ spatial abilities (see Section 6.5.1). Furthermore, students give feedback during interviews to see if they feel they understand mechanical assembly sectioned drawings better (see Section 6.2.4). The educator should combine all the relevant information he or she collected during the implementation of the framework to determine and evaluate the whole process. This may be done with students’ marks for assignments (determining if there is any improvement in their marks), students’ feedback during interviews and the educator’s own observations (see Addendum J) during the implementation of the framework. After the educator has evaluated the implementation of the intervention, he or she could decide that the students are on a level where they understand sectioned mechanical assembly drawings better and the cycle does not need to be repeated. If the educator decides that the students are still struggling with sectioned mechanical assembly drawings, the cycle may be repeated to help the students obtain ICT skills, spatial visualization skills and SDL skills.

7.2.5.2.6 Repeat cycle

During phase 6, the educator should decide which part of the students' skills still needs attention. This may be divided into the different skills the students have to obtain during the intervention. The different skills the students should obtain are ICT skills, spatial visualization skills and SDL skills. Amendments and changes should be made for the next cycle for implementation.

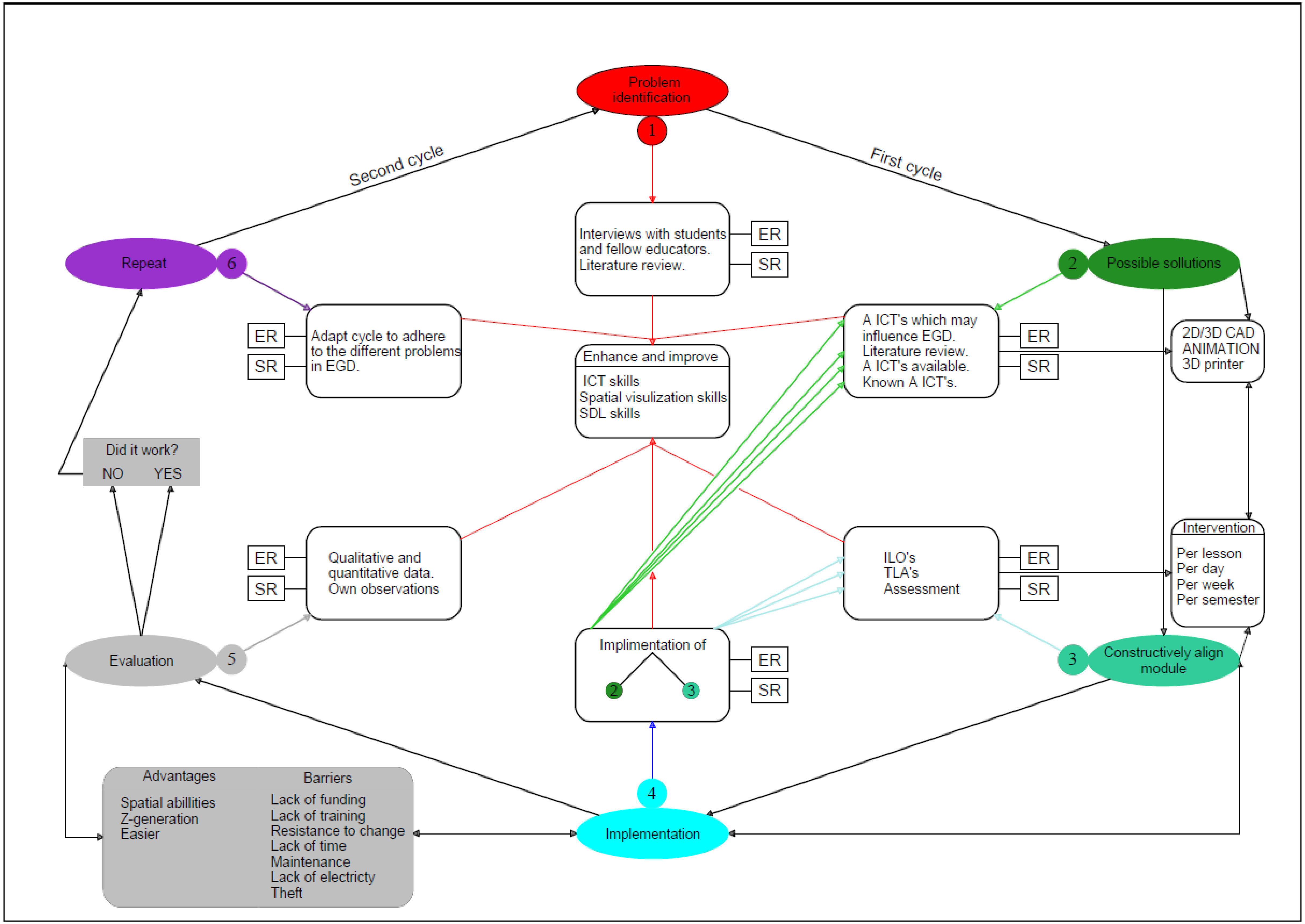


Figure 7-2: **EGD-ICT-SDL integration framework.**

7.2.5.3 Conclusion of framework

Throughout the implementation of the framework, the educator should observe and keep track of the process in his or her journal, identifying barriers in implementing the framework. The framework may change with each implementation since each year's groups of students are different, advanced ICTs change at an alarming rate, students' skills differ and students' willingness to comply may differ from year to year or semester to semester. If this framework is followed specifically to improve students' spatial abilities in sectioned mechanical assembly drawings as well as their ICT and SDL skills, the intervention in Chapter 5 can also be used as a guideline with reference to this framework.

7.3 Contribution of the study

In the study, I identified advanced ICTs that improve students' spatial visualization skills, specifically in sectioned mechanical assembly drawings (see Section 6.4.1.1, Section 6.2.4). The advanced ICTs that will lead students to improve their spatial abilities are 3D printing (models), animations (videos) and the use of CAD software (2D and 3D CAD) (see Section 6.2.3). There are many other advanced ICTs that could be tested, which may lead to the improvement of spatial abilities among students (see Sections 6.2.3 and 2.5). It was furthermore established that the use of advanced ICTs improves students' SDL skills, specifically students' intentional learning skills (see Section 6.4.1.2). A framework was developed for the implementation of the integration of advanced ICTs in EGD to improve students' ICT skills, spatial visualization skills, and SDL skills (see Section 7.2.5).

Methodological contributions of this action research entails that a theoretical contribution was added in the research field of EGD as well as a practical contribution regarding the implementation of 3D modelling in the EGD classroom.

7.4 Limitations of this study

The limitations identified in the study after the literature review, the intervention and the analysis of the data were taken into consideration are discussed below.

Very little research has been done in the field of EGD in education in South Africa. Therefore, most of the literature used was research in the engineering fields relevant to the drawings they use. EGD is a niche area in education, and more research should be done in this area in secondary and tertiary education fields.

The classes lasted for 11 weeks, with only 22 contact sessions, which might not have been long enough to observe all of the students' abilities to perform in the EGD classroom. Furthermore, the small population of participants, (n=48) might not represent the majority of the EGD students in the Further Education and Training sector.

Another limitation that I observed throughout the study is that while students' SDL skills (specifically their intentional learning skills) did improve, improvement in their self-monitoring skills could not be verified as the Cronbach alpha had a negative value (see Section 6.4.1.2). It seems as if the students did not understand the question as I intended; therefore, for further research, the question should be adapted for better understanding.

7.5 Recommendations for further research

If possible, it would be more beneficial if the implementation of advanced ICTs could be conducted over a longer period of time, not only in one semester. Without any use of advanced ICTs, any EGD module is time-consuming as students have to adhere to Bloom's cognitive domain (EGD theory), psychomotor domain (drawing skills) and affective domain (values) being implemented to complete each module (see Section 2.3.4).

The EGD modules on secondary and tertiary level have different topics (see Table 2-2) that students should complete before obtaining their certificate or degree. These topics should be explained. Difficult topics should be researched and the implementation of these topics should be adapted to help students understand these topics better.

There are still many advanced ICTs that may lead to the improvement of spatial abilities and drawing skills among students that could be tested (see Sections 6.2.3 and 2.5).

Research could be done to determine if there is a difference in understanding in EGD according to gender, as it has been suggested that male students tend to do better in EGD than female students (Ali *et al.*, 2012; Lauer, Yhang & Lourenco, 2019; Ogunkola & Knight, 2019).

7.6 Conclusion

In the study, promoting ICT skills, spatial visualization skills and improving SDL skills through the implementation of advanced ICTs in the EGD environment were researched and explained. The study consists of seven chapters. Chapter 1 focused on the introduction and the research problem. Furthermore, the rationale for the study was discussed, and the primary and secondary research questions, as well as the research aim and objectives, were determined. Chapter 2 was the first literature chapter, which focused on the history of EGD, how EGD fits into the school curriculum and how it compares with other countries, different career opportunities in EGD and the barriers and advantages of using EGD in the 21st century. In Chapter 3, a literature study was done with regard to learning theories in teaching and learning, spatial visualization in EGD and SDL. Chapter 4 focused on the research design and methodology followed to do the research; a mixed-methods action research methodology was used. In Chapter 5, the planning, design and implementation of the module EGDD421 as intervention were deliberated. In Chapter 6, the results of the qualitative and quantitative research were given, and the importance of and connection between the methods were explained. In the final chapter, the conclusions and recommendations with regard to the research questions and aims were provided. Furthermore, a framework to implement advanced ICTs to enhance ICT skills, spatial visualization skills and SDL skills was given.

BIBLIOGRAPHY

Abdalla, O.H.O. 2018. Impact of information and communication technology on promoting scholastic activities*.* Khartoum: Sudan University of Science and Technology.

Abraham, L.N. & Otuaga, A. 2017. Use of ICT tools for human performance improvement in technical drawing contents delivery at secondary school level. *International journal of educational research and technology*, 8(3):25-33.

Adams, J.P. & Turner, S.J. 2008. Problem solving and creativity for undergraduate engineers: process or product? https://www.heacademy.ac.uk/system/files/p061-adams_0.pdf Date of access: 20 Apr. 2018.

Adler, S. 2008. Reverse engineering employing CT for CAD. *CAM applications, 3D scanning technologies magazine*, 1(3):8-14.

Ahmed, J. 2010. Documentary research method: new dimensions. *Indus journal of management and social sciences*, 4(1):1-14.

Alexander, R. 2009. Game studies, literary anthropology, and strategies of distinction; or, why it pays to take another look at the work of Wolfgang Iser. *Journal for computer game culture*, 1(1):1-15.

Al-Huneidi, A. & Schreurs, J. 2011. Constructivism-based blended learning in higher education. *International journal of scientific research*, 7(1):581-591.

Ali, D.F., Noordin, M.K., Nasir, A.N.M. & Nordin, M.S. 2012. Visualization skills among engineering student: pilot study. *Engineering education*, 1(1):36-40.

Alias, M., Black, T.R. & Gray, D.E. 2002. Effect of instructions on spatial visualisation ability in civil engineering students. *International education journal*, 3(1):1-12.

Allen, J. & Kouppas, P. 2012. Computer aided design: past, present, future. *Design and designing: a critical introduction*:97-111.

Alqahtani, A.S., Daghestani, L.F. & Ibrahim, L.F. 2017. Techniques used to improve spatial visualization skills of students in engineering graphics course: a survey. *International journal of advanced computer science and applications*, 8(3):91-100.

American Society for Testing and Materials. 2012. Standard terminology for additive manufacturing technologies. West Conshohocken: American Society for Testing and Materials International.

Anon. 2018. Almost everything you always wanted to know about 3D scanning. http://www.dirdim.com/lm_everything.htm Date of access: 16 Aug. 2018.

Apelian, D. 2007. Looking beyond the last 50 years: the future of materials science and engineering. *The journal of the minerals, metals & materials society,* 59(2):65-73.

Archer, E., Herman, H., Van Vuuren, J. & Hugo, D. 2017. Introduction to ATLAS.ti: basic operations, tips and tricks for coding. 6th ed. Pretoria: Creative Commons.

Arenas-Gaitán, J., Rondán-Cataluña, F.J. & Ramírez-Correa, P.E. 2018. Modelling the success of learning management systems: application of latent class segmentation using FIMIX-PLS. *Interactive learning environments*, 26(1):135-147.

Assarroudi, A., Heshmati Nabavi, F., Armat, M.R., Ebadi, A. & Vaismoradi, M. 2018. Directed qualitative content analysis: the description and elaboration of its underpinning methods and data analysis process. *Journal of research in nursing*, 23(1):42-55.

Babbie, E. & Mouton, J. 2001. The practice of social science research. Belmont, CA: Wadsworth.

Babbie, E.J. 2010. The practice of social research. 12th ed. Belmont, CA: Wadsworth.

Babbie, E.R. 2016. The practice of social research. 14th ed. Boston, MA: Cengage Learning.

Bada, S.O. & Olusegun, S. 2015. Constructivism learning theory: a paradigm for teaching and learning. *Journal of research method in education*, 5(6):66-70.

Balderas, A., De-La-Fuente-Valentin, L., Ortega-Gomez, M., Dodero, J.M. & Burgos, D. 2018. Learning management systems activity records for students' assessment of generic skills. *IEEE access*, 6:15958-15968.

Barr, R. 2012. Engineering graphics outcomes for the global engineer. (*In* Global Graphics, Proceedings of the 66th Mid-year Conference of the Engineering Design Graphics Division of the American Society for Engineering Education. Galveston, TX: American Society for Engineering Education p. 109-125).

Barr, R., Juricic, D. & Krueger, T. 1994. The role of graphics and modeling in the concurrent engineering environment. *Engineering design graphics journal*, 58(3):12-21.

Baumers, M., Dickens, P., Tuck, C. & Hague, R. 2016. The cost of additive manufacturing: machine productivity, economies of scale and technology-push. *Technological forecasting and social change*, 102(C):193-201.

Bell, S. 2010. Do we really need a new Constructivist institutionalism to explain institutional change? *British Journal of political Science,* 41(1): 883-906.

Berényi, L. & Deutsch, N. 2018. Effective teaching methods in business higher education: a students' perspective. *International journal of education and information technologies*, 12:37-45.

Berman, B. 2012. 3-D printing: the new industrial revolution. *Business horizons*, 55(2):155-162.

Bertoline, G.R., Wiebe, E.N., Hartman, N.W. & Ross, W.A. 2010. Fundamentals of graphics communication. 6th ed. Boston, MA: McGraw-Hill.

Beyers, R.N. 2009. A five dimensional model for educating the net generation. *Journal of educational technology & society*, 12(4):218-227.

Biggs, J. & Tang, C. 2011. Teaching for quality learning at university. 4th ed. Maidenhead: McGraw-Hill.

Bignante, E. 2010. The use of photo-elicitation in field research. Exploring Maasai representations and use of natural resources. *EchoGéo*, 11(1):1-23.

Bingimlas, K.A. 2009. Barriers to the successful integration of ICT in teaching and learning environments: a review of the literature. *Journal of mathematics, science technology education*, 5(3):235-245.

Bloom, B.S. 1956. Taxonomy of educational objectives. Handbook: The cognitive domain. New York, NY: McKay.

Blurton, C. 2002. New directions of ICT-use in education http://www.unesco.org/education/educprog/lwf/dl/edict.pdf Date of access: 7 Aug. 2015.

Bobylev, D. 2017. Comparison of 3D modelling software. Saimaa University of Applied Sciences. (Thesis – Degree Programme in Mechanical Engineering and Production Technology).

Bocherens, H., Drucker, D.G., Billiou, D., Geneste, J. & Van der Plicht, J. 2006. Bears and humans in Chauvet Cave (Vallon-Pont-d'Arc, Ardeche, France): insights from stable isotopes and radiocarbon dating of bone collagen. *Journal of human evolution*, 50(3):370-376.

Bonnardel, N. & Zenasni, F. 2010. The impact of technology on creativity in design: an enhancement? *Creativity and innovation management*, 19(2):180-191.

Booker, P.J. 1963. A history of engineering drawing. London: Chatto and Windus.

Boylan, P., Micarelli, A., Pirrottina, V. & Sciarrone, F. 2000. Constructivism, self-directed learning and case-based reasoners: a winning combination https://www.aaai.org/Papers/Symposia/Fall/2000/FS-00-02/FS00-02-004.pdf Date of access: 18 Aug. 2018.

Bradbury, H., Waddell, S., O'Brien, K., Apgar, M., Teehankee, B. & Fazey, I. 2019. A call to action research for transformations: the times demand it. London: Sage Publications.

Branoff, T. & Dobelis, M. 2012. Engineering graphics literacy: measuring students' ability to model objects from assembly drawing information. (*In* Global Graphics, Proceedings of the 66th Mid-year Conference of the Engineering Design Graphics

Division of the American Society for Engineering Education. Galveston, TX: American Society for Engineering Education. p. 22-24).

British Educational Communications and Technology Agency. 2004. A review of the research literature on barriers to the uptake of ICT by teachers https://dera.ioe.ac.uk/1603/1/becta_2004_barrierstouptake_litrev.pdf Date of access: 10 Apr. 2018.

Brockett, R.G. & Hiemstra, R. 2018. Self-direction in adult learning: perspectives on theory, research and practice. London: Routledge.

Brooks, J.G. & Brooks, M.G. 2001. Becoming a constructivist teacher. *(In* Costa, A.L., *ed.* Developing minds: a resource book for teaching thinking. 3rd ed. Alexandria: Association for Supervision & Curriculum. p. 150-157).

Brown, S. & Jayaram, U. 2013. Perspectives of an engineering CAD and visualization sequence for freshmen and sophomores in ME. (*In* Proceedings of the ASME 2013 International Design Engineering Technical Conferences (IDETC) and Computers and Information in Engineering Conference (CIE). Portland, OR: American Society of Mechanical Engineers. p. 1-10).

Brudigam, K.L. & Crawford, R.H. 2012. Spatial ability in high school students. Paper presented at 2012 American Society for Engineering Education Annual Conference & Exposition, San Antonio, Texas, June 2012. https://peer.asee.org/21928 Date of access: 16 Aug. 2019.

Brusic, S., Fales, J., Kuetemeyer, V.F. & Thompson, E. 2004. Technology today and tomorrow. Glencoe: McGraw-Hill Education.

Bullard, M.J., Weekes, A.J., Cordle, R.J., Fox, S.M., Wares, C.M., Heffner, A.C., Howley, L.D. & Navedo, D. 2019. A mixed-methods comparison of participant and observer learner roles in simulation education. *Academic emergency medicine education and training*, 3(1):20-32.

Burke, M. 2017. The Routledge handbook of stylistics. London: Routledge.

Buthelezi, T., De Beer, J., Du Toit, A., Golightly, A., Gravett, S., Havenga, M., Lubbe, A., Makonye, J.P., Petersen, N. & Phahamane, P. 2016. Self-directed learning research: an imperative for transforming the educational landscape. s.l.: AOSIS.

Buwono, M.A. & Ciptaningrum, D.S. 2019. Suggested blended learning models to teach English for senior high school teachers in Indonesia. (*In* The 5th International LLTC Proceedings. Online submission. p. 53-60).

Byrne, E., Daykin, N. & Coad, J. 2016. Participatory photography in qualitative research: a methodological review. *Visual methodologies*, 4(2):1-12.

Camerota, F. 2006. Teaching Euclid in a practical context: linear perspective and practical geometry. *Science & education*, 15(2-4):323-334.

Candy, P. 2009. Linking thinking: self-directed learning in the digital age. Sidney, Australia: Department of Education, Science and Training.

Candy, P.C. 1991. Self-direction for lifelong learning. A comprehensive guide to theory and practice. s.l.: ERIC.

Carey, P. 2017. #Decolonise! DEFSA 14th National Conference Proceedings. (*In* Giloi, S. & Botes, H., *eds.* DEFSA. s.l.: Design Education Forum of Southern Africa (DEFSA). p. 1-297).

Carmona, M.G. & Marin, J.A.M. 2013. ICT trends in education. *European scientific journal*, 9(19):1-987.

Carter, V. 2015a. TurboCAD 2D training guide 2D CAD for turboCAD users. South Africa: Tri-CAD technologies www.tricad.co.za Date of access: 18 Aug. 2018.

Carter, V. 2015b. TurboCAD 3D training guide 3D CAD training for turboCAD users. South Africa: Tri-CAD technologies www.tricad.co.za Date of access: 23 Sep. 2018.

Cazan, A.-M. & Schiopca, B.-A. 2014. Self-directed learning, personality traits and academic achievement. *Procedia-social and behavioral sciences*, 127:640-644.

Chaudhary, B. & Nagar, U.P.I. 2018. The role of ICT In promoting constructivism. *International journal of technical research & science*, 3(3):1-4.

Chedi, J. 2015. Technical drawing/graphic skills acquisition for teaching and learning and challenges in technology education. *Journal of science, technology*, 3(3):128-133.

Chen, P. 2009. Application of constructivism theory in community nursing instruction. *China Higher Medical Education*, 4: 120-135.

Cheng, M. & Yuen, A.H.K. 2018. Student continuance of learning management system use: a longitudinal exploration. *Computers & education*, 120:241-253.

Chevalier, J.M. & Buckles, D.J. 2019. Participatory action research: theory and methods for engaged inquiry. London: Routledge.

Cho, Y. & Kwon, S. 2003. Rapid geometric modeling for construction automation. *Korean society of civil engineers journal of civil engineering*, 7(3):225-231.

Coghlan, D. 2019. Doing action research in your own organization. Los Angeles, CA: Sage Publications.

Cohen, L., Manion, L. & Morrison, K. 2011. Research methods in education. 7th ed. Canada: Routledge.

Cohen, L., Manion, L. & Morrison, K. 2018. Research methods in education. 8th ed. London: Routledge.

Cohen, L., Manion, L., Morrison, K. & Morrison, K. 2009. Book reviews: research methods in education. 6th ed. *The Australian educational researcher*, 36:147-156.

Constantine, K.L. 2017. An investigation of the influence of gender and mindset on spatial training effects. East Lansing, MI: Michigan State University. (Dissertation – PhD).

Contero, M., Naya, F., Company, P., Saorín, J.L. & Conesa, J. 2005. Improving visualization skills in engineering education. *IEEE computer graphics and applications*, 25(5):24-31.

Coupal, L.V. 2004. Constructivist learning theory and human capital theory: shifting political and educational frameworks for teachers' ICT professional development. *British journal of educational technology*, 35(5):587-596.

Creswell, J. 2008a. Educational research: planning conducting and evaluating quantitative and qualitative research. Upper Saddle River, NJ: Prentice Hall.

Creswell, J. 2008b. Research design: qualitative, quantitative, and mixed-methods approaches. Upper Saddle River, NJ: Prentice Hall.

Creswell, J.W. 2003. Research design; qualitative, and, mixed methods approaches. 2nd ed. Thousand Oaks, CA: Sage Publications.

Creswell, J.W. & Creswell, J.D. 2018. Research design: qualitative, quantitative, and mixed methods approaches. 5th. ed. Thousand Oaks, CA: Sage Publications.

Creswell, J.W. & Poth, C.N. 2017. Qualitative inquiry and research design: choosing among five approaches. London: SAGE Publications.

Dang, Q. 2018. The multi-model of peer relationship from the perspective of constructivism. (*In* Proceedings of the 2018 7th International Conference on Social Science, Education and Humanities Research (SSEHR 2018). s.l.: Francis Academic Press. p. 376-380).

Davies, B.L. & Yarwood, A. 1986. Engineering drawing and computer graphics. Wokingham: Van Nostrand Reinhold.

Davis, C.A., Bailey, C., Nypaver, M., Rees, T. & Brockett, R.G. 2010. Learning projects of graduate students: an update of Tough's study. *International journal of self-directed learning*, 7(1):14-28.

De Vos, A., Strydom, H., Fouché, C. & Delport, C. 2014. Research at grass roots: for the social sciences and human service professions. Pretoria: Van Schaik.

De Vos, A., Strydom, H., Fouche, C., Poggenpoel, M., Schurink, E. & Schurink, W. 2001. Research data analysis. Pretoria: Van Schaik.

De Vos, A.S. 2011. Research at grass roots: for the social sciences and human services professions. 4th ed. Pretoria: Van Schaik.

De Vos, A.S., Delport, C., Fouché, C.B. & Strydom, H. 2011. Research at grass roots: a primer for the social science and human professions. Pretoria: Van Schaik.

De Wet, N., Somefun, O. & Rambau, N. 2018. Perceptions of community safety and social activity participation among youth in South Africa. *PLoS one*, 13(5):1-11.

Department of Basic Education. 2011. Curriculum and Assessment Policy Statement Grades 10-12 Engineering Graphics and Design. Pretoria: Government Printing Works.

Department of Basic Education. 2014a. Curriculum and Assessment Policy Statement (CAPS) Grades 10-12 Electrical Technology. Pretoria: Government Printing Works.

Department of Basic Education. 2014b. Curriculum and Assessment Policy Statement (CAPS) Grades 10-12 Mechanical Technology. Pretoria: Government Printing Works.

Department of Basic Education. 2014c. Curriculum and Assessment Policy Statement (CAPS) Grades 10-12 Civil Technology. Pretoria: Government Printing Works.

Department of Education. 2004. White Paper on Transforming Learning and Teaching through Information and Communication Technologies (ICTs). Cape Town Government Printing Works.

Department of Education. 2005. National Curriculum Statement Grades 10-12 (General) Engineering Graphic and Design. Pretoria: Government Printing Works.

Department of Education. 2007. National Curriculum Statement Grades 10-12 (General) Learning Programme Guidelines Engineering Graphics and Design. Pretoria: Government Printing Works.

Dhakal, P.K. 2018. Use of ICT tools in teaching mathematics in higher education. *International journal of multidisciplinary perspectives in higher education*, 3(1):81-88.

Dosemagen, D.M. & Schwalbach, E.M. 2019. Legitimacy of and value in action research. *The Wiley handbook of action research in education*:161-183.

Du Toit-Brits, C. 2017. Embedding motivation in the self-directedness of first-year teacher students. *South African journal of higher education*, 31(1):50-65.

Du Toit-Brits, C. & Van Zyl, C.M. 2017 Embedding motivation in self-directedness of first-year teacher students. *South African Journal of Higher Education,* 31: 50-56.

Dustman, E.L., Kohan, M.B. & Stringer, E.T. 2014. Starting small and building out with Ernie Stringer: personal insights into action research and educational change. *Action research*, 12(4):426-443.

Dweck, C.S. 2008. Can personality be changed? The role of beliefs in personality and change. *Current directions in psychological science*, 17(6):391-394.

Dynan, L., Cate, T. & Rhee, K. 2008. The impact of learning structure on students' readiness for self-directed learning. *Journal of education for business*, 84(2):96-100.

Efron, S.E. 2013. Action research in education: a practical guide. New York, NY: Guilford Press.

Elo, S. & Kyngäs, H. 2008. The qualitative content analysis process. *Journal of advanced nursing*, 62(1):107-115.

Elston-Jackson, C.A. 2011. Technology and social networking during lecture. Hamilton, Canada: McMaster University. (Thesis – MA).

Engelbrecht, J. 2015. Engineering graphics and design. Pretoria: HSE.

Erstad, O. & Voogt, J. 2018. The twenty-first century curriculum: issues and challenges. New York, NY: Springer.

Etikan, I., Musa, S.A. & Alkassim, R.S. 2016. Comparison of convenience sampling and purposive sampling. *American journal of theoretical and applied statistics*, 5(1):1-4.

Fadiran, O.A., Van Biljon, J. & Schoeman, M.A. 2017. How can visualisation principles be used to support knowledge transfer in teaching and learning? (*In* proceedings on Information Communications Technology and Society (AICTAS). s.l., SA: ASEE. p. 63-69).

Fakeye, D. 2010. Students' personal variables as correlates of academic achievement in English as a second language in Nigeria. *Journal of social sciences*, 22(3):205-211.

Farias, C., Mesquita, I., Hastie, P.A. & O'Donovan, T. 2018. Mediating peer teaching for learning games: an action research intervention across three consecutive sport education seasons. *Research quarterly for exercise and sport*, 89(1):91-102.

Felder, R.M. & Brent, R. 2016. Teaching and learning STEM: a practical guide. San Francisco, CA: Jossey-Bass.

Feng, X., Ahmed, V. & Mahdjoubi, L. 2003. Spatial visualization of building components. (*In* Proceedings of the 9th Annual ARCOM Conference. Brighton, England: ARCOM. p. 705-714).

Ferris, G. 2019. Collaborative test-taking for peer-to-peer teaching and learning across ability levels. Paper presented at the Community of Scholars Day 2019, Lesley University, 27 March 2019 https://digitalcommons.lesley.edu/community_of_scholars/2019/session_1/9/ Date of access: 23 Sep. 2019.

Fischer, G. & Sugimoto, M. 2006. Supporting self-directed learners and learning communities with sociotechnical environments. *Research and practice in technology enhanced learning*, 1(1):31-64.

Fisher, M., King, J. & Tague, G. 2001. Development of a self-directed learning readiness scale for nursing education. *Nurse education today*, 21(7):516-525.

Fleisig, R.V., Robertson, A. & Spence, A.D. 2004. Improving the spatial visualization skills of first year engineering students. (*In* Proceedings of the Canadian Engineering Education Association (CEEA) https://ojs.library.queensu.ca/index.php/PCEEA/article/view/4050/4002 Date of access: 17 Sep. 2018.

Flick, U. 2018. An introduction to qualitative research. London: Sage Publications.

Forterre, P. 2015. The universal tree of life: an update https://www.frontiersin.org/articles/10.3389/fmicb.2015.00717/full Date of access: 12 Apr. 2019.

French, T.E. & Svensen, C.L. 1966. Mechanical drawing. London: McGraw-Hill.

Friese, S. 2019. Qualitative data analysis with ATLAS.ti. New York, NY: Sage Publications.

Fritz, S. 1995. Found: wonders in a secret cave. *Popular science*, 246(6):1-124.

Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C.B., Wang, C.C., Shin, Y.C., Zhang, S. & Zavattieri, P.D. 2015. The status, challenges, and future of additive manufacturing in engineering. *Computer-aided design*, 69(1):65-89.

Garrison, D.R. 1997. Self-directed learning: toward a comprehensive model. *Adult education quarterly*, 48(1):18-33.

Gehringer, C., Rode, H. & Schomaker, M. 2018. The effect of electrical load shedding on pediatric hospital admissions in South Africa. *Epidemiology*, 29(6):841-847.

Geiler, C. 2014. Enhanced use of information and communication technology by professional nurses in distance education. Potchefstroom: North-West University. (Mini-dissertation – Magister in Health Service Management).

Ghavifekr, S., Kunjappan, T., Ramasamy, L. & Anthony, A. 2016. Teaching and learning with ICT tools: issues and challenges from teachers' perceptions. *Journal of educational technology & society*, 4(2):38-57.

Gibbs, G.R. 2018. Analyzing qualitative data. 2nd ed. New York, NY: Sage Publications.

Gilakjani, A.P., Lai-Mei, L., Ismail, H.N. & Science, C. 2013. Teachers' use of technology and constructivism. *International journal of modern education and computer science*, 5(4):49-63.

Gillies, R.M. 2007. Cooperative learning: Integrating theory and practice. Thousand Oaks, CA: Sage Publications.

Glaw, X., Inder, K., Kable, A. & Hazelton, M. 2017. Visual methodologies in qualitative research: autophotography and photo elicitation applied to mental health research. *International journal of qualitative methods*, 16(1):1-24.

Goetsch, D.E., Rickman, R.L. & Chalk, W.S. 2016. Technical drawing for engineering communication. 7th ed. Boston: Cengage Learning.

Goldie, J.G.S. 2016a. Connectivism: a knowledge learning theory for the digital age? *Medical teacher*, 38(10):1064-1069.

Gorska, R., Leopold, C., Sorby, S. & Shiina, K. 1998. International comparisons of gender differences in spatial visualization and the effect of graphics instruction on the development of these skills. *Journal for geometry and graphics*, 8(1):1-98.

Grasso, D. & Burkins, M. 2010. Holistic engineering education: beyond technology. Burlington: Springer Science & Business Media.

Guba, E.G. & Lincoln, Y.S. 1985. Naturalistic inquiry. Newbury Park, CA: Sage Publications.

Guba, E.G. & Lincoln, Y.S. 1994. Competing paradigms in qualitative research. *Handbook of qualitative research*, 2(105):163-194.

Guglielmino, L.M. 1977. Self-directed learning readiness scale http://www.lpasdlrs.com/ Date of access: 14 Apr. 2018.

Guglielmino, L.M. 2013. The case for promoting self-directed learning in formal educational institutions. *South African journal of education*, 10(2):1-18.

Hagevik, R., Aydeniz, M. & Rowell, C.G. 2012. Using action research in middle level teacher education to evaluate and deepen reflective practice. *Teaching and teacher education*, 28(5):675-684.

Halili, S.H. & Sulaiman, H. 2018. Factors influencing the rural students' acceptance of using ICT for educational purposes. *Kasetsart journal of social sciences*, 1(1):1-6.

Harris, L.V.A. & Meyers, F. 2007. Graphics: into the 21st century. (*In* Proceedings of the 2007 Annual Conference & Exposition. Honolulu, Hawaii: ASEE. p. 1-12).

Harris, L.V.A. & Meyers, F. 2009. Engineering design graphics: into the 21st century. *Engineering design graphics journal*, 71(3):20-34.

Hays, D.G. & Singh, A.A. 2011. Qualitative inquiry in clinical and educational settings. New York, NY: Guilford Press.

Heikkilä, A. & Lonka, K. 2006. Studying in higher education: students' approaches to learning, self-regulation, and cognitive strategies. *Studies in higher education*, 31(1):99-117.

Hendroanto, A., Van Galen, F., Van Eerde, D., Prahmana, R., Setyawan, F. & Istiandaru, A. 2017. Photography activities for developing students' spatial orientation and spatial visualization. *Journal of physics: conference series*:1-9.

Hennessy, S., Harrison, D. & Wamakote, L. 2010. Teacher factors influencing classroom use of ICT in Sub-Saharan Africa. *Journal of African studies*, 2(1):39-54.

Henning, E., Van Rensburg, W. & Smit, B. 2004. Finding your way in qualitative research. Pretoria: Van Schaik.

Hidayat, N., Hadi, S., Basith, A. & Suwandi, S. 2018. Developing e-learning media with the contiguity principle for the subject of autocad. *Jurnal pendidikan teknologi dan kejuruan*, 24(1):72-82.

Hiemstra, R. 1994. Self-directed learning. (*In* Rothwell, W.J. & Sensenig, K.J., *eds*. The sourcebook for self-directed learning. s.l.: HRD Press).

Higgs, J. & Boud, D. 1991. Self-directed learning as part of the mainstream of physiotherapy education. *Australian journal of physiotherapy*, 37(4):245-251.

Hinchey, P.H. 2016. A critical action research reader. New York, NY: Peter Lang.

Holzer, S. 1994. From constructivism to active learning. *The innovator*, 2(2):1-50.

Huang, T.-C. & Lin, C.-Y. 2017. From 3D modeling to 3D printing: development of a differentiated spatial ability teaching model. *Telematics and informatics*, 34(2):604-613.

Ibragimova, E.M., Bakulina, L.T. & Ibragimov, M.G. 2016. The development of modern learning theories: Comparative analysis. *The Turkish online Journal of Design*, 1: 2500-2505.

Isaacs, S. 2007. ICT in education in South Africa www.infodev.org Date of access: 12 Apr. 2018.

István, S. & László, K. 2012. Construction design and analysis with computer aided engineering tools. *International journal of production research,* 52(21):6235-6253.

Ivankova, N.V. 2015. Mixed methods applications in action research: from methods to community action. Thousand Oaks, CA: Sage Publications.

Ivanova, A. & Smrikarov, A. 2009. The new generations of students and the future of e-learning in higher education. *Proceedings of e-learning*, 9(1):17-25.

Jacobs, F.H. 2017. The five-tiered approach to evaluation: context and implementation. *(In* Jacobs, F.H., *ed.* Evaluating family programs. New York, NY: Routledge. p. 37-68).

Jacobs, M., Vakalisa, N.C.G. & Gawe, N. 2016. Teaching-learning dynamics. 5th ed. Cape Town: Pearson Education South Africa.

James-Gordon, Y. & Bal, J. 2003. The emerging self-directed learning methods for design engineers. *The learning organization*, 10(1):63-69.

Jian, Z. 2011. Teaching of engineering drawing in the 21st century. (*In* Proceedings of the 2011 Second International Conference on Mechanic Automation and Control Engineering. Piscataway, NJ: IEEE. p. 1713-1715).

Joelson, S.B. 2011. Engineering drawing guide for students and professional engineers. 2d ed. Hillcrest: Immanual Works.

Johnson, A.P. 2012. A short guide to action research. 4th ed. Upper Saddle River, NJ: Pearson.

Johnson, B. & Christensen, L.B. 2017. Educational research: quantitative, qualitative, and mixed approaches. 6th ed. Thousand Oaks, CA: Sage Publications.

Johnson, R.B. & Christensen, L. 2016. Educational research: quantitative, qualitative, and mixed approaches. 5th ed. New York, NY: Sage Publications.

Jordan, K., Wüstenberg, T., Heinze, H.-J., Peters, M. & Jäncke, L. 2002. Women and men exhibit different cortical activation patterns during mental rotation tasks. *Neuropsychologia*, 40(13):2397-2408.

Kaplan, D.E. 2018. Behaviorism in online teacher training. *Psychology of music*, 9(4):570.

Katsioloudis, P., Jovanovic, V. & Jones, M. 2014. A comparative analysis of spatial visualization ability and drafting models for industrial and technology education students. *Journal of technology education*, 26(1):88-101.

Katsioloudis, P.J. & Jovanovic, V. 2014. Spatial visualization ability and impact of drafting models: a quasi experimental study. *Engineering design graphics journal*, 78(2):1-11.

Kek, M. & Huijser, H. 2009. What makes a deep and self-directed learner: exploring factors that influence learning approaches and self-directed learning in a PBL context at a Malaysian private university. Journal/publication details.

Kelentrić, M., Helland, K. & Arstorp, A. 2018. Professional digital competence framework for teachers. Norway: Ministry of Education and Research.

Kemmis, S. & McTaggart, R. 1988. The action research planner. 3rd ed. Victoria, Australia: Deakin University.

Kemp, A.C. 2012. Improving my teaching experience with students in engineering graphics and design: an action inquiry. Bloemfontein: University of the Free State. (Dissertation – MEd).

Kemp, D.T. 1978. Stimulated acoustic emissions from within the human auditory system. *The journal of the acoustical society of America*, 64(5):1386-1391.

Khaldi, K. 2017. Quantitative, qualitative or mixed research: which research paradigm to use? *Journal of educational and social research*, 7(2):15-24.

Kharade, K. & Thakkar, R. 2012. Promoting ICT enhanced constructivist teaching practices among pre-service teachers: a case study. *International journal of scientific and research publications*, 2(1):1-7.

Khomo, T.G. 2018. The use of information and communication technology by mathematics and physical science teachers at secondary schools. Pretoria: University of South Africa. (Dissertation – MA).

Khoza, S.D. 2013. Difficulties in sectional drawing: a case of student teachers at a university based in the Eastern Cape. Pretoria: Tshwane University of Technology. (Thesis – PhD).

Khoza, S.D. 2017. Identifying the gaps of fourth year degree pre-service teachers' pedagogical content knowledge in teaching engineering graphics and design. *International journal of technology and design education*, 27(4):537-548.

Killen, J. 2009. Teaching Strategies for Outcomes-Based Education. Cape Town: Juta.

Kim, C.W. & Kwon, S.W. 2003. Human-assisted rapid 3D workspace modeling using sparse point clouds for heavy equipment operation on construction sites. *Architectural research*, 5(1):69-76.

Kim, T.K. 2015. T test as a parametric statistic. *Korean journal of anesthesiology*, 68(6):540.

King, N., Horrocks, C. & Brooks, J. 2018. Interviews in qualitative research. London: Sage Publications.

Kivunja, C. & Kuyini, A.B. 2017. Understanding and applying research paradigms in educational contexts. *International journal of higher education*, 6(5):26-41.

Knowles, M.S. 1975. Self-directed learning: a guide for learners and teachers. New York, NY: Association Press.

Korstjens, I. & Moser, A. 2018. Series: practical guidance to qualitative research. Part 4: trustworthiness and publishing. *European journal of general practice*, 24(1):120-124.

Koshy, V. 2010. Action research for improving educational practice: a step-by-step guide. 2nd ed. Los Angeles, CA: Sage Publications.

Kosnik, C., Menna, L., Dharamshi, P. & Beck, C. 2018. Constructivism as a framework for literacy teacher education courses: the cases of six literacy teacher educators. *European journal of teacher education*, 41(1):105-119.

Kostikova, I. 2018. Information and communication technologies in students' language learning. *International journal of education and science,* 1(2): 7-14.

Krippendorff, K. 2018. Content analysis: an introduction to its methodology. Thousand Oaks, CA: Sage Publications.

Kruger, G.M. 2018. The relationship between investment in ICT and mathematics achievement. Pretoria: University of Pretoria. (Thesis – PhD).

Kubheka, P. 2018. Strengthening the teaching of mini-practical assessment task in a senior phase technology class. Bloemfontein: University of the Free State. (Dissertation – MA).

Kuhn, T.S. 1962. The structure of scientific revolutions. Chicago, IL: Chicago Press.

Kumar, R. 2019. Research methodology: a step-by-step guide for beginners. London: Sage Publications.

Kumpikaite-Valiuniene, V. 2016. Distance learning and Facebook's usage in the study process: students' attitude. *International journal of information and education technology*, 6(2):122.

Kuna, P., Hašková, A., Skačan, M. & Záhorec, J. 2018. How to teach CAD/CAE systems. *International journal of engineering pedagogy*, 8(1):148-162.

Kus, A., Unver, E. & Taylor, A. 2009. A comparative study of 3D scanning in engineering, product and transport design and fashion design education. *Computer applications in engineering education*, 17(3):263-271.

Kusurkar, R.A., Croiset, G. & Ten Cate, O.T.J. 2011. Twelve tips to stimulate intrinsic motivation in students through autonomy-supportive classroom teaching derived from self-determination theory. *Medical teacher*, 33(12):978-982.

Kvon, G.M., Vaks, V.B., Masalimova, A.R., Kryukova, N.I., Rod, Y.S., Shagieva, R.V. & Khudzhatov, M.B. 2018. Risk in implementing new electronic management systems at universities. *EURASIA journal of mathematics, science and technology education*, 14(3):891-902.

Lauer, J.E., Yhang, E. & Lourenco, S.F. 2019. The development of gender differences in spatial reasoning: a meta-analytic review. *Psychological bulletin*, 145(6):537.

LeBow, V., Bernhardt-Barry, M.L. & Datta, J. 2018. Improving spatial visualization abilities using 3D printed blocks. Paper presented at the 2018 ASEE Annual Conference & Exposition. Salt Lake City: Utah.

Lee, V.L. 2016. Beyond behaviorism. London: Routledge.

Leedy, P.D. & Ormrod, J.E. 2013. Practical research: planning and design. 10th ed. New Jersey, NJ: Pearson Education.

Leedy, P.D., Ormrod, J.E. & Johnson, L.R. 2019. Practical research: planning and design. 12th ed. New York, NY: Pearson.

Lefèvre, W. & Baldasso, R. 2005. Picturing machines 1400-1700. *Aestimatio: critical reviews in the history of science*, 2:58-63.

Leopold, C., Gorska, R.A. & Sorby, S.A. 2001. International experiences in developing the spatial visualization abilities of engineering students. *Journal for geometry and graphics*, 5(1):81-91.

Leung, L. 2015. Validity, reliability, and generalizability in qualitative research. *Journal of family medicine and primary care*, 4(3):324.

Lieu, D.K. & Sorby, S.A. 2015. Visualization, modeling, and graphics for engineering design. s.l.: Nelson Education.

Lin, L. 2008. An online learning model to facilitate learners' rights to education. *Journal of asynchronous learning networks*, 12(1):127-143.

Liu, A., Hodgson, G. & Lord, W. 2010. Innovation in construction education: the role of culture in e-learning. *Architectural engineering and design management*, 6(2):91-102.

Liu, Z. & Zhang, S. 2018. A study on teaching reform of higher vocational courses based on constructivism. (*In* Proceedings of the 2018 2nd International Conference on Education, Economics and Management Research [ICEEMR 2018]. s.l.: Atlantis Press).

Lockhart, S.E., Goodman, M. & Johnson, C. 2018. Modern graphics communication. London: Peachpit Press.

Louw, D.A. & Louw, A.E. 2007. Child and adolescent development. Bloemfontein: Psychology Publications.

Lubis, A.H. 2018. ICT integration in 21st-century Indonesian English language teaching: myths and realities. *Cakrawala pendidikan,* (1):page range.

Mackenzie, N. & Knipe, S. 2006. Research dilemmas: paradigms, methods and methodology. *Issues in educational research*, 16(2):193-205.

Mahmud, S.N.D., Nasri, N.M., Samsudin, M.A. & Halim, L. 2018. Science teacher education in Malaysia: challenges and way forward. *Asia-pacific science education*, 4(1):8.

Makgato, M. 2015. The teaching and learning of technology: spotlight on sectional drawing among student teachers in an Eastern Cape university, South Africa. (*In* Proceedings of the 2015 TENZ Conference on 20/20 vision. Hamilton, New Zealand: TENZ. p. 1-12).

Malan, A.C. 2014. Training needs of primary school principals in the use of ICTs in school management of township and rural schools. Potchefstroom: NWU. (Dissertation – MEd)

Maree, K. 2016. First steps in research. 2nd ed. Pretoria: Van Schaik.

Martín-Erro, A., Domínguez, M. & Espinosa, M.M. 2016. The role of sketching in engineering design and its presence on engineering education. (*In* Proceedings of INTED2016 Conference 7-9 March 2016, Valencia, Spain: INTED. p. 3465-3471).

Masethe, M.A., Masethe, H.D. & Odunaike, S.A. 2017. Scoping review of learning theories in the 21th century. (*In* Proceedings of the World Congress on Engineering and Computer Science. San Francisco, CA: EUA. p. page range).

Matluba, D., Gulruh, B. & Yuldasheva, D. 2019. Effective technologies of teaching a foreign language as a second language. (*In* International Scientific and Practical Conference Innovative Ideas of Modern Youth in Science and Education. Barcelona, Spain: IATED. p. 370-371).

Mazana, M.Y., Montero, C.S. & Oyelere, S.S. 2019. Information and communication technology in mathematics education – integration readiness in Tanzania higher education institutions. (*In* International Conference on Social Implications of Computers in Developing Countries. s.l.: Springer. p. 409-420).

Mbam, B.C. 2017. Information and communication technology (ICT) in communication profession. *International journal of communication: an interdisciplinary journal of communication studies*, 5(1):page range.

McCarthy, R.V., McCarthy, M.M., Ceccucci, W. & Halawi, L. 2019. What do descriptive statistics tell us. Applying predictive analytics. s.l.: Springer.

McGill, T., Koppi, T. & Armarego, J. 2015. ICT industry involvement with ICT education and research in universities: industry perceptions. *Innovation in teaching and learning in information and computer sciences*:1-18.

McKenney, S. & Reeves, T.C. 2018. Conducting educational design research. Canada: Routledge.

McMillan, J.H. & Schumacher, S. 2010. Research in education: evidence-based inquiry. 7th ed. London: Pearson Education.

McNiff, J. 2002. Action research for professional development: concise advice for new researchers. http://www.jeanmcniff.com/ar-booklet.asp Date of access: 7 Aug. 2019.

McNiff, J. 2010. Action research for professional development: concise advice for new action researchers. New rev. ed. Poole: September Books.

McNiff, J. 2014. Writing and doing action research. London: Sage Publications.

McNiff, J. 2017. Action research: all you need to know. London: Sage Publications.

Mdlongwa, T. 2012. Information and communication technology (ICT) as a means of enhancing education in schools in South Africa. *Policy brief, Africa institute of South Africa*, vol(iss):page range.

Melovitz-Vasan, C., Gentile, M., Huff, S. & Vasan, N. 2018. Student perception of active learning group in a problem-based learning curricular environment. *Medical science educator*, 28(1):195-201.

Mentz, E. & Oostuizen, I. 2016. Self-directed learning research: an imperative for transforming the educational landscape. Durbanville: AOSIS.

Merriam, S.B. & Grenier, R.S. 2019. Qualitative research in practice: examples for discussion and analysis. s.l.: Jossey-Bass.

Merriam, S.B. & Tisdell, E.J. 2015. Qualitative research: a guide to design and implementation. s.l.: John Wiley & Sons.

Merriam-Webster Dictionary (online). 2018. https://www.merriam-webster.com/dictionary Date of access: 9 Mar. 2018.

Mertens, D.M. 1998. Research methods in education and psychology: integrating diversity. Thousand Oaks, CA: Sage Publications.

Metz, S.S., Donohue, S. & Moore, C. 2012. Spatial skills: a focus on gender and engineering. *International journal of science education*, 31:3.

Meyer, I. & Gent, P. 2016. The status of ICT education in South Africa and the way forward. s.l.: National Education Collaboration Trust.

Miles, M.B., Huberman, A.M. & Saldaña, J. 2014. Qualitative data analysis: a methods sourcebook. 3rd ed. Thousand Oaks, CA: Sage Publications.

Mills, G.E. 2018. Action research: a guide for the teacher researcher. 6th ed. New York, NY: Pearson.

Mintrop, R. 2019. Design-based school improvement: a practical guide for education leaders. Harvard, MA: Harvard Education Press.

Mohler, J.L. & Miller, C.L. 2009. Improving spatial ability with mentored sketching. *Engineering design graphics journal*, 72(1):page range.

Monette, D., Sullivan, T. & DeJong, C. 2005. Applied social research: a tool for the human services. Australia: Thomson Brooks/Cole.

Morling, K. 2010. Geometric and engineering drawing 3E. London: Routledge.

Muller, P.O. 1993. Substantiv-derivation in den Schriften Albrecht Durers. Berlin: Walter de Gruyter.

Muslem, A., Yusuf, Y.Q. & Juliana, R. 2018. Perceptions and barriers to ICT use among English teachers in Indonesia. *Teaching English with technology*, 18(1):3-23.

Naade, N., Alamina, J. & Okwelle, P. 2018. Effect of 7E's's constructivist approach on students' achievement in electromagnetic induction topic in senior secondary school in Nigeria. *Journal of education, society and behavioural science*:1-9.

Nardi, P.M. 2018. Doing survey research: a guide to quantitative methods. New York, NY: Routledge.

Nastasi, B.K. & Hitchcock, J.H. 2016. Mixed methods research and culture-specific interventions: program design and evaluation. Los Angeles, CA: Sage Publications.

Newton, S., Alemdar, M., Hilton, E., Linsey, J. & Fu, K. 2018. Incorporating industrial design pedagogy into a mechanical engineering graphics course: a discipline-based education research (DBER) approach. *International journal of STEM education*, 5(1):29.

Niemann, F.P. 1976. 'n Didaktiese studie van die onderrig van tegniese tekene (n1 en n2) aan vakleerlinge aan tegniese kolleges in die Republiek van Suid-Afrika. Bloemfontein: University of the Free State. (Dissertation – MEd)

Noordin, S. & Ahmad, W.F.W. 2010. Implementation of design and learning theories in multimedia courseware development: lines & planes in 3-dimensions. (*In* 2010 International Conference on User Science and Engineering (i-USEr). s.l.: IEEE. p. 93-97).

North-West University. 2019. Yearbook 2019 Faculty of Education: Bachelors of Education. Potchefstroom.

Norton, L. 2018. Action research in teaching and learning: a practical guide to conducting pedagogical research in universities. London: Routledge.

Oddi, L.F., Ellis, A.J. & Roberson, J.E.A. 1990. Construct validation of the ODDI continuing learning inventory. *Adult education quarterly*, 40(3):139-145.

Ogbomo, E.F. 2011. Issues and challenges in the use of information communication technology (ICTs) in education. *Information impact: journal of information and knowledge management*, 2(1):page range.

Ogunkola, B. & Knight, C. 2019. Technical drawing course, video games, gender, and type of school on spatial ability. *The journal of educational research*:1-15.

Okafor, A.C. 2015. Gender inequality in Nigeria. *Journal of research in arts social sciences*, 4(1):69-80.

Olakunle, A.A. 2018. Constructivist teaching strategies: paradigm shift for effective teaching and learning in senior secondary schools in Nigeria. *American journal of research,* (7-8):74-86.

Oliver, R.M., Wehby, J.H. & Nelson, J.R. 2015. Helping teachers maintain classroom management practices using a self-monitoring checklist. *Teaching and teacher education*, 51:113-120.

Olkun, S. 2003. Making connections: improving spatial abilities with engineering drawing activities. *International journal of mathematics teaching and learning*, 3(1):1-10.

Olowookere, S. & Iyiola, M. 2018. Challenges and prospects of the application of ICT in the teaching of business subjects. *Nigerian journal of business education*, 3(2):187-198.

Oosthuizen, I.J., Du Toit, P., Lubbe, S.I. & Klopper, R.M. 2012. Using action research to solve everyday problems in classrooms – a position paper. *Alternation: international journal for the study of Southern African literature and languages*, 218-236.

Orde, B.J. 1996. A correlational analysis of drawing ability and spatial ability. *Dissertation Abstracts International*, 57(5):1943.

Ormrod, J.E. & Leedy, P.D. 2005. Practical research: planning and design. Upper Saddle River, NJ: Publisher.

Oswald, D.F. 2003. Instructional-design theory for fostering self-directed learning. Bloomington, IN: Indiana University. (Thesis – PhD).

Ottway, J.R. 2018. Integrating CAD and CAM for design-build projects. Paper presented at the 2018 ASEE Annual Conference & Exposition. Salt Lake City, Utah https://peer.asee.org/30680 Date of access: 12 Mar. 2019.

Oviawe, J. 2016. Benefits and limitations of e-learning for technical drawing in edo state model secondary schools, Nigeria. *International journal of academic research in progressive education and development*, 5(3):52-64.

Padayachee, I. 2017. Educator perceptions of virtual learning system quality characteristics. *South African computer journal*, 29(3):95-126.

Pahl, C., Giesecke, S., Hasselbring, W. 2009. Ontology-based modelling of architectural styles. *Information and software technology*, 51(12):1739-1749.

Pan, Z., Polden, J., Larkin, N., Van Duin, S. & Norrish, J. 2012. Recent progress on programming methods for industrial robots. (*In* ISR 2010 (41st International Symposium on Robotics) and ROBOTIK 2010 (6th German Conference on Robotics)). Warsaw, Poland: VDE. p. 1-8).

Patanasakpinyo, T., Batinov, G., Whitney, K., Sulaiman, A. & Miller, L. 2019. Enhanced prediction models for predicting spatial visualization (VZ) in address verification task. (*In* Proceedings of 34th International Conference on Computers and Their Applications. Honolulu, Hawaii: EPiC. p. 247-256).

Piaget, J. & Inhelder, B. 1971. Mental imagery in the child. London: Routledge & Kegan Paul.

Plano Clark, V.L. & Creswell, J. 2011. Designing and conducting mixed methods research. Los Angeles, CA: Sage Publications.

Rabah, J. 2015. Benefits and challenges of information and communication technologies (ICT) integration in Québec English schools. *Turkish online journal of educational technology*, 14(2):24-31.

Ramadan, A., Chen, X. & Hudson, L.L. 2018. Teachers' skills and ICT integration in technical and vocational education and training TVET: a case of Khartoum state-Sudan. *World journal of education*, 8(3):31-43.

Rambrij, R. 2018. Technology literacy for teachers in rural schools: constructing key concepts in technology education for teachers in the Ilembe District. Durban: Durban University of Technology. (Thesis – PhD).

Ranjan, S. s.a.. Constructivism: a sustainable learning approach. *Gitarattan journal of education*:37.

Raynaud, D. 2016. Knowledge and beliefs regarding linear perspective. *Studies on binocular vision*, 47:15-35.

Reddy, K.V. 2008. Textbook of engineering drawing. Hyderabad: BS Publications.

Reid, A., Hart, E.P. & Peters, M. 2014. A companion to research in education. Dordrecht: Springer.

Reuter, R., Hauser, F., Gold-Veerkamp, C., Mottok, J. & Abke, J. 2017. Towards a definition and identification of learning obstacles in higher software engineering education. (*In* Proceedings of the 9th International Conference on Education and New Learning Technologies (IATED EDULEARN), Barcelona, Spain: EDULEARN. p. 10259-10267).

Shariffudin, R.S., Lee, M.F. & Othman, W. 2006. E-engineering drawing: a web based system for teaching and learning engineering drawing for upper secondary school. (*In* Proceedings of the 6th South East Asian Association for International Research (SEAAIR) Annual Conference, Langkawi: SEAAIR. p. 96-101).

Robertson, J. 2010. Promoting self directed learning skills in first-year students. *Computers and education*, 57(2):1628-1644.

Rodriguez, J. & Rodriguez-Velazquez, L.G. 2017. Spatial visualization skills in courses with graphics or solid modeling content. (*In* proceedings of 2017 IEEE Global Engineering Education Conference (EDUCON). Athens: IEEE. p. 1778-1781).

Rust, C. 2017. Facilitating the implementation of computer-aided design into the engineering graphics design classroom. Pretoria: University of Pretoria. (Dissertation – MEd).

Rutten, N., Van Joolingen, W.R. & Van der Veen, J.T. 2012. The learning effects of computer simulations in science education. *Computers & Education*, 58(1):136-153.

Sakarovitch, J. 2009. Gaspard Monge founder of “constructive geometry”. (*In* Proceedings of the Third International Congress on Construction History. Berlin: NEUNPLUS1. p. 1293-1299).

Saldaña, J. 2015. The coding manual for qualitative researchers. London: Sage Publications.

Sampaio, A.Z. 2019. Enhancing BIM Methodology with VR Technology. s.l.: Intech Open, p. 59-79.

SANS (South African National Standards). 1994. Building drawing Practice. Pretoria: SABS, Standard Divisions. (SANS 10143-1:1994).

SANS (South African National Standards). 2011. Engineering Drawings Part 1: General principles. Pretoria: SABS, Standard Divisions. (SANS 10111-1:2011).

Schreier, M. 2018. Sampling and generalization. *The Sage handbook of qualitative data collection*:84-98.

Seidel, J. 1998. The ethnograph: a users guide. Version 5.0. Colorado: Qualis Research.

Selivanova, N.L. & Tagunova, I.A. 2016. The role of information technologies in the development of school social education practice. (*In* SHS Web of Conferences. Moscow: EDP Sciences. p. 01061).

Serdar, T. & Harm de Vries, P. 2015. Enhancing spatial visualization skills in engineering drawing course. (*In* Proceedings of the 122nd Meeting of the American Society for Engineering Education, Seattle: ASEE).

Sharma, G. & Dumpala, R. 2015. Teaching of mechanical engineering concepts through three-dimensional geometric modeling. *International journal of mechanical engineering education*, 43(3):180-190.

Shenton, A.K. 2004. Strategies for ensuring trustworthiness in qualitative research projects. *Education for information*, 22(2):63-75.

Singh-Pillay, A. & Sotsaka, D.S. 2017. Engineering graphics and design teachers' understanding and teaching of assembly drawing. *EURASIA journal of mathematics, science and technology education*, 13(5):1213-1228.

SolidWorks. 2018. Solidworks online help http://help.solidworks.com/2018/english/SolidWorks/sldworks/c_introduction_toplevel_topic.htm?verRedirect=1 Date of access: 15 Sep. 2018.

Sorby, S.A. & Wysocki, A.F. 2003. Introduction to 3D spatial visualization: an active approach. s.l.: Cengage Learning.

Sorby, S.A. 2009. Educational research in developing 3-D spatial skills for engineering students. *International journal of science education*, 31(3):459-480.

Spady, W. 2001. Beyond counterfeit reforms: forging an authentic future for all learners: a scarecrow education book. s.l.: ERIC.

Spear, R. 2019. Best CAD software of 2019 https://www.toptenreviews.com/software/multimedia/best-cad-software/ Date of access: 15 Mar. 2019.

Srivastava, S. & Dangwal, K.L. 2017. Constructivism: a paradigm to revitalize teacher education. *International journal of applied research*, 3(5):753-756.

Stewart, R.A. 2007. Investigating the link between self directed learning readiness and project-based learning outcomes: the case of international master's students in an engineering management course. *European journal of engineering education*, 32(4):453-465.

Sujanem, R., Poedjiastuti, S. & Jatmiko, B. 2018. The effectiveness of problem-based hybrid learning model in physics teaching to enhance critical thinking of the students of SMAN. *Journal of physics: conference series*:012040.

Sullivan, B., Glenn, M., Roche, M. & McDonagh, C. 2016. Introduction to critical reflection and action for teacher researchers. London: Routledge.

Sutherland, I. 2012. The TX-2 computer and sketchpad. *Lincoln laboratory journal*, 19(1):82-84.

Tajvidi, M. & Fang, N. 2015. Application of computer simulation and animation (CSA) in teaching and learning engineering mechanics. (*In* proceedings of American

Society for Engineering Education (ASEE) Annual Conference and Exposition. Seattle, WA: ASEE. p. 23560).

Tambaoan, R.S. & Gaylo, D.N. 2019. Differentiating Instruction in a mathematics classroom: its effects on senior high school learners' academic performance and engagement in basic calculus. *International journal of English and education,* 8(2):272-286.

Taylor, C., Wilkie, M. & Baser, J. 2006. Doing action research: a guide for school support staff. London: Sage Publications.

Thanh, N.C. & Thanh, T. 2015. The interconnection between interpretivist paradigm and qualitative methods in education. *American journal of educational science*, 1(2):24-27.

Thornton, K. 2010. Supporting self-directed learning: a framework for teachers. *Research and practice in English language teaching in Asia*:59.

Timothy, T., Chee, T.S., Beng, L.C., Sing, C.C., Ling, K.J.H., Li, C.W. & Mun, C.H. 2010. The self-directed learning with technology scale (SDLTS) for young students: an initial development and validation. *Computers & education*, 55(4):1764-1771.

Titmus, C.J. 2014. Lifelong education for adults: an international handbook. Sydney: Elsevier.

Tolmay, P.J. 2017. Die implementering van projekgebaseerde leer deur eerstejaar-ingenieurstudente om selfgerigte leer te bevorder. North-West University: Potchefstroom Campus. (Dissertation – MEd).

Triana, M., Zubainur, C.M. & Bahrun, B. 2019. Students' mathematical communication ability through the brain-based learning approach using autograph. *Journal of research and advances in mathematics education*, 1(1):1-10.

Tripp, D. 2003. Action inquiry. *Action research e-reports,* (17):1-22.

Trnova, E. & Trna, J. 2015. Motivational effect of communication technologies in connectivist science education. *Online journal of communication and media technologies*, 5(3):107-119.

Trochim, W.M. 2006. Qualitative measures. *Research measures knowledge base*, 361:29-31.

United Nations Educational, Scientific and Cultural Organisation. 2011. UNESCO ICT Competency Framework for Teachers. Paris.

Urdarevik, S.A.M. 2013. Learning the essential concepts of engineering graphics and autocad® 2014: all books and monographs by WMU authors. Kalamazoo, MI: Western Michigan University.

Valls, R., Black, C. & Lee, M.M. 2019. Five years of integrating science and dance: a qualitative inquiry of constructivist elementary school teachers. *Research in dance education*:1-17.

Van As, F. 2018. Communities of practice as a tool for continuing professional development of technology teachers' professional knowledge. *International journal of technology and design education*, 28(2):417-430.

Van der Poll, H., Van der Poll, V. & Andrew, J. 2018. E-learning technologies for open distance learning knowledge acquisition in managerial accounting. *Informing Science and IT Education*: 189-203.

Victor, A.A. & Bolanle, R.R. 2017. Extent of information and communication technology (ICT) utilization for students' learning in tertiary institutions in Ondo State, Nigeria. *Online submission*, 3(3):2369-2376.

Viljoen, W.J. 2014. Die integrasie van rekenaarondersteunde tekeninge as hulpmiddel in die onderrig van onderwysstudente in ingenieursgrafika en-ontwerp. Bloemfontein: University of the Free State. (Dissertation – MEd).

Vitruvius, M. 1914. The ten books on architecture. Translated in English by M.H. Morgan). New York, NY: Dover.

Wang, H.-C., Chang, C.-Y. & Li, T.-Y. 2006. The comparative efficacy of 2D-versus 3D-based media design for influencing spatial visualization skills. *Computers in human behavior*, 23(4):1943-1957.

Waurzyniak, P. 2010. Masters of manufacturing: Patrick J. Hanratty. *Manufacturing Engineering*, 145(1):39-45.

Webster, V.A. 2017. Development of organic machines and biohybrid robots. Cleveland, OH: Case Western Reserve University. (Dissertation – PhD).

Weinberg, R.S. & Tomal, J.A. 2005. Advising student software development teams for maximum performance. *Interactive convergence: critical issues in multimedia*:179.

Weisberg, D.E. 2008. The engineering design revolution: the people, companies and computer systems that changed forever the practice of engineering. *Cyon research corporation*:1-26.

Wheeler, M.W. 2018. The effects of record-keeping on teacher self-efficacy and student self-regulation in the primary Montessori classroom. Saint Paul, Minnesota: St. Catherine University. (Dissertation – MEd).

Whitehead, J. 2009. You and your action research project. London: Routledge.

Whitehead, J. & McNiff, J. 2006a. Action research living theory. London: Sage Publications.

Whitehead, J. & McNiff, J. 2006b. Action research: living theory. New York: Sage Publications.

Williamson, S.N. 2007. Development of a self-rating scale of self-directed learning. *Nurse researcher*, 14(2).

Wilson, B.G. 2017. Constructivism for active, authentic learning. *Trends and issues in instructional design and technology*:61.

Wilson, J.D. 2018. Student learning in higher education. London: Routledge.

Winton, A. 2016. Using photography as a creative, collaborative research tool. *The qualitative report*, 21(2):428-449.

Wisniewska, D. 2011. Mixed methods and action research: similar or different? *GLOTTODIDACTICA XXXVII Poznań University Press* : 59-72.

Wohlers, T. & Gornet, T. 2014. History of additive manufacturing. Fort Collins, Colorado: Wohlers Associates.

Xiao, Y., Wan, S., Wang, F. & Li, Y. 2016. The application of 3D printing and ICT technology in structure research. (*In* Proceedings of the 19th World Conference on Non-Destructive Testing (NDT). Munich: NDT. p. 71-75).

Yasin, R.M., Halim, L. & Ishar, A. 2012. Effects of problem-solving strategies in the teaching and learning of engineering drawing subject. *Asian social science*, 8(16):65-79.

Yue, J. 2006. Spatial visualization by isometric drawing. (*In* Proceedings of the 2006 IJMEINTERTECH Conference. New Jersey, NJ: Union. p. 302-326).

Yuming, L. 2010. Strategic ponders of Beijing constructing world city. *Journal of Beijing vocational college of finance and commerce,* (1):3.

Zhu, D.C., Ferguson, M.S. & DeMarco, J.K. 2008. An optimized 3D inversion recovery prepared fast spoiled gradient recalled sequence for carotid plaque hemorrhage imaging at 3.0 T. *Magnetic resonance imaging*, 26(10):1360-1366.

ADDENDUM A

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Private Bag X6001, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Web: http://www.nwu.ac.za

School for Natural Sciences and Technology
Faculty of Education Sciences, NWU
Potchefstroom
Building B9
Room G05

Tel: 0182994234

Email: 25311697@nwu.ac.za

PARTICIPANT INFORMATION AND CONSENT FORM

I herewith wish to request your consent to participate in this research, which involves EGDD 421 education students in the FET phase of the NWU Potchefstroom campus. Before you give consent, please acquaint yourself with the information below.

The details of the research are as follows:

TITLE OF THE RESEARCH: A Framework for advanced Information Communication Technologies integration within Higher Education Engineering Graphics and Design to improve spatial visualization

PROJECT SUPERVISOR: Prof CP van der Westhuizen
ADDRESS: Building C6 Potchefstroom campus
CONTACT NUMBER: 018 299 4734

MEMBER OF PROJECT TEAM PhD-Student: Mr AC Kemp
ADDRESS: Building B9
CONTACT NUMBER: 018 299 4234

This study has been approved by the Ethics committee of the Faculty of Education Sciences of the North-West University and will be conducted according to the ethical guidelines of this committee. Permission was also asked from the Dean of the Faculty of Education Sciences as well as the Director of the School of Natural Sciences and Technology.

What is this research about?
The principle aim of this proposed study is to describe a suitable framework to foster spatial visualization skills with the integration of advanced ICT's in EGD within Higher Education. The research objectives are to:

- Determine the main advantages and barriers of EGD and ICT globally and in South-Africa;
- determine to what extent ICT's are implemented in EGD in Higher Education at this tertiary institution;
- discover to what extent does advanced ICT's enhance spatial visualization;

- discover ICT and spatial visualization skills to be further developed to enhance EGD within Higher Education and
- to propose a suitable framework for the implementation of advanced ICT integration in EGD to foster spatial visualization.

Participants
All students registered for EGDD421.

What is expected of you as participant?
To attend all EGDD 421 classes and complete Session 1 -10 of 3D CAD.
Write a pre and post-test regarding mechanical assembly drawings.
Complete a questionnaire twice at the start of the semester and at the end of the semester.
To give feedback on the implementation of ICT in EGD in focus group discussions.

Benefits to you as participant

For the EGD student teacher this study proposes the integration of EGD and ICT to improve spatial visualization. Furthermore, it should improve the student teachers' ability to understand mechanical assembly drawings and how the different components fit together and it should improve the student teachers' ability to understand the sectioning of mechanical drawings.

For the educator this study should improve the educator's understanding of sectioned mechanical assembly drawings and how to integrate EGD and ICT to improve the students' spatial visualization. It should furthermore advance the educators teaching and learning of EGD.

Risks involved for participants
Not applicable

Confidentiality and protection of identity
All tests and questionnaires will be done anonymously.
Data and results will be kept and stored in a secure location for 5 years.

Dissemination of findings
The study will entail the researcher to develop a Mental Machine Assembly Cutting Test (MMACT) which will improve on the student teachers' spatial visualization of sectioned drawings and assembly drawings. The study will add to the body of knowledge to improve the integration of ICT and EGD on secondary and tertiary level.

If you have any further questions or enquiries regarding your participation in this research, please contact the researchers for more information.

By signing below, I …………………………………..………… agree to take part in a research study entitled:

The relationship between the professional wellbeing of teachers and principals' leadership styles.

I declare that:

- I have read this information and consent form and understand what is expected of me in the research.
- I have had a chance to ask questions to the researcher and all my questions have been adequately answered.
- I understand that taking part in this study is voluntary and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the research process before it has finished, if the researcher feels it is in my best interests, or if I do not follow the research procedures, as agreed to.

Signed at (place)___________________________on (date) ______/______/2017

______________________ ______________________

Signature of participant **Signature of witness**

ADDENDUM B

NORTH-WEST UNIVERSITY ®
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Focus group interview (students):

The following questions will be used in order to explore the possible ways students construct their understanding of sectional mechanical assembly drawings.

1. As an Engineering Graphics and Design (EGD) student teacher tell me, which drawings are seen as one of the most difficult drawings?
2. As an EGD student teacher tell me why you think sectional mechanical assembly drawings are important in the secondary and tertiary curriculum?
3. What challenges do you think students have in understanding sectional mechanical assembly drawings?
4. What can be used in EGD teaching to overcome the challenges in understanding sectional mechanical assembly drawings?
5. What do you think the main advantages are in implementing Information Communication Technologies (ICT's) in EGD?
6. Have you ever used advanced ICT's in EGD, which ICT's did you use?
7. What do you think the main barriers are in implementing ICT's in EGD?
8. To what extent does advanced ICT's enhance the student's spatial visualization to improve the understanding of sectional mechanical assembly drawings?

ADDENDUM C

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Focus group interview (Lecturers):

The following questions will be used in order to explore the possible ways students construct their understanding of sectional mechanical assembly drawings.

1. As an Engineering Graphics and Design (EGD) lecturer tell me why you think sectional mechanical assembly drawings are seen as one of the most difficult drawings?
2. As an EGD lecturer tell me why you think sectional mechanical assembly drawings are important in the secondary and tertiary curriculum?
3. What challenges do you think students have in understanding sectional mechanical assembly drawings?
4. What can be used in EGD teaching to overcome the challenges in understanding sectional mechanical assembly drawings?
5. What do you think the main advantages are in implementing Information Communication Technologies (ICT's) in EGD?
6. Have you ever used advanced ICT's in EGD, which ICT's did you use?
7. What do you think the main barriers are in implementing ICT's in EGD?
8. To what extent does advanced ICT's enhance the student's spatial visualization to improve the understanding of sectional mechanical assembly drawings?

ADDENDUM D

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Focus group interview (students):

The following questions will be used in order to explore if advanced ICT's did construct students' understanding of sectional mechanical assembly drawings.

1. As an Engineering Graphics and Design (EGD) student teacher, tell me if the use of CAD helped you to understand and be able to draw assembly of sectional mechanical assembly drawings? **Motivate why.**

2. As an Engineering Graphics and Design (EGD) student teacher, tell me if the animations on The Depot™ helped you to understand and be able to draw the online sessions? **Motivate why.**

3. As an Engineering Graphics and Design (EGD) student teacher, tell me if 3D components (printed on 3D printer) will help you to understand the assembly of sectional mechanical assembly drawings? **Motivate why.**

ADDENDUM E

Name: ______________________

Surname: ______________________

Student number: ______________________

NORTH-WEST UNIVERSITY ®
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Pre-test

Self-Directed learning with Technology Scale (SDLTS) for Engineering Graphics and Design (EGD 421) students.

Directions: Please read each statement and circle the number that best describes your thoughts and feelings about your own learning. There is no right or wrong answer.

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree

1	I go online to ask my lecturer questions on my EGD lessons when I am not in class.	1	2	3	4	5
2	I use the computer to share my thoughts and ideas about my EGD classwork (e.g., through multimedia, The Depot, eFundi)	1	2	3	4	5
3	I found out more information on the internet to help me understand my EGD lessons better.	1	2	3	4	5
4	I use the computer to work with information for my EGD learning.	1	2	3	4	5
5	I practice skills that I learnt in class through drawing on CAD.	1	2	3	4	5
6	I use the computer to become better at a skill that I am interested in (e.g., drawing skills)	1	2	3	4	5
7	I use the computer to get ideas from different websites and people to learn more about a topic.	1	2	3	4	5

(Timothy et al: 2010)

ADDENDUM F

Name: ______________________

Surname: ______________________

Student number: ______________________

NORTH-WEST UNIVERSITY ®
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Post-test

Self-Directed learning with Technology Scale (SDLTS) for Engineering Graphics and Design (EGD 421) students.

Directions: Please read each statement and circle the number that best describes your thoughts and feelings about your own learning. There is no right or wrong answer.

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree

1	I go online to ask my lecturer questions on my EGD lessons when I am not in class.	1	2	3	4	5
2	I use the computer to share my thoughts and ideas about my EGD classwork (e.g., through multimedia, The Depot, eFundi)	1	2	3	4	5
3	I found out more information on the internet to help me understand my EGD lessons better.	1	2	3	4	5
4	I use the computer to work with information for my EGD learning.	1	2	3	4	5
5	I practice skills that I learnt in class through drawing on CAD.	1	2	3	4	5
6	I use the computer to become better at a skill that I am interested in (e.g., drawing skills)	1	2	3	4	5
7	I use the computer to get ideas from different websites and people to learn more about a topic.	1	2	3	4	5

(Timothy et al: 2010)

ADDENDUM G

NORTH-WEST UNIVERSITY ®
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Benodigdhede vir hierdie vraestel/Requirements for this paper:			
Antwoordskrifte/ Answer scripts:		Multikeusekaarte (A5)/ Multi-choice cards (A5):	
Presensiestrokies (Invulvraestel)/ Attendance slips (Fill-in paper):		Multikeusekaarte (A4)/ Multi-choice cards (A4):	
Rofwerkpapier/ Scrap paper:	X	Grafiekpapier/ Graph paper:	

Sakrekenaars/Calculators: Ja/Yes

Ander hulpmiddels/Other resources:

Skootrekenaar/
Laptop

Tipe Assessering/ Type of Assessment:	**Voor toets / Pre-Test**	Kwalifikasie/ Qualification:	**BEd**
Modulekode/ Module code:	**EGDD 421**	Tydsduur/ Duration:	**3 ure** / **3 hours**
Module beskrywing/ Module description:	**Ingenieursgrafika en Ontwerp / Engineering Graphics and Design**	Maks/ Max:	**80**
Eksaminator(e)/ Examiner(s):	**Mnr/Mr AC Kemp**	Datum/ Date:	
Moderator(s):		Tyd/ Time:	

Inhandiging van antwoordskrifte/Submission of answer scripts: Gewoon/Ordinary

Beantwoord die volgende vrae op Turbo CAD.
Gebruik die korrekte tekentegnieke en toon toepaslike konstruksie- en projeksielyne.
Waar mate nie gegee word nie, moet u eie logiese afleidings gebruik word.
Rond die tekenblad af met die nodige A3 omranding, tekensimbole, byskrifte, ens.
Netheid en uitleg sal ook in aanmerking geneem word.
Stoor u tekening as volg: U van en studentenommer en dien u tekening in op eFundi

Answer the following questions on Turbo CAD.
Use the correct drawing techniques and show applicable construction lines and projection lines.
Where measurements are not given, make your own logical deductions.
Finish off the drawing page with the necessary A3 border, drawing symbols, captions, etc.
Neatness and exposition will be taken into account.
Save your drawing as follows: Your surname and student number and submit your drawing on eFundi

VRAAG 1 / *QUESTION 1*

Onderdelelys / *Parts list*

Nommer/*Number*	Onderdele/*Parts*	Aantal/*Required*
1	Voetstuk/ *Base*	1
2	Beweegbare kaak/ *Movable jaw*	1
3	Klemkaak vir beweegbare kaak /*Movable jaw clamp plate*	1

4	Allenskroef / *Allen screw*	2
5	Klemskroef / Clamping screw	1
6	Hefboom vir klemskroef / *Clamping screw lever*	1
7	Keerring / *Retaining clip for clamping screw*	1
8	Keerringsluitmoer / *Lock nut for retaining nut*	1

Teken volgens skaal 1:1 in eerstehoekse ortografiese projeksie, die volgende aansig van die saamgestelde **Masjienskroef** (Figuur 1).

*Draw according to scale 1:1 in first angle orthographic projection, the following view of the assembled **Machine vice** (Figure 1).*

1.1 'n Volsnit-vooraansig / *A fully sectioned front view.*

1.2 'n Linkeraansig / *A left view*

1.3 'n Bo-aansig / *A top view*

1.4 Geen verborge besonderhede word verlang nie / *No hidden detail required.*

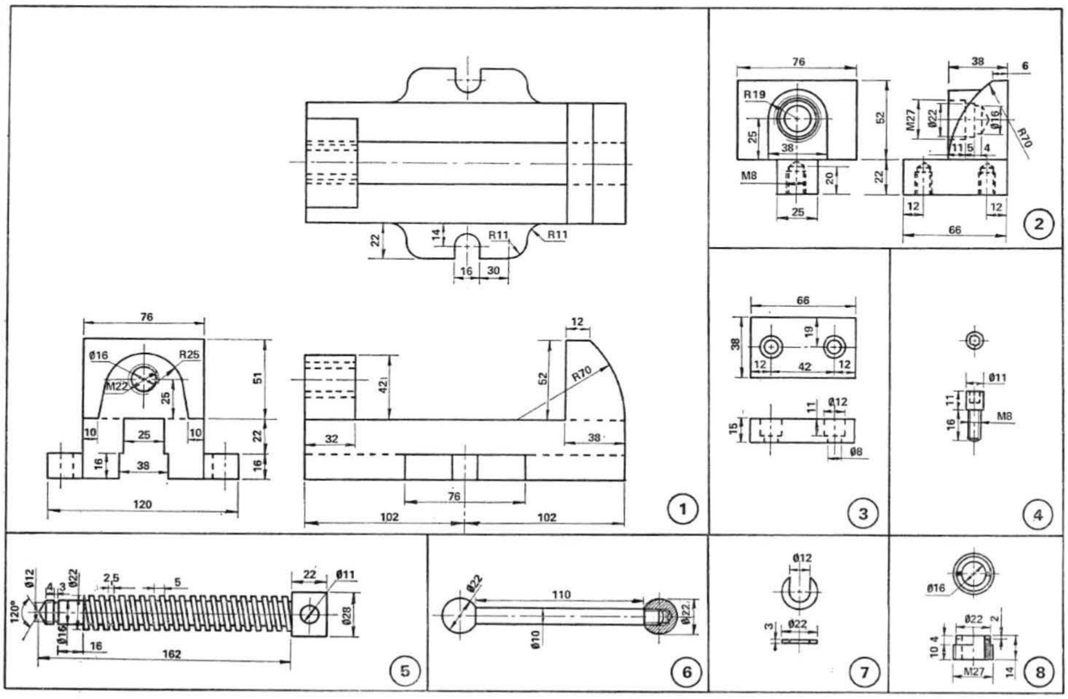
1.5 Titel, skaal, simbool en 10 afmetings / *Title, scale, symbol and 10 dimensions.*

1.6 Stoor die tekening volgens 'n geskikte skaal en rond die tekening af met 'n A3 titelblok.

Save the drawing to an appropriate scale and finish off the drawing with an A3 title block.

[80]

Figuur / Figure 1



Viljoen, KN. nd. Machine Drawing and Design. South Africa: Nasou Limited.

TOTAAL/TOTAL: 80

Verwysingsnommer: 8.1.7.2.2

ADDENDUM H

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Benodigdhede vir hierdie vraestel/Requirements for this paper:			
Antwoordskrifte/ Answer scripts:		Multikeusekaarte (A5)/ Multi-choice cards (A5):	
Presensiestrokies (Invulvraestel)/ Attendance slips (Fill-in paper):		Multikeusekaarte (A4)/ Multi-choice cards (A4):	
Rofwerkpapier/ Scrap paper:	x	Grafiekpapier/ Graph paper:	

Sakrekenaars/Calculators: Ja/Yes

Ander hulpmiddels/Other resources:

Skootrekenaar/ Laptop

Tipe Assessering/ Type of Assessment:	Post test	Kwalifikasie/ Qualification:	BEd
Modulekode/ Module code:	EGDD 421	Tydsduur/ Duration:	3 ure 3 hours
Module beskrywing/ Module description:	Ingenieursgrafika en Ontwerp / Engineering Graphics and Design	Maks/ Max:	80
Eksaminator(e)/ Examiner(s):	Mnr/Mr AC Kemp	Datum/ Date:	
Moderator(s):		Tyd/ Time:	

Inhandiging van antwoordskrifte/Submission of answer scripts: Gewoon/Ordinary

Beantwoord die volgende vrae op Turbo CAD.
Gebruik die korrekte tekentegnieke en toon toepaslike konstruksie- en projeksielyne.
Waar mate nie gegee word nie, moet u eie logiese afleidings gebruik word.
Rond die tekenblad af met die nodige A3 omranding, tekensimbole, byskrifte, ens.
Netheid en uitleg sal ook in aanmerking geneem word.
Stoor u tekening as volg: U van en studentenommer en dien u tekening in op eFundi

Answer the following questions on Turbo CAD.
Use the correct drawing techniques and show applicable construction lines and projection lines.
Where measurements are not given, make your own logical deductions.
Finish off the drawing page with the necessary A3 border, drawing symbols, captions, etc.
Neatness and exposition will be taken into account.
Save your drawing as follows: Your surname and student number and submit your drawing on eFundi

VRAAG 1 / *QUESTION 1*

Onderdelelys / *Parts list*

Nommer/*Number*	Onderdele/*Parts*	Aantal/*Required*
1	Voetstuk/ *Base*	1
2	Kap / *Cap*	1
3	Boonste helfte van draaglaer/*Upper half of bearing*	1

4	Onderste helfte van draaglaer / *Lower half of the bearing*	1
5	Bout / *Bolt*	2
6	Moer / *Nut*	2
7	Sluitmoer / *Lock nut*	2

Teken volgens skaal 1:1 in eerstehoekse ortografiese projeksie, die volgende aansig van die saamgestelde **Laerhouer** (Figuur 1).

*Draw according to scale 1:1 in first angle orthographic projection, the following view of the assembled **Block bearing** (Figure 1).*

1.1 ʼn Volsnit-vooraansig / *A fully sectioned front view.*

1.2 ʻn Linkeraansig / *A left view*

1.3 ʻn Bo-aansig / *A top view*

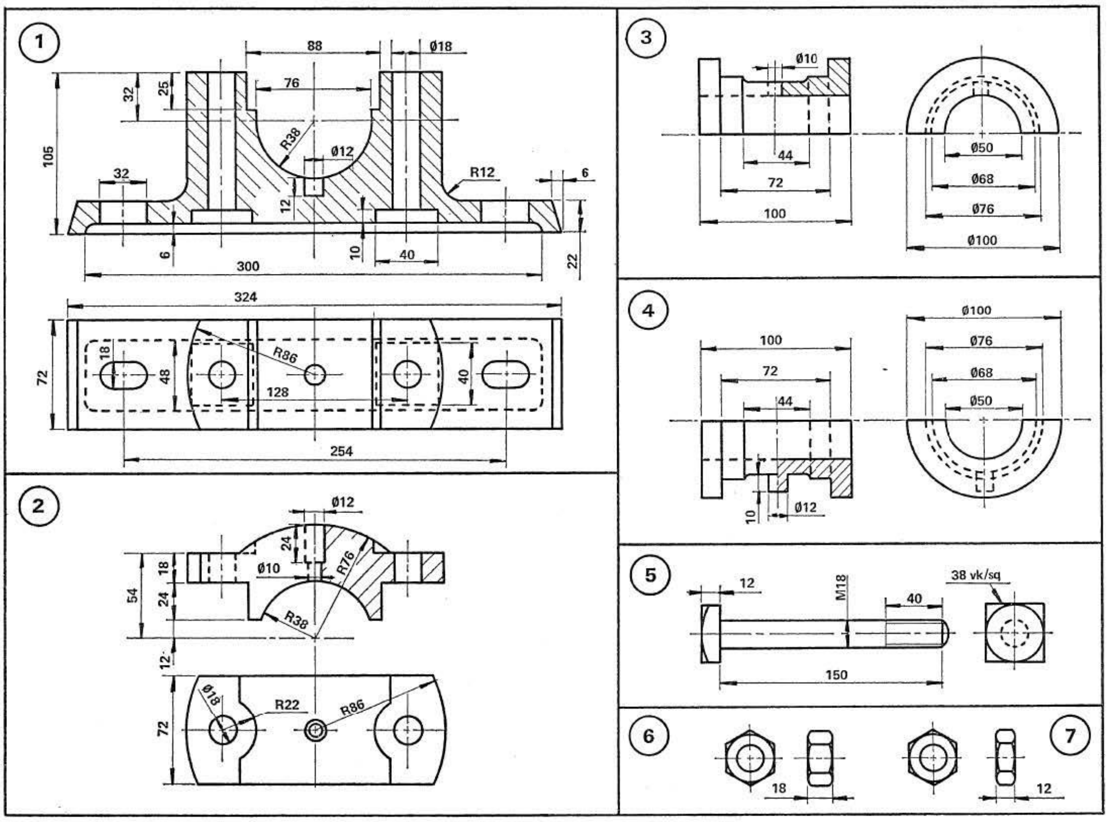
1.4 Geen verborge besonderhede word verlang nie / *No hidden detail required.*

1.5 Titel, skaal, simbool en 10 afmetings / *Title, scale, symbol and 10 dimensions.*

1.6 Stoor die tekening volgens ʻn geskikte skaal en rond die tekening af met ʼn A3 titelblok.

Save the drawing to an appropriate scale and finish off the drawing with an A3 title block.

Figuur / *Figure 1*



Viljoen, KN. nd. Machine Drawing and Design. South Africa: Nasou Limited.

TOTAAL/TOTAL: 80

Verwysingsnommer: 8.1.7.2.2

ADDENDUM I

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS
Fakulteit Opvoedkunde / Faculty Education
Privaatsak / Private Bag X6001, Potchefstroom
Suid-Afrika / South Africa 2520
T: 018 299 4656
F: 086 661 8589
http://www.nwu.ac.za

3 September 2019

To Whom It May Concern

I hereby confirm that the ethics application, as stated below, was approved at the Ethics Committee meeting of the Faculty of Education of 17 August 2017.

Ethics number: NWU-00532-17-A2

Project head: Prof C van der Westhuizen

Project team: AC Kemp

Title: A Framework for advanced Information Communication Technologies integration within Higher Education Engineering Graphics and Design to improve spatial visualization

Period: 1 June 2017 – 1 June 2018

Clearance given for only one year. Extension can be requested after a year.

Risk level: Low

Should you have further enquiries in this regard, you are welcome to contact Prof Jako Olivier at 018 285 2078 or by email at Jako.Olivier@nwu.ac.za or Ms Erna Greyling at 018 299 4656 or by email at Erna.Greyling@nwu.ac.za .

Yours sincerely

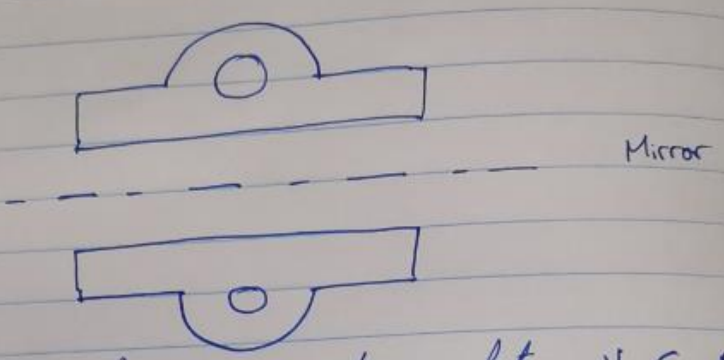
Prof J Olivier
Chair Edu-REC

ADDENDUM J

14.08.17

Session 2

Gietstuk



- Funksies wat help met die skets V, G, M, J
  V - Vertex snaps to begining and end of lyn
  G - Grid snaps to grid.
  M - Middle snap to middle of lyn
  J - Project ⊥ 90°

  ICT skills

- 3D Model deur die klas gestuur, studente kan presies sien wat van hul verwag word.

  Spatial skills.

- Scenario - Diefstal vir Sessie 3 - Critical skills

- Observasies deur die les. - Studente geniet die 3D sketse meer as 2D.
  Studente snap die werk ook baie makliker.
  Veral as hul die model sien hul hand het verstaan hul dit wel beter.

PROOF OF EDITING

CERTIFICATE OF LANGUAGE EDITING

Dr. L. Hoffman

Kroonstad

BA, BA(Hons), MA, DLitt et Phil, Certificate (English Grammar for Editors)

Member of South African Translators' Institute – No. 1003545

Cell no: 079 193 5256 Email: larizahoffman@gmail.com

DECLARATION

To whom it may concern

I hereby confirm that I have proofread and edited the language of the following thesis, including the bibliography.

Title of thesis

A framework for advanced Information Communication Technologies integration within Higher Education Engineering Graphics and Design to improve spatial visualization

Candidate

A.C. Kemp

Lariza Hoffman

Kroonstad

29 October 2019