University of Zululand

Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University

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DECLARATION

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

10 December 2018

Signature Date

ABSTRACT

Studies pertaining to the relationship and effect of prior spatial experience, gender and how they influence three-dimensional (3D) solid modelling as well as different cognitive styles on the spatial visualisation skills has little to no evidence, especially in graphics design students at rural–universities. Additionally, graphics design students often struggle to understand, process and convert multi-faceted objects from orthographic two-dimensional (2D) views into isometric projections (3D). However, ongoing study established a strong link between spatial visualisation skills and the effective completion of graphics design content. Moreover, conventional teaching and learning practice using textbooks, physical models, and pencil drawings were found to be insufficient for improving spatial visualisation skills among pre-service teacher students at a rural-university. These challenges formed the basis of the present study which focused on the relation and effect of prior spatial experience, gender, three-dimensional (3D) solid modelling software and different cognitive styles on the spatial visualisation skills of graphics design students at a rural–university. Students at this university are from disadvantaged and under-resourced schools and they arrive at university with little or no computer-based experience. Underpinned by Piaget's perception and imagery theory, the study determined the effect of 3D solid computer modelling on students' spatial visualisation skills. The study was carried out at the University of Zululand (UNIZULU) a rural-based university, comprising 200 pre-service teachers undertaking a graphics design module.

Research method included mixed methods sequential research design. The study employed a spatial experience questionnaire, the Purdue Spatial Visualisation Test and semi-structured interviews to evaluate students' prior spatial experiences, gender differences, spatial visualisation skills and cognitive styles before and after a 3D solid computer modelling intervention.

Based on the research focus, the findings showed no relation between prior spatial experience, gender and spatial visualisation skills, however, mathematics and sketching activity emerged as strong predictors for spatial visualisation. The findings also showed that there was a significant difference with a moderate positive effect in the spatial visualisation skills between the students in the experimental group and those in the control group. As a consequence, a model was developed, aimed at improving rural-based instruction and learning for 2D to 3D drawing.

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ACRONYMS AND ABBREVIATIONS

- 2D drawing – a way of representation using orthographic projection to create an image where only two of the three dimensions of the object are seen such as in polygons (Morling, 2010).

- 3D drawing – a way of representing an object, also referred to as a pictorial, so that all three dimensions of the object are visible such as in cubes, prisms, pyramids, spheres, cones, and cylinders (Morling, 2010).

- 2D to 3D drawing – the process of converting the 2D views of an object into a 3D pictorial representation of the object (Benade & Van den Heever, 1993).

- Isometric projection - Isometric projection is a method of drawing with instruments which gives a pictorial view of an object (Morling, 2010).

- Orthographic projection – Orthographic projection is a multi-view drawing allowing any number of views of the same object (Morling, 2010).

- Pictorial – These are drawings that are ideal for showing a realistic appearance of an object, similar to a picture, in 3D, such as isometric, oblique and perspective (Wilson, 1991, p. 177).

- Spatial visualisation - is the ability to imagine the manipulations of objects mentally; this requires the mental rotation of a 2D or 3D object in space (Halpern, Oh, Tremaine, Chiang, & Silver, 2016).

- 3D solid computer modelling - a three-dimensional, computer- generated model of an object that resides in three-dimensional space.

- Technology education - the preparation of teachers that will teach the subject of technology (Makgato & Khoza, 2016).

- Solid modelling - a 3D computer- generated model of an object that resides in three-dimensional space.

- Visualisation – “the formation of mental images” (Kösa & Karakuş, 2017).

CHAPTER 1: ORIENTATION TO THE STUDY

1.1 INTRODUCTION

This study was conducted to understand and explain the nuances of pre-service teachers' spatial visualisation skills. The pre-service teachers, in this study, were enrolled for a graphics design module at a rural-based South African university. The purpose of this study was to investigate the relationship and impact of factors such as prior spatial experience, gender, three dimensional (3D) solid modelling and different cognitive styles on students' spatial visualisation skills. The intention of this study was to develop an instructional and learning model for two dimensional (2D) to 3D drawing at a rural–university.

In the past 34 years, substantial research has given indication that spatial visualisation skills are an important human skill, a vital trait in human intelligence and fundamentally important in engineering and technology fields (Linn & Petersen, 1985; Rafi, Anuar, Samad, Hayati, & Mahadzir, 2005; Rodriguez & Rodriguez, 2016). Sufficient work has already shown that "the link between visualisation and engineering drawing is well established and not only do practising engineers report using visual images as an essential part of the design process, but many teachers of engineering graphics state that visualisation forms an integral part of the courses they teach" (Potter & Van der Merwe, 2001, p. 3). Besides the positive link between spatial visualisation and graphics design, work by amongst others, Newcombe and Baenninger (1989) and Rafi, Samsudin and Ismail (2006) found that Prior Spatial Experience (PSE) to be a determining factor in the development of spatial visualisation ability. Also, researchers such as Heyden, Atteveldt, Huizinga and Jolles (2016) and Strong and Smith (2002) suggested that there was a strong relationship between gender and spatial visualisation skills. However, it still remained to be seen as to how factors such as; (1) prior spatial experience, (2) gender, (3) 3D solid computer modelling and (4) different cognitive styles impacted spatial visualisation skills in particular a graphics design module at a rural–university such as the University of Zululand (UNIZULU).

Furthermore, various strategies to improve spatial visualisation skills are reported in literature, however thus far, research is scarce on how the implementation of strategies such as computer mediated engineering drawing (Rafi, Samsudin, & Ismail, 2006), a web-based virtual environment (Rafi, Anuar, Samad, & Hayatib, 2005), spatial visualisation by isometric drawing (Yue, 2006) and 3D computer solid modelling (Dorta, Saorin, & Contero, 2008) could improve the cognition of spatial visualisation of graphics design students at a rural–university. Along these lines, and what was investigated in this study, was the use of 3D solid computer modelling to enhance spatial visualisation skills.

Coupled with the aforementioned contestations, the current study was essential because over the years (6 years) the number of candidates in the graphics design module offered by the Mathematics, Science and Technology Education Department (MSTE) at UNIZULU has grown to around 250 students with a steady increase of female students. The growth in student enrolment placed great pressure on available resources which in turn necessitated lecturers to investigate the implementation of alternative instructional strategies for teaching large classes. To provide quality education in a rural–university, it was thus imperative to investigate the possible relationship as well as effects of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles on spatial visualisation skills of students. Following (1) the rural-ness of the university and most significantly (2) the importance of comprehending the aforementioned variables and how they influenced the cognition of graphic design, the current research was undertaken to evaluate spatial visualisation cognition via 3D solid computer modelling with the aim of developing a unique model for teaching and learning 2D to 3D drawing.

For the most part, the literature review addressed the current state of the research based on the topic together with the research questions. This included, but was not limited to; spatial visualisation, gender, prior spatial experience (PSE), 3D solid computer modelling, cognitive processes in 2D and 3D visualisation, and concluded with Pedagogical Content Knowledge (PCK).

1.2 BACKGROUND TO THE STUDY

Technology Education lecturers at UNIZULU have the responsibility of teaching prospective technology education teachers a graphics design module. The graphics design module content included basic sketching and drawing conventions viz. line work, scale, dimensioning, and engineering drawing skills in both 2D and 3D.

UNIZULU is a rural–university in Kwazulu-Natal province of South Africa. The majority of students at the university come from previously disadvantaged and under resourced schools (Mabusela & Adams, 2017). Students entering the graphics design module have diverse backgrounds and different levels of spatial experience. Among other things, on completion of the graphics design module, it was expected that students have the ability to understand and apply basic 2D projection methods and 3D representation techniques. The graphics design module content, investigated in the current study, was not dissimilar to what Kösa and Karakuş (2017, p. 298) described as “traditional engineering graphic design courses mainly focus on the creation of 2D drawings using orthographic and 3D drawing using isometric projection methods.” The experience over the years at UNIZULU was that students often struggled to convert multi-faceted objects from orthographic views into isometric projections that is 2D to 3D drawing. Similarly, Kösa and Karakuş (2017) believed, that completing tasks where students must draw different views of an object required them to visualise the object as a whole and, these tasks were “quite difficult.” Case in point, refer to Figure 1 which shows a typical exercise from this study’s graphics design module requiring students to convert the three given orthographic views of an object into an isometric projection. In order to successfully complete this kind of exercise, work by Yue (2006), Morling (2010) and Ligocki (2011) advanced, but was not limited to; knowledge and understanding of line types, planes of projection, length, height and depth measurements and placement of isometric axes, to be crucial for producing isometric projections.

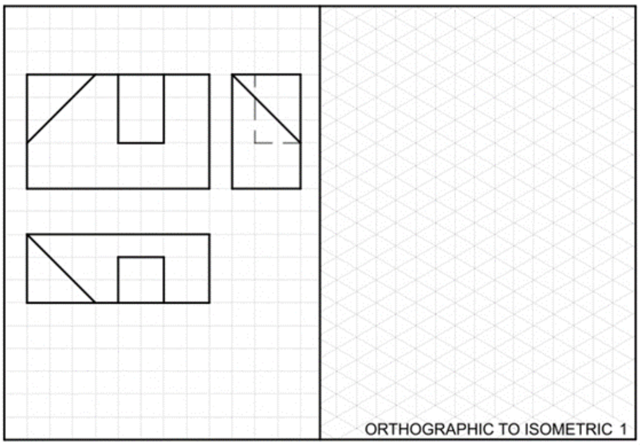


Figure 1: Example exercise: to convert the three orthographic views into isometric.

Typical answers for the first exercise (cf. Figure 1), produced by two students, are shown in Figures 2 and 3 respectively. Figure 2 shows that, even with an isometric grid, the student was not able to visualise the three given views, to form a 3D image and produce an isometric drawing. Student A (cf. Figure 2), merely “attached” the three views together, which demonstrated an inability of visualisation skills, and seemingly ignoring all principles of isometric procedural understanding. Several reasons for this anomaly could be advanced including, lack of spatial visualisation skills (Rafi & Samsudin, 2007; Duffy, Sorby & Bowe, 2016; Rodriguez & Rodriguez, 2016), a misunderstanding of line types, multi-view drawings and isometric principles (Yue, 2006; Ligocki, 2011; Makgato & Khoza, 2016) and the idea that isometric projection is very abstract and must be practiced through sketching and drawing activities (Olkun, 2003; Yue, 2006; Morling, 2010). Furthermore, work by Morling (2010) and Nivens, Carver-Peters and Nivens (2012) described the procedural steps for making isometric projections as: (1) position the object, (2) draw the isometric axes, (3) mark of the length, height and depth measurements, (4) sketch the enclosing box, (5) add details and (6) darken the visible lines. Ostensibly, student B (cf. Figure 3), followed the procedural steps for making an isometric projection however, did not visualise the object completely. Even though student B drew the front view, the side view and the top view in the correct isometric positions, the hidden features of the object was ignored and the three views were merely drawn in the correct “faces” on the isometric grid. Gathering from the answers provided by students in the current study, and related discussions from literature, a common theme that emerged was the relevance of spatial visualisation skills in producing accurate graphics design content.

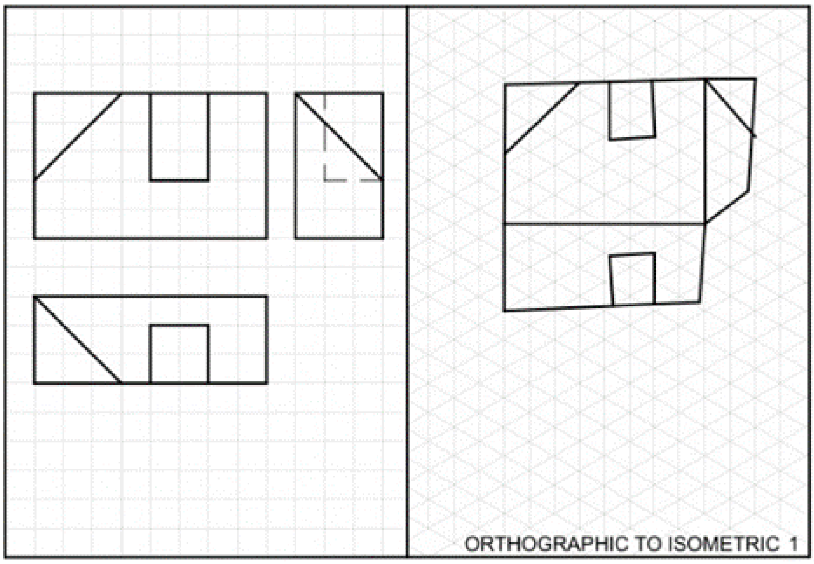


Figure 2: Student A’s answer to exercise.

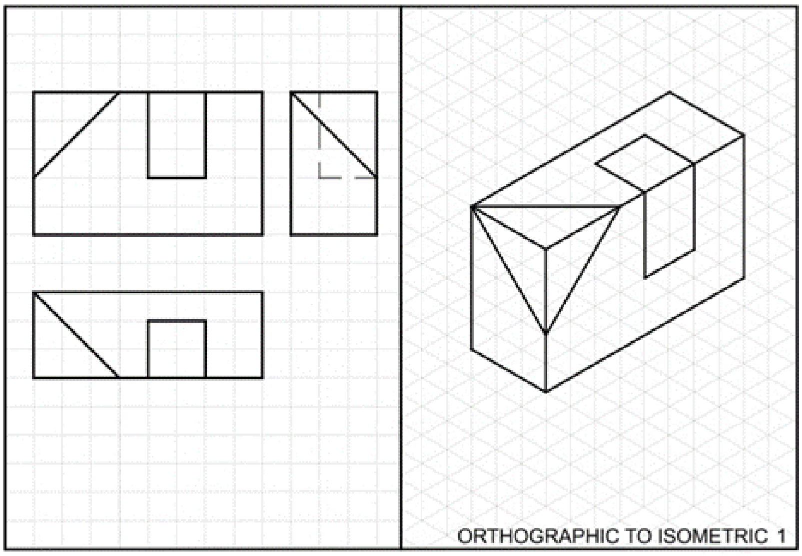


Figure 3: Student B’s answer to exercise.

The expected answer for the first exercise is given in Figure 4. It shows how the front left corner of the object is “sliced off”. Figure 4 further shows that there is a “groove” cut into the object as represented by the hidden (dashed) lines in the side view. In order to visualise and produce the 3D image of a multi-faceted object therefore requires substantial cognitive faculty.

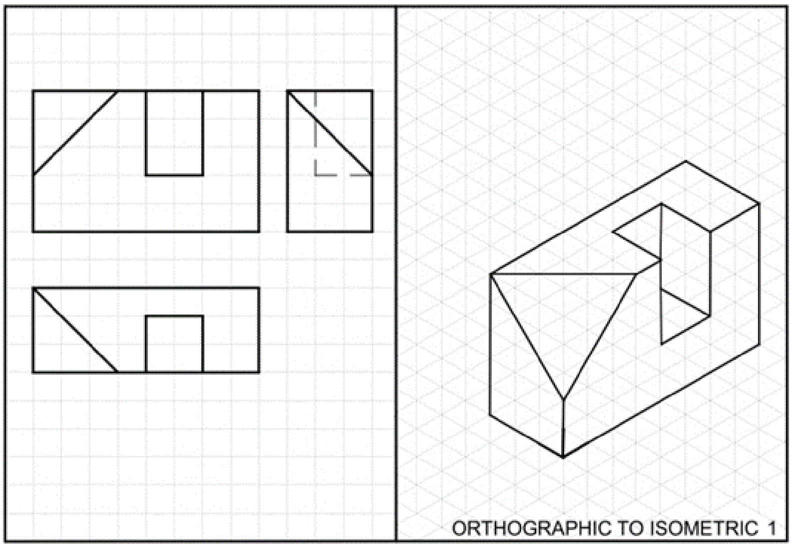


Figure 4: Expected answer to isometric exercise.

What became clear from the analysis of the cases presented here, as well as several other cases not presented here, was that 2D to 3D drawing required much more cognitive faculty than merely following a rigid set of procedures culminating in multiple exercises. Furthermore, given that first-year graphics design students enter the university with varied prior spatial experiences and backgrounds, and thus, varying degrees of spatial visualisation skills, there is a need for supplementary attention in some students. Additionally, no research has been conducted to determine the spatial visualisation skills of pre-service student teachers at UNIZULU, neither was any research done to determine the effects of prior spatial experience, gender, 3D solid computer modelling or cognition styles on spatial visualisation skills among students at a rural–university.

1.3 SCOPE OF THE STUDY

Following the background, the focus of this study was on the effects that prior spatial experience, gender, 3D solid computer modelling and different cognition styles had on the spatial visualisation skills of graphic design students at a rural-based South African university. Therefore, the rural-based context and delimitations of the study impose constraints upon the ability to generalise the results of the study to other populations.

The sample in the current study was 200 pre-service technology education students at the University of Zululand (UNIZULU). UNIZULU is situated in a rural area of Kwazulu-Natal province in South Africa (www.unizulu.ac.za). Most students attending UNIZULU come from rural areas where they matriculated from disadvantaged schools (low quintile schools) with low matric results, and of these students, the majority struggle at first year and are likely to drop out of the university (University of Zululand, Policy and Procedures on the Promotion of Academic Excellence, 2018). Within this context, the concept of a rural–university will be discussed followed by the unique problems that rurality brings about in education such as the history of apartheid, the disparity in access to services, social inequality and limited information technology infrastructure.

1.3.1 Conceptualising rurality in education – Context of UNIZULU.

Kettler, Puryear and Mullet (2016) argued that conceptualizing or understanding rurality in education is challenging and that no single agreed upon definition of rural nor unitary rural variable exists in the field of education research. In addition, Leibowitz (2017) indicated that in research on rurality, it is difficult if not impossible to define rurality. For example, in the United States of America there are a variety of coding systems that can be used to research rurality by considering factors such as population size, population density, percentage of population that is urban and remoteness from urban areas Leibowitz (2017). Moreover, Dani and Shah (2016, p. 65) suggested that a rural–university could be one operating in a rural area, or a university educating rural people to promote “sustainable development”. Ibid however, indicated that under the circumstances of rapid urbanization, a “rural area” could not hold true for a long period of time because the region which is considered a rural area today may not remain so even after five years. Moreover, the moment rural people migrate to urban areas, they no longer remain rural people, in other words, the very concept of rural–university is a dubious one (Dani & Shah, 2016).

In South Africa, various denotations have been used when presenting rurality, for example, in the 2016 report on educational enrolment and achievement, rural was defined as “any area that is not classified as urban; rural areas may comprise one or more of the following: tribal areas, commercial farms and informal settlements”

(Statistics SA, 2016:). However, Leibowitz (2017) points out that a discussion of rural-based universities in South Africa needs to be located within the context of the history of apartheid policies that also shaped the landscape of higher education in the country. Rural-based universities in South Africa was the result of the so-called “apartheid policy of separate development”, and became institutionalised through the “Extension of University Education Act of 1959” (Nkomo & Sehoole, 2007). This education act formalised and entrenched racially segregated education in the tertiary sector, and it was within this background that UNIZULU was established in 1960 (Ndimande, 2018). UNIZULU was stationed in the rural village of KwaDlangezwa on land that was donated by the Mkhwanazi Traditional Authority – traditional authority is a form of leadership in which the authority is largely tied to tradition or custom (Ndimande, 2018). UNIZULU, like other rural-based institutions in South Africa, were poorly funded, and were mostly geographically isolated in areas with limited economic productivity and substandard infrastructure (Nkomo & Sehoole, 2007). In 2002, UNIZULU became a comprehensive university tasked with expanding the range and variety of its academic offerings. However, the legacy of the past still remains resulting in students being under-prepared for university education (Mabusela & Adams, 2017). In addition, students lack the necessary skills to use available resources, there is lack of adequate teaching and learning spaces and laboratories, and students have challenges in academic writing and study skills (Ndimande, 2018).

Additionally, Mabusela and Adams (2017) indicated that UNIZULU still attracts many of its students from rural communities around South Africa with the majority being from poverty-stricken rural areas in the north of Kwa-Zulu Natal province. Much of these rural areas are deprived of access to a range of services such as: electricity, safe drinking water, sewage, television, and libraries (Mabusela & Adams, 2017).

Furthermore, the majority of South Africa’s rural-based schools for instance has no electricity, no running potable water, no proper sanitation and substandard buildings (Modisaotsile, 2012). In general, classrooms are overcrowded, has a shortage of learning materials, has no ceilings, are not decorated with educational media and broken furnishings are not repaired or replaced (Modisaotsile, 2012). The result of all these shortcomings are that students entering universities are not ready for higher education (Mabusela & Adams, 2017). In addition, the experience of the researcher over a period of more than 24 years in higher education was that, rural students are deprived of much of what today can be considered “basic needs” for education. Moreover, similar to the South African context, Fleming and Grace (2017) pointed out that, not only is there a wider choice of services available in urban/metropolitan areas, but there are direct and indirect costs associated with travelling to these services. For example, rural and regional Australians incur significantly more time and financial costs than do urban Australians to access the same services (Fleming & Grace, 2017).

Another concern faced by rural-based South African universities was that a large number of students were introduced to computers and internet technology for the first time when they entered the university (Mabusela & Adams, 2017; Oyedemi & Mogano, 2018). The unequal and skewed patterns of home and school access create a social stratification of two classes of young South Africans which Oyedemi and Mogano (2018) describe as the digitally privileged and the digitally disadvantaged.

> *The digitally privileged youth are those with digital wealth measured in terms of varieties of platforms to internet access: at home, on their mobile digital technologies and at school. They are introduced to digital communication technologies early in life at primary and secondary school level. This group of students has acquired digital skills that allow them to utilise computers and the internet for a variety of devices; and they tend to be from urban, middle class and affluent households. The digitally disadvantaged group lacks the knowledge, skills and abilities to use the internet and other technologies for academic, social, political and self-empowering activities. Their lack of skills is a result of the lack of access to digital technologies at home and at the schools they attended. This group is usually from poor socio-economic backgrounds and they live in rural and semi-rural areas. As a result, they are introduced to these technologies only when entering university* (Oyedemi & Mogano, 2018: p. 177).

Thus, the demands of university education require students to have access to adequate skills of digital communication technologies. Evans and Le Roux (2016) and Mabusela and Adams (2017) affirm that UNIZULU is currently offering blended-learning that requires students to attend their classes as well as engaging in e-learning. Although, UNIZULU has several computer laboratories the greatest challenge is that there are merely 600 computers for 15 000 students, excluding post graduates and students who are part-time engaged in various projects (Mabusela & Adams, 2017). The lack of computers is to students' detriment because Mabusela and Adams (2017) found that the majority of students in their study (88%) said that computers improved their academic performance. According to Evans and Le Roux (2016), a large percentage (more than 60%) of UNIZULU students interviewed in their study reported that they gained access to the internet most regularly in computer labs on the university campus. However, the majority of students have no internet access at home. In addition, the lack of access to the internet at home is disproportionately skewed when comparing South African university students from rural areas and villages, with their urban counterparts such that 83.7% of students in rural areas claiming that they do not have internet access at home (Statistics SA, 2016).

In conclusion, rurality cannot be given a precise and comprehensive definition and should be discussed in relation to dimensions such as geography, space, history, culture and material resources. Although in certain regions there might be broad tendencies associated with rurality, actual conditions vary across schools and universities, families and individuals. Therefore, any assumptions made by this study cannot be generalised to another population other than the population discussed in this study.

1.4 PROBLEM STATEMENT

Research has sufficiently established the positive link between graphics design and spatial visualisation skills. Research has also shown that spatial visualisation skills can be improved through 3D solid computer modelling activities however, the relation between these factors on rural–university students' cognition had to be determined. The impact of various factors (PSE, gender, and cognitive styles) on spatial visualisation have been reported in several studies. As to whether these factors have had any relation to spatial visualisation skills of rural–university students still remained to be determined.

The current study therefore set out to determine the mental visualisation processes involved in producing 3D drawings and whether or not the application of 3D solid computer modelling software enhanced students' achievement in spatial visualisation skills and by implication improve their skills in converting orthographic views into isometric drawings.

1.4.1 Purpose of the study

The purpose of this study was to investigate the relationship and impact of prior spatial experience, gender, 3D solid computer modelling and cognition styles on students' spatial visualisation skills. The study culminated in the development of a learning model for 2D to 3D drawing. The proposed model was based on the study's findings of the relation and impact of PSE, gender, 3D solid computer modelling and cognitive styles on students' spatial visualisation skills. Furthermore, the study was guided by Piaget's theory on the development of perception and imagery and grounded in the theory surrounding PCK.

1.4.2 Objectives of the study

- To find out rural students' level of prior spatial experience (PSE) and the relation thereof with spatial visualisation skills.
- To examine if any relation(s) exist/s between gender and spatial visualisation ability.
- To examine if the application of 3D solid computer modelling software offsets any differences in low spatial visualisation skills.
- To investigate the visualisation cognitive processes in terms of 3D drawings from 2D views.

1.4.3 Research Questions and sub-research questions

Research Question–1. What are rural students' level of prior spatial experience and its relation with spatial visualisation as a form of cognition?

Research Question–1.1 What is the relation of academic-type spatial activities with students' spatial visualisation skills?

Research Question–1.2 What is the relation of non-academic-type spatial activities with students' spatial visualisation skills?

Research Question–1.3 How does the completion of an engineering orientated school subject impact students' spatial visualisation skills?

Research Question–1.4 Which construct(s) of spatial activities are the best predictor of students' spatial visualisation skills?

Research Question–2. What is the relation between gender and spatial visualisation ability?

Research Question–3. What effect does the use of 3D solid computer modelling software have on rural students' spatial visualisation skills?

Research Question–4. What are the mental processes rural students engage in, when constructing meaning from 2D views to produce 3D representations?

Research Question-4.1 How do students use sketching during 2D to 3D visualisation processes?

1.5 LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The essence of this study was to investigate the relationships and impact of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles on spatial visualisation skills and, develop instructional and learning improvements of 2D to 3D drawing in a graphics design module. Accordingly, the nature of the study's objectives was informed by Piaget's perception and imagery theory in order to understand and explain how spatial visualisation skills are developed. In addition, a conceptual framework to understand and determine the procedural knowledge and processes for 2D to 3D visualisation was developed to augment the theories surrounding PCK. The interaction of the 2D to 3D conceptual framework and PCK was used to ground and support the development of a teaching and learning instructional model for 2D to 3D drawing. These theories brought together the various factors of spatial visualisation skills in the following way:

1.5.1 Piaget's perception and imagery theory

Piaget's theory on perception and imagery guided this study to make meaning of how students learn and develop spatial visualisation skills. Spatial visualisation skills are considered vital in understanding and applying graphics design content such as 2D to 3D drawing (Friess, Martin, Esparragoza, & Lawanto, 2016). Studies on spatial ability and visual imagery in engineering graphics courses by researchers such as Makgato and Khoza (2016), Potter and Van der Merwe (2001) and Sorby (1999) ascribes that perception and imagery are figurative processes which can be trained throughout the human life-span and that the processess involved in mental imagery also applied to adults. Makgato and Khoza (2016) and Potter and Van der Merwe (2001) described Piaget's theory on perception and mental imagery as comprising of four stages of perception, namely, stage 1- sensori-motor, stage 2- pre-operations, stage 3- concrete operations and stage 4- formal operational. Of importance to the current study was the concrete operational stage during which a person (age 7-12 years) can perform reversable mental actions on concrete objects and the formal operational stage where persons' (age 12 years and up) can classify, order and reverse mental operations and are capable of abstract reasoning. Reversable mental actions on concrete objects is one of the cornerstones of spatial visualisation skills which in turn is vital in 2D to 3D cognition. Makgato and Khoza (2016) accentuated the importance of these four stages for students' perception and visualisation in engineering graphics courses. In so far as Piaget's theory suggests that post-secondary education students are formal operational thinkers, Khoza (2016) however concluded that a high percentage of post-secondary students have yet to reach the formal-operational stage. This has significant implications for teaching, even in higher education, since reaching the formal operational stage is a result of a combination of maturation and experience from earlier of piaget's stages of cognitive development (Khoza, 2016).

Thus the current study was informed by Piaget's perception and imagery theory with respect to the acquisition of spatial visualisation skills in adulthood. The employment of this theory assisted the current study in determining if prior spatial experience accrued by a person through active participation in various spatial activities could have a positive impact on spatial visualisation skills. Moreover, Piaget's perception and imagery theory grounded investigations into the relation and impact of factors such as prior spatial experience, gender, cognitive styles and the use of 3D solid computer modelling on students' spatial visualisation skills.

1.5.2 Spatial visualisation

Various studies by researchers such as Linn and Petersen (1985), Olkun (2003), Rafi, Samsudin and Ismail (2006), Yue (2006), Rodriguez and Rodriguez (2016), Branoff and Carolina (2014), Duffy, Sorby and Bowe (2016), Halpern, Oh, Tremaine, Chiang, and Silver (2016) and Kösa and Karakuş (2017) have been completed to understand and explain the nuances of spatial visualisation. Studies have investigated spatial visualisation from different perspectives for example, the effects, relationships, fundamentals and improvement of spatial skills through various strategies. The different perspectives which researchers used to investigate spatial visualisation resulted in various interpretations and definitions of what spatial visualisation skills are. There is however consensus in literature that the concept of spatial visualisation is one of three factors of spatial ability, the other two factors being spatial perception and mental rotation (Kösa & Karakuş, 2017; Olkun, 2003). However, what studies could thus far not agree on was a clear definition of spatial ability and what kind of skills it is comprised of (Kösa & Karakuş, 2018). Further evidence showed that spatial ability is characterised by a number of features which included but was not limited to skills in representing, transforming, generating and recalling symbolic, non-linguistic information (Linn & Petersen, 1985). According to Rafi, Anuar, Samad, Hayati and Mahadzir (2005) spatial ability of an individual often refered to the ability to manipulate or transform the image of spatial patterns into other arrangements. On the other hand, as one of three factors of spatial ability, spatial visualisation is described as ”the ability to imagine the rotation of depicted objects, the folding or unfolding of flat patterns, the relative changes in position of an object in space, or the motion of machinery" (Rafi et al., 2005, p. 12). An explanation, which resonated with the current study's objectives was provided by Kösa and Karakuş (2017) who stated that, spatial visualisation is the ability to imagine the manipulations of objects mentally, this requires the mental rotation of a 2D or 3D object in space. Regardles, it is important to recognise from the work of Duffy et al. (2016), Kösa and Karakuş (2017), Rafi et al. (2005) and Rodriguez and Rodriguez (2016) that spatial visualisation and mental rotation are important abilities particularly in the fields of Engineering, Graphic Design, Computer Graphics and Mathematics. Thus, in context of the graphics design module offered at UNIZULU, it was fair to assume that spatial visualisation was a fundamentally important skill for students to master in achieving the desired outcomes of the module.

1.5.3 Prior Spatial Experience (PSE)

This study endeavored to determine if prior spatial experience had any relation with students' spatial visualisation skills at a rural–university. The prevailing point of view in literature is that prior spatial experience is a determining factor in the development of spatial visualisation ability (Newcombe & Baenninger, 1989; Rafi, Samsudin & Ismail, 2006; Strong & Smith, 2002). From the point of view of Verdine, Golinkoff, Hirsh-Pasek and Newcombe (2017), spatial skills are malleable and the extent to which different children are provided early spatial experiences is also quite variable. However, many of the factors that likely influenced spatial visualisation skills would be expected to remain relatively stable across the pre-school years for individual children and thus it could be expected that the combination of genetic and environmental factors that create individual differences in spatial visualisation skills would set the stage for childrens' continued acquisition and refinement of spatial visualisation skills (Verdine et al., 2017). The views from the researchers mentioned here reinforced the need to investigate the relationship between prior spatial experience and graphics design students' spatial visualisation skills considering the importance that literature attributed to it for understanding and producing efficient graphics design content. Supplementary work by Cherney, Bersted, and Smetter (2014), Newcombe and

Baenninger (1989) Salthouse et al. (1990) and Strong and Smith (2002) suggested that prior spatial experience consists of two distinct components; (1) academic-type spatial activities or ”specific intensive training” which is acquired through formal training sessions, that is mathematics and engineering drawing; and (2) non-academic-type spatial activities which is acquired through life experiences, that is playing games and partaking in sport. Non-academic-type prior spatial experience is considered by Newcombe and Baenninger (1989) to be activities which include freedom to explore one’s environment, playing with toys that require manipulation in space and spatial creativity such as Lego blocks and Erector sets, participation in contact sports which are spatial in nature and partaking in scouting activity which requires map reading and orienteering. Conversely, Salthouse et al. (1990, p. 130) suggested that “partaking in activities which require the production or interpretation of drawings in which 3D objects are represented in 2D form and the designing and building of furniture or scale models to be relevant prior spatial experience for enhanced spatial visualisation.” Newcombe and Baenninger (1989) found that non-academic-type spatial activities correlated with higher spatial test scores, although it was mentioned that the magnitude of this effect was very small. However, compelling evidence by Newcombe and Baenninger (1989) implied that spatial training has a fairly strong, but possibly narrow, improvement on spatial test scores. In addition, Stieff and Uttal (2015) considered the impact of spatial training on Science, Technology, Engineering and Mathematics (STEM) achievement and concluded that spatial training led to an average improvement of almost half standard deviation in spatial ability measures. Furthermore, Stieff and Uttal (2015) affirmed the belief that prior spatial training leads to improvements in spatial ability, however, they suggested that the true effect thereof still remains unknown. With reference to the current study, the initial review of literature brought about new questions with regard to prior spatial experience and spatial visualisation skills which had to be answered. These questions broadend this study’s search for answers and included but not limited to, a distinction made between academic-type and non-academic-type activities, the impact of Engineering Graphics Design (EGD) on spatial visualisation skills and the question of which prior spatial experience construct(s) would be the best predictor for students’ spatial visualisation skills?

1.5.4 Spatial visualisation and gender

The second objective of this study affiliated to the relationship between gender differences and spatial visualisation skills at a rural–university. The consensus in research studies was that gender is a significant predictor for spatial visualisation ability (Strong & Smith, 2002; Terlecki, Nora and Little, 2007; Rafi, Samsudin and Ismail, 2006; Sorby, 1999). Among these studies, Strong and Smith (2002) investigated the fundamental trends in engineering graphics with a focus on spatial visualisation and found that a positive relationship exists between gender and spatial visualisation skills. Ibid found that spatial ability differences did exist between sexes but the differences depended upon the students' field of study. Ibid concluded that females may be two to three times more likely to lag behind males in 3D spatial skills. In addition, Terlecki et al. (2007, p. 996) mentioned that "robust gender differences, favouring men and boys, are found on a wide variety of spatial tasks, with the most profound effects being observed on tests of mental rotation." Terlecki et al. (2007) suggest that experience with spatial activities may account for this difference, at least in part, for example men and boys have more computer and videogame experience than women and girls. On another note, Rafi et al. (2006, p. 155) proposed that "gender differences in spatial aptitude may be caused by several socio-cultural factors such as gender-typed socialisation". Children's' conception of how to behave is shaped by the gender-linked beliefs about them which resulted from their parental notions on gender-related abilities (Rafi et al., 2006). In support of the impact of socio-cultural factors on spatial visualisation, Sorby (1999, p. 24) suggested that "environmental factors are the primary reasons for male/female differences in spatial skill levels". Rafi et al. (2006) also stated that girls are inadvertently not encouraged to pursue an interest in masculine domains which are heavily loaded with spatial reasoning aspects and they may also underestimate their potentials in spatial domains due to their parental beliefs that affect their self-perception of capability. Moreover, Rafi et al. (2006) found that male children have more opportunities to engage in spatial activities at an early age through gender-biased activities that promote spatial skills development.

In conclusion, a review of literature established that there is significant evidence to support the existence of significant differences in spatial visualisation abilities between males and females. These differences can be attributed to a number of factors such as field of study, experience with spatial activities and socio-cultural factors. The present study addressed this issue by evaluating the extent to which gender differences existed in students' spatial visualisation skills.

1.5.5 Three Dimensional (3D) Solid Modelling

A further objective of this study was to examine if the implementation of 3D solid computer modelling would have had any measurable impact on students' spatial visualisation skills. 3D solid computer modelling is described in literature, as the representation of the solid parts of an object on computer which is the most advanced method of geometric modelling in three dimensions (Kurtuluş & Uygan, 2010). The typical geometric computer model is made up of "wire frames" that show the object in the form of wires, this "wire frame structure" can be 2D or 3D and can provide surface representation to the wire frame thus giving 3D views of geometric objects which appear solid (cf. Figure 5) on a computer screen (Hsu, 2010).

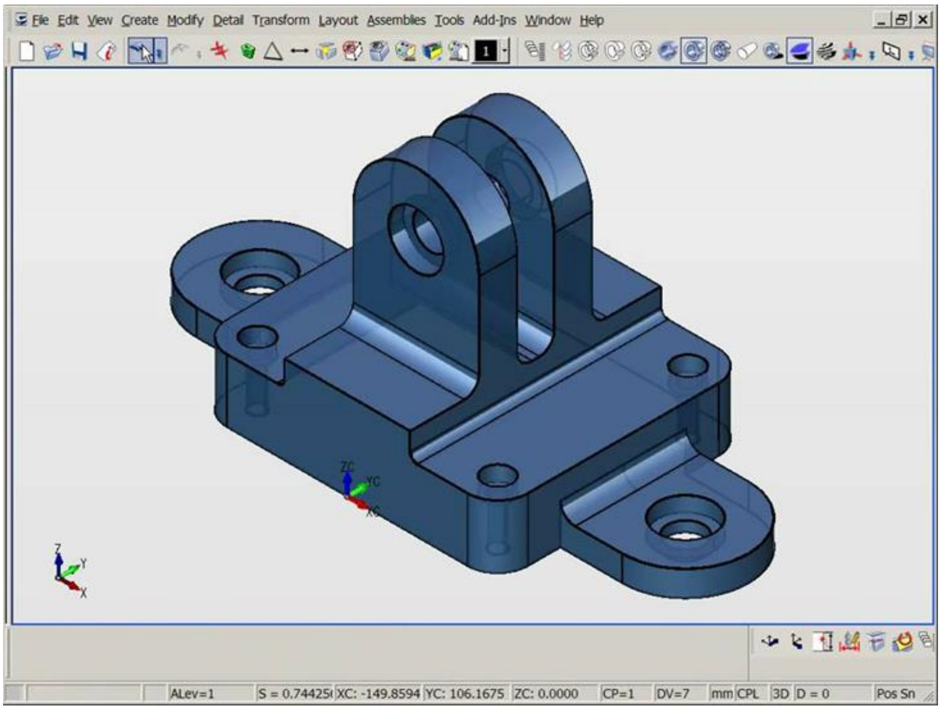


Figure 5: 3D solid computer modelling Software.

Furthermore, 3D solid computer modelling is one of the most important applications of CAD software and has been becoming increasingly popular of late (Fleisig, Robertson, & Spence, 2011). Three dimensional (3D) solid modelling software helps the designer to see the designed object as if it was the real manufactured product and it can be seen from various directions and in various views (Hsu, 2010). This helps the designer to be sure that the object looks exactly as they want it to be. It also gives additional vision to the designer as to what more changes can be done to the object. In the case of the current research, the 3D solid computer modelling computer software that was used is, “SketchUp”. Martín-Dorta et al. (2008) and Kurtuluş and Uygan, (2010) agreed that a SketchUp-based course is a good option to use in a graphics design course for improving spatial skills because of several advantages such as, being freely downloadable from the Internet, easy to learn and it combines a simple yet robust tool-set with an intelligent drawing system. In addition, SketchUp enabled students to “build” or model and modify 3D objects quickly and easily (Christou, Pitta-Pantazi, Pittalis, Mousolidas, & Matos, 2007). Regarding the current study’s investigation into 3D solid computer modelling and in the context of a rural setting with limited resources, the reasons provided here and supported by various authors was a determining factor for the use of SketchUp as the 3D modelling software of choice for the current study.

1.5.6 Cognitive processes in 2D and 3D visualisation

Assimilating from the problem statement of this study, that graphics design students have had difficulties in producing 3D drawings from 2D views, and guided by Piaget’s perception and imagery theory, it was important to investigate the different cognitive styles of students during 2D to 3D activities. Work done by Moore-Russo, Viglietti, Chiu, and Bateman (2013) described a “spatially literate” person as one that must (1) visualise spatial objects; and (2) reason about properties of and relationships between spatial objects. Moore-Russo et al. (2013) further suggested that spatial literacy is independent of a specific content area and is related to an individual’s cognitive processes. Gutiérrez (1996) described visualisation as a process of generating cognitive representations of spatial objects through visual images that may be facilitated by external representations or physical actions. Pillay (1998, p. 4) stated that “most spatial problems require subjects to indulge in the construction of 3D mental representations as a means to comprehend and manipulate given spatial information.” Relevant to the current study, it still remained unclear how students accessed mental models for the purpose of visualising a 3D object from its 2D views. Furthermore, Pillay (1998, p. 4) suggested that “there are three processes by which we can construct and understand spatial information; (1) we may retrieve a previously constructed mental representation and modify it; (2) construct a completely new representation or; (3) just encode an external representation into an internal representation”. In addition, Moore-Russo et al. (2013) mentioned that when people visualise, some might hone in on the relationships between the parts of an object while others tend to focus on the overall pictorial appearance of the object. Blazhenkova and Kozhevnikov (2009) identified two distinct types of individuals that is object visualisers, who use imagery to construct vivid high-resolution images of individual objects, and spatial visualisers, who use imagery to represent and transform spatial relations. Blazhenkova and Kozhevnikov (2009, p. 640) based these two distinct types of individuals on the existence of an “object imagery system” that processes the visual appearance of objects and scenes in terms of their shape, vividness, colour, and texture and a; “spatial imagery system” that processes objects’ location, movement, spatial relations and transformations. Thus, regardless of whether an individual is considered an “object visualiser” or a “spatial visualiser”, what is evident is that during the visualisation processes of encoding, integrating and constructing a 3D object from its 2D views, the cognitive processes are flexible and interactive. What the current study was concerned with was to determine the mental processes that students employed to construct a 3D mental image of an object when the 2D views of the object was presented as a stimulus. In order to achieve this study’s objective of analysing students’ different cognitive styles, the study embarked on an investigation of several instructional sources for 2D to 3D drawing. Findings made from instructional sources, combined with the spatial visualisation cognition styles of students brought about a conceptual framework for the 2D to 3D visualisation process (cf. Annexure E).

1.5.7 Pedagogical Content Knowledge (PCK)

The objectives of this study, relating to prior spatial experience, gender, 3D solid computer modelling and cognition styles, amalgamated into the development of a model for teaching and learning 2D to 3D drawing in a graphics design module at a rural–university. The development of the learning model was two-fold. Firstly, the proposed model was informed by the findings made by research questions 1 to 4 in this study. In essence, research questions 1 to 4 endeavoured to determine how the factors of prior spatial experience, gender, 3D solid computer modelling and cognition styles related and impacted the teaching and learning of 2D to 3D drawing at a rural–university. Secondly, the proposed model was based on the theoretical framework of the advances made in initial teacher education with specific focus on Pedagogical Content Knowledge (PCK). PCK was first defined by Shulman at a keynote address at the American Educational Research Association in San Francisco, California (Kok, 2017). Shulman (1987) described PCK as the kind of knowledge which goes beyond knowledge of subject matter or teaching method per se to the dimension of subject matter knowledge (SMK) for teaching. Etkina (2010, p. 11) provides the following distinction between General Pedagogical Knowledge (GPK) and PCK;

> *teachers should know how people learn, how memory operates, and how a brain develops with age, this knowledge is called general pedagogical knowledge or the knowledge of how people learn. However, most importantly, teachers of a specific subject should possess special understandings and abilities that integrate their knowledge of this subject's content and student learning of this content, this special knowledge is called PCK and is what distinguishes the science knowledge of teachers from that of scientists*.

Shulman (1987) observed that teacher education focused more on generic pedagogical knowledge rather than pedagogical content knowledge which he referred to as "the missing paradigm." Shulman (1987, p. 34) outlined seven categories that constituted the knowledge of teachers:

> *content knowledge; general pedagogical knowledge; curriculum knowledge; pedagogical content knowledge; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational ends, purposes and values.*

However, among these categories of teachers' knowledge, PCK is of special interest because it identifies the distinctive bodies of knowledge for teaching (Shulman, 1987). Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) agreed with Shulman and considered PCK to be one of the cornerstones of teacher knowledge. Rollnick et al. (2008) argued that if it is possible to describe and model how PCK is formed, it may be possible to target areas for improvement in teacher education. When put in context of the current study, it was important to know which knowledge areas of 2D to 3D drawing should be targeted as well as which domains of teacher knowledge needed to be considered in order to develop an instructional and learning model in order to improve students' ability to convert 2D drawings into 3D representations.

1.6 METHODOLOGY

The nature of the research questions in the current study necessitated the use of a mixed methods sequential research design (QUAN→QUAL), because the focus was on collecting, analysing, and mixing both quantitative and qualitative data (Creswell, Klassen, Plano Clark, & Clegg Smith, 2014). According to Schoonenboom and Johnson (2017), the ultimate purpose of mixed methods research is about heightened knowledge and validity. Informed by the study's research questions, the constructivist paradigm was complemented by the positivist paradigm in order to seek elaboration, enhancement, illustration and clarification of the results.

1.6.1 Research design

A detailed explanation of the current study's research design is given in chapter 4 under section 4.4. The study used a mixed method research approach to investigate and understand the relationship and impact of spatial visualisation skills on students' ability to produce accurate graphics design content at a rural–university. The reason for using mixed method approaches was that it provided a better understanding of research problems than the use of a single approach (De Vos, Strydom, Fouche', & Delport, 2011). Similar to the research design of the current study, Schoonenboom and Johnson (2017) pointed out that a mixed methods approach in which quantitative and qualitative methods are developmental and complementary, seeks to use the results from one method to help develop or inform the other method. Thus, one can use separate but related qualitative and quantitative research questions (Schoonenboom & Johnson, 2017). The current study followed a sequential mixed methods design during which the quantitative component preceded the qualitative component. The quantitative component was addressed during research questions 1 to 3 in this study. Research questions 1 to 3 investigated the relationships and impact of the factors prior spatial experience, gender and 3D solid computer modelling on students' spatial visualisation skills through the application of questionnaire and tests. The qualitative component of this study, which sought to determine students' cognitive styles during graphics design activities, was addressed during research question 4 which made use of semi-structured interviews. The participants in the qualitative component of this study depended on and were selected based on their performance during the quantitative component of the study.

To address research questions 1, which intended to determine the relation between prior spatial experience with students' spatial visualisation skills, a non-experimental correlational design was employed. According to Imenda and Muyangwa (2006), correlational studies seek to describe the relationships between two continuous variables – for example, in the current study the relationship between prior spatial experiences and spatial visualisation skills. Moreover, research question 1 also intended to explore the relationships between academic-type and non-academic-type prior spatial experiences and the previous completion of an engineering orientated subject at school with spatial visualisation skills. In addition, research question 1 also sought to determine the factor(s) of spatial activities which could be the best predictor for spatial visualisation skills. Therefore, Multiple regression, which according to Pallant (2010) is based on correlation, was used because it allows for a more sophisticated exploration of the interrelationship among a set of variables. In the same light, research question 2 focussed on the relationship between gender and spatial visualisation skills. Of note, prior investigations into spatial visualisation that utilised similar research designs were, amongst others, Rafi and Samsudin (2007) who intended to determine the relationships of spatial experience, previous mathematics achievement and gender with perceived ability in learning engineering drawing, as well as Rodriguez and Rodriguez (2016) who contemplated a comparison of spatial visualisation skills in courses with either graphics or solid modelling content. Thus, in the current study, research question 2 was investigated through a correlational study design with a one-way between-groups Analysis of variance (ANOVA) because, as Pallant (2010) indicated, an ANOVA compares the variance in scores between one categorical variable – which in the current study is gender – and one continuous variable – which is a spatial visualisation test score.

Furthermore, to examine research question 3 – the effect of 3D solid computer modelling on students' spatial visualisation skills – the study employed the pretest-posttest control-group quasi experimental design. The pretest-posttest design is considered to be an experiment where measurements are taken both before and after a treatment (De Vos, Strydom, Fouche & Delport, 2011). In simple terms, this type of design enabled the researcher to examine the effects of the intervention of 3D solid computer modelling on the spatial visualisation skills of the experimental group. If extraneous variables – 3D solid computer modelling – have brought about changes between the pre-test and the post-test, these would be reflected in the scores of the control group, thus only the post-test change – spatial visualisation skill – between the experimental group that is over and above the change that occurred in the control group can be attributed to the treatment (Imenda & Muyangwa, 2006). In the current study, as suggested by Imenda and Muyangwa (2006), the control and experimental groups were treated exactly the same, except for the 4-week 3D solid computer modelling intervention which only the experimental group underwent.

In the current study, research question 4 followed a qualitative research approach based on a constructivist/interpretivist paradigm with a phenomenological design structure. The research was conducted through semi-structured interviews. Creswell et al. (2014) argued that the best criteria to determine the use of phenomenology is when the research problem required a profound understanding of human experiences common to a group of people. Padilla-Díaz (2015) added that descriptive or hermeneutical phenomenology refers to the study of personal experiences and required a description or interpretation of the meanings of phenomena experienced by participants in an investigation. In the current study, a purposive group of graphics design students were selected to articulate their lived experiences with regard to solving a 2D to 3D visualisation problem. Therefore, as Creswell et al. (2014) suggested, students in this study were individually interviewed by the researcher in order to find the underlying factors and common meanings attributed to the mental processes that they engaged in when constructing meaning from 2D views to produce 3D drawings. Thus, the role of the phenomenological researcher was to “construct” the studied object – 2D to 3D drawing – according to its own manifestations, structures and components (Creswell et al., 2014).

1.6.2 Sampling

The population from which this study’s sample was drawn were 250 first year students (male and female) enrolled for a graphics design module at the University of Zululand. A detailed description of the population and sample for this study is provided under chapter 4 in section 4.5. It is generally stated that the larger the population, the smaller the percentage of that population the sample needs to be (De Vos, Strydom, Fouche', & Delport, 2011, p. 226). De Vos et al. (p. 225) stated that “in most cases a 10 percent sample should be sufficient for controlling for sample errors.” De Vos et al. (2011, p. 224) offers a table (see Table 1) as an indication of what the size of a sample ought to be.

Table 1: *Guidelines for sampling*

Population	Percentage suggested	Number of respondents
20	100%	20
30	80%	24
50	64%	32
100	45%	45
200	32%	64
500	20%	100

Note. From De Vos, Strydom, Fouche' & Delport, 2011, p. 224

To address the quantitative research questions 1 to 3 in this study, probability sampling based on randomisation was used. In a random sample each person in the population has the same known probability to be representatively selected (De Vos et al., 2011, p. 226). De Vos et al. (2011, p. 226) further indicated that “a representative sample is important when the study wanted to generalise from the sample to the larger population and that if for example gender is a variable relevant to the research, a representative sample would have approximately the same number of men and women." Representativeness was addressed during random sampling in this study as gender is a variable being correlated in research question 2.

Research question 4 in this study attempted to answer what the cognitive processes that students engaged in were during 2D to 3D cognition. This part of the study was qualitative and thus had a different strategy to determine the sample size. De Vos et al. (2011, p. 391) said that "there are no rules for sample size in qualitative inquiry and sample size depended on what we want to know, the purpose of the inquiry, what is at stake, what will be useful and what will have credibility." De Vos et al. (2011, p. 391) indicated that "in qualitative research, sampling occurs subsequent to establishing the circumstances of the study, thus the sampling is undertaken after the actual investigation have commenced." Qualitative researchers seek out individuals, groups and settings where the specific processes being studied are most likely to occur and a process of constant comparison between individuals or groups being studied is essential, since the researcher is in pursuit of understanding all aspects of his or her research topic (De Vos et al., 2011, p. 392). Furtheremore, the overall purpose of the use of the relevant sampling technique in qualitative research is to collect the richest data and a wide and diverse range of information (De Vos et al., 2011, p. 392). The sampling method for the qualitative part of this study focussed on individuals in the study and their performance in the pre-test and post-test as well as the self-report spatial experience questionnaire (SEQ). Based on a sum total of their performance, participants were categorised into two categories of spatial visualisation skills that is advanced and elementary. Five students were selected from the two categories and invited for interviews.

1.6.3 Data collection instruments

A detailed account of this study's data collection instruments is offered in chapter 4 under section 4.6.

To address research question 1 in this study, all participants completed a self-report spatial experience questionnaire (SEQ) (cf. Annexure B). The purpose of the SEQ was to examine the level of prior spatial experiences of each participant. The SEQ consisted of a list of 20 spatial activities such as sketching, drawing, map reading, driving a car, playing sport, using tools and playing chess. Each item had a four-point scale ranging from two extremes (that is very often and never) to be rated by participants on the questionnaire. Two levels of spatial experience were categorised based on the total scores of the questionnaire such that elementary experience is 49 and below, and advanced experience is 50 and above (cf. Table 2: Research journey of the study).

For research question 2, a questionnaire was used to determine biographical data including; gender and whether a participant did an engineering orientated subject at school including EGD, Civil – Mechanical – Electrical Technology (cf. Annexure A).

The instrument for research question 3 was the Purdue Spatial Visualisation Test – Visualisation through Rotations (PSVT: R). The PSVT: R was used to obtain a baseline measurement of students' spatial visualisation ability (cf. Annexure C). The test had 30 items related to spatial visualisation ability with items on rotation and different points of view. The PSVT: R served as the pre-test and post-test to determine the impact of 3D solid computer modelling on spatial visualisation skills.

Under research question 4, the intent was to understand and analyse the cognitive processes students used when mentally imagining 3D objects. Students were given three views of an object and asked to draw it in 3D (cf. Annexure D). Through semi-structured interviews students were prompted to reveal the procedure of their thinking in completing the drawing. The interview proceeded on three levels that is (1) encoding information (2) integrating information and (3) constructing 3D mental representation. Through discourse analysis the cognition of 3D drawings from 2D views were analysed to determine conceptual and procedural knowledge (cf. Table 2, Research journey of this study).

Table 2: *Research journey of this study*

Purpose	**Objectives**	**Research Questions**	**Research approach**	**Research design**	**Data collection instrument**
The purpose of this study was to investigate the relationship and impact of prior spatial experience, gender and cognition styles on students' spatial visualisation skills and the enhancement of these skills through the application of 3D solid computer modelling**.**	To determine students' level of prior spatial experience (PSE) and the relation thereof on spatial visualisation skills.	1. What are students' level of prior spatial experience and its relation with spatial visualisation as a form of cognition?	Quantitative	Non-experimental correlational study. Randomised sampling.	Spatial Experience Questionnaire SEQ (cf. Annexure B)
	To examine if any relation(s) exist/s between gender and spatial visualisation ability	2. What is the relation between gender and spatial visualisation ability?	Quantitative	Non-experimental correlational study	Biographical Questionnaire (cf. Annexure A)
	To examine if the application of 3D solid computer modelling software offsets any differences in low spatial visualisation skills.	3. What effect does the use of 3D solid computer modelling software have on students' visualisation skills?	Quantitative	Pretest-posttest quasi experiment	Purdue Spatial Visualisation Test /Visualisation through Rotations and Isometric views. (cf. Annexure C)
	To investigate students' cognitive styles in terms of 3D drawings from 2D cognition.	4. What are the mental processes students engage in, when constructing meaning from 2D views to produce 3D representations?	Qualitative	Phenomenology	Semi-structured interview tool (cf. Annexure D)

1.6.4 Reliability and validity

In the current study, data was collected using 4 instruments (cf. Table 2 Research journey of the study, Data collection instruments). To ensure the content and face validity of the Spatial Experience Questionnaire and the semi-structured interview tool, the instruments was judged by a panel of two experts such that (1) the measure covers the universe of facets that make up the concept and (2) the language used on the instruments was consistent and agreed with the participants' context. The second instrument, the Purdue Spatial Visualisation Test, was a standardised test and has been used in several studies of which Rafi, Anuar, Samad, & Hayatib (2005, p. 709); and Bodner & Guay (1997, p. 9) reports a reliability coefficient of .68. A reliability coefficient in the range .6 to .99 would in most instances suffice (Imenda & Muyangwa, 2006, p. 113).

To ensure that the qualitative data was dependable, the analysis of the semi-structured interview scripts as well as the analysis of the documents which were produced by the students during the interviews, was discussed with a graphics design subject specialist. Therefore, the qualitative data analysis was not only dependent on the researcher's interpretation but also on the interpretation of a subject specialist who made similar conclusions. Kivunja and Kuyini (2017) argued that the researcher can make inferences which in themselves are influenced by his/her own construction of meaning however, the findings truly emerge from the data if every person who is involved in the same data analysis come to the same outcome.

1.6.5 Data analysis

A comprehensive account of the data analysis procedures for the current study was given in chapter 4 under section 4.10. To determine if a significant relation existed between the variables PSE, gender and 3D solid computer modelling, and the dependent variable spatial visualisation skills, descriptive and inferential statistics were used. The data were analysed using Multiple regression, Analysis of variance (ANOVA) and Analysis of covariance (ANCOVA) (cf. Table 3, Methods of data analysis). After collection of the data, it was prepared for data entry by checking, editing and coding and entered into Statistical Package for the Social Sciences (SPSS) for analysis. Research question 4, which demanded a qualitative approach, required a non-numerical examination and interpretation of observations and interviews through discourse analysis (cf. Table 3, Methods of data analysis).

Table 3: Methods of data analysis

Research Questions	**Approach**	**Sources of data**	**Methods of data analysis**
1. What are rural students' level of prior spatial experience and its relation with spatial visualisation as a form of cognition?	Quantitative	Spatial Experience Questionnaire SEQ (cf. Annexure B)	Descriptive and inferential statistics, ANOVA Multiple regression
2. What is the relation between gender and spatial visualisation ability?	Quantitative	Questionnaire (cf. Annexure A)	ANOVA
3. What effect does the use of 3D solid computer modelling software have on rural students' visualisation skills?	Quantitative	Purdue Spatial Visualisation Test /Visualisation through Rotations and Isometric views. (cf. Annexure C)	ANCOVA
4. What are the mental processes rural students engage in, when constructing meaning from 2D views to produce 3D representations?	Qualitative	Semi-structured interview tool (cf. Annexure D)	Discourse analysis

1.7 ETHICAL CONSIDERATIONS

The researcher was responsible for the protection of the rights and welfare of the participants in the study in line with the University of Zululand's research ethics guide dated January 2016.

To seek ethical approval, the following documentation was prepared:

- Research ethics protocol/application form
- A fully motivated research proposal
- Participant's informed consent form
- All data collection instruments
- Request to conduct research.

The researcher was also the lecturer of the module taken by the students. The following points was undertaken with respect to insider research:

- Students received reassurance about why they are being included in the study.
- Students were briefed that refusal to participate will not be interpreted as potentially damaging to their module.
- Reassurance was provided that refusal to participate will have no negative consequences for them.
- Participants gave written consent to partake in the research (cf. Annexure E).

To ensure confidentiality and anonymity of participants the following steps were taken:

- To answer the online instruments each participant created a self-enrolment account with a unique password only known to them. The participants were asked not to share the password with anyone.
- During the semi-structured interviews anonymity was established by not recording any personal biographical data such as surname, name/s and student number on the interview schedule.

1.8 CHAPTER DIVISION

This study consists of six chapters which are divided as follows:

1.8.1 CHAPTER 1: ORIENTATION TO THE STUDY

At the centre of this study was the need to investigate and understand spatial visualisation skills. In chapter one the researcher provided an overview of the importance of spatial visualisation skills in graphics design courses. What followed was an outline to the study's background during which the context and problem statement was revealed. Furthermore, a rudimentary review of literature on the topic was done within the theoretical framework of the study. Finally, the first chapter presented the objectives and the research methods that was used to answer the study's research questions.

1.8.2 CHAPTER 2: LITERATURE REVIEW

In the second chapter the researcher provided literature relevant to the study's objectives and research questions. An extensive discussion on spatial visualisation skills, prior spatial experience, gender, spatial visualisation and 3D solid computer modelling was done for grounding the study within the body of knowledge.

1.8.3 CHAPTER 3: THEORETICAL FRAMEWORK

In chapter 3 the nature of the study's objectives and research questions, which are supported by three relevant theoretical and conceptual frameworks were discussed. Firstly, Piaget's perception and imagery theory was used for grounding research questions 1 to 3. Research questions 1 to 3 sought to determine the nuances of spatial visualisation. In research question 4, a conceptual framework for 2D to 3D drawing was developed and used to explain students' cognition processes. Finally, a teaching and learning model for 2D to 3D drawing was developed. The model was guided by the theory and notions of PCK, integrated with Piaget's theory and informed by the conceptual framework for 2D to 3D drawing.

1.8.4 CHAPTER 4: METHODOLOGY

Within chapter 4 the researcher presented the methodology by warranting the research design, sample size, instruments and data collection techniques for the study.

1.8.5 CHAPTER 5: DATA PRESENTATION

Chapter 5 presented the study's quantitative data in tables and figures followed by detailed discussions on the analysis and interpretation of the findings with relevance to the research objectives of the study. In turn, the qualitative data were presented as themes and quotations.

1.8.6 CHAPTER 6: DISCUSSIONS

Chapter 6 provided a synthesis of the main findings of the study. The chapter culminated in the presentation of a model for the successful teaching and learning of 2D to 3D drawing that will be used to assist students in the graphics design module at the University of Zululand.

1.8.7 CHAPTER 7: SUMMARY, CONCLUSION AND RECCOMMENDATIONS

Chapter 7 presented the summary, conclusion, recommendations, limitations and further research.

1.9 SUMMARY

Chapter 1 presented an overview, background and scope of the current study. The chapter also highlighted the problem statement as well as the purpose and objectives of this study. The research questions were unpacked and the theoretical and conceptual frameworks, which grounded the study were discussed. Furthermore, an analytical review of literature was provided to show the contributions of this study to the body of knowledge. This chapter also gave an indication of the methodology used by the researcher to answer the research questions. Finally, a brief overview of the remaining chapters of the study was provided.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Chapter 1 brought to light that graphics design students at a rural–university often experienced difficulties during technical drawing activities which require the conversion of 2D views of an object into the 3D representation of the object. Subsequently, a commencing review of several studies in the field of graphics design education alluded to a strong relationship between graphics design and spatial visualisation skills. Several studies on graphics design and spatial visualisation skills also reported various strategies which educators can use to improve the spatial visualisation skills of students. However, literature did not provide sufficient evidence on the improvement of students' spatial visualisation skills at a rural–university such as the University of Zululand (UNIZULU). Hence, an insight was provided into the nuances of what rurality is and how geography, space, history, culture and disparate material resources impact on the development of spatial visualisation skills. Furthermore, chapter 1 presented Piaget's theory on perception and mental imagery which framed this study in Piaget's formal operational stage where persons' can classify, order and reverse mental operations and are capable of abstract reasoning. In order to gather all relevant sources and locate this study within the context of existing literature chapter 2 provides a detailed review into the effect of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles on spatial visualisation.

Since the main focus of the study revolved around graphic design students' difficulties with 2D to 3D drawing, the literature review addressed various aspects surrounding spatial visualisation skills. Thereafter, an examination was made into prior spatial experiences and 3D solid computer modelling in order to determine the essence of these constructs' relationship with spatial visualisation. Moreover, a detailed probe was conducted into Piaget's perception and imagery theory as well as the cognitive processes involved during 2D to 3D drawing. Finally, and in response to difficulties which graphics design students experience with 2D to 3D drawing, the current chapter explored various teaching and learning models considered to enhance spatial visualisation skills. The chapter concluded with a study on the notion of Pedagogical

Content Knowledge (PCK) as a framework for developing a teaching and learning model for 2D to 3D drawing.

2.2 SPATIAL VISUALISATION

Since early investigations into spatial ability by researchers such as McGee (1979), further studies have been completed to understand and explain the nuances of spatial ability (Kösa & Karakuş, 2018). According to McGee (1979), the two main factors of spatial ability include spatial visualisation and spatial orientation. Spatial visualisation refers to the ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus, whereas spatial orientation comprises the comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented (Kösa & Karakuş, 2018). However, there is some evidence that spatial ability is characterised by a number of features which include but is not limited to skills in representing, transforming, generating and recalling symbolic, non-linguistic information (Linn & Petersen, 1985). According to Rafi, Anuar, Samad, Hayati, and Mahadzir (2005) spatial ability of an individual often refers to the ability to manipulate or transform the image of spatial patterns into other arrangements. In other words, as one of three factors of spatial ability, spatial visualisation is described as the ability to imagine the rotation of depicted objects, the folding or unfolding of flat patterns, the relative changes in position of an object in space, or the motion of machinery.

As cognition process, Rafi et al. (2005) describe spatial visualisation as the ability to rotate or fold objects in two or three dimensions and to imagine these changing configurations. Strong and Smith (2002) conclude that spatial visualisation is the ability to manipulate an object in an imaginary 3D space and create a representation of the object from a new viewpoint. For instance, Strong and Smith (2002) ask if one can imagine the front, back and the side of a house and what it would look like if you were flying over it in a small plane? A recent definition of spatial visualisation is provided by Kösa and Karakuş (2017, p. 3) who state that “spatial visualisation is the ability to imagine the manipulations of objects mentally; this requires the mental rotation of a 2D or 3D object in space.” This definition of spatial visualisation resonates with the current study’s investigation into the difficulties which graphic design students have in

2D to 3D drawing, however, what still needed to be investigated was how spatial visualisation skills could be measured.

The main focus of this study was to investigate the relationship and impact of prior spatial experience, gender and 3D solid computer modelling on students' spatial visualisation skills. With this in mind it was imperative to find a suitable instrument to measure students' spatial visualisation skills. What emanated from literature was that several tests have been developed for testing or measuring spatial visualisation (Mohler, 2008). Typically, these tests have 20 to 30 items each requiring the student to choose one of five possible solutions for each item (Sorby & Baartmans, 2000). These spatial visualisation tests aim to evaluate students' ability to mentally rotate an object, unfold a developed surface or section a solid object (Fleisig, Robertson, & Spence, 2011). However, one spatial visualisation test, The Purdue Spatial Visualisation – Rotation Test (PSVT: R) cropped up as the most commonly chosen by researchers to evaluate spatial visualisation skills. The test originally consisted of three sections (developments, rotations, and views), each containing 12 problems:

- The first section was developments (folding 2D flat patterns along fold lines) into 3D objects (surface models).
- The second section was the orthogonal rotations of 3D objects about the axes of the Cartesian coordinate system (R).
- The third section was the visualisation of isometric views of 3D objects (V).

Although the PSVT: R test is referred to as a standardised test, many researchers adapted the test to suit their specific purposes (Ahmad & Samsudin, 2006; Aytaç & Candas, 2010). According to Candas (2010), the PSVT: R test was chosen by researchers because of its higher correlation with similar instruments measuring visualisation. In order to determine to what extent the use of 3D solid computer modelling software impacted on graphic design students' spatial visualisation, the current study determined the level of spatial visualisation of participating students by applying the PSVT: R. The significance of using the PSVT: R is that various studies have reported the test to be reliable (Guay & Bodner, 1997; Helweg, 2001). During the test students are shown a criterion object and a view of the same object after undergoing a rotation (R) in space (Guay, 1977). Students are then shown a second object and asked to indicate what their view of that object would be if the second object were rotated by the same amount in space. Since the development of the PSVT: R test numerous studies have used it as both teaching and research tools to measure spatial visualisation in students and to diagnose and improve students' spatial visualisation skills in graphic design and Computer Assisted Design (CAD) courses (Yue, 2006). Worth mentioning among these studies which measured spatial visualisation skills of students, Battista (1990) examined gender differences in high school geometry; Rodriguez and Rodriguez (2016) compared courses with either graphics or solid modelling content; Friess, Martin, Esparragoza, and Lawanto (2016) studied improvements in an introductory graphics design course and Kösa and Karakuş (2017) undertook to determine the effects of computer aided design software on spatial visualisation. In the current study the PSVT: R consisted of 30 items. The implementation of the PSVT: R served as the pre-test and the post-test. The pre-test scores were used as a baseline score (spatial visualisation skills) to determine the statistical significance between spatial visualisation skills of a control group and an experimental group. After a 4-week 3D solid computer modelling intervention strategy, the results of the post-test scores were used to examine the effectiveness of the intervention.

2.2.1 Spatial Visualisation and Gender

In this section the relationship between gender differences and spatial visualisation skills was examined at a rural–university in South Africa. The objective was to investigate if there were any relations between spatial visualisation and gender. Although every effort was made to find rural-based studies, as far as could be determined, studies on the effects of gender on spatial visualisation skills were conducted mostly at schools and universities in the United States of America and in Europe. Thus, the importance of the current study was to shed light on the relationship between gender and rural-based students' spatial visualisation skills. In turn, an understanding of the differences in gender would lead to the development of relevant instructional methods for the teaching and learning of 2D to 3D drawing.

There is consensus in literature that gender is a significant predictor for spatial visualisation ability however, the magnitude of gender difference varies across studies (Strong & Smith, 2002; Vander Heyden et al., 2016). For example, Strong and Smith (2002, p. 2) suggest that a “positive relationship has been shown to exist between gender and spatial visualisation”. *Ibid* found that spatial ability differences did exist between sexes but the differences depended upon the students’ field of study. *Ibid* concluded that females may be two to three times more likely to lag behind males in 3D spatial skills. In addition, Terlecki, Nora and Little (2007) mention that “robust gender differences, favouring men and boys, are found on a wide variety of spatial tasks, with the most profound effects being observed on tests of mental rotation.” Terlecki et al. (2007, p. 65) suggest that “experience with spatial activities may account for this difference, at least in part, for example men and boys have more computer and videogame experience than women and girls.”

Various studies have shown that males perform better than females on spatial visualisation tests (Battista, 1990; Sorby, 1999 & Rafi et al., 2006). For example, significant gender differences, favouring males, were observed among students who did not take a Design and Computer Graphics course, however, this gender gap was not observed among the students who took a Design and Computer Graphics course (Farrell & Harding, 2015). Therefore, without the genders engaging in spatial activities, males seem to have the advantage over females in terms of spatial visualisation skills, however, this advantage appear to diminish with spatial experiences. There is also a great deal of evidence to suggest that spatial skills of women lag significantly behind those of their male counterparts (Sorby, 1999). Ever since, the difference in spatial visualisation between genders has been widely accepted, and some researchers have proposed that this difference has resulted in fewer females in certain careers, such as engineering and architecture than males (Strong & Smith, 2002). In addition, Heyden et al. (2016) argue that sex differences in spatial ability emerge in the course of childhood, notably around 10- years of age, and that the better performance of boys in these tests is particularly evident for mental rotation tasks. The significance of the finding by Heyden et al. (2016) to the current study is that the link was already established between mental rotation and spatial visualisation skills (Rafi et al., 2005). However, on other spatial tasks, such as the paper folding test, no consistent sex differences are found (Vander Heyden et al., 2016). Consequently, it is important to note that the type of spatial visualisation test that the researcher administer to determine spatial visualisation skills is of importance, and that the mental rotation test is preferred by researchers. Thus, as far as the graphics design students at a rural–university is concerned, it still remained to be determined what the differences are in spatial visualisation skills between females and males.

Furthermore, Rafi, Samsudin and Ismail (2006, p. 155) propose that “gender differences in spatial aptitude may be caused by several socio-cultural factors such as gender-typed socialisation”. Children’s conception of how to behave is shaped by the gender-linked beliefs about them resulted from their parental notions on gender-related abilities (Rafi et al., 2006). In support of socio-cultural factors, Sorby (1999, p. 24) suggests that “environmental factors are the primary reasons for male female differences in spatial skill levels”. As Rafi et al. (2006) also state, “girls are inadvertently not encouraged to pursue an interest in masculine domains which are heavily loaded with spatial reasoning aspects and they may also underestimate their potentials in spatial domains due to their parental beliefs that affect their self-perception of capability”. Rafi et al. (2006) further found that male children have more opportunities to engage in spatial activities at an early age through gender-biased activities that promote spatial skills development. The current study was concerned with the relationship and impact of various environmental factors on rural–university students’ spatial visualisation skills.

In conclusion, a review of literature established that there is compelling evidence to support the existence of significant differences in spatial visualisation abilities between males and females. These differences can be attributed to a number of factors such as field of study, experience with spatial activities and socio-cultural factors. However, what research has not yet established is the relation between spatial visualisation ability and gender at a rural-based South African university. The present study addressed this issue by evaluating to what extent gender differences existed between graphic design students’ spatial visualisation within the context of a rural–university in Kwazulu-Natal province of South Africa.

2.3 PRIOR SPATIAL EXPERIENCE

The objective of the present study was to investigate the relationship of students' academic-type prior spatial experience and non-academic-type prior spatial experience with spatial visualisation skills. As reported in chapter 1 on page 6, the study was set against the backdrop of students at a rural–university and the challenges that these students face prior to and on entering university. There is general agreement in literature that prior spatial experience is a determining factor in the development of spatial visualisation ability (Newcombe & Baenninger, 1989; Rafi, Samsudin, & Ismail, 2006; Strong & Smith, 2002). Work by Newcombe and Baenninger (1989); Salthouse et al. (1990); and Strong and Smith (2002) suggest that prior spatial experience consists of two distinct components: (1) academic-type spatial activities or "specific intensive training" which is acquired through formal training sessions that is mathematics and engineering drawing; and (2) non-academic-type spatial activities which is acquired through "life experiences" that is playing games and partaking in sport. Non-academic prior spatial experience is considered by Newcombe and Baenninger (1989) to be activities which include freedom to explore one's environment, playing with toys that require manipulation in space and spatial creativity such as Lego blocks and Erector sets, participation in contact sports which are spatial in nature and partaking in "scouting" activity which requires map reading and orienteering.

With regard to the rural–context of the current study, Roux (2006) reports that several indigenous Zulu games, which are mostly played in the rural areas, have shown to develop cognitive learning. Roux (2006) explains that the cognitive concepts developed through playing indigenous Zulu games comprises concept learning such as the learning of skill concepts and perceptual motor learning that includes the learning of the "spatial world". Furthermore, several of these indigenous games has shown a positive relation to the development of spatial skills including; *Ushumpu* or "kick the ball", *Ugxa* or "hopscotch" and *Ingqathu* or "rope skipping" (Nxumalo S., personal communication, March 15, 2018).

Conversely, Salthouse et al. (1990, p.130) suggest that "partaking in activities which require the production or interpretation of drawings in which 3D objects are represented in 2D form and the designing and building of furniture or scale models to be relevant prior spatial experience for enhanced spatial visualisation." The suggestion made by Salthouse (1990) could hold true for university students who previously completed the subjects Engineering Graphics Design (EGD), Mathematics or Physical Science in their school curriculum in view of the fact that these subjects were described by Baenninger and Newcombe (1989, p. 329) as; "subjects which include geometric material." Furthermore, several researchers have conducted studies to determine if engineering graphics content has any relation with students' spatial visualisation skills. Worth mentioning are studies by Sorby (1999); Rafi et al. (2006); Alias, Gray, and Black (2002); Michau (2012); Pedrosa, Barbero, and Miguel (2014); and Sorby, Metz, and Ribe (2017) which alluded to prior completion of engineering graphic courses to be important experience for spatial visualisation skills because it includes, amongst others, strong components of descriptive geometry and sketching. Moreover, although each study has produced slightly different results, it seemed that completion of engineering graphics content to have a positive relation with spatial visualisation skills. However, the studies reported here, which are mainly set in the United States of America and in Europe, does not reflect the context of teaching and learning engineering graphics content in a rural-based setting. Thus, the need to establish the relationship of teaching and learning prior engineering content with spatial visualisation skills in a rural–setting.

Off importance to the current study, which sought to answer if the completion of an engineering orientated school subject to have any relation with spatial visualisation skills, was that there are four engineering related school subjects offered in South Africa. These four school subjects, which all include engineering graphics content, are Engineering Graphics Design, Electrical Technology, Civil Technology and Mechanical Technology. However, although the engineering-based school subjects were introduced into the South African school curriculum in 2005, very few rural schools offer these subjects due to lack of skilled teachers, lack of facilities and underfunding (Holmes, 2010). The significance of this research, that as far as could be determined, was that the relation between academic-type prior spatial experience and spatial visualisation skills of students at a rural–university in South Africa was unknown. Forthwith the relationship between non-academic-type prior spatial activities and spatial visualisation skills will be discussed.

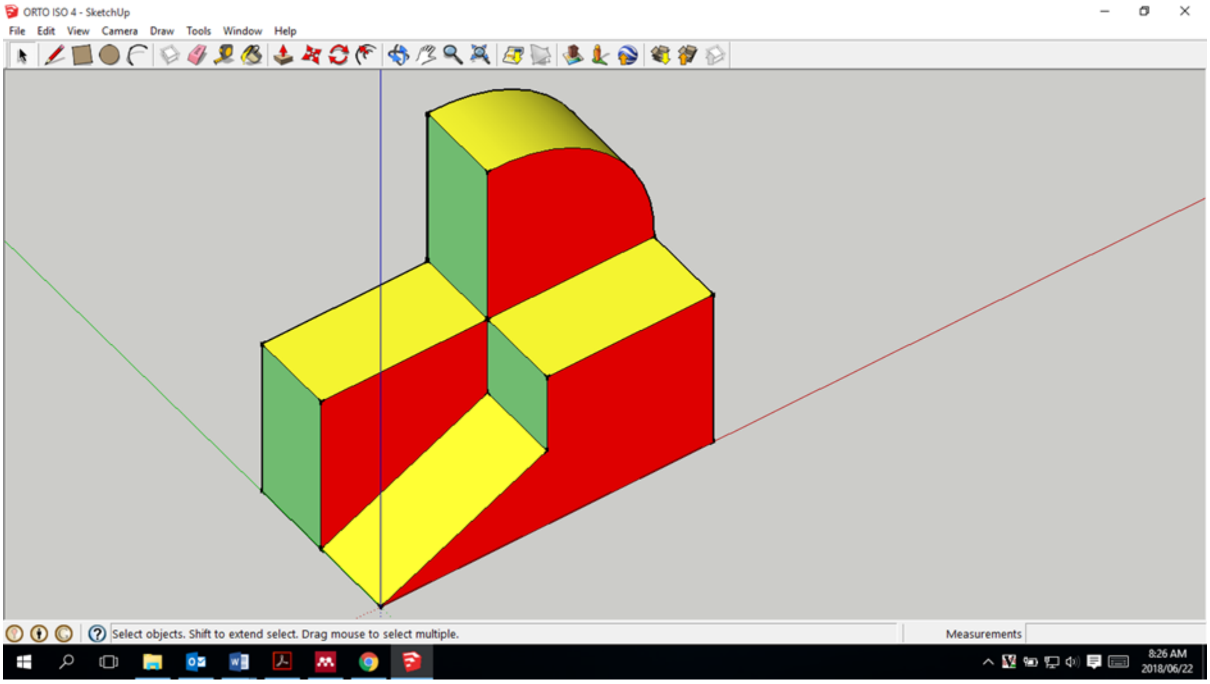
With reference to non-academic prior spatial experience, Strong et al. (2002), allude to activities such as model building, sketching, assembly of parts, actively playing video games and playing chess as activities which enhance spatial visualisation skills. Whether the non-academic activities mentioned, and others not mentioned here, were part of the constructs of rural-based students' repertoire still had to be investigated. Newcombe and Baenninger (1989) found that non-academic spatial activities correlated with higher spatial test scores although the magnitude of this effect is small. In contrast, Newcombe and Baenninger (1989) implies that spatial training has a fairly strong, but possibly narrow, improvement on spatial test scores. In addition, Stieff and Uttal (2015) consider the impact of spatial training on STEM achievement and concluded that spatial training led to an average improvement of almost half standard deviation in spatial ability measures. Furthermore, Stieff and Uttal (2015) affirm the belief that prior spatial training leads to improvements in spatial ability, however, they suggested that the true effect thereof still remains unknown. On a different note, Rafi et al. (2006) did not distinguish between academic-type and non-academic-type spatial activities and reported that a significant difference in spatial visualisation skills could be attributed to students with a higher level of spatial experience. Akin to the objectives of the current study the level of prior spatial experience was evaluated in two categories; (1) academic-type and (2) non-academic-type spatial activities. With reference to prior spatial academic-type activities the focus in the current study was on the completion of an engineering orientated school subject, the marks achieved in a Mathematics module and the marks achieved in a Physical Science module at a rural–university.

Mindful of the objectives of the current study, the most frequently used measure for prior spatial activity, as reported by Newcombe, Bandura, and Taylor (1983), is a questionnaire designed by McDaniel, Guay, Ball and Kolloff (1978) which consists of 81 "sex-typed" spatial activities of which 40 are masculine, 21 feminine and 20 neutral. During later work, Signorella, Krupa, Jamison, and Lyons (1986) condensed these 81 items into a "spatial activity questionnaire" to include only 30 items. Signorella et al. (1986, p. 476) justified the exclusion of 51 items from the original questionnaire by stating that "a shorter version of the questionnaire would make the questionnaire more useful as it eliminated items which had no correlation with the total score". During a later study, in which Rafi et al. (2006) strived to determine the differences of prior spatial experience in learners, the researchers categorised participants into “high” and “low” spatial experience by adapting and implementing a spatial experience questionnaire (SEQ) which was originally designed by McDaniel, Guay, Ball and Kolloff (1978). As Rafi et al. (2006, p. 33) explain “the SEQ include a 25-item self-report questionnaire consisting of a list of spatial activities such as sketching, drawing, map reading, driving a car, playing sport, using tools and playing chess.” Each item has a four-point scale ranging from two extremes (that is very often and never) to be rated by participants (Rafi et al., 2006). Two levels of spatial experience were categorised and based on the total scores of the questionnaire such that low experience was 42 and below, and high experience was 43 and above (Rafi et al., 2006). However, irrespective of the categories, items or scales of a prior spatial experience questionnaire, Newcombe and Baenninger (1989, p. 23) cautions that “with any spatial activity participation scale when used with adults is that it is by necessity a retrospective measure because activity participation usually changes drastically over a lifetime”.

With respect to whether prior spatial experience was a spatial visualisation skill determinant of graphics design students at a rural–university still remained to be determined. In the current study academic-type prior spatial experience was determined by: (1) eliciting responses from students regarding experience obtained at school in an engineering orientated subject and in addition, (2) computing the mathematics module marks and science and technology module marks students obtained during their first semester of study. Non-academic-type prior spatial experience for this study was determined by implementing a 20 item spatial experience questionnaire to evaluate the relation thereof with spatial visualisation skills (see Annexure B).

2.4 3D solid computer modelling

A number of studies, such as Saorín and Contero, (2008); Kurtuluş and Uygan, (2010); Martín-Dorta, and Rodriguez and Rodriguez, (2016) report of the effectiveness of 3D solid computer modelling on the improvement of students’ spatial visualisation skills. Regardless, as far as available research the studies mentioned here were not rooted in a rural-based context and furthermore, no literature could be found of similar investigations in South Africa. For this reason, and due to the fact that graphics design students at a rural–university often struggled with 2D to 3D drawing activities, the current study attempted to determine if the use of 3D solid computer modelling computer software would offset any difference in their spatial visualisation skills. Three Dimensional computer solid modelling, which is described as the representation of the solid parts of an object on a computer (cf. Figure 6), is one of the most advanced methods of geometric modelling in three dimensions (Kurtuluş & Uygan, 2010). The typical geometric model is made up of “wire frames” that show the object in the form of wires. This “wire frame structure” can be two dimensional (2D) or three dimensional (3D) and can provide surface representation to the wire thus giving 3D views of geometric models which makes the object appear solid on the computer screen (Hsu, 2010).



Select objects. Shift to extend select. Drag mouse to select multiple.

Figure 6: A 3D Computer Model of an Object.

With the advent of computer-based educational technology, 3D solid computer modelling is described as one of the most important applications of CAD software and has become increasingly popular of late (Fleisig et al., 2011). Commonly, 3D solid computer modelling CAD software assists the designer to see the designed object as if it was the real manufactured product as it can be seen from various directions and in various views (Hsu, 2010). This helps the designer to be sure that the object looks exactly as they wanted it to be. It also gives additional vision to the designer as to what more changes can be done to the object. Hsu (2010) describes parametric modelling as a type of 3D solid computer modelling which means that the parameters of the model, such as dimensions, may be modified to change the geometry of the model. When for instance a dimension is changed, the geometry of the part is updated, thus, the parameter drives the geometry (Hsu, 2010).

Moreover, what makes modern 3D solid computer modelling applications easier to use (user friendly) is that it conforms to the parametric and history-based approaches. The power of the parametric approach is that when one dimension is modified, all linked dimensions are updated according to specified mathematical relations, instead of having to update all related dimensions individually (Hsu, 2010). Furthermore, history-based modelling emphasises that the order in which parts are created is critical, for example, a hole cannot be created before a solid volume of material in which the hole occurs has been modelled (Hsu, 2010). If the solid volume is deleted, then the hole is deleted with it in a parent-child relation. The child (hole) cannot exist without the parent (solid volume) existing first (Hsu, 2010).

A typical 3D solid computer modelling computer programme such as SketchUp conforms to both parametric and history-based modelling techniques (Martín-Dorta et al., 2008). Martín-Dorta et al. (2008) and Kurtuluş and Uygan, (2010) agree that a SketchUp-based course is a good option to use in a remedial graphics design course for improving spatial skills because of several advantages such as; being freely downloadable from the Internet, easy to learn and it combines a simple, yet robust tool-set with an intelligent drawing system. In addition, it enables students to build and modify 3D models quickly and easily (Christou, et al., 2007).

Regarding the current study, in the context of a rural setting with limited resources, the reasons provided here and supported by various authors was a determining factor for the use of SketchUp as the 3D modelling software.

2.5 PIAGET’S PERCEPTION AND IMAGERY THEORY

The purpose of this study was to find out why graphics design students had difficulty to convert the 2D views of an object into a 3D representation of the object. Not only is this a fundamental skill in graphic design but, it is to a large extent a cognitive function which as previously been discussed in sections 2.2 and 2.3 above, is depended on a person’s spatial visualisation ability and prior spatial experiences.

There have been various theories attempting to predict and explain the nuances of spatial visualisation. Some of these theories are merely listed due to the fact that they delineate from the objectives of the current study. These include; the theory of figural concepts and the cognitive load theory. The theory of figural concepts states that; “geometrical figures represent mental constructs which possess, simultaneously, conceptual and mental representation of space property” (Jones, 1998, p. 30). Jones (1998) indicates that, Fischbein (1993) argues that all geometrical figures represent mental constructs which possess, simultaneously, conceptual and figural properties. However, the figural concepts theory is limited to explaining the mental representation of geometrical figures only and does not explain the conceptualisation of more complex multi-faceted objects such as those encountered in a graphics design context. Furthermore, the cognitive load theory, wherein Pillay (1998, p. 6) argues that; “the cognitive load imposed by task information often exhausts our limited cognitive resource and therefore the need to construct three-dimensional mental representations of intermediate stages in the trajectory that transforms orthographic drawings to pictorial representation, freed cognitive resources to attend to teaching and learning the transformation.” However, the cognitive load theory demand that the intermediate stages in solving 2D to 3D problems must be provided in order to reduce the cognitive load. With reference to the current study, the intermediate phases in solving 2D to 3D problems were not provided and students had to depend on all their cognitive abilities to solve the problems.

However, one theory that was closely related with the current study was Piaget’s perception and imagery theory. The current study used Piaget’s perception and imagery theory to understand and explain what the relationship and impact of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles are on the spatial visualisation of students at a rural–university.

The strong link between spatial abilities and graphics design has already been detailed in section 2.2 of this study. However, several of the studies involving spatial ability and visual imagery in engineering graphics courses, by researchers such as Makgato and

Khoza (2016); Potter and Van der Merwe (2001) and Sorby (1999), mention that perception and imagery are figurative processes which can be trained throughout the human life-span. For instance Potter and Van der Merwe (2001, p. 7) found in line with Piaget's theory on perception and mental imagery that:

> *students vary in their ability to use mental imagery, and may require training to do so. Those students with well-developed abilities in using mental imagery for the purposes of visualisation are likely to experience few difficulties in learning the different methods of graphical illustration which engineers use in practice.*

Moreover, Makgato and Khoza (2016) and Potter and Van der Merwe (2001) describe Piaget's theory on perception and mental imagery as comprising of "four stages of perception"; namely, stage (1) sensori-motor, stage (2) pre-operations, stage (3) concrete operations and stage (4) formal operational. However, the two stages of Piaget's theory which have relevance to the current study's objectives were the concrete operational stage, during which a child (age 7-12 years) can perform reversible mental actions on concrete objects and, the formal operational stage where children (age 12 years and up) can classify, order and reverse mental operations and are capable of abstract reasoning.

The relevance of the concrete operational and formal operational stages during 2D to 3D drawing were attested by Kösa and Karakuş (2017) who believed that spatial visualisation is the ability to imagine rotations of objects or their parts in 3D space. Spatial visualisation therefore includes mental rotation and spatial perception (Kösa & Karakuş, 2018). Consequently, Piaget's perception and imagery theory has been used in several studies, akin to the current study's objectives, for establishing the relationship and impact of students' spatial visualisation skills with graphics design content.

However, with regard to spatial relations, Fleisig, Robertson and Spence, (2011) indicate that individuals progress sequentially through three stages of understanding viz. topological relationships, projective representation, and Euclidean. During an individual's early years they discover topological relationships such as the grouping of objects, order, enclosure by other objects and immutability of topological properties to folding or stretching (Fleisig et al., 2011). Topological skills are primarily 2D and are acquired by most children by the age of 3-5 (Sorby, 2007). In the projective representation stage individuals learn to represent 3D objects from different perspectives to their own which is akin to rotating the point of view or the object itself (Fleisig et al., 2011). Sorby (2007) points out that the projective stage begins in adolescence and development continues throughout university. Most children have typically acquired this skill by adolescence however, if the object is unfamiliar, many students in high school or even college have difficulty visualising at this stage of development (Sorby, 2007). During the last stage, Euclidean, individuals learn to visualise and manipulate Euclidean notions of distance, proportion, area, angle, and volume in combination with those of translation, rotation and reflection (Fleisig et al., 2011; Sorby 2007). The last two stages overlap during undergraduate studies for most students (Fleisig et al., 2011).

On closer inspection Piaget's perception and imagery theory suggested that post-secondary education students should be formal operational thinkers. However, Khoza (2016), concluded that a high percentage of post-secondary students have yet to reach the formal-operational stage. According to Khoza (2016) this has significant implications for teaching, even in higher education, since reaching the formal operational stage is a result of a combination of maturation and experience from earlier stages. While maturation might come with age, experience is most likely to be the consequence of education (Linn & Petersen, 1985; Makgato & Khoza, 2016). Makgato and Khoza (2016, p. 612) highlight the importance of the four stages for students' perception and visualisation in engineering graphics courses. Piaget's theory of intellectual development explain how individuals' understandings of the world change during development and how students themselves actively construct knowledge (Makgato & Khoza, 2016).

Thus, the current study was informed by Piaget's perception and imagery theory with respect to the acquisition of spatial visualisation skills in adulthood. The employment of this theory assisted the current study in determining if prior spatial experience accrued by a person through active participation in various spatial activities was a determinant for developing spatial visualisation skills. From the work of Makgato and

Khoza (2016); Potter and Van der Merwe (2001); and Sorby and Baartmans (2000), Piaget’s perception and imagery theory can be summarised as follows:

- *Perception and imagery are figurative processes which can be trained throughout the human life-span.*
- *Perception and mental symbolism derives from activity.*
- *The internal abbreviated imitation of the perceptual activity constitutes the visual image.*
- *The visual image is based on the internal imitation of the originally perceived object.*
- *Mental imagery thus develops through action, and can be developed through activities which involve imitation. Both copying and sketching form the basis for the development of visual imagery.*

Conscious of the objectives of the current study, Piaget’s theory on perception and mental imagery frames a person’s ability to acquire spatial visualisation skills through prior spatial experiences and 3D computer solid modelling. Therefore, the activities from which perception and mental symbolism derives are examined in the current study. Therefore, this study ventured to determine the relationship and impact of prior spatial experience, gender and 3D solid computer modelling on spatial visualisation skills of rural–university students.

2.6 COGNITIVE PROCESSES IN 2D AND 3D VISUALISATION

The cognitive visualisation processes employed by graphics design students at a rural–university, when they are attempting to convert 2D views into 3D objects, largely remained unknown. Consequently, it was necessary to investigate what the mental processes were which student engaged in when constructing meaning from 2D views to produce 3D representations. Additionally, this review of literature enabled the current study to develop a conceptual framework (see Annexure E) to guide the conceptual and procedural knowledge for 2D to 3D drawing. Thus far, research shows that spatial visualisation skills are a fundamental component of technology education especially during the transition from 2D views to 3D representations (Duffy et al., 2016; Kösa & Karakuş, 2018; Sorby et al., 2017). With this in mind, an objective of the current study was to determine how first year graphics design students applied their spatial visualisation skills in constructing mental images of 3D objects from the 2D views of the object. This facet of graphics design was described as solving 2D to 3D problems. A better understanding of spatial visualisation skills therefore provided the current study with a frame of reference to understand how students apply spatial visualisation skills when solving 2D to 3D problems.

In literature, spatial visualisation is described as the ability to imagine the rotation of depicted 2D and 3D objects, the folding or unfolding of flat patterns, or the relative changes in position of an object in space (Duffy et al., 2016; Kösa & Karakuş, 2018; Makgato & Khoza, 2016). Furthermore, there is some evidence that spatial skills are characterised by a number of features which include but is not limited to representational skills, transforming, generating and recalling symbolic non-linguistic information (Linn & Petersen, 1985). There is also evidence to suggest that spatial visualisation is a cognitive skill which requires the ability to manipulate an object in an imaginary 3D space and create a representation of the object from a new viewpoint (Sorby et al., 2017; Strong & Smith, 2002). In addition, Gutiérrez (1996) describes visualisation as a process of generating cognitive representations of spatial objects through visual images that may be facilitated by external representations or physical actions.

The focus for the current study was to determine how students mentally or otherwise manipulate 2D and 3D images when solving 2D to 3D problems. Moreover, this study investigated the cognitive processes which students employed when mentally creating these images. Similarly, Pillay (1998, p. 4), attempted to understand the complex cognitive processes and strategies employed by students to learn spatial representations such as assembly tasks. Pillay (1998) reports observing cognitive activities such as integrating information from various sources, constructing meaning of abstruse elements in the graphical information, constructing hidden or obscured information, constructing and maintaining 3D representations of the components and the complete object, retrieving relevant schemas, encoding/constructing information from given spatial representations and finally, performing transformations on these representations. Based on investigations into assembly procedures of spatial tasks, Pillay (1998, p. 4) suggests that there are three processes by which a person can construct and understand spatial information:

1. *we may retrieve a previously constructed mental representation and modify it,*
2. *construct a completely new representation, or*
3. *just encode an external representation into an internal representation*.

Supplementary to the three processes suggested by Pillay (1998), Pittalis and Christou (2010) point out that regardless of which of these processes are involved the representation of a 3D object by means of a 2D figure demands considerable conventionalising. However, these 2D to 3D conventions, which is not trivial, was not taught in school (Pittalis & Christou, 2010). For this reason, there is a need to explicitly interpret and apply conventions for drawing 3D objects otherwise students may misread a drawing and may not understand whether it represents a 2D or a 3D object (Pittalis & Christou, 2010, p.1 93). In support of Pillay's (1998) notion, that relevant information is "retrieved" in order to integrate knowledge, McNeil (2014) suggests that a person developed mental models to represent knowledge used in cognitive tasks and to make sense of experiences in the physical world. These mental models are highly individualised and ever changing as new teaching and learning takes place to represent knowledge in a holistic schematic organisation in which a set of ideas are related together in a meaningful way (McNeil, 2014). In addition to Pillay's (1998) assumption, that information may be retrieved from previously constructed material in the brain, Ullman, Wood, and Graig (1990) mention two different ways on how visual imagery information are stored in the long-term memory of the brain that is (1) facts about objects and (2) encodings of the literal appearance of the object. Ullman et al. (1990, p. 267) mention that "facts about objects" include names, size and function and "encodings of the literal appearance of the object" include a list of coordinates where points should be placed. In addition, Pillay (1998, p. 5) argues that "when presented with instructional material, learners first try and retrieve existing representations and use them directly, failing that, they retrieve representations that fit the best and modify them in accordance with the new information”. Moreover, when retrieving a previously constructed representation, we need to establish a connection between the new and existing representations (Pillay, 1998). Thus, during the process of mentally constructing a 3D representation from a 2D orthographic drawing Pillay (1998) suggests that a person may begin either by encoding and constructing 3D mental representations of various components and then use these representations to construct a 3D representation of the complete object. Alternatively, a 3D representation of the overall object may be constructed with limited detail and held in memory, then be elaborated on gradually as the 3D representation of components becomes meaningful (Pillay, 1998).

Another point of view with regard to visualisation is provided by Moore-Russo, Viglietti, Chiu, and Bateman (2013). Ibid mention that when people visualise some might focus on the relationships between the parts of an object while others tend to focus on the overall pictorial appearance of the object. However, Pillay (1998) argues that it is also possible that individuals may use both these processes, therefore combining it into a process where mental images fluctuate between the parts of an object and the overall picture of the object. What’s more, when visualising, Blazhenkova and Kozhevnikov (2009) identify two distinct types of individuals that is (1) object visualisers, who use imagery to construct vivid high-resolution images of individual objects, and (2) spatial visualisers, who use imagery to represent and transform spatial relations. Blazhenkova and Kozhevnikov (2009, p. 640) base these two distinct types of individuals on the existence of an “object imagery system” that processes the visual appearance of objects and scenes in terms of their shape, vividness, colour, and texture and a “spatial imagery system” that processes an object’s location, movement, spatial relations and transformations. Thus, regardless of whether an individual is considered an “object visualiser” or a “spatial visualiser”, what is evident is that during the visualisation processes of encoding, integrating and constructing a 3D object from its 2D views, the thinking process is proceeding in a flexible and interactive way.

Furthermore, Sorby (1999) describes visual thinking as three types of imagery viz. (1) the type that we see, “people see images not things,” (2) the type that we imagine in our mind’s eye and, (3) the type that we draw or paint. However, expert visual thinkers utilised all three types of imagery in a flexible interactive way (Sorby, 1999).

What literature has shown thus far was that researchers were in agreement that spatial visualisation skills was critically important in the field of engineering and graphics design. However, what research has so far failed to answer pertinently was how students used their spatial visualisation skills when solving 2D to 3D problems. Relevant to the current study, it still remained unclear how students accessed or retrieved relevant information from their existing mental models for the purpose of visualising a 3D object from its 2D views. What also remained unknown was how students applied their spatial visualisation skills as cognition process and what type of thinking strategies they employed when faced with a 2D to 3D problem.

2.6.1 Sketching as thinking process

In like manner, the current study desired to determine how rural–university students used sketching activities during the 2D to 3D visualisation process. For the most part, a successful spatial visualisation process depends on sketching in creating and modifying external representations and to materialise external thoughts (Leblanc, 2015). The previous section in this paper (section 2.6) alluded to the cognitive processes involved in visualising and converting a 3D object from its 2D views. However, work done by Fish and Scrivener (2007); Gagnier, Atit, Ormand, and Shipley (2017); Goldschmidt (2017); and Leblanc (2015) stress the importance of sketching activities to support spatial reasoning. In support of the view that sketching is vital in spatial reasoning tasks Gagnier et al. (2017) state that sketching is often used as a pedagogical tool to help students reason about 3D structures and, Fish and Scrivener (2007) suggest that the necessity to sketch derives from the need to envisage the outcome of the synthesis of objects. In addition, Ullman, Wood and Graig (1990, p. 263) describe sketching as “free hand drawings, usually not to scale and which are used for amongst others, to communicate ideas, to serve as a competence checker and to act as an extension to the draftsman's' short term memory to remember ideas that they might otherwise forget." Typically, during the process of visualising the 3D representation of an object from its 2D views, sketching will be utilised in stages to externalise the mentally created object. Fish and Scrivener (2007) argue that the importance of sketching increases in proportion to the degree of abstraction or difficulty involved in manipulating the object and therefore a system is needed for representing the object to be easily stored and manipulated. In addition, Goldschmidt (2017) affirms that the mastery of the rules of orthogonal projections and the skill of generating drawings lead to the acquisition of representational conventions that allowed for easier representation of objects in space. Sketching thus interacted with visual imagery in a cyclic pattern which is a cognitive mechanism that Fish and Scrivener (2007, p. 117) describe as; "amplifying the mind's eye". Fish and Scrivener (2007) make a compelling argument that there is converging evidence that the external human sign system has analogies in the internal representations used by the brain for perceiving, recognising, imagining and reasoning. In this sense, sketching uses abbreviated 2D sign systems to represent 3D visual experience while also exhibiting a "sketch denotational system" which process information in the brain (Fish & Scrivener, 2007, p. 119).

Thus, sketching played a vital role in managing the 2D to 3D visualisation process. Moreover, sketching was used as a pedagogical tool to assist with reasoning strategies, to retain ideas in the short term memory and to envisage the desired outcome of a 2D to 3D drawing. However, it still needed to be determined how students in the current study employed sketching during the mental processes of creating 3D objects from 2D views.

2.7 LEARNING MODELS FOR ENHANCING SPATIAL VISUALISATION

The objectives of this study, which sought to determine the relationship and impact of prior spatial experience, gender, 3D solid computer modelling and students' different cognitive styles of spatial visualisation, culminated into the development of a model for learning 2D to 3D drawing. With this in mind, a review of literature was undertaken to discover learning models for enhancing rural–university students' spatial visualisation skills. Also taken into consideration was the large classes of graphics design students that lecturers at UNIZULU have to deal with. Although literature revealed various models and programmes to improve spatial visualisation skills to enhance learning of graphics content and to develop 2D and 3D drawing cognition, none of these studies were set in a rural-based South African context. For example, a study at an urban South African university, by Potter and Van der Merwe (2001), designed a learning model in which activities such as modelling, copying, sketching and drawing were organised in a series of remedial loops. The model developed by Potter and Van der Merwe (2001) was reported to be successful with pass rates for the course improving from 64% to 76%. However, the programme was undertaken with small groups of students who were selected for a pre-university year in engineering. The progress of the students was monitored closely by questionnaires, interviews and course progress tests as well as psychometric tests (Potter & Van der Merwe, 2001). Although the model developed by Potter and Van der Merwe (2001) did have qualities which will be considered, the differences related to the current study were in the nature of the content that is engineering students versus education students. Furthermore, the reliance on resources that included physical modelling of objects in large classes required extensive resources.

Rafi, Samsudin, and Ismail (2006) utilised a computer mediated multi-media programme which replicated typical engineering drawing tasks comprising of multi 2D orthographic views together with isometric representations. Similar to the work of Rafi et al. (2006), Amosa, Hamdalat and Sherifat (2016) and Michau (2012) suggest that presenting technical drawing content, information and animations on topics of 2D views and 3D objects through the medium of a Power Point Presentation is effective. In addition, Olkun (2003) also suggests that using geometrical objects and representing them in two-dimensional space can enhance spatial abilities. Despite these learning models of Rafi, Samsudin and Ismail (2006) and Amosa, Hamdalat and Sherifat (2016) making a valuable contribution to enhancing spatial visualisation, the models are resource intensive and would be placing additional cognitive demand on students at a rural–university.

Regardless of the models thus far noted from the works of Potter and Van der Merwe (2001), Olkun, (2003), Rafi et al. (2006), Dorta et al. (2008), Michau (2012) and Amosa, et al. (2016), the conclusion drawn was that there remained insufficient evidence from theory and practice that the current graphics design module at a rural–

university did not ensure adequate improvement in students' spatial visualisation skills in terms of converting 2D views of an object into the 3D representation. Thus, the unique characteristics and prior spatial experiences of technology education students which entered and studied graphics design at a rural–university embodied guiding factors for developing a learning model for the enhancement of spatial visualisation skills. On this basis, it was envisaged that the learning model to be developed would be grounded in Piaget's theory on perception and mental imagery, the conceptual framework for 2D to 3D visualisation (see Annexure E), the theory of PCK (as discussed in section 2.8), as well the objectives of the study which sought to:

- investigate the students' level of prior spatial experience and its relation with spatial visualisation skills
- examine if any relations existed amongst gender and spatial visualisation skills
- examine if the application of 3D solid computer modelling software offset any differences in low spatial visualisation skills.
- analyse the cognitive styles in terms of 3D drawings from 2D cognition.

2.8 A CONCEPTUAL FRAMEWORK FOR 2D TO 3D VISUALISATION

Guided by Piaget's theory on the development of perception and mental imagery, as well as Piaget's constructivist theory, an intensive review of literature brought to light a conceptual framework for the current study's objective to analyse the cognitive styles in terms of 3D drawings from 2D views. The conceptual framework unfolded but was not limited from studies by researchers including Blazhenkova and Kozhevnikov (2009); Moore-Russo et al. (2013); Pillay (1998); Pittalis and Christou (2010); Fish and Scrivener (2007); Leblanc (2015); and Goldschmidt (2017). Contributions made by researchers in establishing a 2D to 3D conceptual framework for the current study is summarised in Table 4 and illustrated in Annexure E.

Table 4: *A summary of the main work supporting the 2D to 3D conceptual framework of the current study*

Researcher	Cited Work	Contribution to Conceptual Framework
Pillay (1998)	"students are often presented with orthographic drawings as the instructional format… they are required to encode information from the three different views, integrate the information and construct three-dimensional mental representations of individual components"	• Encode – what information is provided by the 2D views? • Integrate – retrieve and combine knowledge, conventions and experience • Construct – create a 3D mental image
Blazhenkova and Kozhevnikov (2009)	"Neuropsychological data, however, suggest the existence of two distinct imagery subsystems that encode and process visual information in different ways, that is, an object imagery system that processes the visual appearance of objects and scenes in terms of their shape, colour information and texture and a spatial imagery system that processes object location, movement, spatial relationships and transformations and other spatial attributes of processing"	• Object visualisers – imagine colour, shape, patterns, vividness or details, for example imagine an object where the FV, TV and SV have different colours. • Spatial visualisers – imagine location, relation between objects, relation between parts of the object, the object's movement, rotation or transformation. For example imagine an object standing on a table.
Moore-Russo, Viglietti, Chiu, and Bateman (2013)	"when visualising, some individuals hone in on the relationships between the parts of an object while others tend to focus on the overall pictorial appearance of the object"	• Focus on the relationship between underlying parts • Focus on the overall pictorial appearance
Pittalis and Christou (2010)	"the representation of a 3D object by means of a 2D figure demands considerable conventionalising … there is a need to explicitly interpret and utilise conventions for drawing 3D objects explicitly…"	• Conventions – knowledge of the fundamental drawing standards, methods and rules
Fish and Scrivener (2007)	"the necessity to sketch derives from the need to envisage the outcome of the synthesis of objects... typically, during the process of visualising the 3D representation of an object from its 2D views, sketching will be utilised in stages to externalise the mentally created object"	• Sketching as thinking process

The conceptual framework for the current study, illustrated in Annexure E, was used to guide the researcher in understanding the cognition processes of students when visualising 3D objects from 2D views. The conceptual framework presented here is by nature a fluid process, meaning that, depending on the level of spatial visualisation and the level of prior spatial experiences, a student could access the process at any stage. This is supported by Pittalis and Christou (2010) who argue that 3D visualisation is depended on the knowledge and experience of a person. Therefore, a student with more prior knowledge and greater experience in spatial skills could enter the visualisation process, as presented in Annexure E, at a more advanced level compared to a student with lower knowledge and less experience. Therefore, from the work of the researchers indicated here, when a 3D object is visualised from its underlying 2D views one or more of the following stages of the visualisation process are involved:

1. Encode - Information is encoded from the three given views (stimulus).
    - Searching for relationships between the views (Pillay, 1998).
    - Focus on either the underlying parts or the overall pictorial appearance (Moore- Russo et al., 2013).
    - Object visualisers focus on colour, texture, shape, patterns and details (Blazhenkova & Kozhevnikov, 2009).
    - Spatial visualisers focus on location, relation, rotation and transformation (Blazhenkova & Kozhevnikov, 2009).

2. Integrate - Information is retrieved from existing knowledge and combined with encoded information. Prior knowledge includes conventions, sources and experiences.
    - Retrieve information stored in the brain resulting from knowledge and experiences (Pillay, 1998).

- Compare and contrast knowledge to make sense of the stimulus (layout of the views, conventions -line types, methods etc.) (Pittalis & Christou, 2010).
- Synthesising perceived information with prior knowledge (Blazhenkova & Kozhevnikov, 2009; Moore-Russo et al., 2013).

3. Construct - Creating a 3D visual image of the complete object in the brain. Use sketching as a tool in the thinking process.
    - Create an initial visual image to fit the stimulus (Pillay, 1998).
    - Reflect on and modify the image, can involve sketching (Fish & Scrivener, 2007; Pillay, 1998).
    - Mentally construct the final 3D image, modify the sketch (Fish & Scrivener, 2007; Pillay, 1998).

Based on this conceptual framework, a routine visualisation process with regard to visualising the 3D representation (isometric) of an object from its 2D views (orthographic) could progress as follows (cf. Figure 7). A prominent spatial visualiser would focus on the location, position and relationships between different parts or components of the object (Moore-Russo et al., 2013). A visual image of the final object is then internally constructed failing which the following processes are triggered:

- Information is encoded from the three orthographic views searching for relationships between the different parts of the object (Pillay, 1998).
- The spatial visualiser focusses on the location and relation of different parts of the object to one another (Blazhenkova & Kozhevnikov, 2009). For example, one might reason that plane (a, b, c and d) is to the left with relation to plane (i, j, k and l) and plane (a, b, c and d) has a lower location in relation to plane (e, f, g and h).
- If the object is complex and multifaceted, the spatial visualiser also encodes object information in a combined process.

- Knowledge of orthographic and isometric drawing fundamentals and conventions as well as prior experiences are retrieved from the brain and integrated with the visual stimulus (Pittalis & Christou, 2010). Fundamental knowledge of orthographic projection, minimum which is the location of the front view, top view and side view as well as the relationship between lines and planes are integrated. Knowledge of isometric drawing will include the location of the three axes length, height and depth as well as the "crating method" described by Benade and Van den Heever (1993, p. 121) whereby an object is built up from its base by positioning the parts of the object in space, much like stacking crates on top of one another.
- The spatial visualiser could imagine or draw parallel projectors between the three views to analyse the location and position of different components of the object such as planes and lines.
- A mental image of the object is internally constructed. If the mental image is unclear, sketching as thinking process is employed (Leblanc, 2015). The image is then modified in the brain while rotating and transforming the image until the individual parts of the object fits in position, location and in relation to one another.

In contrast to a spatial visualiser, a prominent object visualiser, when confronted with a mental task of converting orthographic views into an isometric projection, would be focussing on the patterns and shape of the three views and construct a complete pictorial image of the object, failing which the following processes will occur (Moore-Russo et al., 2013):

- Information is encoded from the three orthographic views by focussing on patterns, shapes, details and where possible colour (Blazhenkova & Kozhevnikov, 2009). For example, one could reason that the overall appearance of the object is four small cube-like shapes fitting into a larger cube (cf. Figure 7).
- If the object is complex and multifaceted, the object visualiser could also encode spatial information in a combined process.

- Knowledge of orthographic and isometric drawing fundamentals and conventions as well as prior experiences are retrieved from the brain and integrated with the visual stimulus (Pittalis & Christou, 2010). Fundamental knowledge of orthographic projection, minimum which is the layout of the front view, top view and side view as well as the relationship between 2D and 3D shapes and figures. Knowledge of isometric drawing will include the placement of the three axes length, height and depth as well as the "blocking method" described by Benade and Van den Heever (1993, p. 121) whereby an object is imagined as being placed in an imaginary square block which is just large enough to contain the final object (cf. Annexure I). The different shapes of the object are then cut away from the square block much like cutting out the final shape from a piece of wood.
- The object visualiser could imagine or draw parallel projectors between the three views to analyse which different shapes correspond between the three views.
- A mental image of the final object could then be constructed. If the mental image is unclear, sketching as thinking process could be employed (Fish & Scrivener, 2007; Leblanc, 2015). The image could then be modified until the final shape appears from the overall shape.

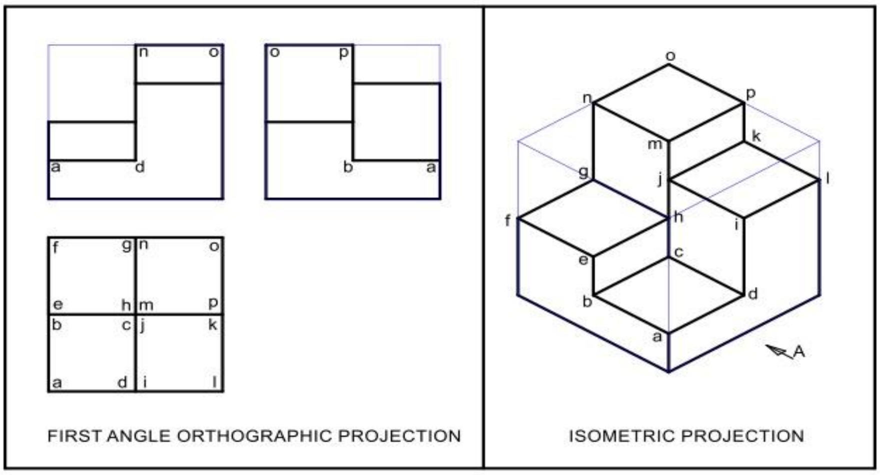


Figure 7: Orthographic (2D) to isometric (3D) model to explain the visualisation process.

Inferring from the discussions above, there are stages during the 3D visualisation process where spatial visualisers and object visualisers could be employing unique mental strategies and there are stages when the mental strategies between the two groups are similar. However, it still remained unclear if students in the current study exclusively used one of these cognitive processes or a combination of the two 3D visualisation processes. Pillay (1998) suggests that it is indeed possible to combine the two 3D visualisation processes into a process where mental images fluctuates between the parts of an object and the overall picture of the object. Based on the conceptual framework presented here an instructional and learning model for 2D to 3D drawing should include activities and experiences where students are allowed to encode information from 2D views, integrate information from existing knowledge and construct 3D images by using spatial and object visualisation techniques.

Finally, the study's objectives assimilated into the development of model, for teaching and learning 2D to 3D drawing, which in turn was guided by the theories and notions surrounding Pedagogical Content Knowledge (PCK). Therefore, Piaget's perception and imagery theory, the conceptual framework for 2D to 3D visualisation and PCK amalgamated into the development of an instructional model for teaching and learning 2D to 3D drawing at a rural–university. Although Piaget's theory, the 2D to 3D conceptual framework and PCK were already discussed in detail under chapter 2 of this study however, what follows is an insightful explanation and synthesis of these three frameworks.

2.9 PEDAGOGICAL CONTENT KNOWLEDGE (PCK)

As alluded to in section 2.7, the current study endeavoured to develop a model for learning 2D to 3D drawing in a graphics design module at a rural–university. Although various learning models have been developed with some success, as reported in section 2.7, none of these models specifically addressed the unique characteristics and context of students at a rural–university. The development of this study's 2D to 3D model was two-fold. Firstly, the proposed model was guided by the results obtained from research questions 1 to 4 in this study. In essence, research questions 1 to 4 determined how the factors of prior spatial experience, gender, 3D solid computer modelling and cognition styles impacted the learning of 2D to 3D drawing. Secondly, the proposed model was based on a combination of the study's theoretical and conceptual frameworks, as well as the theories and advances made in initial teacher education with specific focus on PCK.

PCK was first defined by Shulman in a keynote address at the American Educational Research Association in San Francisco California (Gess-Newsome, 2015). Shulman (1987) describes PCK as the kind of knowledge which goes beyond knowledge of subject matter or teaching method per se to the dimension of Subject Matter Knowledge (SMK) for teaching. Etkina (2010, p. 11) provides the following distinction between General Pedagogical Knowledge (GPK) and PCK:

> *teachers should know how people learn, how memory operates, and how a brain develops with age. This knowledge is called general pedagogical knowledge or the knowledge of how people learn. However, most importantly, teachers of a specific subject should possess special understandings and abilities that integrate their knowledge of this subject's content and student learning of this content, this special knowledge is called PCK and is what distinguishes the science knowledge of teachers from that of scientists.*

Shulman (1987) observes that teacher education focused more on generic pedagogical knowledge rather than PCK. Shulman (1987) refers to PCK as 'the missing paradigm." Shulman (1987) outlines seven categories that constitute the knowledge of teachers

> *content knowledge; general pedagogical knowledge; curriculum knowledge; pedagogical content knowledge; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational ends, purposes and values.*

However, among these categories PCK was of special interest because it identified the distinctive bodies of knowledge for teaching (Shulman, 1987). Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) agree with Shulman and considered PCK to be one of the cornerstones of teacher knowledge. Rollnick et al. (2008) argued that if it is possible to describe and model how PCK is formed, it may have been possible to target areas for improvement in teacher education. When placed in context of the current study, it was important to know which knowledge areas of 2D to 3D drawing should be targeted to achieve an improvement in students' ability to convert 2D drawings into 3D representations. Rather than targeting what content to teach students, PCK focused on the strategies and techniques applied in teaching; those strategies and techniques that bring about the best learning experiences for every learner (Shulman, 1987). Nilsson (2014) concurs that PCK involved teachers' understanding of how to help a group of students understand specific subject matter using multiple instructional strategies, representations and assessments while working within the contextual, cultural and social limitations in the learning environment. PCK also involves knowing how to take advantage of different teaching approaches that make a learning experience most suitable for the learners Shulman (1987). According to Makgato and Khoza (2016), these learning experiences included being flexible and adjusting instruction to account for various learning styles, abilities and interests. Knowing how to best teach a concept so that the learners will receive the best learning experience spoke to the essence of PCK (Makgato & Khoza, 2016). In addition to knowing how to best teach a concept, Khoza (2016) argues that the different teaching approaches employed will vary from teacher to teacher and from differing contexts but, invariably will revolve around similar principles for each approach. Thus, with relevance to the current study's endeavour of developing a model for learning 2D to 3D drawing, it was important to know what literature revealed about the nuances of PCK models.

2.9.1 Models of PCK

Different models have been employed to trace the transformation of subject matter knowledge to PCK as manifested in the classroom (Rollnick, 2017). Work done by Gess-Newsome (2015); Khoza (2016); Nilsson (2014); and Rollnick (2017) suggest five aspects of a PCK model which itself was derived from Shulman's (1987) knowledge bases. The five aspects of this model gave insight into how teachers developed their PCK. In the view of Magnusson, Krajcik and Borko (1999), experienced teachers' PCK encompassed:

- Orientation to teaching
- Knowledge of curricula
- Knowledge of students' prior understanding of the subject
- Knowledge of representations and instructional strategies, and
- Knowledge of assessment.

As detailed in the model, Magnusson et al. (1999) argues that teachers' orientations to teaching is shaped by knowledge of curricula, knowledge of students, knowledge of representations and knowledge of assessment. As these components may interact in very complex ways, teachers needed to develop knowledge of all aspects of PCK (Magnusson et al., 1999). As such, PCK was the result of a transformation of knowledge from other domains. Therefore, the importance of PCK in the current study was brought to the fore in the development of a 2D to 3D instructional model for students at a rural–university. The model of PCK developed by Magnusson et al. (1999) has been used by a number of researchers as a basis to capture the essence of PCK and as a springboard to develop more robust and predictive ways to think about teacher knowledge (for example Gess-Newsome, 2015; Nilsson, 2014; Rollnick, 2017; Rollnick et al., 2008).

A more abbreviated point of view was provided by Etkina (2010, p. 11), who describes the three pillars of knowledge on a "traditional teacher training path" as content knowledge, pedagogical knowledge and pedagogical content knowledge. The researcher explained that content knowledge is knowledge of the discipline that teachers will teach; pedagogical knowledge is general knowledge of how students learn and how schools work; and pedagogical content knowledge is knowledge of subject matter for teaching, knowledge of students' difficulties and prior conceptions in the domain, knowledge of domain representations and instructional strategies, and knowledge of domain specific assessment methods (Etkina, 2010).

Moreover, deep content knowledge is a necessary condition for the development of PCK (Etkina, 2010; Khoza, 2016). On a different note, if teachers themselves do not understand the nuances of a concept, the deep relationships between this particular concept and other concepts, and the ways through which this concept was constructed by the teaching community, then translating these nuances into student understanding is impossible (Etkina, 2010). Likewise, understanding of the processes of teaching and learning is crucial for the development of the orientation towards teaching, assessment methods and understanding of the role of students' ideas (Etkina, 2010). For example, the awareness of the complex nature of brain activity should affect how teachers deal with what is widely perceived as "student misconceptions". In addition, PCK is highly domain specific; therefore, it is critical that future teachers develop PCK in the specific topics that they will be teaching (Khoza, 2016). Along these lines, the fundamental building blocks for the development of a 2D to 3D drawing model at a rural–university should include a strong grounding in content knowledge with specific focus on orthographic and isometric competencies.

Furthermore, a PCK model that has been found useful for the purposes of the current study is that of Rollnick et al. (2008). Rollnick et al. (2008) developed the model to extend Shulman's notion of PCK by classifying the categories of the knowledge base into knowledge domains for teaching and manifestations (cf. Figure 8). Rollnick et al. (2008, p. 13) suggest that "many attempts have been made to model the integration of teacher knowledge to produce PCK (for example Cochran et al., 1993), but most examined only the underlying knowledge rather than how this knowledge is combined to produce what happens in the classroom." Furthermore, Rollnick et al. (2008, p. 13) indicated that their model focussed on "the role of subject matter knowledge because that was an issue of concern in South Africa". Moreover, Rollnick et al. (2008, p. 13) conclude that many of the established models of PCK included subject matter knowledge as a component of PCK, but few gave prominence to its central role in the construction of teacher knowledge. Also, Rollnick's model showed the integration of teachers' internal knowledge domains to produce the visible product of integration of these domains in the classroom which they refer to as manifestations (Rollnick et al., 2008). In the model (cf. Figure 8) it can be seen that the internal knowledge domains are shown in the bottom half of the diagram while the manifestations are shown in the top part of the diagram. Consequently, in the current study, Rollnick's model was applied because it separated the teachers' internal thought processes from those that can be observed directly in the classroom (Davidowitz & Rollnick, 2011).

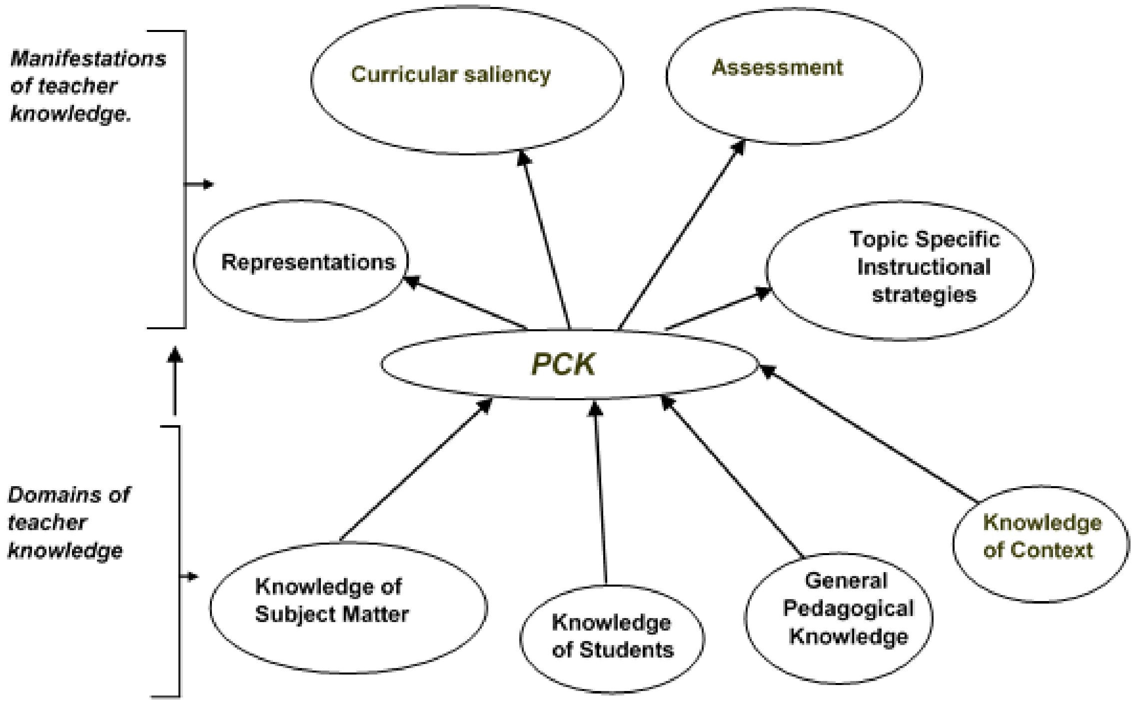


Figure 8: Rollnick's PCK model, from Rollnick et al. (2008, p. 1371*).*

Although Rollnick's model does not cover all manifestations in a classroom a few representative manifestations were included in the model including; subject matter representations, topic-specific instructional strategies, curricular saliency and assessment (Rollnick et al., 2008). The four manifestations represented here were important considerations which guided the current study's development of a 2D to 3D instructional model. Forthwith each category in the model will be discussed in more detail.

2.9.2 Manifestations of teacher knowledge

Rollnick's model, Figure 8, shows that within the knowledge domain, PCK include: "knowledge of subject matter, knowledge of students', general pedagogical knowledge and knowledge of context". On the other hand, manifestations refer to observable teaching practices in the classroom (Rollnick et al., 2008). In the current study Rollnick's model was used to differentiate between knowledge and practice, referring to the PCK in practice as manifestations of PCK. These manifestations externalise the internal teacher knowledge and were important factors included in the 2D to 3D instructional model.

2.9.3 Representations

Shulman (2000) indicates that a teacher should be able to construct or provide alternative representations in the form of examples, illustrations, analogies or explanations that will enable students to understand the topic being taught. These forms of representations may develop from research or through the experience that one has in teaching (Shulman, 2000). Complementary to Shulman (1986), Rollnick et al. (2008) argue that effective representations, which can be used in teaching, resulted from the blending of the four knowledge domains in the model (cf. Figure 8). The four knowledge domains are "knowledge of subject matter, knowledge of students, general pedagogical knowledge and knowledge of context". With reference to the current study, Rodriguez and Rodriguez (2016) mention that 3D solid computer modelling and Gambari, Yusuf and Balogun (2015) add that computer presentations and simulations are effective representations in learning graphics design. Therefore, in the current study a model for teaching and learning 2D to 3D drawing included application and practice in 3D computer modelling. In support of the idea to use representations in learning, Makgato an Khoza (2016) report that one of the difficulties experienced by Engineering Graphics and Design (EGD) teachers were that the facilitation of sectional drawing and other EGD concepts remain theoretical, with no simulations, practical observation and concrete visualisation. With this in mind, it was critical to include a variety of presentations in the development of a 2D to 3D drawing model. These representations included, but was not limited to simulations, video, concrete object demonstrations and 3D solid computer modelling.

2.9.4 Curricular saliency

Davidowitz and Rollnick (2011) and Khoza (2016) acknowledge the importance of the topic to the overall curriculum that teachers are dealing with. Khoza (2016) observes curricular saliency as an ability lacking in novice teachers, however, experienced teachers manage to cover the curriculum they teach because of their ability to select the important content to be taught by looking at what is central and peripheral in the taught topics. Thus, this ability made a teacher include or omit some content and determines the depth of the content the teacher should enter into (Rollnick et al., 2008). Associated with the current study, Khoza (2016) indicates that when a lecturer facilitates sectional drawing, he/she needs to emphasize its importance to the entire curriculum of engineering graphics and design by relating it to other concepts that are still to come, like assembly drawing and detail drawings. Similarly, the current study focussed on the development of 2D to 3D drawing with an emphasis on developing students' spatial visualisation through 3D solid computer modelling instead of the narrow focus on multiple exercises with increased difficulty as often found in graphics design instructional material.

2.9.5 Assessment

Analogous to the PCK model forwarded by Magnusson et al. (1999), Rollnick et al. (2008) pointed out that assessment comprises the teachers' understanding of the procedures or approaches that would be fitting to test students understanding of important sections of scientific learning and the advantages and disadvantages of using certain ways to evaluate students understanding. Assessment involved the teachers' choice for both formative and summative tasks and this was shaped by the teachers' knowledge of the subject matter (Rollnick et al., 2008). Furthermore, some lecturers were unable to employ various assessment strategies because their knowledge of the subject matter was affected by the fact that they did not have current material and workbooks to facilitate (Rollnick et al., 2008). In turn, this translated into the lack of useful strategies that assisted students to learn successfully. For example, with relevance to learning sectional drawing content in engineering graphics, Makgato and Khoza (2016) indicated that the decision as to whether give homework or group presentations of the problem by using a model or just a mark taken from the classroom practice was up to the lecturer. In the current study, the development of a 2D to 3D learning model included a baseline assessment of students' spatial visualisation skills and regular assessment of students' progress in spatial skills and content knowledge.

2.9.6 Topic specific instructional strategies

Magnusson et al. (1999) points out that topic specific instructional strategies, which are considered an aspect of a teachers' PCK, are the specific strategies which are useful for assisting students to understand concepts in the topic being taught. Davidowitz and Rollnick (2011) argue that topic specific strategies are the product of an important set of thought processes and was an intrinsic part of a teacher's practice and often only observable in action. The topic specific instructional activities included experiments, simulations and problems that the teacher could use to improve understanding of concepts and their relationship to the topic (Makgato & Khoza, 2016). After observing a chemistry lesson in practice, Davidowitz and Rollnick (2011, p. 361) describe the topic specific instructional strategies used by the lecturer as;

> *large models to illustrate the 3D nature of the molecules being discussed, multiple representations of simple structures to signal the importance of being able to interpret these and allowing students sufficient time to copy structures and reactions from the chalkboard.*

However, Magnusson et al. (1999) argue that the teacher should not only know topic specific instructional strategies but should also know the limitations and strengths associated with the strategies used in order to choose the strategies that would be most useful in teaching the topic. The knowledge of choosing the best strategies, which are an important aspect of teaching, stems from the act of learning from teaching and which are generated by teachers as a result of reflection on their practice (Gess-Newsome, 2015). Such knowledge grows as teachers individually, collectively, or with a facilitative expert, consider instructional actions and consequences and seek larger perspectives (Gess-Newsome, 2015). For this reason, the current study experimented with a new practice, 3D solid computer modelling, for learning 2D to 3D drawing. By examining what occurred in the classroom, the inclusion of 3D solid computer modelling was considered as an effective topic specific instructional strategy for 2D to 3D drawing.

2.9.7 Domains of teachers' knowledge

The aim of this review was to understand what aspects of subject matter knowledge, knowledge of students, general pedagogical knowledge and knowledge of context to consider when developing a model for learning 2D to 3D drawing. Here follows a detailed discussion on the categories under the domain of "teacher knowledge" in Rollnick's et al. PCK model (cf. Figure 8).

2.9.8 Knowledge of subject matter

During an earlier discussion under PCK (section 2.8), it was noted that Shulman (1987) outlined seven categories that constitute the knowledge of teachers: content knowledge; general pedagogical knowledge; curriculum knowledge; pedagogical content knowledge; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational ends, purposes and values. Shulman (1987) mentions the first knowledge base as Content Knowledge (CK) and describe it as the knowledge, understanding and disposition that are to be learned. Shulman (1987, p. 9) further suggests that content knowledge rests on two foundations; (1) the accumulated literature and studies in the content areas, and (2) the historical and philosophical scholarship on the nature of knowledge in those areas. Later work however described the transformation of content knowledge into Subject Matter Knowledge (SMK) as a process of decompression or unpacking of content knowledge (Davidowitz & Rollnick, 2011). Nonetheless, studies by among others Rollnick et al. (2008) and Etkina (2010) used the term subject matter knowledge. For instance, Rollnick et al. (2008) point out that knowledge of subject matter refers to the teacher's raw untransformed subject matter knowledge in a particular learning area or concept and Nixon et al. (2016) say that teachers needed to understand the subject matter they teach including knowledge of the concepts of their discipline and concepts that cut across the different disciplines. What's more, studies by Davidowitz and

Rollnick (2011); Gess-Newsome (2015) and Rollnick (2017) have provided evidence that SMK is a foundational component of PCK and important for teaching. For example, Rollnick et al. (2008) found that three South African teachers' SMK influenced their methods of representing the subject matter to students, their design of assessment tasks, and their choice of instructional strategies. In another study, Nixon et al. (2016) reported that for some teachers, SMK facilitated the development of new representations while for others, inadequate SMK inhibited this development. Nixon et al. (2016) argue that SMK is known to influence classroom practice for example, an investigation into experienced science teachers' instruction as they taught in their area of specialisation, revealed that when they taught in a new subject area for which they were not certified and had taught less than twice, they acted like novices in many ways. Therefore, teachers needed to understand and develop the processes and practices associated with their discipline because SMK are the basis for many of the instructional decisions that will be made in a classroom (Gess-Newsome, 2015). Furthermore, studies by Boothe, Barnard, Peterson, and Coppola (2018) and Davidowitz and Rollnick (2011) have shown that the SMK of secondary science teachers improve as they interact with the curriculum and engage in professional development programmes. With reference to the development of a 2D to 3D model for the current study, it would be important to consider the relevant subject matter knowledge because an important consensus from the PCK literature is that the greater a teacher's subject matter knowledge, the more effective their instruction. With this in mind, the next section (section 2.8.9) took an in depth look at the relevant subject matter knowledge for learning 2D to 3D drawing.

2.9.9 Relevant subject matter knowledge for learning 2D to 3D drawing

An important objective of the current study was to develop a learning model for 2D to 3D drawing. Literature has shown that a teachers' SMK is vitally important for effective instruction in the subject. Subsequently, the study undertook a review of five commonly used instructional sources on orthographic and isometric (2D to 3D) instruction. Amongst these instructional sources, Benade and Van den Heever (1993), Maguire and Simmons (1998), and Morling (2010) agree that 2D representation uses orthographic projection to create an image where only two of the three dimensions of the object are seen such as in polygons. On the other hand, in a 3D representation, also referred to as a pictorial, all three dimensions of an object are visible such as in cubes, prisms, pyramids, spheres, cones, and cylinders (Benade & van den Heever, 1993; Morling, 2010). A summary of the similarities and differences of the essential attributes of orthographic and isometric projection as described in the 5 instructional sources are shown in Table 5. In addition, Table five also shows the terminology and procedures applicable to the current study.

Table 5: *A summary of similarities and differences between five instructional sources on the procedure of learning 2D to 3D drawing*

Book Title	**Geometric and Engineering Drawing**	**Textbook of Engineering Drawing**	**Teach Yourself Technical Drawing**	**Modern Technical Drawing**	**Basic Technical Drawing**	**Current Study**
Author/s and Date	Morling, 2010	Reddy, 2008	Maguire and Simmons, 1998	Benade and Van den Heever, 1993	Wilson, 1991	
Defining orthographic projection.	Orthographic projection is a multi-view drawing allowing any number of views of the same object. Orthographic projection has two forms: first angle and third angle.	'ORTHO' means right angle and orthographic means right angled drawing. When the projectors are perpendicular to the plane on which the projection is obtained, it is known as orthographic projection.	Orthographic drawings give views which are produced by observing separate faces of a component in order to demonstrate all its physical features.	In multi-view orthographic projection the projection lines are parallel with each other and perpendicular to the projection planes.	When a craftsman is required to make a certain component, a working drawing must be prepared. This type of drawing is called *orthographic projection* or *multi-view drawing*.	Orthographic projection is a multi-view drawing in which the views of an object are projected perpendicular to the plane on which the projection is obtained.
Defining isometric projection.	Isometric projection is a method of drawing with instruments which gives a pictorial view of an object.	It is a pictorial orthographic projection of an object in which a transparent cube containing the object is tilted until one of the solid diagonals of the cube becomes perpendicular to the vertical plane and the three axes are equally inclined to this vertical plane.	Isometric drawing is a technique of illustrating an object after it has been tilted so that lengths along each of its three principal axes have been equally foreshortened.	An isometric view is in fact an orthographic pictorial view of which the base isometric axes form 30º each with the horizontal. The surfaces appear to meet each other at 120º angles. Isometric projection shows approximately 81% of their true lengths. Isometric drawing	Isometric drawings are ‘built up’ about three axes which we will call *isometric axes*.	Isometric projection gives a pictorial view of an object after it has been tilted so that lengths along each of its three principal axes have been equally foreshortened.

				assumes the true length are full size.		
Naming the planes of projection.	Horizontal Plane Front Vertical Plane End Vertical Plane	Horizontal Plane Vertical Plane Auxiliary Vertical Plane	Horizontal Plane Vertical Plane Vertical Plane	Horizontal Plane Vertical Plane Auxiliary Vertical Plane	Horizontal Plane Vertical Plane Profile plane	Horizontal Plane (HP) Vertical Plane (VP) Auxiliary Vertical Plane (AVP)
Naming the dimensions?	Length Height Breadth	Length Height Breadth	Width Height Depth	Width Height Depth	Width Height Depth	Length (L) Height (H) Depth (D)
Naming the views.	Front Elevation Plan End Elevation	Front View Top View Side View	Front View Plan View End View	Front View Top View Side View	Front View Top View Side View	Front View (FV) Top View (TV) Side View (SV)
Instructional methods: sequence of content.	Isometric projection including: Isometric axes, isometric lines, block shaped objects, isometric circle. Orthographic projection including: Third angle orthographic, principle planes of projection, projection a block shaped object, unfolding of planes	Orthographic projection: plane geometry, solid geometry, first angle orthographic projection, Planes of projection. Isometric projection: principles, scale, angles, simple objects, isometric lines, non-isometric lines, circles	Orthographic projection: first angle, planes of projection, polystyrene block, exercise of simple block shaped objects on grid. Isometric: Axes at 30 degrees, isometric lines, non-isometric lines, circles	Orthographic: first angle, principle planes, dimensions, auxiliary planes, project onto planes, rabatment, project points, lines, laminas and then objects. Isometric: axes at 30 degrees, dimensions on axes, block method, crating method.	Orthographic projection: third angle orthographic, principle planes, projection, folding of planes, block shaped object. Isometric drawings: axes 120 degrees, X, Y and Z axes, Block method, block-in, circle.	Orthographic projection: first angle orthographic, principle planes, project views onto the planes, rabatment, simple block-shaped objects. Isometric: isometric axes 30 degrees, associate dimensions on axes, block-shaped objects, isometric lines, crating method, simple block-shaped objects.

It follows that, orthographic projection is described as a way of visualising different views of an object such as the top view, the front view and the side view; and when the object is rotated, the viewer viewing the object could see each individual side (Morling, 2010, p. 118). In addition, orthographic projection is also referred to as multi-view drawings, working drawings or 2D drawings (Benade & van den Heever, 1993; Maguire & Simmons, 1998). Isometric projection is described as a pictorial view of an object after it has been tilted so that the lengths along each of its three principal axes have been equally foreshortened (Maguire & Simmons, 1998). According to Benade and Van den Heever (1993, p. 121) there are two common methods of drawing isometric projections that is the “blocking method” and the “crating method”. In the “blocking method” the object is imagined as being placed in a square like block, made from polystyrene or wood, which is just large enough to contain the object (cf. Annexure I). Garmendia et al. (2007) describe the “blocking method” as a method to eliminate volumes starting from the prism surrounding the part. The object is then visualised by cutting away pieces (eliminating volumes) from the square block until the final object remains (Benade & van den Heever, 1993). Furthermore, when using the “crating method”, or as described by Garmendia et al. (2007, p. 318) the “composition of solids method”, the object is imagined as consisting of smaller individual pieces which are then constructed together from the ground up, much like stacking crates, until the final object appears (cf. Annexure I).

The relationship between orthographic and isometric projection flows from the previous examples. A multi-faceted object (cf. Figure 9) is suspended between three planes of projection also referred to as being placed in a “glass box” so that the object is above the Horizontal Plane (HP) and in front of the Vertical Plane (VP) (Wilson, 1991). According to Benade and Van den Heever (1993) a plane is a perfectly flat surface onto which a view or image can be projected. Wilson (1991) describes a projection as a drawing of a 3D object on a 2D surface such as paper. It is important to note that the angle of projection must always be perpendicular onto the relevant plane (Benade & van den Heever, 1993; Reddy, 2008). In the case presented in Figure 9, the planes are the HP, the VP and the Auxiliary Vertical Plane (AVP). The view looking at the top of the object (Arrow A) is projected directly below the object onto the HP and is named the Top View (TV). The view looking at the front of the object (Arrow B) is projected onto the VP and titled the Front View (FV). The view looking from the left side of the object (Arrow C) is projected onto the AVP and is titled the Left Side View (LSV).

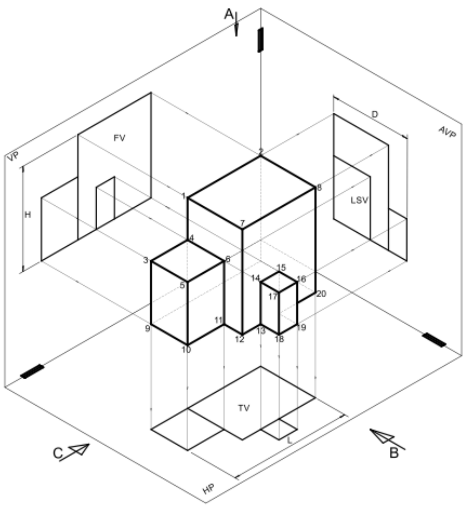


Figure 9: View of a "Glass Box" representing the first angle orthographic projection with an object placed inside the box.

Furthermore, if the object is removed from the "glass box" and imagining that the three planes are hinged by folding down the HP and folding back the AVP so that both planes line up with the VP, the result are the views of the object as given in Figure 9. The front view is positioned above the top view and the left side view is positioned on the right of the front view. The layout of the views in this position resembles first angle orthographic projection (Benade & van den Heever, 1993; Maguire & Simmons, 1998; Reddy, 2008; Morling, 2010).

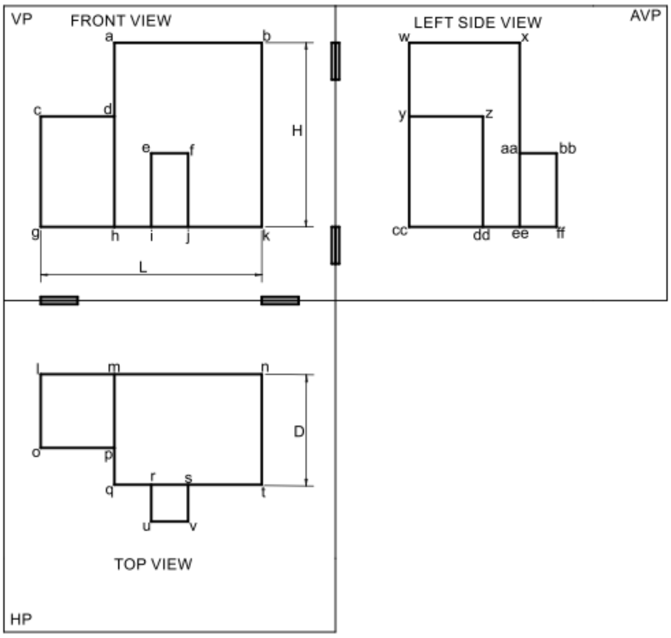


Figure 10: First angle orthographic projection of the object.

With respect to the objective of the current study which sought to determine the mental processes involved in converting orthographic views into isometric projections, assume that only the three views of the object are given in orthographic projection and it is required to produce the isometric projection of the object. Based on the conceptual framework of the current study and supported by instructional methods of converting orthographic views into isometric projections, certain vital information should be encoded from the three views in order to visualise the complete object (Pillay, 1998; Reddy, 2008). Authors, including Benade and Van den Heever (1993), Maguire and Simmons (1998), Reddy (2008) and Morling (2010) agree that each of the three views only shows two dimensions such that the front view shows the length and the height, the top view shows the length and the depth and the side view shows the height and the depth. Furthermore, Morling (2010) explain that a line in one view, for example line (a and b) in the front view is represented by a plane (m, n, t and q) in the top view and line (w and x) in the side view. Inferring from Morling's explanation, line (e and f) in the front view represents plane (r, s, v and u) in the top view. Also, as shown in Figure 10, the front view indicates the height dimensions and it can be seen that the object has three different levels that is level (a and b) on top, levels (c and d) and (e and f) in the middle and level (h, i, j, k and g) towards the bottom forming the base. The base is represented in the top view by (l, m, n, t, v, u, r, q, p and o) however the same points which represents the base here are also representing planes at different levels of height so that (m, n, t and q) is at the top, (l, m, p and o) is in the middle and (r, s, v and u) is the lowest. The review of literature presented here showed that authors of instructional material mostly agreed on the terminology used when explaining the essence of orthographic and isometric projection. Also, except for one author, the sequence of presenting the content of orthographic and isometric projection were for the most part akin to the procedural method as used for this study (cf. Table 5).

2.9.10 General pedagogical knowledge

According to Shulman (1987), General Pedagogical Knowledge (GPK) involve broad principles and strategies of classroom management and organisation that appear to transcend subject matter. What's more, Shulman (1987) say that GPK includes knowledge about learners and learning, assessment, and educational contexts and purposes. Similarly, as found in König (2013), the definition of GPK by Shulman is extended to include; knowledge of theories and learning, knowledge of general principles of instruction, an understanding of the various philosophies of education, general knowledge about learners, and knowledge of the principles and techniques of classroom management. Based on this extended definition of GPK, König (2013, p. 1003) regarded teacher education as effective if; "future teachers in their last year of their training have acquired general pedagogical knowledge allowing them to prepare, structure and evaluate lessons (structure), to motivate and support students as well as manage the classroom (motivation/classroom management), to deal with heterogeneous learning groups in the classroom and to assess students (assessment)". In the course of a case study, to find what lies at the heart of good undergraduate teaching of organic chemistry, Davidowitz and Rollnick (2011) provide an example of a lecturer's manifestation of GPK. After analysing five lessons taught by the lecturer, Davidowitz and Rollnick (2011, p. 365) point out that;

> *underlying the instruction is his belief in the importance of understanding basic principles in order to master organic chemistry and this belief arises from his very strong background in organic chemistry as a discipline, his understanding of students and their context, and finally, the general pedagogical knowledge*

> *that he has developed through several years of practice, leading to decisions, such as, not to use PowerPoint presentations in his lectures*.

In a nutshell, Rollnick et al. (2008) sum up that GPK refers to the understanding of what counts as good teaching, the best teaching approaches in a given context, informed by knowledge of applicable learning theories. In this way, the current study's 2D to 3D instructional model ensured that the learning material was contextualised and, included individual as well as group activities.

2.9.11 Knowledge of students

As early as the 1980's, Shulman (1987, p. 14) first regarded "knowledge of students and their characteristics" as an important component of pedagogical content knowledge (PCK). Indeed, Shulman (1987, p. 15) provides a model of pedagogical reasoning in action which include a component called; "transformation – adaptation and tailoring to student characteristics". Shulman (1987) describes the importance for teachers to know how to adapt material to the characteristics of students and tailor or fit the material to students in a specific class rather than to students in general. Although Shulman (1987, p. 15-17) provides a detailed description of teachers' knowledge of students, a brief account is;

> *consideration of conceptions, preconceptions, misconceptions, difficulties, language, culture, motivations, social class, gender, age, ability, aptitude, interests, self-concepts and attention.*

However, Tanisli and Kose (2013) included knowledge of students as an integral component of PCK, in fact, the authors mention that some studies placed knowledge of students at the centre of pedagogical content knowledge. In addition to Shulman's (1987) explanation of knowledge of students, Magnusson et al. (1999) portray knowledge of students to include cognitive and physical development, understanding students' differences that might require instructional differentiation, and how to capitalise on personal and community assets to enrich instruction. Furthermore, Rollnick et al. (2008, p.1369) give the following description; "knowledge of students is an appreciation of students' prior knowledge, how they learn, their linguistic skills, reading and writing abilities as well as interests and aspirations".

Moreover, a meaningful account of a university lecturers' knowledge of students is provided by Davidowitz and Rollnick (2011). After observing the lecturer's lesson, Davidowitz and Rollnick (2011, p. 365) detail the following;

> *the models he uses for teaching would be very different from the type of representations he would use in discussions with fellow scientists. In particular, his use of multiple representations in the classroom is essential to convey meaning to undergraduate students. Hence, the nature of the content produced for teaching purposes differs substantially from that used for chemistry research. Similarly, his explanations are a product of his content knowledge and his understanding of the students he is teaching – their linguistic competence and their background knowledge. Finally, he learns from his interactions with the students, adding to his knowledge of students and context, thus improving his ability to make the subject matter more meaningful.*

Thus, a clear picture of the importance for teachers to know their students emerged from the study of literature. It is incumbent on every teacher to determine the characteristics of his/her students in order to develop, adapt and tailor learning material and teaching strategies for that specific class. Therefore, to develop a model for learning 2D to 3D drawing it was important to have sufficient and relevant knowledge of students as a guiding factor. Hence, the components of the knowledge of students which this study is concerned with were taken from the study's findings of research questions 1 to 4. The current study's research questions, components of the model, findings of the study and the impact on a proposed model for teaching and learning 2D to 3D drawing is illustrated in Table 6.

Table 6: *Knowledge of students considered in an instructional model for teaching and learning 2D to 3D drawing.*

Research Questions	**Component of the model**	**Expected outcomes of the study**	**Impact on 2D to 3D model development**
1. What are rural students' level of prior spatial experience and its relation with spatial visualisation as a form of cognition?	• Prior spatial experience • Prior knowledge • Spatial visualisation skills	• What did the study find about PSE? • What are the influence of rural-based education?	• How can the model reflect PSE? • How must the model address spatial visualisation skills? • What rural-based factors must be considered?
2. What is the relation between gender and spatial visualisation ability?	• Gender	• What did the study find about gender differences?	• Must there be a difference in the activities for gender groups?
3. What effect does the use of 3D solid computer modelling software have on rural students' visualisation skills?	• 3D solid computer modelling skills	• What did the study find about the impact of 3D solid computer modelling?	• How can the model include 3D solid computer modelling strategies?
4. What are the mental processes rural students engage in, when constructing meaning from 2D views to produce 3D representations?	• Cognitive styles (conceptual framework for procedural knowledge, Annexure E) • Cognitive development (Piaget's theory)	• What did the study find about 2D to 3D cognition styles?	• How can the model accommodate different cognition styles for learning 2D to 3D? • How can the model include sketching as thinking skill?

2.9.12 Knowledge of context

In order to develop an instructional model for 2D to 3D drawing, knowledge of the context of teaching and learning were considered. Knowledge of context was described as all the contextual variables influencing the teaching situation, for example availability of resources, class size, students' socio-economic background, curriculum, the situation in the country, classroom conditions, and time available for teaching and learning (Rollnick et al., 2008). In addition, Gess-Newsome (2015) indicates that within the specificity of classroom practice, there is an acknowledgement that the context of the classroom played an important role which go beyond what teachers know and believe. For instance, the types of curriculum materials, supplies, and supports available would impact the type of instruction a teacher can deliver (Gess-Newsome, 2015). In addition, Davidowitz and Rollnick (2011) say that the number of classroom preparations that is assigned to an individual teacher, the amount of planning time available, and the assignment of responsibilities outside the classroom (that is, coaching, clubs) could limit the amount of time and attention that a teacher can dedicate to instructional planning for any given class. Moreover, other school features such as political and cultural influences of parents and/or community values, disruptions to the school day, and the number of competing types of school reform initiatives can also influence teaching decisions (Davidowitz & Rollnick, 2011). However, not all of these contextual features were within the control of the teacher. Therefore, it was important to identify the contextual factors which needed to be considered for developing a 2D to 3D instructional model to benefit the characteristics of a typical graphics design student at a rural–university. Table 7 shows the contextual factors and the impact thereof on the development of the 2D to 3D learning model.

Table 7: *Contextual factors in the current study*

Contextual variables influencing 2D to 3D (General to rural-based graphic design students)	**Impact on 2D to 3D model development**
• Students come from rural-based schools with little or no educational technologies	• Learning how to use new technologies like computers take time
• Low prior spatial experiences (PSE)	• 2D to 3D depends on PSE
• Low spatial visualisation (SV)	• 2D to 3D depends on SV, these skills take time to develop
• Enter a rural–university with large classes	• The context for learning in large classes are different
• Language difficulties- second language English	• Difficulties understanding new terminology
• Low computer literacy skills	• Learning 3D solid computer modelling programme takes time
• Limited computers for practice	• 3D solid computer modelling needs time to practice over and above normal classes

2.10 SUMMARY

This chapter provided a detailed review of available literature to understand the impact of prior spatial experience, gender, 3D solid computer modelling and cognitive styles of learning on the spatial visualisation skills of students at a rural–university. The study's main focus revolved around graphic design students' difficulties with 2D to 3D drawing. In essence, literature concurred that spatial visualisation skills are a fundamental component for high achievement in graphics design courses. Furthermore, prior spatial experience, which was categorised into academic-type and non-academic-type experiences, was for the most part considered a crucial factor in attaining high level spatial visualisation skills. However, the literature was silent on the impact of prior spatial experiences on spatial visualisation skills of rural–university students. Similarly, gender was considered to be a determining factor for high spatial visualisation skills with literature favouring males over females.

However, most studies were not set in rural-based contexts and therefore the unique rural-based setting of the current study will shed light on the issue of gender. Moreover, literature revealed various instructional strategies for improving spatial visualisation skills and concluded that 3D solid computer modelling to be an effective strategy. Furthermore, a detailed probe into Piaget’s perception and imagery theory showed that imagery is continuously developed, even into adulthood and depended to a large extent on activities such as sketching. Likewise, the cognitive processes involved during 2D to 3D drawing revealed a conceptual model which the study employed to make sense of rural-based students’ cognitive styles during visualisation processes.

Finally, this chapter explored various teaching and learning models for enhancing spatial visualisation skills as well as the theories surrounding pedagogical content knowledge and concluded with a framework for developing a teaching and learning model for the enhancement of 2D to 3D drawing at a rural–university. The contribution of each of the theories to the instructional model are summarised in Table 8.

Table 8: *Summary of the contributing theories to the 2D to 3D instructional model.*

Objective	**Theoretical framework**	**Contribution to 2D to 3D model**
To develop a model for instruction and learning 2D and 3D drawings unique to a graphics design module at the University of Zululand.	Piaget's perception and imagery theory	Provide opportunities for students to model problems. Provide activities for copying 3D models. Provide opportunities for freehand sketching, mental modification through sketching, and sketching as competence checker. Activities to focus more on the development of spatial visualisation skills.
	Conceptual 2D to 3D visualisation framework	Provide activities and experiences where students are allowed to encode information from 2D views. Activities to integrate information from existing knowledge. Activities to construct 3D images by using spatial and object visualisation techniques. Familiar to unfamiliar objects.
	PCK	Representations – provide activities on 3D solid computer modelling. Curricular saliency – focus and relate 2D to 3D drawing to other parts of the curriculum. Assessment – base line assessment of spatial visualisation and continuous assessment to determine progress. Topic specific instructional strategies – 3D solid computer modelling. Relevant subject matter knowledge (SMK) – Activities to develop skills in line types, plane geometry, solid geometry, orthographic projection and isometric projection. Knowledge of context – Develop spatial visualisation, computer literacy and language proficiency and terminology. Model designs from known contexts.

CHAPTER 3: THEORETICAL FRAMEWORK

3.1 INTRODUCTION

The current study endeavoured to address what the effects of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles have on graphics design students' spatial visualisation skills at a rural–university. The study emanated from the difficulty which students experienced to convert the 2D views of an object into a 3D representation of the object. In a graphics design context, the conversion of 2D to 3D is acknowledged as transforming multiple orthographic views of an object into a pictorial representation of the object. Not only is 2D to 3D drawing considered a fundamental skill in graphics design but, it depended to a large extent on complex cognitive functions which included encoding, perception, representational skills, transforming, generating and recalling symbolic non-linguistic information (Newcombe & Baenninger, 1989; Pillay, 1998; Ligocki, 2011). In addition, various studies have reported that spatial visualisation skills were shaped and influenced by numerous factors such as prior spatial experience (Sorby & Baartmans, 2000; Rafi & Samsudin, 2007); gender (Battista, 1990; Salthouse et al., 1990; Chan, 2007); 3D solid computer modelling (Kurtuluş & Uygan, 2010; Rodriguez & Rodriguez, 2016); and divergent cognitive styles (Blazhenkova & Kozhevnikov, 2009; Moore-Russo et al., 2013).

There have been various theories attempting to predict and explain the nuances of spatial visualisation. Some of these theories are merely listed due to the fact that they delineate from the objectives of the current study. These include the theory of figural concepts and the cognitive load theory. The theory of figural concepts states that; "geometrical figures represent mental constructs which possess, simultaneously, conceptual and mental representation of space property" (Jones, 1998, p. 30). Jones (1998) pointed out that all geometrical figures represented mental constructs which possess, simultaneously, conceptual and figural properties. However, the figural concepts theory was limited in explaining the mental representations and manipulation of 2D geometrical figures and does not explain the conceptualisation and pictorial complexities of multi-faceted objects such as those encountered in a graphics design context (Accascina & Rogora, 2006). Furthermore, the cognitive load theory, wherein Pillay (1998, p. 6) argues that;

> *the cognitive load imposed by task information often exhausts our limited cognitive resource and therefore the need to construct three-dimensional mental representations of intermediate stages in the trajectory that transforms orthographic drawings to pictorial representation, freed cognitive resources to attend to teaching and learning the transformation.*

However, the cognitive load theory demanded that the intermediate stages in solving 2D to 3D problems must be provided in order to reduce the cognitive load. With reference to the current study, the intermediate phases in solving 2D to 3D problems were not provided and students had to depend on all their cognitive faculties to solve graphic problems.

However, one theory that was closely related with the current study was Piaget's perception and imagery theory. The current study used Piaget's perception and imagery theory to understand and explain what the impact of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles had on the spatial visualisation of students at a rural–university. Furthermore, the current study promulgated Piaget's theory as an epistemology of constructivism which was used to explain how students know what they know.

3.2 PIAGET'S PERCEPTION AND IMAGERY THEORY

Piaget (1976) proposed four stages of cognitive development; sensory-motor, which was pre-verbal; pre-operational representation, which created the underpinnings of language and symbol; concrete operational, which preceded full capability of abstraction; and finally, formal or hypothetic-deductive operational, which allowed for full abstraction such as reasoning on hypotheses and the ability of propositional logic.

Piaget's theory implored that development preceded learning (Sorby, 2007) and that learning at higher levels becomes possible only as the individual passes through the four stages of development (Fleisig et al., 2011). Piaget's theory on perception and imagery assimilated with the theory of constructivism which argued that people produce knowledge and form meaning based upon their experiences (Vérillon, 2000).

Furthermore, individuals in Piaget's fourth stage of cognitive development were typified by the ability to delve into the hypothetical without having to see or interact with the concrete, therefore, abstract thought is possible (Greeson & Zigarmi, 1985). An individual in this last stage of development was capable of reason "on the basis of simple assumptions which have no necessary relation to reality or to the subject's beliefs, and from the time when he relied on the necessary validity of an inference, as opposed to agreement of the conclusions with experience" (Piaget, 1976). With regard to the current study, first year undergraduate graphics design students would thus be in the fourth Piagetian stage of cognitive development.

Moreover, Greeson and Zigarmi (1985) argued that every person made sense of his/her world by synthesizing new experiences into what one has previously come to understand. This supported the importance of experience in making increasingly more complicated understandings. Bodner, (1986, p.44) argued that in a constructivist model of knowledge the primary question of epistemology was, "How do we come to know what we know?" In addition, Bhattacharjee (2015) indicated that constructivism maintained that people constructed their own understanding and knowledge of the world through experiencing things and reflecting on those experiences. Constructivism is a theory that asserts that learning is an activity that is individual to the learner (Bodner, 1986). This theory hypothesized that individuals will try to make sense of all information that they perceive, and that each individual will, therefore, "construct" their own meaning from that information (Bhattacharjee, 2015). Thus, with reference to the first two research questions in the current study, which sought to determine the impact of students' prior spatial experiences and gender on their spatial visualisation skills, Piaget's perception and imagery theory alluded to experience, or play, and interaction with the environment as contributing factors to the development of spatial development (Greeson & Zigarmi, 1985). In addition, Sorby (199) argued that the primary reasons for gender differences in spatial skill levels included the assertions that spatial ability was related to environmental factors such that males have different experiences than females when growing up. The importance of research questions one and two in the current study were to provide an understanding of the type of prior spatial activities which students at a rural–university partook in and, if these activities and environmental factors have any impact on their spatial visualisation skills. Consequently, a closer look at Piaget's theory on spatial development.

Fleisig, Robertson and Spence, (2011) indicated that Piaget's theory on spatial relations suggested that individuals progressed sequentially through three stages of understanding; topological relationships' projective representation and Euclidean. During an individual's early years they discover topological relationships such as the grouping of objects, order, enclosure by other objects and immutability of topological properties to folding or stretching (Fleisig et al., 2011). In the projective representation stage, individuals learned to represent objects from different perspectives to their own, which is akin to rotating the point of view or the object itself (Fleisig et al., 2011). It was the projective spatial abilities that allowed for understanding of spatial relationships between multiple objects simultaneously and, importantly, the concept of viewpoint (Greeson & Zigarmi, 1985). In the projective representation stage was where cognitive faculties such as object orientation, viewer perspective and similar advanced spatial visualisation abilities developed. Fleisig et al. (2011) pointed out that the projective stage began in adolescence and development continued throughout university. During the last stage, Euclidean, individuals learned to conserve and manipulate Euclidean notions of distance, proportion, area, angle, and volume. The last two stages overlapped during undergraduate studies for most students (Fleisig et al., 2011). The current study focussed on Piaget's projective spatial development.

Research question three in the current study undertook to examine what the effect of using 3D solid computer modelling on rural–university students' spatial visualisation skills are. Cognisance must be taken of the fact that students at a rural–university has low levels of computer literacy on entering the university (Mabusela & Adams, 2017). Studies have shown that spatial visualisation skills could be enhanced by presenting a variety of different representations of objects, for example through concrete representations such as wooden blocks cut to a size and shaped to be depicted graphically by the student and, the latest being computer assisted drawing programmes and animations (Martín-Dorta et al., 2008; Marunic & Glazar, 2014; Pedrosa et al., 2014). According to Davidowitz and Rollnick (2011), a representation is a schema, transformation, model, symbol, or a map of an idea, concept, or a combination of these. Representations in education are commonly divided into internal and external representations. External representations occur outside the mind and can serve to communicate organized thoughts for ourselves or others, and include such things as graphs, text, diagrams, drawings, equations, models and prototypes (Ebersbach & Hagedorn, 2011; Shulman, 2000). The perception and active use of representations in education was confirmed by Piaget's theory which suggested that; knowledge was not a copy of reality; to know an object was not simply to look at it and make a mental copy or image of it; to know an object was to act on it; to modify or transform it; to understand the process of this transformation; and as a consequence to understand the way the object was constructed (Greeson & Zigarmi, 1985). The external representation provided in the current study is the implementation of a 3D solid computer modelling computer programme during which students model, modify and view 3D objects from different viewpoints. Therefore, with regard to constructivism, the role of the teacher is very important because instead of giving a lecture the teacher in this theory function as facilitator whose role is to aid the student when it comes to their own understanding (Vérillon, 2000).

Furthermore, the use of external representations in the form of 3D computer solid modelling of objects, such as used in the current study, could provide the link between students' internal conception of how an object looks when rotated and how it should look in 2D on paper. On the other hand, internal representations are distinct and are formed internally in the mind and consist of mental images or schemas that exist as part of the cognitive structure of the brain (Shulman, 2000). Internal representations are impossible to gauge directly because they occur inside the mind however, they dictate how an individual generates external representations, and in this sense they can be gauged indirectly (Shulman, 2000). Also, Bhattacharjee (2015) argued that constructivist theory asserted that knowledge can only exist within the human mind, and that it does not have to match any real world reality. Learners will be constantly trying to derive their own personal mental model of the real world from their perceptions of that world. As they perceive each new experience, learners will continually update their own mental models to reflect the new information, and will, therefore, construct their own interpretation of reality (Bodner, 1986). Thus, research question 4 of the current study endeavoured to investigate the internal thought processes of students when they are involved with spatial visualisation tasks such as converting 2D images to 3D representations. Greeson and Zigarmi (1985) argued that the application of various representations in the classroom also invoked the Piagetian developmental factor of experience. Given that all students have different existing mental images, or schemas, and unique cognitive structures, the presentation of multiple and varied representations allowed the concepts being represented to fit into the diverse cognitive frameworks in the minds of students (Greeson & Zigarmi, 1985).

Figure 11 illustrates the main constructs regarding spatial visualisation skills in the current study, allied with the theoretical framework that underpins the study. Students in the current study arrived at the university with different levels of prior spatial experiences in terms of academic and non-academic type, gender and the detriment of rural-based education. An assessment of students' spatial visualisation skills therefore established the relationship between prior spatial experiences and initial spatial visualisation skills prior to the application of 3D solid computer modelling intervention. An examination of students' different cognitive styles indicated the potential for more tangible enhancements of spatial visualisation skills during instruction as a function of the significance of developmental representations. In other words, those students with a greater extent of developmental representations, such as 3D solid computer modelling and sketching, also had greater spatial visualisation skills.

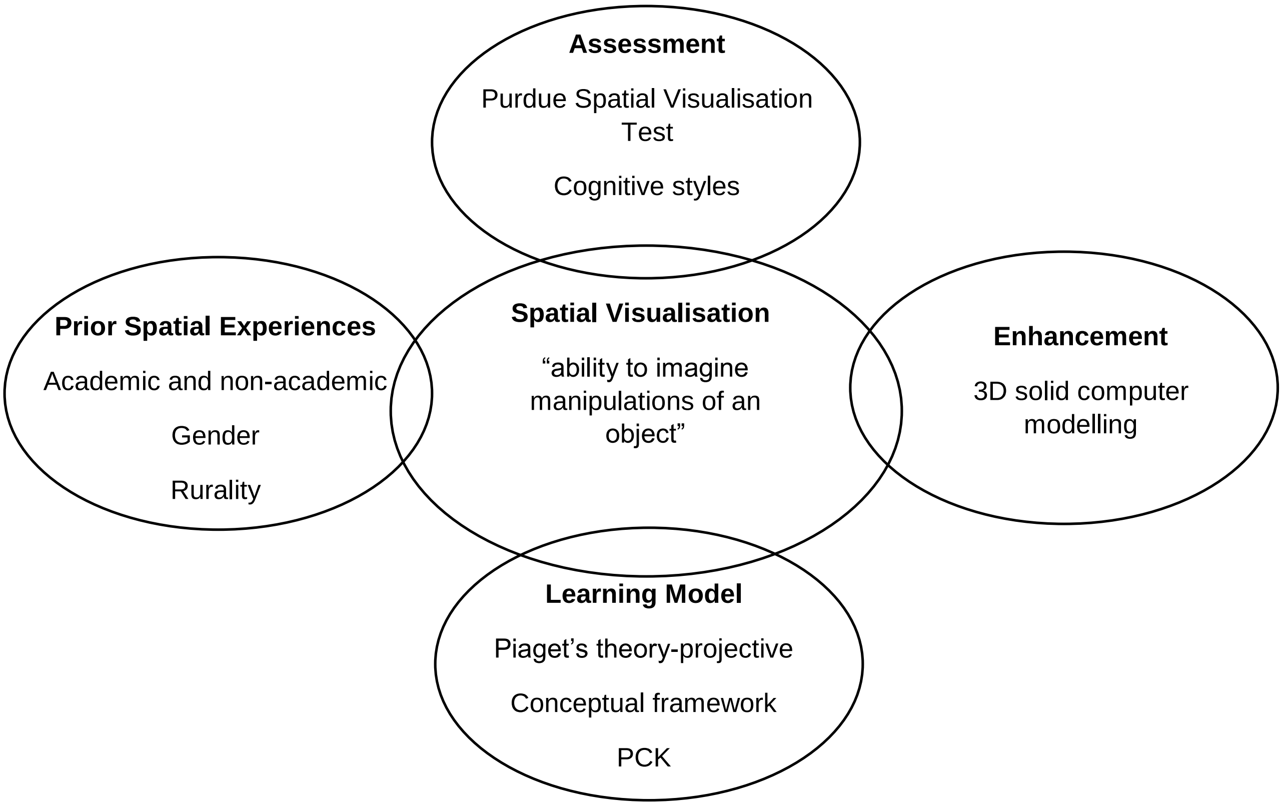


Figure 11: Piaget’s spatial and imagery theory and spatial visualisation skills enhancement.

3.3 SUMMARY

This chapter highlighted Piaget’s perception and imagery theory which grounded the current study’s research questions on the impact of prior spatial experiences, gender, 3D solid computer modelling and different cognitive styles on students’ spatial visualisation skills. Given the unique circumstances surrounding a rural-based education, Piaget’s projective stage of spatial development explicated the understanding of the enhancement of spatial visualisation skills through various representations, for example 3D solid computer modelling.

CHAPTER 4: METHODOLOGY

4.1 INTRODUCTION

Spatial visualisation skills, which substantially depended on prior spatial experiences, and acknowledged by researchers such as Newcombe and Baenninger (1989), Strong and Smith (2002) and Rafi et al. (2006), were essential for achieving success in graphics design modules (chapter 2 section 2.3). Research, by authors such as Battista (1990), Friess et al. (2016), Rodriguez and Rodriguez (2016) and Kösa and Karakuş (2017), have shown that spatial visualisation skills could be enhanced through various instructional methods such as sketching, virtual environments and computer assisted design programmes (chapter 2 section 2.3). The current study was conducted at a rural–university where students often entered the university unprepared for tertiary studies Mabusela and Adams (2017). Studies have noted that students' unpreparedness for tertiary education has been partly ascribed to factors such as poverty, gender inequality, inadequacy of educational resources, and lack of qualified teachers (Ndimande, 2018). The aforementioned factors formed the context for the current study and hence the essence was to investigate the relations and impact of graphic design students' prior spatial experience, gender differences, 3D solid computer modelling intervention and different cognitive styles on spatial visualisation skills. Based on the findings of the aforementioned constructs, the study endeavoured to develop an instructional and learning model for 2D to 3D drawing at a rural–university. The nature of the research questions in the current study necessitated the use of a mixed methods sequential research design (QUAN→QUAL). This was because the focus was on collecting, analysing, and mixing both quantitative and qualitative data (Creswell et al., 2014). According to Schoonenboom and Johnson (2017), the ultimate purpose of mixed methods research is about heightened knowledge and validity. Informed by the study's research questions, the constructivist paradigm was complemented by the positivist paradigm in order to seek elaboration, enhancement, illustration and clarification of the results.

In this chapter, the purpose, research questions, research paradigm, epistemological and ontological views, research design, population and sampling, data collection instruments, intervention procedure, reliability, validity and data analysis methods are explained in pursuance of the objectives of the study.

4.2 PURPOSE AND RESEARCH QUESTIONS OF THE STUDY

The purpose of this study was to investigate the relationship and impact of prior spatial experience, gender, 3D solid computer modelling and cognition styles on students' spatial visualisation skills. The study culminated in the development of an instructional and learning model for 2D to 3D drawing, based on the relationships and effects which existed between prior spatial experience (PSE), gender, 3D solid computer modelling, different cognitive styles and spatial visualisation skills. The study was guided by the following research questions:

4.2.1 Research Questions and sub-research questions

Research Question–1 What are students' level of prior spatial experience and its relation with spatial visualisation as a form of cognition?

Research Question–1.1 What is the relation of academic-type spatial activities with students' spatial visualisation skills?

Research Question–1.2 What is the relation of non-academic-type spatial activities with students' spatial visualisation skills?

Research Question–1.3 How does the completion of an engineering orientated school subject impact students' spatial visualisation skills?

Research Question–1.4 Which construct(s) of spatial activities are the best predictor of students' spatial visualisation skills?

Research Question–2 What is the relation between gender and spatial visualisation ability?

Research Question–3 What effect does the use of 3D solid computer modelling software have on students' spatial visualisation skills?

Research Question–4 What are the mental processes students engage in, when constructing meaning from 2D views to produce 3D representations?

Research Question–4.1 How do students use sketching during the 2D to 3D visualisation process?

Research questions 1 to 3 were guided by quantitative research methods in order to determine the students' prior experiences, demographics and spatial visualisation skills. Research question 4 depended on qualitative data to understand and interpret how students used cognitive structures to make meaning of 2D to 3D drawing. The preceding research questions' findings (Research Question–1 to Research Question–4) were considered to develop an instructional and learning model for 2D to 3D drawing for this study. It followed that the study amalgamated quantitative and qualitative research methods in a mixed methods research design hence, a closer look at the different research paradigms.

4.3 RESEARCH PARADIGM(S)

A research paradigm is the conceptual lens through which a researcher looks at the world in order to examine the methodological aspects, determine the research methods and establish how the data will be analysed in a study (Kivunja & Kuyini, 2017). In line with the research questions of the current study, Creswell et al. (2014) implied that mixed methods research is an approach or methodology focusing on questions that call for real-life contextual understandings, multi-level perspectives and cultural influences. Therefore, the characteristics of mixed methods research that directed the current study was, confirmatory, by assessing the magnitude and frequency of constructs, as well as exploratory, by exploring the meaning and understanding of constructs (Creswell et al., 2014).

According to Kivunja and Kuyini (2017), a large number of paradigms have been proposed for educational settings however, they all can be grouped into three main taxonomies namely; positivist, interpretivist/constructivist, or critical. In addition, Kivunja and Kuyini (2017) cited researchers such as Tashakkori and Teddlie who proposed the “Pragmatic paradigm”, with positivist and interpretivist/constructivist elements. Thus, appertaining to the research questions of the current study, only the positivist and constructivist/interpretivist paradigms were integrated.

4.3.1 The positivist paradigm

According to Kivunja and Kuyini (2017) the positivist paradigm defined a worldview of research which is grounded in “scientific” methods of investigation. Hall (2013) argued that in its pure form the scientific method followed a process of experimentation that explored observations, answered questions and relied on deductive logic. In addition, the scientific method involved the formulation of hypotheses, testing those hypotheses, offering operational definitions, making extrapolations and deriving conclusions (Hall, 2013). In the current study, research questions 1 to 3 percolated within the positivist paradigm. Research questions 1 to 3, investigated the relations and impact of prior spatial experiences, gender and 3D solid computer modelling on students’ spatial visualisation skills by collecting verifiable empirical data through the application of questionnaires.

The epistemological stance underlying research questions 1 to 3, for the current study, was perceived that reality can be measured and hence the focus is on reliable and valid tools, such as the PSVT: R and SEQ, to measure the constructs of spatial visualisation skills and prior spatial experience. Therefore, the current study investigated students’ prior spatial experiences, gender and the magnitude of their spatial visualisation skills through the application of questionnaires. However, the investigations into the prior spatial experiences of students, in light of the positivist paradigm in the current study, was complemented by the constructivist paradigm. For the current study, the constructivist paradigm guided the research question which endeavoured to determine how students used their prior spatial experiences to create 2D to 3D knowledge. The constructivist view on experience was that people produce knowledge and form meaning based on their experiences (Piaget, 1976). Therefore, research question 4 of this study investigated the mental processes which students engaged in to produce knowledge and construct meaning of 2D to 3D drawing from their prior spatial experiences.

4.3.2 The constructivist/interpretivist paradigm

The focal point of the constructivist/interpretivist paradigm was to understand the subjective world of the participants experience by placing emphasis on understanding the respondents and their interpretation of the world around them (Kivunja & Kuyini, 2017). Consequently, the constructivist/interpretivist paradigm’s principal belief was that reality was socially constructed and therefore the goal of research here was to rely as much as possible on the participants’ views of the situation being studied (Kivunja & Kuyini, 2017). Moreover, constructivism is a paradigm typically associated with the qualitative research method (Creswell et al., 2014). Research question 4 in the current study investigated the mental processes which students engaged in when constructing meaning from 2D views to produce 3D representations. The ability to produce 2D to 3D drawings depended to a large extent on students’ spatial visualisation skills. Studies by Rafi and Samsudin (2007), Kurtuluş and Uygan (2010) and Rodriguez and Rodriguez (2016) reported that prior spatial experience was fundamental in developing spatial visualisation skills. Furthermore, constructivist theory in support of the work of Rafi and Samsudin (2007), Kurtuluş and Uygan (2010), and Rodriguez and Rodriguez (2016), affirmed that people produced knowledge and formed meaning based upon their experiences. Therefore, it could be argued that research question 4 in the current study was grounded in the constructivist/interpretivist paradigm. Moreover, research question 4 was investigated through semi-structured interviews, along with solving a 2D to 3D problem, which allowed students to construct meaning of the situation they were in. The researcher’s intent was to make sense of, and interpret the meanings which students disclosed regarding 2D to 3D drawing. In addition, the constructivist/interpretivist paradigm assumes the epistemological view that reality needs to be interpreted and that the underlying meaning of events and activities need to be discovered (Schoonenboom & Johnson, 2017). In addition to interpreting the underlying events, such as knowledge and meaning of visualisation, Kivunja and Kuyini (2017) argued that the constructivist/interpretivist paradigm assumed a subjectivist epistemology. A subjectivist epistemology, according to Kivunja and Kuyini (2017), was where the researcher made meaning of their data through their own thinking and cognitive processing informed by their interactions with participants.

The relevance of the subjectivist epistemological views in the current study was brought about by the researcher's interpretation of the meaning that students made regarding 2D to 3D drawing. The researcher was the lecturer of the graphics design module from which this study originated. Furthermore, research question 4 of the study was viewed from a relativist ontological perspective. The positioning of research question 4 in a relativist ontological perspective was predicated by researchers such as Kivunja and Kuyini (2017) who argued that the researcher will construct knowledge socially as a result of his or her personal experiences of the real-life.

Moreover, it is important to recognise that the researcher and the respondents was engaged in interactive processes during which they intermingle, dialogue, question, listen, read, write and record research data (Kivunja & Kuyini, 2017). Ibid argued that the assumption of a relativist ontology, such as framed in this study's research question 4, meant that one believed that the situation studied has multiple realities. In the current study, these ontological realities of 2D to 3D visualisation, were explored, and meaning made of them, through semi-structured interviews between the researcher and the students.

4.4 RESEARCH DESIGN AND INSTRUMENTATION

This study used a mixed methods research approach to investigate and understand the relations and impact of spatial visualisation skills on students' ability to produce accurate graphics design content at a rural–university. The reason for using mixed methods was that it provided a better understanding of research problems, such as 2D to 3D visualisation in this study, compared to the use of a single approach (De Vos, Strydom, Fouche', & Delport, 2011). Similar to the research design of the current study, Schoonenboom and Johnson (2017) pointed out that a mixed method approach in which quantitative and qualitative methods were developmental and complementary, sought to use the results from one method to help develop or inform the other method. Thus, one can use separate but related qualitative and quantitative research questions (Schoonenboom & Johnson, 2017).

The current study followed a sequential mixed methods design during which the quantitative component preceded the qualitative component. The quantitative component was addressed during research questions 1 to 3. Research questions 1 to 3 investigated the relation and impact of the factors; prior spatial experience, gender and 3D solid computer modelling on students' spatial visualisation skills. Guided by a positivist paradigm, research questions 1 to 3 in this study, collected data through the application of the PSVT: R and the SEQ. The qualitative component of this study, which sought to examine students' cognitive styles during graphics design activities (2D to 3D visualisation), was addressed during research question 4. The essence of research question 4 was to discover the underlying meaning of students' mental processes during 2D to 3d visualisation. Therefore, this study made use of semi-structured interviews along with discourse analysis to collect qualitative data. Furthermore, the participants in the qualitative component of this study were selected for semi-structured interviews based on their performance during the quantitative component of the study.

To address research question 1, which intended to determine the relations between prior spatial experience and students' spatial visualisation skills, a non-experimental correlational design was employed. According to Imenda and Muyangwa (2006), correlational studies seek to describe the relationships between two continuous variables – for example, in the current study the relationship between prior spatial experiences and spatial visualisation skills. Moreover, research question 1 also explored the relationship between academic-type and non-academic-type prior spatial experiences. Additionally, the previous completion of an engineering orientated subject at school and its relation with spatial visualisation skills was explored in research question 1. In addition, research question 1 sought to determine which of the factor(s) of spatial activities could be the best predictor(s) for spatial visualisation skills. Therefore, multiple regression, which according to Pallant (2010) was based on correlation, was used since it allowed for in depth examination of the interrelationship among a set of variables, in this case prior spatial experience and spatial visualisation.

In the same light, research question 2 focussed on the relationship between gender and spatial visualisation skills. Of note, similar investigations into spatial visualisation, that utilised mixed method design were, Rafi and Samsudin (2007) who intended to determine the relationships of spatial experience, previous mathematics achievement and gender with perceived ability in learning engineering drawing. In addition, Rodriguez and Rodriguez (2016) contemplated a comparison of spatial visualisation skills in courses with either graphics or solid modelling content. Thus, in the current study, research question 2 was investigated through a correlational study design with a one-way between-groups Analysis of variance (ANOVA) considering, as Pallant (2010) indicates, an ANOVA compares the variance in scores between one categorical variable which, in the current study was gender, and one continuous variable which, in this study was spatial visualisation.

Furthermore, to examine research question 3, regarding the effects of 3D solid computer modelling on students' spatial visualisation skills, the current study employed a pretest-posttest control group quasi experimental design. A pretest-posttest design was considered to be an "experiment" where measurements are taken both before and after a treatment (De Vos, Strydom, Fouche', & Delport, 2011). In simple terms, this type of design enabled the researcher to examine the effects of a 3D solid computer modelling intervention on the spatial visualisation skills of students in an experimental group. Thus, if extraneous variables, such as 3D solid computer modelling, have brought about changes between the pre-test and the post-test, these would be reflected in the scores of the control group. Thus, only the post-test changes in the experimental groups' spatial visualisation skills, which was over and above the changes that occurred in the control group, can be attributed to the treatment (Imenda & Muyangwa, 2006). In this study, as suggested by Imenda and Muyangwa (2006), the control and experimental groups were treated exactly the same, except for the 4–week 3D solid computer modelling intervention which the experimental group underwent.

In the current study, research question 4 followed a qualitative research approach based on a constructivist/interpretivist paradigm with a phenomenological design structure. The research was conducted through semi-structured interviews accompanied by a 2D to 3D problem-solving activity. Creswell et al. (2014) argued that the best criteria to determine the use of phenomenology was when the research problem required a profound understanding of human experiences common to a group of people. Padilla-Díaz (2015) added that descriptive or hermeneutical phenomenology referred to the study of personal experiences and required a description or interpretation of the meanings of phenomena experienced by participants in an investigation. In the current study, a purposive group of graphics design students were selected to articulate their lived experiences with regard to solving a 2D to 3D visualisation problem. The criteria for selecting the purposive group of students focussed on individuals in the study's population and their performance in a diagnostic 2D to 3D assessment, the pretest-posttest scores and their prior spatial experiences. Based on their performance, the participants were divided into two categories i.e. an advanced group and elementary group. As such, a convenient sample of five students were purposively selected from the sample. To achieve the objective of analysing different cognitive styles, students in this study were individually interviewed by the researcher in order to find the underlying essences and common meanings attributed to the mental processes that they engaged in when constructing meaning from 2D views to produce 3D drawings. Thus, the investigator's role was one of a phenomenological researcher in order to construct meaning of students' cognitive styles during 2D to 3D drawing (Creswell et al., 2014).

4.5 POPULATION AND SAMPLING

To investigate the research questions, the current study drew from a population of 250 first year education students (female and male) enrolled for a graphics design module at UNIZULU. The sample consisted of a control group and an experimental group. The control group was 100 students *(female = 54, male = 46)* and the experimental group was 100 students *(female = 43, male = 57)*. Both the control-and-experimental groups were registered at the same rural–university for the same graphics design module. In addition, both groups in this study faced the same criteria for entrance into the university's mathematics, science and technology education programme. With regard to sampling, it is generally accepted that the larger the population, the smaller the percentage of that population the sample needs to be (De Vos, Strydom, Fouche', &

Delport, 2011, p. 226). For instance, De Vos et al. (p. 225) stated that “in most cases a 10 percent sample should be sufficient for controlling for sample errors. In support, De Vos et al. (2011, p. 224) offers a table (see Table 9) as an indication of what the size of a sample ought to be.

Table 9: *Guidelines for sampling (De Vos, Strydom, Fouche' and Delport (2011, p. 224).*

Population	Percentage suggested	Number of respondents
20	100%	20
30	80%	24
50	64%	32
100	45%	45
200	**32%**	**64**
500	20%	100

Moreover, to address the quantitative research questions (Research Question–1 to Research Question–3) in this study, probability sampling based on randomisation was used. In a random sample, each person in the population has the same known probability to be representatively selected (De Vos et al., 2011, p. 226). According to Imenda and Muyangwa (2006), an important feature of the pretest-posttest control-group design is the random assignment of a population’s subjects to the groups in order for each subject to be given an equal chance. Additionally, De Vos et al. (2011, p. 226) indicated that “a representative sample was important to generalise from the sample to the larger population and that if for example gender is a variable (characteristic) relevant to the research, a representative sample will have approximately the same number of men and women.” Therefore, representativeness was addressed during random sampling in this study since gender was a variable being correlated in research question 2.

On the other hand, research question 4 in this study investigated the cognitive processes that students engaged in during 2D to 3D visualisation and cognition. This part of the study followed a qualitative approach and thus had a different strategy to determine the sample size. De Vos et al. (2011, p. 391) opined that “there are no rules for sample size in qualitative inquiry and sample size depends on what we want to know, the purpose of the inquiry, what is at stake, what will be useful and what will have credibility.” In addition, De Vos et al. (2011, p. 391) indicated that in “qualitative research, sampling occurred subsequent to establishing the circumstances of the study, thus the sampling was undertaken after the actual investigation have commenced”. Likewise, qualitative researchers sought out individuals, groups and settings where the specific processes being studied were most likely to occur and a process of constant comparison between individuals or groups being studied was essential, since the researcher was in pursuit of understanding all aspects of his or her research topic (De Vos et al., 2011, p. 392). Furtheremore, the overall purpose of the relevant sampling techniques in qualitative research was to collect the richest data from a wide and diverse range of information (De Vos et al., 2011).

Therefore, the sampling method for the qualitative part of this study focussed on individuals in the study and their performance in the pre-test and post-test, as well as the self-report spatial experience questionnaire (SEQ). Based on a sum total of their performance, participants were categorised into two categories that is an advanced group and an elemenetary group with reference to spatial visualisation skills. As such, a convenient sample of five students were purposively selected from the sample of university students whom were enrolled for a graphics design module.

4.6 DATA COLLECTION INSTRUMENTS

Conscious of the objectives of this study, which sought to determine the relation and impact of prior spatial experience, gender, 3D solid computer modelling and cognitive styles on spatial visualisation skills, four data collection instruments were adapted and developed. The data collection instruments, which was discussed in more detail under sections 3.6.1 to 3.6.4, were; a biographical questionnaire, a spatial experience questionnaire, the Purdue Spatial Visualisation Test (PSVT: R) and a semi-structured interview schedule. The two questionnaires mentioned here, together with the PSVT: R, were hosted “on-line” through the Learning Management System (LMS) of the university. Hosting the three instruments online allowed for automated grading of the quantitative data. Apart from the semi-structured interviews, the on-line instruments were completed by students, during a session specifically organised for that reason at the university's computer laboratory. The first instrument, the biographical questionnaire (see Annexure A) was used to determine, amongst other information, the gender and school-based spatial experience of participants. The second instrument, the spatial experience questionnaire (SEQ; see Annexure B), consisted of 20 spatial-orientated activities, with responses on a 4-point Likert scale between never and very often. The third instrument, the Purdue Spatial Visualisation Test: Rotation (PSVT: R; see Annexure C), was used to determine the spatial visualisation skills of participants before and after the 3D solid computer modelling intervention. The fourth instrument, a semi-structured interview schedule (see Annexure D), was used to collect qualitative data surrounding students' mental processes when visualising 3D objects from their 2D views. The semi-structured interview was guided in its construction by the conceptual framework for 2D to 3D drawing (see Annexure E). Apart from the data collected by the instruments discussed, the students' marks which, they achieved in two first semester university modules; mathematics and science and technology, were also used during this study as constructs for academic-type prior spatial experience. What follows is a detailed discussion of each instrument followed by the application thereof during each research question.

4.6.1 Biographical information (Annexure A)

The aim of this instrument was to orientate students about the purpose of the study as well as to give assurance about their confidentiality when answering the questions. The instrument determined students' biographical information such as age and gender, as well as their background in school subjects such as engineering graphics design (EGD), Civil Technology, Mechanical Technology or Electrical Technology. This information was used to build a "spatial experience" picture of each participant which was then used to investigate the relationship with spatial visualisation.

4.6.2 Spatial Experience Questionnaire (Annexure B)

The spatial experience questionnaire (SEQ) used in this study was a self-report non-academic-type instrument. The SEQ was implemented to investigate sub research question 1.2 concerning the relationship between non-academic-type prior spatial experience and spatial visualisation skills. The purpose of this instrument in the current study was to investigate the level of non-academic-type prior spatial experiences of each student in the study. Used during the quantitative component of the study, the SEQ met both the epistemological and ontological stances of this study. Ontologically, the study's view was that there is no single reality or truth while the study's epistemological view was that reality, such as prior spatial experience, can be measured with reliable and valid instruments.

Initially, the SEQ for this study, was adapted from a similar instrument used by Rafi et al. (2006) who strived to determine the differences of prior spatial experience of students with relation to their mathematics abilities. Rafi et al. (2006) categorised participants into "high" and "low" spatial experience levels by adapting and implementing a SEQ. However, the SEQ used by Rafi et al. (2006), was originally designed by McDaniel, Guay, Ball and Kolloff (1978). Rafi et al. (2006, p. 152) explain the following with regard to the SEQ:

> *the SEQ included a 25-item self-report questionnaire consisting of a list of spatial activities such as sketching, drawing, map reading, driving a car, playing sport, using tools and playing chess. Each item has a four-point scale ranging from two extremes (that is very often and never) to be rated by participants. Two levels of spatial experience were categorised based on the total scores of the questionnaire such that low experience was 42 and below, and high experience was 43 and above.*

Consequently, the non-academic-type spatial experience questionnaire (SEQ) used in this study consisted of a list of 20 mostly neutral spatial activities such as; playing traditional games, sketching, drawing, map reading, driving a car, playing sport, using tools and playing chess. Each item had a four-point scale ranging from two extremes (that is never and very often) to be rated by students.

4.6.3 Purdue Spatial Visualisation Test: Rotation (Annexure C)

The Purdue Spatial Visualisation Test: Rotation (PSVT: R) was implemented in the current study to collect quantitative data. The purpose of the PSVT: R in this study was to determine the level of students' spatial visualisation skills before and after the 3D solid computer modelling intervention. The PSVT: R met both the epistemological and ontological stances of this study as reflected previously in section 4.3. The PSVT: R was developed during the 1970's by Guay as a result of psychologists intensely studying spatial visualisation from the perspective of cognition and perception. The PSVT: R was a multiple-choice test. The test originally consisted of three sections (developments, rotations, and views), each containing twelve problems:

- The first section was developments (folding 2D flat patterns along fold lines) into 3D objects (surface models).
- The second section was the orthogonal rotations of 3D objects about the axes of the Cartesian coordinate system (R).
- The third section was the visualisation of isometric views of 3D objects (V).

Although the PSVT: R test is referred to as a standardised test for measuring spatial visualisation, many researchers such as Ahmad and Samsudin (2006), Aytaç and Candas (2010) adapted the test to suit their specific purposes and contexts. The PSVT: R test is chosen by researchers because of its high correlation with similar instruments measuring visualisation. In order to determine to what extent the use of 3D solid computer modelling software impacted on graphic design students' spatial visualisation, the current study determined the level of spatial visualisation of participating students by applying the PSVT: R. Moreover, the significance of using the PSVT: R in this study, was that various studies, such as Guay and Bodner, (1997), Helweg (2001), and Kösa and Karakuş (2017), have reported the PSVT: R to be reliable. During application of the PSVT: R, students were shown a criterion object and a view of the same object after undergoing a rotation (R) in space (cf. Figure 9). Students were then shown a second object and asked to indicate what their view of that object would be if the second object were rotated by the same amount in space. One point was given for every correct answer and no points are allocated for an incorrect or blank answer. The total score of each student was computed to a percentage, the higher the percentage the higher the spatial visualisation skill level of each student.

In addition, numerous studies have used the PSVT: R as both teaching and research tools to measure spatial visualisation in students and to diagnose and improve students' spatial visualisation skills in graphic design and CAD courses (Yue, 2006). Worth mentioning among these studies, which measured spatial visualisation skills of students were; Battista (1990) who examined gender differences in high school geometry, and Rodriguez and Rodriguez (2016) who compared graphics design content with spatial visualisation. In addition, Friess, Martin, Esparragoza, and Lawanto (2016) studied improvements in an introductory graphics design course and Kösa and Karakuş (2017) studied the effects of computer aided design software on spatial visualisation. In the current study, the PSVT: R consisted of 30 items. The first 20 items represented visualisation through rotation and the last 10 items represented visualisation by viewpoints. The implementation of the PSVT: R in this study served as the pre-test and the post-test. The pre-test scores were used as a baseline score (spatial visualisation skills) to determine the statistical significance between spatial visualisation skills of a control group and an experimental group. After a 4-week 3D solid computer modelling intervention strategy, the results of the post-test were used to examine the effectiveness of the intervention.

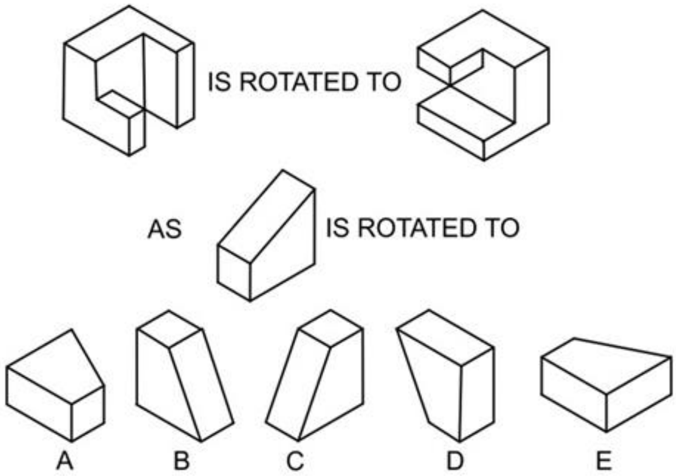


Figure 12: Purdue Spatial Visualisation Test – Visualisation through Rotation (PSVT: R) from https://www.lib.purdue.edu/uco/ForResearchers/works.html

To conclude, permission (cf. permission letter and acceptance in Annexure G) was sought from Purdue University which are the copy right holders of the PSVT: R. An online assessment was completed to evaluate the fair use of the PSVT: R. The result of the evaluation favoured this study for fair use for which no permission was required (see Annexure G).

4.6.4 Semi-Structured Interview Schedule (Annexure D)

The purpose of the semi-structured interviews in this study was to determine the mental processes which students employed during visualisation of 2D to 3D activities. Students were purposefully selected for interviews based on their performance in the pre-test and post-test (PSVT: R), as well as the self-report spatial experience questionnaire (SEQ). The sum total of their performance determined whether students were categorised into either elementary level or advanced level spatial visualisation skills. As such, a sample of five students were purposively selected from a sample of 200 university students who were enrolled for a graphics design module. Using simple randomised selection, three students from the elementary level group and two students from the advanced level group constituted the sample size of five. Students were then invited to the semi-structured interviews individually. On the day of the interview, the purpose of the study was provided and it was explained to the student that the interview will be recorded on video, that the documents will be kept for analysis and that most importantly it was confidential.

During the interview, students were shown three views of a multi-faceted object presented in first angle orthographic projection. The three views were drawn on a block grid. While drawing the answer on an isometric grid, students had to give an account of the mental processes they were going through such that they were “thinking aloud”. The semi-structured interviews proceeded on three levels based on the conceptual framework for 2D to 3D drawing developed for this study (see Annexure E). These three levels, from which the questions for the interview was derived were; (1) encoding information (2) integrating information and (3) constructing a 3D mental representation. After completion of the interviews, the video recordings were analysed and a line-by-line discourse for each interview produced. Furthermore, the isometric solutions produced by each student, together with the video recordings, was analysed and re-produced in a “sequence of sketches”. The sequence of sketches gave insight into the procedure that each student undertook during the 2D to 3D visualisation process.

4.7 3D solid computer modelling intervention

An objective of this study was to determine whether the application of 3D solid computer modelling have had any impact on graphic design students’ spatial visualisation skills at a rural–university. Although 3D solid computer modelling has previously been found to be effective in spatial visualisation studies by for instance, Dorta, Saorin, and Contero (2008), no studies involving spatial visualisation and 3D solid computer modelling have been conducted in the unique context of students at a rural–university. For this reason, the study employed a pretest-posttest control-group quasi experimental design with 3D solid computer modelling as the intervention.

Table 10 shows the position of the 4-week intervention for the experimental group within the 14 weeks’ graphics design curriculum for the module. The theoretical component for both the control and experimental groups remained the same.

Table 10: *Graphics design content and 4–week 3D solid computer modelling intervention*

WEEK		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Control group	Theory														
		Introduction to drawing	Line work and sketching	Plane geometry	Isometric drawing	Orthographic projection	ORTO to ISO	ORTO to ISO Multi-faceted	Oblique drawing	Engineering drawing	Sectioning	Perspective	Ergonomics	Solid geometry	Assembly drawing
Experimental group	Practice				4–Week 3D solid computer modelling										

Apart from the 4–week intervention, which only the experimental group underwent, for the remainder of time the instructional methodology was the same. Table 11 shows the activities which the control and experimental groups undertook for the duration of the 4–week intervention of the current study. The 4–week 3D solid computer modelling intervention programme presented in Table 11, occurred during weeks 4 to 7 of the learning programme and was preceded by introduction to drawing, instruments, line types, scale, geometric construction and freehand drawing and plane geometry. During weeks 4 to 7 the content focussed on pictorial drawing (isometric) and orthographic projection. Table 11 does not reflect the theoretical course content which both groups received through the same methodology, but only the activities and exercises which students did for reinforcement of the theory. Only the experimental group partook in 3D solid computer modelling exercises and activities.

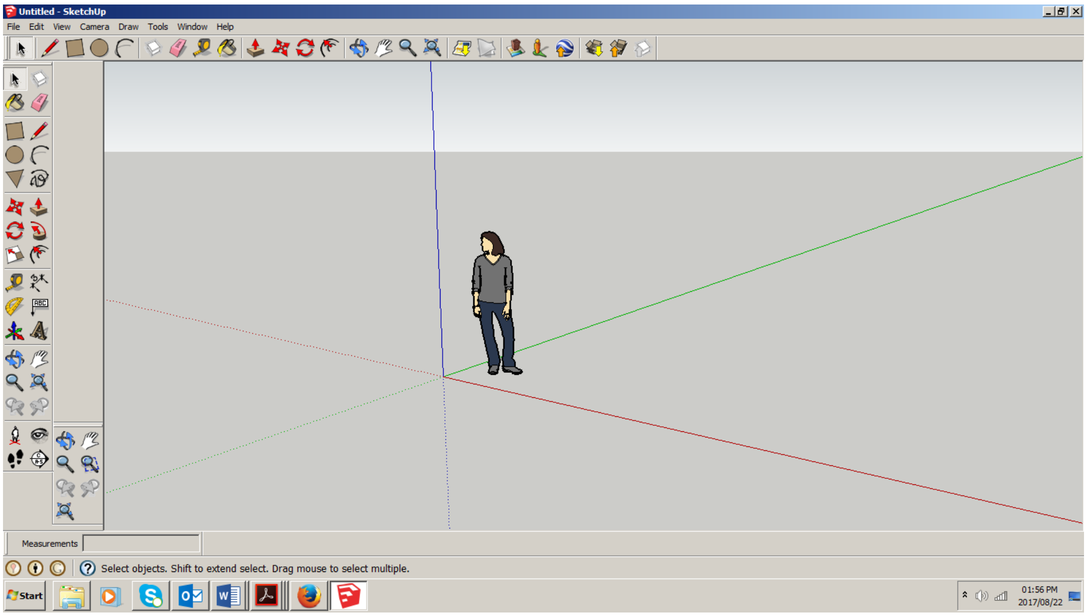
Table 11: *Activities for control group and experimental group during 4–weeks intervention*

4–Week intervention	**Control group practical activities**	**Experimental group practical activities**
Week 4 Isometric projection	• Do pre-test • Match isometric views with individual views • Sketch simple objects on isometric grid • Sketch simple isometric objects freehand	• Do pre-test • In the computer lab learn basics of SketchUp: using the mouse, basic commands and push/ pull function • Model lines, laminas, polygons and solids

Week 5 Orthographic projection	• Experience with simple coloured physical objects: prisms, pyramids, blocks • Draw the isometric projection on grid paper of physical objects • Use instruments to draw simple isometric	• Experience with simple physical coloured objects: prisms, pyramids, blocks • Use more SketchUp tools: move, rotate, offset, paint • Measure and model physical 3D objects: use modelling tools to pan, orbit and change view
Week 6	• Use block grid to draw first angle orthographic projection of simple objects from isometric • Use instruments to draw more complex objects from orthographic to isometric	• Model more complex 3D objects from isometric views. • Model more complex 3D objects from orthographic views in groups. • Groups publish models on LMS, discuss and improve.
Week 7	• Draw with instruments isometric projections of assemblies with up to 5 parts from orthographic views. • Draw orthographic projections of basic machines • Design through sketching and with instruments: problem solving	• Model complex 3D objects from orthographic views. • Assemble and Model 3D objects from orthographic views, maximum 5 parts • Design 3D models for problem solving

The 4–week 3D solid computer modelling intervention thus developed and proceeded over three distinct stages namely; orientation, modelling from 3D (isometric) views and modelling from 2D (orthographic) views.

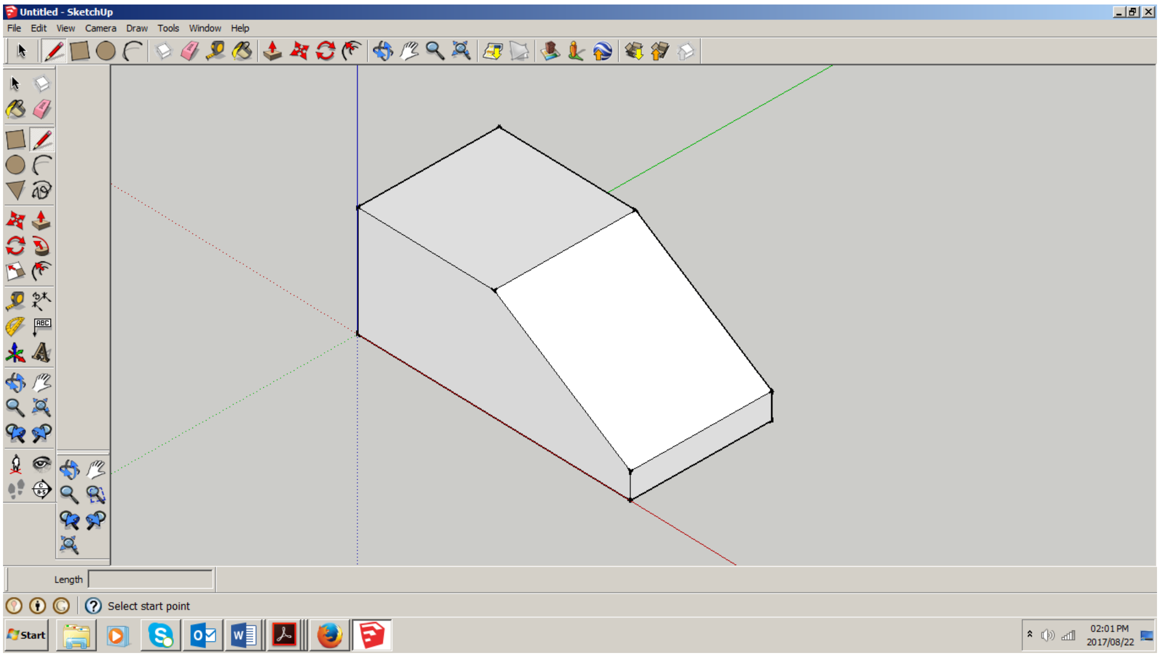
Stage 1 - Orientation: During the first stage, the objective was to provide basic training in the operation of SketchUp. Students learned the most important functions of the programme, such as using the mouse (pan and orbit), using commands and drawing lines and polygons in a 3D space. Students also learned how to make extrusions using the “push-pull” tool as a basic modelling operation (cf. Figure 13, SketchUp Orientation).



Select objects. Shift to extend select. Drag mouse to select multiple.

Figure 13: SketchUp, Orientation.

Stage 2 - Modelling from 3D isometric views presented on paper to 3D in SketchUp: During this stage, students created 3D computer models corresponding to the objects given by their Isometric projection (cf. Figure 14, SketchUp isometric drawing). Students attempted to model the objects utilising a variety of tools and processes. The objects selected for isometric projection increased in complexity.

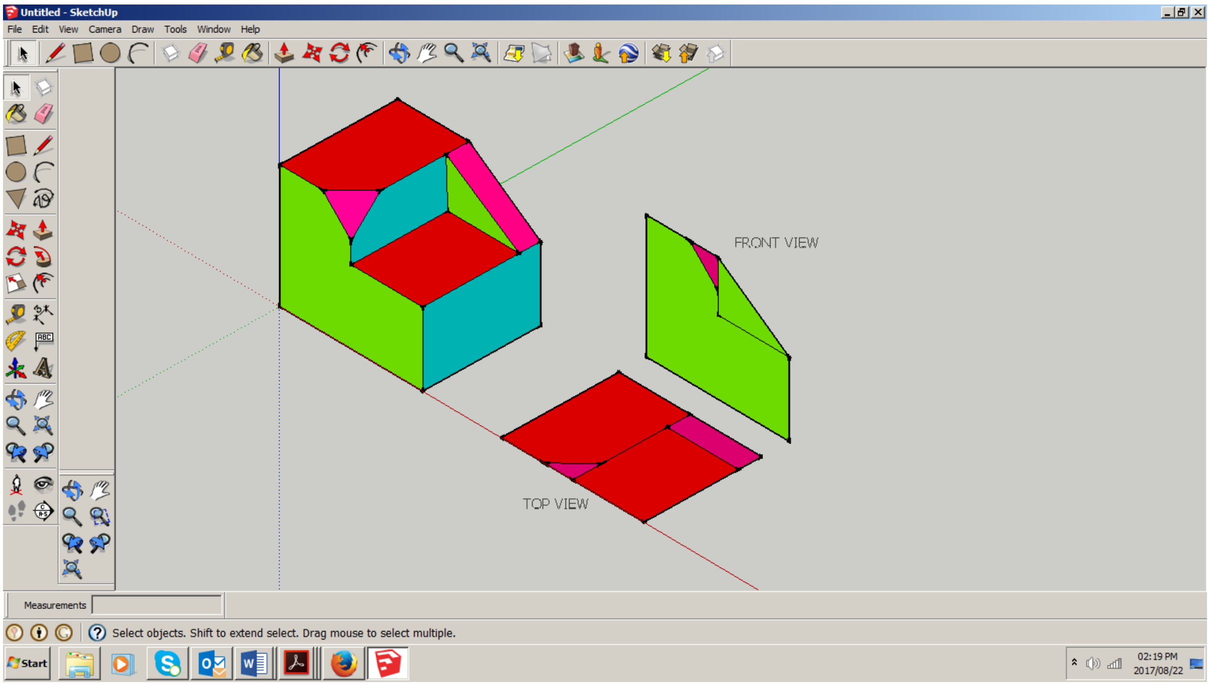


Select start point

Figure 14: SketchUp, Isometric drawing.

Stage 3 - Modelling from orthographic views to 3D models in SketchUp

During this stage, students had to model the 3D objects as represented by their orthographic views (cf. Figure 15, SketchUp Orthographic to Isometric). Students received an introductory lesson on the basics of orthographic projection (First Angle Orthographic Projection, week 5) and got the opportunity to complete and discuss various exercises in tutorial groups. During 3D modelling students had to imagine and construct a mental image of the object using only the information provided by its orthographic projections (views) and then had to create a 3D model on SketchUp. Students also formed small tutorial groups to solve the exercises at this level and to develop social abilities related to group work and to initiate discussions. The results of the group exercises were published on the Learning Management System (LMS) Moodle, for the whole class to analyse and make comments. The lecturer then published the solutions to exercises on the LMS which lead to the second phase, in which students used the exercises and the published solutions for individual reflection and analysis.



Select objects. Shift to extend select. Drag mouse to select multiple.

Figure 15: SketchUp, Orthographic to Isometric drawing.

4.8 RELIABILITY OF INSTRUMENT(S)

The current study set out to investigate the relationship and impact of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles on graphics design students' spatial visualisation skills at a rural–university. The nature of the research questions in this study required the study to follow a mixed methods research design. Therefore, this study had a quantitative component (Research Question–1 to Research Question–3), guided by a positivist paradigm in which the epistemological view was that reality can be measured with reliable and valid instruments. On the other hand, this study had a qualitative component (Research Question–4) guided by a constructivist/interpretivist paradigm where the epistemological view was that reality needs to be interpreted by discovering underlying meaning of events. Thus, the important issues surrounding instrument reliability was discussed for the quantitative instruments, viz. the SEQ and PSVT: R first followed by the quantitative instrument, viz. the semi-structured interviews.

4.8.1 Quantitative instrument reliability

Reliability refers to consistency of measure, that is the extent to which a given instrument produces stable or consistent results (Imenda & Muyangwa, 2006). Two frequently used indicators of a scale's reliability are test-retest reliability and internal consistency (Pallant, 2010).

The current study used two quantitative instruments, the first was the SEQ to measure prior spatial experience and the second, the PSVT: R to measure spatial visualisation skills respectively. With reference to the SEQ, a similar study on spatial visualisation and prior spatial experience by Rafi and Samsudin (2007) reported an internal consistency that was computed and resulted in a reliability coefficient of .89. In the current study, the computed Cronbach Alpha was .87, which according to Pallant (2010) suggested a very good internal consistency. Furthermore, the PSVT: R has been shown to be a reliable instrument in studies where Guay and McDaniel (1978) used the PSVT: R with 101 undergraduate students and reported the Kuder-Richardson reliability coefficient as .86. In addition, Kösa (2011) translated the PSVT:

R into Turkish and used the test on 74 high school students and 216 pre-service mathematics teachers on two different occasions and reported internal consistency coefficients of .81 and .85 (Kösa & Karakuş, 2017). Within the current study, the Cronbach Alpha was computed to estimate internal consistency and resulted in a coefficient of .82. According to Pallant (2010), a minimum internal consistency as measured by Cronbach's alpha is .70, while on another note, a reliability coefficient in the range .60 to .99 would in most instances suffice (Imenda & Muyangwa, 2006, p. 113).

4.8.2 Qualitative instrument reliability

According to Kivunja and Kuyini (2017), the criterion of dependability should be used in qualitative research in preference to the criterion of reliability. De Vos et al. (2011) explained that dependability refers to the ability of observing the same outcome or finding under similar circumstances. De Vos et al. (2011) argued that the qualitative researcher dealt with human behaviour which was by its very nature continuously variable, contextual, and subject to multiple interpretations of reality, s/he is not able to reproduce exactly the same results.

To ensure that the qualitative data was dependable, the analysis of the semi-structured interview scripts as well as the analysis of the documents which were produced by the students during the interviews, was discussed with a graphics design subject specialist. Therefore, the qualitative data analysis was not only dependent on the researcher's interpretation but also on the interpretation of a subject specialist who made similar conclusions. Kivunja and Kuyini (2017) argued that the researcher can make inferences which in themselves were influenced by the researcher's own construction of meaning however, the findings truly emerge from the data if every person who was involved in the same data analysis come to the same outcome.

4.9 VALIDITY OF INSTRUMENT(s)

The validity of an instrument is the extent to which it measures what it is supposed to measure (De Vos et al., 2011). Imenda and Muyangwa (2006) referred to four types of instrument validity namely, content validity, predictive validity, concurrent validity and construct validity. However, in an experimental study, such as the current study, internal validity and external validity were of critical importance (Imenda & Muyangwa, 2006). De Vos et al. (2011, p. 153-154) defined internal validity as the degree to which changes in the dependent variable was indeed due to the independent variable and not to some other unintended variable and external validity means the extent to which results could be generalised to the whole population.

4.9.1 Quantitative instrument validity

To ensure the content and face validity of the SEQ and PSVT: R, the instruments were judged by a panel of two experts such that (1) the measure covered the universe of facets that make up the concept and (2) the language used on the instruments was consistent and agrees with the participants.

In the current study, threats to internal and external validity in the quantitative instruments were minimised as follows:

- To minimise the threats of selection and diffusion of intervention, both control and experimental groups were randomly selected from 250 teacher education students whom were enrolled for a graphics design module at a rural-university.
- To minimise the threat of maturation, the control and experimental groups were randomly populated with students of similar age and level of education.
- The validity of the data collection instruments used in this study have been justified in several other studies. Likewise, to minimise the instrument threat both pre-test and post-test were administered online with proper instructions and time frames.

- To minimise the history and test threats, the interaction between the pre-test and post-test were kept to four weeks.
- To control for the threat of data collection, both control and experimental groups were taught and tested by the same lecturer. Also, the researcher ensured that only the experimental group had access to the 3D solid computer modelling intervention strategy through strict control of passwords.

4.9.2 Qualitative instrument validity

In relation to qualitative studies, Kivunja and Kuyini (2017) suggested that instead of internal validity, the criterion of “credibility” is to be used to refer to the extent to which data were believable, trustworthy or authentic. Kivunja and Kuyini (2017) explained that credibility related to the researcher’s ability to investigate the question; “How do the findings align with reality as constructed by the researcher and the research participants?” De Vos et al. (2011) also mentioned transferability, dependability and conformability as measures of qualitative constructs. Therefore, to ensure the credibility of the semi-structured interview schedule, the instrument was judged by a panel of two graphics design experts in order to affirm that the language used on the instrument was consistent and relevant with the participants’ contextual understanding. In addition, the panel of experts judged whether the complexity of the orthographic drawings designed for the study was suitable for determining the stated research objectives. Also, the orthographic drawings presented to the students during the semi-structured interviews were designed to eliminate the chance of any student having information close to the object, in other words, it was a completely unfamiliar object. Furthermore, credibility of the analysis and meaning of students’ discourse were ensured by objectively reflecting what was said by the students without subjective connotation by the researcher. This understanding of credibility is in keeping with the epistemological view of this study which does not aim to seek an ultimate truth but rather focuses on identifying the constructions by the students concerning the discourse under investigation.

4.10 METHODS OF DATA ANALYSIS

This study set out to investigate the relation and impact of prior spatial experience, gender, 3D solid computer modelling and different cognitive styles of graphics design students on spatial visualisation. Therefore, the current study employed a mixed method research approach. Research questions 1, 2 and 3 required that they be quantitative while research question 4 was qualitative. Data from the quantitative questions were analysed by ANOVA, ANCOVA and Multiple regression statistics (see further explanations under sections 4.10.1 to 4.10.3). Research question 4 was analysed using discourse analysis since the descriptive nature of qualitative research was to understand the meaning attached to the experience, the nature and the impact of the problem (Imenda & Muyangwa, 2006). Henceforth the data analysis techniques for each research question will be discussed.

4.10.1 Prior spatial experience, Research Question–1 data analysis method

The first objective of the study was to investigate the relationship between academic-type prior spatial experience (Research Question–1.1) and non-academic-type prior spatial experience (Research Question–1.2) and the spatial visualisation skills of first year university students who enrolled for a graphics design module at a rural–university. Primarily, the objective sought to comprehend if school subjects such as an engineering orientated subject(s) (Research Question–1.3) was a determinant for spatial visualisation skills, likewise to determine the best spatial activity predictor (Research Question–1.4) of spatial visualisation skills. The objective was modeled on two variables thus the dependent variable was spatial visualisation skills and the independent variables were academic-type and non-academic-type prior spatial experience. Academic-type prior spatial experience consisted of three constructs; completion of an engineering orientated school subject; mathematics first semester module mark; and science and technology first semester module mark. Non-academic-type prior spatial experience included 20 mostly neutral constructs from the spatial experience questionnaire (see Annexure B for details). Therefore, in order to have investigated and determined the relation between prior spatial experience and students' spatial visualisation skills, multiple linear regression analysis was used. According to Pallant (2010), multiple regression allowed for examination of interrelationship among a set of variables. Not only was mutiple linear regression suited to determine the impact of academic-type and non-academic-type prior spatial exsperience on spatial visualisation, but it was also enployed to determine which of the constructs of spatial activities was the best predictor of students' spatial visualisation skills.

4.10.1.1 Scale of measure

Spatial visualisation skills, which was a continuous variable, was measured using the PSVT: R. On the PSVT: R, one point was given for a correct answer and no point was given for an incorrect answer. Academic-type prior spatial experience (Research Question–1.1) was measured in two parts. First on a nominal scale of measure where students had to indicate whether or not they had completed an engineering orientated school subject, and second a continuos scale measure which consisted of the marks which students obtained for both a first semester mathematics and science and technology modules. Non-academic-type prior spatial experience (Research Question–1.2), which was a categorical variable, was measured by the SEQ on a 4-point Likert scale. Non-academic-type prior spatial experience was an ordinal scale of measure.

4.10.1.2 Assumptions

Before the multiple regression analysis was executed, the assumptions of normality, sample size, linearity, multicollinearity and homoscedasticity were first examined. The data of the multiple regression are presented in chapter 5 and discussed in chapter 6 hereafter.

4.10.2 Gender, Research Question–2 data analysis method

The second objective of this study examined if any relationship existed between gender and students' spatial visualisation skills. The procedure followed here was to compare the independent variable – gender with the dependent variable – spatial visualisation. Pallant (2010) suggested that one way Analysis of variance (ANOVA) is suitable for comparing the variance between the different groups (gender) with one dependent continuous variable (spatial visualisation).

4.10.2.1 Scale of measure

Gender, which was a categorical variable, was measured on a nominal scale of measure. Spatial visualisation skills was a continuous variable and was measured using the PSVT: R.

4.10.2.2 Assumptions

The assumptions of normality, equality of variance and independence were first tested. The data on ANOVA are presented in chapter 5 and discussed in chapter 6 hereafter.

4.10.3 3D solid computer modelling, Research Question–3 data analysis method

The third objective of the current study was to determine if the application of 3D solid computer modelling instruction had had any impact on students' spatial visualisation skills in a first year graphics design module at a rural–university. Thus, the current study used a pre-test-post-test control group design to measure students' spatial visualisation skills with the PSVT: R before and after a 4-week 3D solid computer modelling intervention. The control and experimental groups consisted of 100 graphics design students each. The analysis method selected for this objective was Analysis of covariance (ANCOVA).

Pallant (2010) mentioned that ANCOVA can be used with a two-group pre-test–post-test design where the pre-test scores are treated as a covariate to control for pre-existing differences between the control and experimental groups. Furthermore, while controlling for the covariate (pre-test PSVT: R scores) the post-test scores from the PSVT: R for the experimental group and the control group were compared using

(ANCOVA) in order to determine if the intervention of using 3D solid computer modelling had any statistical significance. To determine the strength of the effect size of the 3D solid computer modelling intervention between the experimental group and the control group, the current study used the guidelines for interpreting the partial eta-squared statistics as proposed by Cohen (2013, p. 284); .01 denotes a small effect; .06 a moderate effect, and .14 a large effect.

4.10.3.1 Scale of measure

The dependent variable was spatial visualisation skills which was measured with the PSVT: R before and after the intervention. The 3D solid computer modelling intervention was the independent variable. 3D solid computer modelling had a continuous scale of measure.

4.10.3.2 Assumptions

To meet the assumption of reliability of the covariate, the Cronbach Alpha was computed to estimate internal consistency. Additionally, to determine the normal distribution of data for the pre-test, the Shapiro-Wilk test of normality was computed. The data of ANCOVA are presented in chapter 5 and discussed in chapter 6 hereafter.

4.10.4 Cognitive styles, Research Question–4 data analysis method

The fourth objective of this study was to explore and find meaning of the mental processes which students engaged in when converting orthographic views of an object (2D) into an isometric projection (3D). Guided by a phenomenological design this study used discourse analysis to identify the various constructions regarding 2D to 3D drawing. Therefore, the main focus of this study was to describe the meanings of the phenomena which students attributed to the visualisation of 2D to 3D drawing. Furthermore, Padilla-Díaz (2015) pointed out that data analysis in phenomenology was characterized by identifying common meanings and essences of textual and structural analysis where textual referred to the description of what is expressed by the participants and structural referred to the interpretation of how it is expressed by the participants. In the current study the textual analysis focussed on what prior experience students revealed about 2D to 3D drawing and the structural analysis juxtaposed the students' cognitive processes with a conceptual framework of 2D to 3D visualisation as illustrated in Annexure E.

During an individual interview session, five graphic design students had to complete a set 2D to 3D drawing task. During the interview, which followed a semi-structured design, students had to complete the drawing while at the same time giving a narration of what they were thinking – this protocol was known as – thinking aloud. Thinking aloud has been used to examine the cognitive processes in different disciplines, and it was chosen because such verbalizations present an opportunity to make students' reasoning more coherent and reflective (Halpern et al., 2016). The interviewer regularly prompted the interviewees to explain a certain concept in more detail. The interviews took on average 38 minutes to complete. During the interview the narrations and drawings were sound and video recorded in order to examine the students' actions and gestures during the thinking process. After completion of the interviews, the resulting narrative was transcribed into a line-by-line discourse of each interview and the documents were evaluated against the expected outcomes of the visualisation process that is encode, integrate and construct. Using a constant comparative method common themes were named and coded by identifying underlying similarities between them. The next step was to identify the common themes to be categorised into the three principal components of the conceptual framework for 2D to 3D drawing (see Annexure E) that is encoding, integrating and constructing. Next, the frequency and order of the actions were analysed to understand which actions led students to solve the 2D to 3D problem. Similarities and deviations from the conceptual framework were identified and coded. Documents were analysed to support the narrative and to lend credibility to the data. The sequence of sketches during the 2D to 3D visualisation process were recorded and reproduced by the researcher in a sequential format in order to make meaning of the way that students use sketching activities (Sub research question 4.1). The data of the interviews, narrative and documents are presented in chapter 5 and discussed in chapter 6 hereafter.

4.10.5 Instructional model for 2D to 3D drawing

In order to accomplish objective 5, this study utilised deductive reasoning to develop an instructional model for 2D to 3D drawing. For the most part, the model depended on the results and findings of the first 4 research questions (Research Question–1 to Research Question–4) as well as an integration of Piaget's perception and imagery theory, the conceptual framework for 2D to 3D visualisation and the notions surrounding pedagogical content knowledge.

4.11 SUMMARY

This chapter provided insight into the research approach and design of this study. In short, the study utilised a mixed methods approach by gathering both quantitative and qualitative information about students' spatial visualisation skills. The focal point of the study was guided by a constructivist/interpretivist paradigm in order to understand the impact of students' experiences and by placing emphasis on understanding the individual and their interpretation of 2D to 3D visualisation processes. Also, due to the nature of the research questions which the study sought answers to three distinct research designs were used. These research designs included (1) a non-experimental correlational design, (2) a pretest-posttest control-group quasi experimental design, and (3) a systematic interactive interpretivist paradigm with a phenomenological design structure. Furthermore, the research instruments that were developed to attain the objectives and answer the research questions of this study were discussed. For instance, to answer the research questions (Research Question–1 and Research Question–2) surrounding the impact of prior spatial experience and gender on spatial visualisation skills, two instruments, (1) a biographical questionnaire and (2) a prior spatial experience questionnaire were developed and adapted. Also, in order to answer the research questions (Research Question–1, Research Question–2 and Research Question–3) around the nuances involving spatial visualisation of graphic design students, the PSVT: R, which are used in many similar studies was used. Permission to use this instrument were sought from the relevant copyright holder. Furthermore, a semi-structure interview schedule was developed based on the conceptual framework for 2D to 3D drawing. This interview schedule was used to elicit responses from interviewees regarding their visualisation processes during 2D to 3D drawing. Besides a presentation of the research instruments used in this study, an overview was also provided to situate the 3D solid computer modelling intervention within the curriculum of the graphics design module. Finally, this chapter addressed the reliability and validity issues around the implementation of the data collection instruments as well as the different methods employed to analyse the data. In the next chapter the data which were collected by the research instruments of this study will be presented.

CHAPTER 5: DATA PRESENTATION

5.1 INTRODUCTION

The purpose of this study was to investigate the relationship and impact of prior spatial experience, gender, 3D solid computer modelling and cognition styles on students' spatial visualisation skills at a rural–university. Underpinned by Piaget's theory on perception and mental imagery, which according to Potter and Van der Merwe (2001) and Sorby and Baartmans (2000) advanced that perception and imagery were figurative processes which can be trained and developed throughout the human life-span, the study explored if there were any differences between students with well-developed spatial abilities and those with less-developed spatial abilities.

This chapter presents the study's quantitative and qualitative data which were gathered using the data collection instruments. The first instrument was a biographical questionnaire (see Annexure A). The second instrument, a spatial experience questionnaire (SEQ; see Annexure B), consisted of 20 spatial orientated activities with responses on a 4-point Likert scale between never and very often. The third instrument, the Purdue Spatial Visualisation Test: Rotation (PSVT: R; see Annexure C), was used to determine the spatial visualisation of participants before and after the 3D solid computer modelling intervention of four weeks. The fourth instrument, a semi-structured interview schedule, was used to collect qualitative data surrounding students' mental processes when visualising 3D objects from their 2D views (see Annexure E). The data presented here are ordered according to each research question of the study. The sub-research questions are ordered within the text.

5.2 DATA PRESENTATION - RESEARCH QUESTION 1

Research Question–1. What are students' level of prior spatial experience and its relation with spatial visualisation as a form of cognition?

Experience over the years at a rural–university, both in practice and in theory, was that pre-service education students who enrolled for a graphics design module often have difficulty to convert multi-faceted objects from orthographic views into isometric projections. Investigations thus far have shown that, amongst other factors, students' inability to convert orthographic views into isometric projections is due to poor spatial visualisation skills (Makgato & Khoza, 2016; Pillay, 1998). Cognisant of the importance associated between graphics design content and spatial visualisation skills, the current study set out to determine the relation and impact of academic-type prior spatial experience and non-academic-type prior spatial experience on the spatial visualisation skills of first year pre-service education students. Additionally, the current study sought answers to understand if engineering school subject content was a determinant for spatial visualisation skills. Moreover, this study investigated the best spatial activity predictor of spatial visualisation skills. The sample for research question 1 was the experimental group of one hundred (N=100) students, including 43 females and 57 males. The average age for the participating students were 20 years which, according to Piaget's perception and imagery theory should locate all participants in the formal operational stage. Piaget considered the formal operational stage to be one where children (age 12 years and up) can classify, order and reverse mental operations and are capable of abstract reasoning (Piaget, 1976). Therefore, the relevance of the formal operational stage during the cognition processes of 2D to 3D drawing in this study, was supported by Kösa and Karakuş (2017) who asserted that spatial visualisation is the ability to imagine rotations of objects or their parts in 3D space, and this included mental rotation and spatial perception.

Research question 1 in this study was modelled on two variables, the dependent variable was spatial visualisation skills and the independent variables was academic-type and non-academic-type prior spatial experience. Moreover, there were four sub-research questions investigated under research question 1.

Sub-research question 1.1 investigated the relation between academic-type prior spatial experience on students' spatial visualisation skills. On the other hand, sub-research question 1.2 investigated the relation between non-academic-type prior spatial experience and students' spatial visualisation skills. The variables, reflected in Table 12, specifies inclusively the descriptions and scales of measurement. Academic-type prior spatial experience consisted of three constructs viz. (1) completion of an engineering orientated school subject, (2) mathematics first semester module mark and (3) science and technology first semester module mark. Non-academic-type prior spatial experience included 20, mostly neutral constructs from the spatial experience questionnaire (See Annexure B).

Table 12: Variables of the study

Variables	**Description**	**Scale of Measure**
Dependent Variable	Spatial Visualisation Skills Purdue Spatial Visualisation Test 30 items	Scale Continuous Total Score
Independent Variable 1	Prior Spatial Experience Academic EGD, Mathematics, Science and Technology 3 sub-constructs	Scale Continuous
Independent Variable 2	Prior Spatial Experience Non-Academic SEQ 20 sub-constructs	Scale Continuous Total score

5.2.1 Assumption of normality

A Kolmogorov-Smirnov test was used to test for normality on the dependent variable – Spatial Visualisation and, the two independent variables – Prior Spatial Experience Non-Academic and Prior Spatial Experience Academic. The non–significance of Spatial Visualisation, p > .05, Prior Spatial Experience Non-Academic, p > .05, and Prior Spatial Experience Academic, p > 0.5, indicated that the data was normally distributed in the three variables as shown in Table 13.

Table 13: *Kolmogorov-Smirnov test of normality*

	Kolmogorov-Smirnov^a			**Shapiro-Wilk**		
	Statistics	df	Sig.	Statistics	df	Sig.
Visualisation Total Score	.079	100	.124	.978	100	.088
Prior Spatial Experience Score Non-Academic	.072	100	.200*	.986	100	.404
Prior Spatial Experience Score Academic	.073	100	.200*	.973	100	.057

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

5.2.2 Assumption of multicollinearity

Multicollinearity was examined by inspection of the tolerance and variation inflation factor (VIF) values. Pallant (2010) suggested a tolerance value greater than .1, and the VIF value smaller than 10 as an indication of low muliticolinearity. Tests for multicollinearity indicated that a very low level of multicollinearity was present. The Pearson correlation *r* = -.30 indicated the two independent variables were not highly correlated. Values for *Tolerance* = .999 and *VIF* = 1.001 indicated that multicollinearity assumption was not violated as shown in Table 14.

Table 14: *Pearson correlation between independent variables*

Correlations				**Collinearity Statistics**	
		Prior Spatial Experience Score Non-Academic	Prior Spatial Experience Score Academic	Tolerance	VIF
Prior Spatial Experience Score Non-Academic	Pearson Correlation	1	-.030	.999	1.001
	Sig. (2-tailed)		.768		
	N	100	100		
Prior Spatial Experience Score Academic	Pearson Correlation	-.030	1	.999	1.001
	Sig. (2-tailed)	.768			
	N	100	100		

5.2.3 Evaluating the model

Multiple linear regression was calculated to test if the level of prior spatial experience significantly predicted students' spatial visualisation skills. Prior spatial experience constituted two variables; academic–type and non-academic-type prior spatial activities. Preliminary analysis were performed to ensure that there was no violation of the assumptions of, normality, linearity and multicollinearity. The results of the regression indicated, the two predictors, which were prior spatial experience score academic and prior spatial experience score non-academic, explained 9.8% of the variance (R^2 = .098) of the dependent variable(s) visualisation total score. The adjusted $R^2 = .079$ value showed a relatively small difference of how well the model generalised, as shown in Table 15.

Table 15: *Regression model of spatial visualisation with prior spatial experience*

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.313[a]	.098	.079	16.580

a. Predictors: (Constant), Prior Spatial Experience Score Academic, Prior Spatial Experience Score Non-Academic

b. Dependent Variable: Visualisation Total Score

Multiple linear regressions analysis, with the two predictor variables of prior spatial experience academic and prior spatial experiences non-academic, revealed that the overall relationship between the independent variables and the dependent variable of spatial visualisation skills was not significant, $F_{(2,\ 97)} = 5.25$, $p > .001$, as shown in Table 16.

Table 16: *ANOVA for model with independent variables regressed on spatial visualisation*

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	2888.496	2	1444.248	5.254	.007[b]
	Residual	26665.294	97	274.900		
	Total	29553.790	99			

a. Dependent Variable: Visualisation Total Score

b. Predictors: (Constant), Prior Spatial Experience Score Academic, Prior Spatial Experience Score Non-Academic

5.2.4 Evaluating the independent variables

Multiple linear regressions analysis of the two independent variables of prior spatial experience academic-type and prior spatial experience non-academic-type showed that prior spatial academic-type activities had the largest positive effect on spatial visualisation skills, however the impact thereof on spatial visualisation skills was not significant, (β = .267, p > .005), (cf.Table 17). The current study found that there was no significant relation (p > .05) between academic-type prior spatial experience and spatial visualisation skills.

Table 17: *Regression analysis coefficient for independent variables*

Model		**Unstandardised Coefficients**		**Standardised Coefficients**	**t**	**Sig.**
		B	Std. Error	Beta		
1	(Constant)	-6.452	14.699		-.439	.662
	Prior Spatial Experience Score Non-Academic	.314	.177	.171	1.774	.079
	Prior Spatial Experience Score Academic	.276	.100	.267	2.765	.007

a.Dependent variable: Visualisation Total Score

Sub-research question 1.3 investigated the relation between the completion of an engineering orientated school subject, such as Engineering Graphics and Design, and students' spatial visualisation skills. Also, sub-research question 1.4 investigated, which prior spatial constuct was the best predictor of students' spatial visualisation skills. Therefore, a follow-up multiple linear regression was computed to determine which of the sub-constructs of prior spatial experience activities (academic and non-academic) significantly contributed to spatial visualisation skills. The results revealed that within academic-type prior spatial experience activities, the completion of a mathematics module was a significant predictor of spatial visualisation skills (p < .05). However, the completion of an engineering school subject had no significant impact on spatial visualisation skills (p > .05) as shown in Table 18. Furthemore the sub-constructs, sketching and driving a car under non-academic-type spatial activities were significant predictors of spatial visualisation skills (p < .05). However, using computers, playing sport and building lego blocks had no significant impact on spatial visualisation skills (p > .05) as shown in Table 18.

Table 18: *Regression analysis coefficient for sub-constructs of model*

Model		**Standardized Coefficients**	**Sig.**
		Beta	
1	(Constant)		.785
	Sketching	.282	**.043**
	Driving a car	.255	**.039**
	Prior Spatial Experience Maths	.390	**.001**
	Prior Spatial Experience Science and Technology	-.176	.097
	Did Engineering subject at school	.008	.944
	Measuring	-.075	.565
	Designing	-.039	.732
	Using computers	**-.162**	**.144**
	Building/making things	.117	.333
	Map reading	.112	.319
	Playing chess	.081	.512
	Cycling	-.155	.200
	Using tools	-.062	.650
	Playing sport	**0017**	**.881**
	Dancing	.025	.818
	Playing traditional games	-.172	.214
	Lego	**-.059**	**.634**
	Photography	.013	.911

5.3 DATA PRESENTATION - RESEARCH QUESTION 2

Research Question–2. What is the relation between gender and spatial visualisation ability?

Objective 2 of this study was to determine what the relationship between gender and students' spatial visualisation skills were. This study used the PSVT: R to measure students' spatial visualisation skills before and after the 3D solid computer modelling intervention. The sample for research question 2, was the experimental group of this study, which consisted of one hundred (N=100) students, including 43 females and 57 males (cf. Table 19). The mean score for the PSVT: R pre-test of 43 female students were 39.42 with a standard deviation of 17.86. The mean score for the PSVT: R pre-test for 57 male students were 41.82 with a standard deviation of 19.0. The mean score for the PSVT: R post-test of 43 female students were 51.9 with a standard deviation of 15.0. The mean score for the PSVT: R post-test for 57 male students were 56.75 with a standard deviation of 21.17 as represented in Table 19.

Table 19: *PSVT: R scores for pre-test and post-test*

		N	**Mean**	**Std. Deviation**	**Std. Error**
Pre-test	Female	43	39.42	17.862	2.724
	Male	57	41.82	19.040	2.522
	Total	100	40.79	18.490	1.849
Post-test	Female	43	51.91	15.008	2.289
	Male	57	56.75	21.173	2.804
	Total	100	54.67	18.840	1.884

Table 20 shows the variance in scores, between the two groups (females and males), returned .699 for the pre-test. Thus, the assumption of homogeneity of variance was not violated p > .05 (Pallant, 2010). However, the assumption of variance between groups for the post-test was violated p < .05, therefore the Welch and Brown-Forsythe statistic was considered for the post-test as reflected in Table 21.

A one-way between-groups Analysis of variance was conducted to explore the impact of gender on students' spatial visualisation skills as measured by the PSVT: R. The independent variable, gender, had two categories, female and male with a categorical scale of measurement. The dependent variable, which has a continuous scale of measurement, consisted of the students' spatial visualisation scores as measured by the PSVT: R. There was no statistically significant difference at the p > .05 level in spatial visualisation post-test scores between the genders $F_{(2,\ 98)}$ = 1.63, p = .184 as shown in Table 21.

Table 20: *ANOVA for differences in spatial visualisation and gender*

ANOVA		**F**	**Sig.**	**Welch**	**Brown-Forsythe**
Pre-test	Between Groups	.413	.522	.518	.518
Post-test	Between Groups	1.633	.204	.184	.184

5.4 DATA PRESENTATION - RESEARCH QUESTION 3

Research Question–3. What effect does the use of 3D solid computer modelling software have on students' spatial visualisation skills?

The objective of research question 3 was to determine if the application of 3D solid computer modelling instruction have had any impact on students' spatial visualisation skills in a first year graphics design module at a rural–university. Thus, a pre-test-post-test control group design was used to measure students' spatial visualisation skills with the PSVT: R before and after a 4-week 3D solid computer modelling intervention. To meet the assumption of reliability of the covariate, the Cronbach Alpha was computed to estimate internal consistency and resulted in a coefficient of .816. for the PSVT: R. Pallant (2010) suggested that Cronbach alpha values of above .7 was considered to be reliable. To determine the normal distribution of data for the pre-test, the Shapiro-Wilk test of normality was computed and resulted in .052 for the experimental group and .089 for the control group as shown in Table 22. According to Pallant (2010), if the dependent variable for the specified level was non-statistically significant (p >.05) the data would be considered to be normally distributed.

Table 21: *Descriptive statistics and test of normality between experimental and control groups*

	Group	**Valid**		**Mean**	**Std. Deviation**	**Shapiro-Wilk**	
		N	Percent			Statistic	Sig.
Pre-test	Experimental Group	100	100.0%	40.79	18.49	.978	.052
	Control Group	100	100.0%	41.85	18.83	.971	.089

The significance of the interaction between the PSVT: R pre-test and the PSVT: R post-test for the experimental group and the control group was found to be .148 (cf. Table 23). If the interaction was significant at an alpha level of .05, then the assumption of homogeneity of regression slopes were violated Pallant (2010). However, the assumption of homogeneity of regression slopes were met for the current study p > .05.

Table 22: *Tests of between-subjects' effects PSVT: R pre-test and post-test scores*

Dependent Variable: Post-test			
Source	df	F	Sig.
Group * Pre-test	1	2.114	.148

The data therefore met the assumptions of; reliability of the covariate, linearity and normality and, homogeneity of regression slopes. Thus, the data could, as suggested by Pallant (2010), be analysed using parametric statistics. To determine if any differences in terms of performance of students' PSVT: R pre-test scores existed between the control group and experimental group, an independent samples *t*-test statistical procedure was performed. Furthermore, while controlling for the covariate (pre-test PSVT: R scores), the post-test scores from the PSVT: R for the experimental group and the control group were compared using one-way analysis of covariance (ANCOVA), in order to determine if the intervention of using 3D solid computer modelling had any statistical significance. To determine the strength of the effect size of the 3D modelling intervention between the experimental group and the control group, the current study used the guidelines for interpreting the eta-squared statistic, as proposed by Cohen (2013, p. 284); .01 denoted a small effect; .06 a moderate effect, and .14 a large effect. The finding of the interaction between the pre-test and post-test was significant, since at an alpha level of .05, the assumption of homogeneity of regression slopes was violated (Pallant, 2010, p. 293).

Furthermore, the first year graphics design students' PSVT: R results was presented to depict the changes in their spatial visualisation skills before and after the intervention of a 4-week 3D solid computer modelling programme. Only the experimental group in the current study underwent the intervention. See Table 23 for the results of both the experimental group's and the control group's values of the mean and standard deviation scores, before the 3D solid computer modelling intervention. An independent samples *t*-test was conducted to compare the differences in performance of students' PSVT: R pre-test scores between the control group and experimental group (cf. Table 24). The Levene's test for equality of variance was p =

.98 which did not violate the assumption of equality of variance at a statistical level of .05. Table 23 shows that there was no significant difference in PSVT: R pre-test scores between the experimental group (*M* = 40.8, *SD* = 18.5) and the control group (*M* = 41.9, *SD* = 18.8); *t*(198) = -.40, *p* = .69 (two-tailed). The table further shows the magnitude of the differences in the means (mean difference = -1.06, 95% CI: -6.3 to 4.14) was very small (eta squared = .0008). This finding indicated that there were no statistically significant differences between the spatial visualisation skills of graphics design students in the experimental and control groups before the 3D modelling intervention.

Table 23: *Independent* t-*test of students' PSVT: R pre-test scores*

	Levene's Test for Equality of Variances		**t-test for Equality of Means**							
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		Partial Eta Squared
								Lower	Upper	
Pre-test	.001	.982	-.402	198	.688	-1.060	2.639	-6.265	4.145	.0008

Following the 3D solid computer modelling intervention, both the experimental and control groups took the same PSVT: R test again. Table 24 shows that the means of the PSVT: R post-test for both the experimental group (*M* = 54.7) and the control group (*M* = 47.9) increased. To determine if the increase in the mean scores on the PSVT: R post-test scores between the experimental group and the control group were statistically significant, an ANCOVA was performed.

Table 24: *Descriptive statistics of students' PSVT: R scores after the intervention*

	Group	**N**	**Mean**	**Std. Deviation**
Post-test	Experimental Group	100	54.67	18.840
	Control Group	100	47.97	16.815

A one-way between groups analysis of covariance (ANCOVA) was conducted to compare the effectiveness of a 3D solid computer modelling intervention on graphic design students' spatial visualisation skills. The independent variable was a 4-week

3D solid computer modelling intervention which only the experimental group underwent. The dependent variable consisted of spatial visualisation scores on the PSVT: R test administered to both the experimental and control groups after the intervention was completed. Students' scores on the pre-intervention administration of the PSVT: R test were used as the covariate in the analysis of covariance. Preliminary checks were conducted to ensure that there was no violation of the assumptions of normality, linearity, homogeneity of variance, homogeneity of regression slopes, and reliable measurements of the covariate. Table 25 shows that there was a statistically significant difference between the experimental group and the control group on the post-intervention PSVT: R scores, ($F_{(1,\ 197)}$ = 13.14, p = .000, partial eta squared = .063). The current study used the guidelines for interpreting the eta squared statistics as proposed by Cohen (2013, p. 284); .01 denotes a small effect; .06 a moderate effect, and .14 a large effect. The effect of the 3D modelling intervention on the students' spatial visualisation skills was moderate. There was a strong relationship between the pre-intervention PSVT: R scores and the post-intervention PSVT: R scores as indicated by the partial eta squared value of .365 (cf. Table 26).

Table 25: *Covariance analysis of effectiveness of 3D modelling intervention*

Source	**F**	**Sig.**	**Partial Eta Squared**
Pre-test	113.364	.000	.365
Group	13.135	.000	.063

The ANCOVA results showed that there was a statistically significant difference in the spatial visualisation skills between the students in the experimental group and the students in the control group. The effect of the 3D solid computer modelling intervention on the students' spatial visualisation skills in the current study was moderate. Furthermore, findings showed a strong relationship between the pre-intervention PSVT: R scores and the post-intervention PSVT: R scores as indicated by the partial eta squared value of .365.

5.5 DATA PRESENTATION - RESEARCH QUESTION 4

Research Question–4. What are the mental processes students engage in, when constructing meaning from 2D views to produce 3D representations?

Research question 4 set out to investigate the mental processes which students engaged in when converting orthographic views of an object into an isometric projection. It is important to note that prior to the semi-structured interviews, all students did attend lectures on the fundamental principles of different line types, scale, drawing conventions, orthographic projection and isometric drawing. The findings presented here were informed by the review of literature, guided by Piaget's theory on perception, imagery and spatial relations, as well the current study's conceptual framework for 2D to 3D cognition (cf. Annexure E). According to Piaget (1976), it was projective spatial abilities that allowed for understanding of spatial relationships between multiple objects simultaneously. In this sense projective spatial abilities were the cognitive processes which students applied to encode information, integrate knowledge and mentally construct 3D images from 2D views. This study utilised semi-structured interviews, during which students were shown a first angle orthographic drawing (cf. Annexure D) consisting of three views of a multi-faceted object, and they had to produce the 3D representation of the object in isometric projection. While students were completing the drawing task, they had to provide a step by step account of the mental processes they were following to create an image from the given orthographic views. The resulting interviews were transcribed into a line-by-line discourse of each interview and the 3D drawings produced by the students were evaluated against the expected outcomes of converting the given orthographic views into an isometric projection.

The expected outcomes of the 2D to 3D visualisation process were guided by the three main categories and the sub categories as illustrated in the conceptual framework (cf. Annexure E) of the study's fourth objective, that is

- *encode* – object and spatial visualisers,
- *integrate* – knowledge and experience and
- *construct* – sketching and modifying.

The findings and discussions of the analysis of documents (cf. Annexure H: Figures i & ii) were placed within brackets after the narrative to lend credibility to the narrative. Figure 16 shows the number of associations made by each of the five students with reference to the three stages of the conceptual framework. Figure 16 also shows the researcher's final rating of the solution produced by each student. Answers were considered correct if the 3D drawing accurately represented the three orthographic views in terms of shape and proportion. In Figure 16, it can be seen that the five students made far more associations during the integration stage of the conceptual framework with 35 compared to only 18 associations of the encode and construct stages. Figure 16 also shows, that student (*Ra*) who made the most overall connections of 20, received the highest final rating however, student (*Re*) made only 10 associations with a final rating of 2.

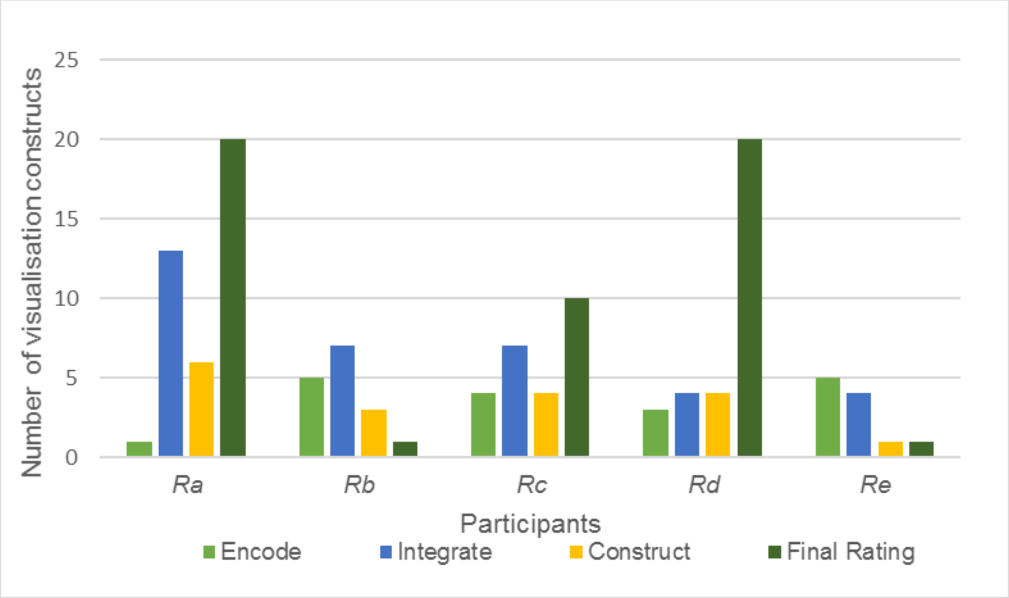


Figure 16: Number of associations made by each student.

The findings in terms of coherences to and/or deviations from the 2D to 3D conceptual framework, with reference to encode, integrate and construct are subsequently discussed.

5.5.1 Encode

In this study, encode referred to students making sense of the information which was presented to them in the form of three given orthographic views. The three orthographic views had to be converted into a 3D pictorial representation using isometric technique. In a previous study, which investigated the cognitive processes and strategies employed by students to learn spatial representations, Pillay (1998) indicated, that in order for students to make sense of orthographic drawings they needed to “encode” information from all the given orthographic views. In addition to encoding information from the given orthographic views, work by Blazhenkova and Kozhevnikov (2009) and Moore-Russo et al. (2013), suggested the existence of two distinct imagery subsystems that encoded and processed visual information in different ways. These two imagery subsystems were described as; (1) an object imagery system, that processed the visual appearance of objects and scenes in terms of their shape, colour information and texture; (2) and a spatial imagery system, that processed object location, movement, spatial relationships and transformations. In general, and aligned with the conceptual framework of the current study, observations and discussions revealed that students, when confronted with the three orthographic views of an object (cf. Figure 17), indicated that certain information such as the position of the views, the length, height and depth and the shape must first be encoded from the orthographic views before it could be visualised.

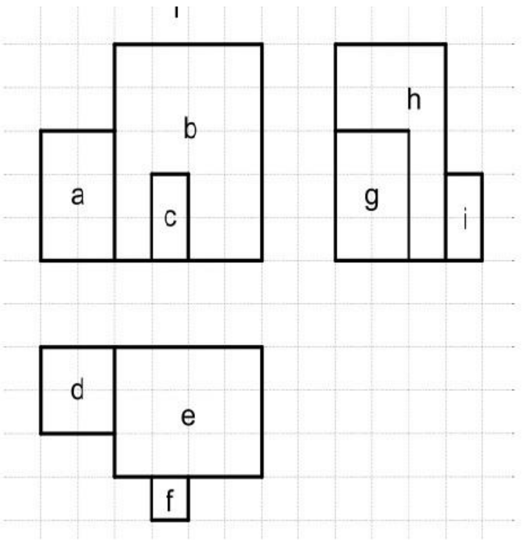


Figure 17: First angle orthographic projection used during interviews.

Findings revealed that students in this study initially relied on an object imagery cognitive process to encode information from the three given orthographic views. For example, with reference to shape, after identifying the three orthographic views, student *Ra* initially said that:

> *I see something that looks like a house, the shape in the front view looks to me like a house with a door to enter and a veranda on the left.*

In addition, student *Rb* replied:

> *I have an image with the shape of rectangle. This small shape block in the front is the same as the small shape one in the top view.*

With reference to object visualisation and the use of colour, student Rb indicated:

> *I will colour in the views to make them stand out separately so I can see the shape better (cf. Figure 18).*

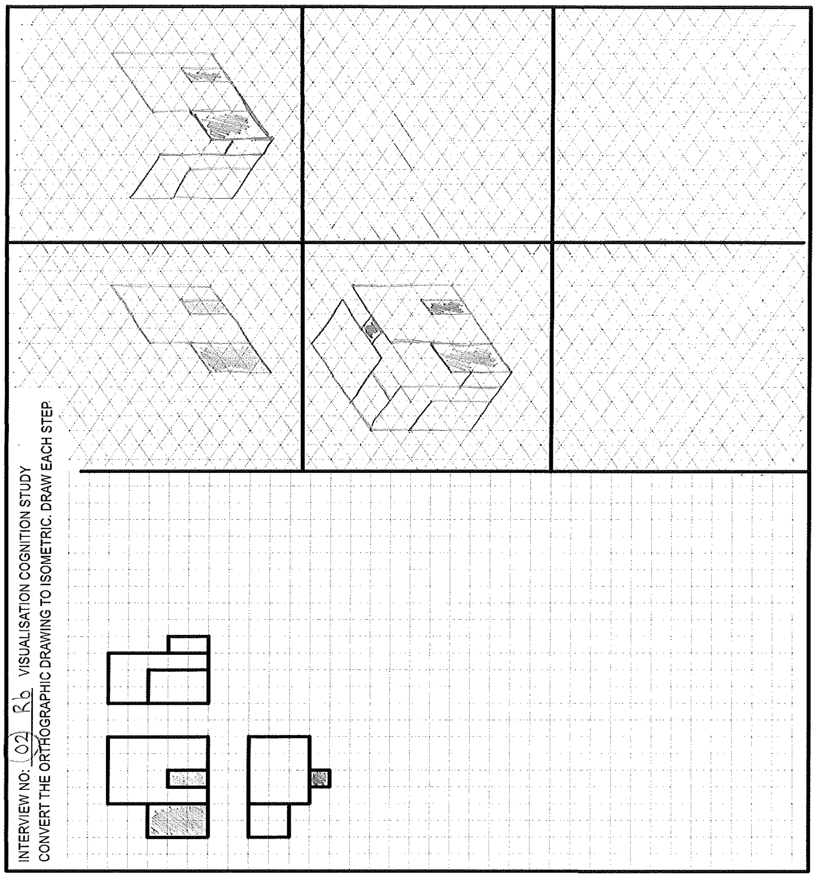


Figure 18: Student's Rb attempt to use colour for improved visualisation.

Student *Rb* coloured in blocks c and f to distinguish them as one part of the object. After asking a question for clarification; "do you see the shape better now that it is coloured?", student *Rb* responded by saying:

> *Yes, I think so… the small rectangle in the front view match with the small shape square in the top view… so I can say it is like a brick shape. (The use of colour assists during encoding of information to determine which features are represented in the different views).*

Moreover, a spatial imagery cognitive system processed object location, movement, spatial relationships and transformations (Blazhenkova and Kozhevnikov, 2009). The current study found that only two students relied on spatial imagery once their object imagery processes could not progress with the visualisation of the object. The findings revealed that students did not initially focus on the relation and location of different parts of an object in space, but they rather focussed on the shape and overall visual appearance of the object (cf. Figure 18). However, it was observed that not all students could successfully traverse from an object imagery to a spatial imagery system, and those students who did, relied on a spatial imagery system which produced better results as seen in Figure 20. The most common associations of a spatial imagery process observed in this study, were object location and spatial relation. For example, the following narrative of student *Rc* explains how the student alternated between object and spatial imagery processes:

Researcher: In your own words, describe to me what mental image comes to your mind when you look at the three orthographic views.

Rc: I'l say it's a building (cf. Figure 17, pointing to the front view) with a garage, I don't know how to describe it, maybe something like a house, but it doesn't have a normal roof, maybe you see those flat houses.

Researcher: Which view tells you that it is a house with a flat roof?

Rc: This view the front view.

Researcher: So you associate the front view with a house that you have seen?

Rc: Yes, sir, I'm trying to associate it with a house or some kind of factory. I know some factories are flat… their roof tops are flat (cf. Figure 17, pointing to the top view, the small square, f.) ...and then you enter here ... this looks like some sort of a door.

Researcher: You said you see a door in the top view. Where is the door in the front view?

Rc: Here, this is the door (cf. Figure 17, pointing to the small rectangle in the front view, c.), but it looks out of the building… it's connected but out.

Researcher: What other relationships do you see?

Rc: I also see different levels (cf. Figure 17, pointing at the front view), three blocks at different levels of height. This is challenging, it is telling us that these blocks are not in the same position… the smallest block is in front of the biggest one.

Researcher: Can you visualise the object now?

Rc: Yes, I have it… I can draw it… let me start with the top and place the three blocks on the top… the same as maybe a houses' plan. (cf. Annexure H, Figure viii, the student continues by drawing a top view in isometric, locating the three blocks in the correct positions)*.*

Researcher: Why did you first draw the top view in isometric?

Rc: I must first see where the three blocks stand… maybe one is obstructing the other and then it needs to be hidden lines. Starting with the top view is easy for me as I can see where the blocks must stand… then I can draw them upwards… the height. (cf. Annexure H, Figure viii, *a*fter drawing the top view in isometric as the base, the student locates the three blocks, similar to that of a house plan. Then proceeds to draw each individual block to its appropriate height. This method could be associated with the crating method. It seems that the students' previous experience assists here that of building a structure from the base up).

In contrast, student *Re* could not transcend from object imagery processes to spatial imagery processes. For instance, student *Re* saw all surfaces in the top view as having the same height, but not as having different levels. On the question of; "How many different levels of height do you see in the given front view?", student *Re* responded; "I don't see it, I cannot see the height." Student *Re* did not correctly identify the three views. "This is the front, top and side view." (cf. Figure 19, Incorrectly pointing to the side view as the top view). On a further question; "how many objects do you see?", student Re responded; "I see three objects here." Thus, student *Re* did not see the three views as representing one object, but saw the three views as individual objects, for example, student *Re* saw the top view in isolation of the front view. Student *Re* was unable to process the spatial relationship between the different views, for example, by processing the interconnection between the surfaces d, e and f in the top view with the corresponding height in the front view (cf. Figure 19).

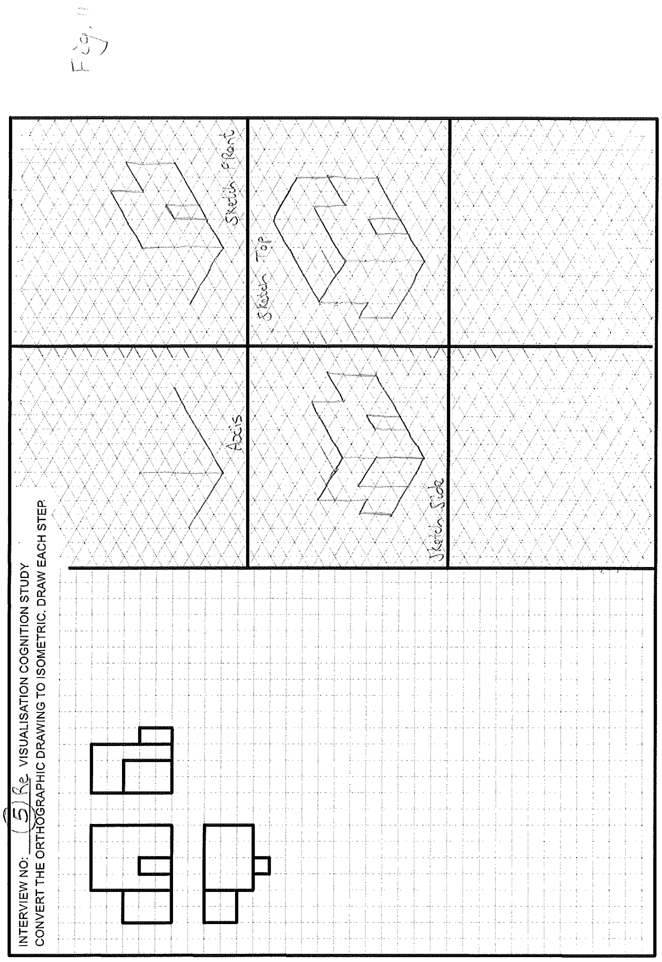


Figure 19: Student Re's attempt to process spatial relations.

Moreover, with reference to encode, Benade and Van den Heever (1993); Reddy (2008) and Morling (2010) were in agreement about the fundamental knowledge and conventions of drawing which are required to successfully convert orthographic projection of an object into an isometric projection. The fundamental knowledge was; knowledge of the projection planes, knowledge of the projection of views onto the plane, the layout of first angle orthographic projection, application of line types, knowledge of dimensions that is length, height and depth, knowledge and application of isometric projection, isometric axes, isometric lines, the "block method" and the "crating method." Moreover, Piaget's perception and constructivist theory asserted that learning was an individual activity and that individuals will try to make sense of all information that they perceived (Piaget, 1976). For example, each individual will, "construct" their own meaning from given information (Bodner & Guay, 1997). However, although there was consensus among students that information needed to be encoded, they had different views on what information was necessary for effective 3D visualisation from 2D views. For instance, all five students recognised that they need to identify the layout and position of the three orthographic views. For instance, student *Ra* explained that:

> *I first need to know which is the front view and which is the top view and the side view. I also need to know the length and the height of the object.*

In addition, student *Rb* indicated:

> *I can see that this is orthographic projection with three views, the top view and front view and side view. I must know how these views fit together.*

However, Student *Rb* identified the front and top views incorrectly, swopping them around.

Additionally, not only did student *Rc* indicate the necessity of knowledge of orthographic views but also knowledge of the three critical dimensions to convert 2D drawing into 3D that is length, height and depth. Student *Rc* said:

> *We have a front view, top view and left side view. Also there is the length and the height here in the front view and the length and depth in the top view.*

In addition, student *Rc* made reference to the necessary procedure needed to produce 3D drawings from 2D views. In the literature reviewed, this procedure was generally referred to as the "block method" and the "crating method" (Benade & van den Heever, 1993). During the "block method" the object's overall size will first be drawn after which the shape of the object is cut from it, whereas the "crating method" follows a procedure where the object is built up from the bottom in stages, much like the stacking of crates on top of one another. Student *Rc* explained:

> *You first must know about orthographic and then about isometric methods and how the views are going to fit in the isometric grid.*

Accordingly, during the encoding stage of the 2D to 3D visualisation process, an individual could use both object and spatial cognitive processes to make sense of the information which was presented in the form of three orthographic views. Even though students in this study demonstrated knowledge and understanding of relevant 2D to 3D procedures, it was observed that those students who managed to assimilate object imagery processes with spatial imagery processes, produced better results. The findings were contrary to Piaget’s theory on spatial development, which alluded to the projective representation stage where cognitive faculties such as object orientation, viewer perspective and similar advanced spatial visualisation abilities were developed. The inadequacies of a proper developed spatial imagery system could at the encoding stage of the 2D to 3D visualisation process prove vital for success. The ensuing section will contemplate the second stage of the 2D to 3D visualisation process, integrate.

5.5.2 Integrate

In the current study, the integrate stage of 2D to 3D visualisation processes referred to the students’ abilities to retrieve relevant information stored in the brain and combining this knowledge with the encoded information from stage one. According to Benade and Van den Heever (1993) and Morling (2010), relevant prior knowledge for 2D to 3D visualisation may include knowledge of the projection planes, layout of first angle orthographic projection, application of line types, dimensions, application of isometric projection and isometric axes. Additionally, the understanding of 3D representations involved complex cognitive faculties such as retrieving and integrating information and procedures from various sources (Pillay, 1998). Pittalis and Christou (2010) contested that the representation of a 3D object by means of a 2D figure demanded considerable conventionalising and experience, therefore, the need to explicitly interpret and utilise conventions for drawing 3D objects was vital. The statement made by Pittalis and Christou (2010) commensurate with Piaget’s theory on spatial imagery and constructivism which argued that people produced knowledge and formed meaning based upon their experiences (Vérillon, 2000).

During the semi-structured interviews, students were asked to give their opinion about the importance of prior knowledge and experience during 2D to 3D visualisation processes. Additionally, students had to recall previous learned knowledge and experiences and making connections with the three orthographic views presented to them. With reference to the integration stage of 2D to 3D visualisation process, observations made in the current study was that students believed knowledge, understanding and experience of orthographic and isometric projection to be fundamentally important. This was evident in the discourse of *Ra* who noted that; *“line types are important”* – and the connection – *“so you will see your drawing how it is at the end, if you just draw outlines you will be confused”.* Student *Ra* could make the necessary connection between the importance of line types and the final 3D drawing. Furthermore, *Rb* said:

> *When you get the three views the first thing to recognise is the length of the object, its either on the top view or the front view … the other thing to look for is the depth, you find the depth on the top view or else on the left side view … then you look for the height .... those are the things you should know before you go for an isometric box method.*

What student *Rb* said was in line with the fundamental knowledge required for 2D to 3D drawing as mentioned by (Morling, 2010). However, student *Rb* could not transfer the knowledge and understanding of orthographic projection and produced an incorrect 3D pictorial representation (cf. Annexure H, Figure ii). With regard to a deeper understanding of orthographic projection, *Rc* said:

> *Yes, if you know how to come about the views from and object you will also know how to bring them together in order to make that object and visualise that object. So you should know which view is projected on which plane, like the front view is projected on the vertical plane and the top view on the horizontal plane.*

Student *Rc* managed to recall deeper knowledge and understanding and integrate this knowledge with the given orthographic views presented. Upon further questioning, student *Rc* indicated that she did Engineering Graphics Design as a school subject and therefore had substantial prior experience. This finding was in line with Piaget’s theory on perception and imagery as well as his constructivist theory which affirmed the importance of prior experience in constructing knowledge.

In relation with knowledge of isometric drawing, *Rd* mentioned:

> *You first need to know about isometric, we have to start at a point on the isometric grid. We must know how the length, height and depth of the views will fit onto the isometric axes* and

Re said:

> *The method of drawing isometric is important. I know the blocking method but there is also another one which I forgot.*

The difference between students' *Rd*'s and *Re's* comments and the subsequent analysis of their solutions about isometric drawing was that *Rd* managed to integrate existing prior knowledge with the given 2D views at hand. Student *Rd* integrated prior knowledge and encoded information from the 2D views by comparing, contrasting and synthesising information between the perceived 2D views and knowledge of 3D pictorial drawing. Student *Rd* did this by correctly identifying and drawing the length, height and depth on the corresponding isometric axes (cf. Figure 20).

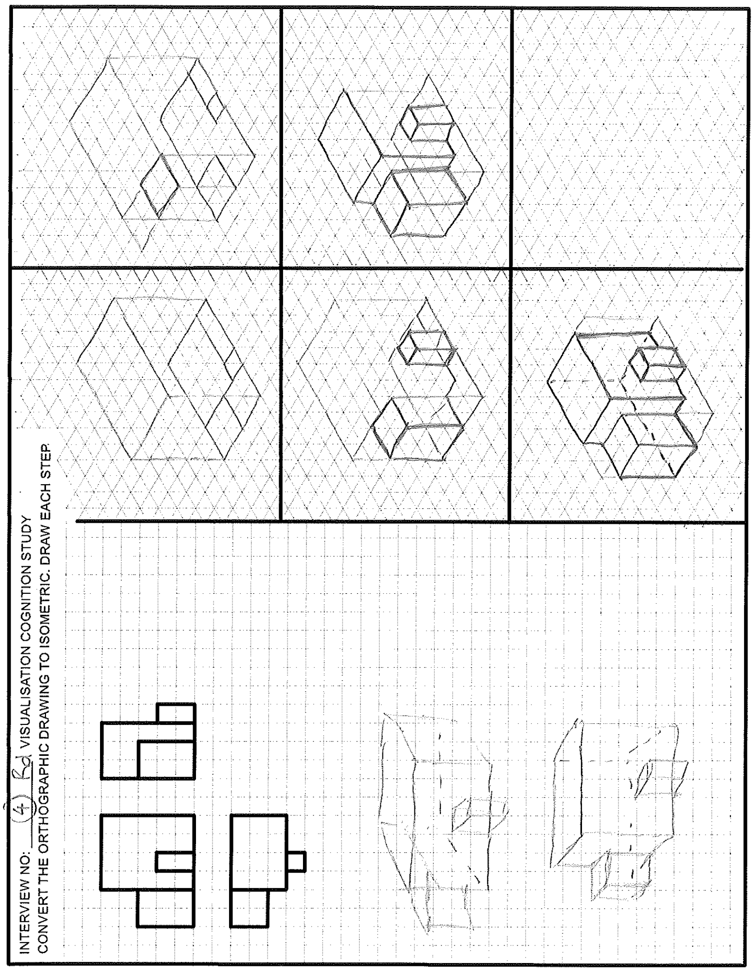


Figure 20: Student Rd's sequence drawings.

On the other hand, student *Re* had a superficial understanding of 3D pictorial drawing. This was because, even though *Re* had prior knowledge of isometric drawing procedural knowledge, it could not be integrated with the given orthographic views. Furthermore, it was observed that student *Re* depended solely on an object visualisation process by adding colour to the different parts of the object, however, without success.

Subsequently, during the integration stage of the 2D to 3D visualisation process information is retrieved from existing knowledge and combined with the encoded information from stage one. Integration takes effect through retrieving information stored in the brain, comparing and contrasting knowledge and synthesising perceived information with prior knowledge. Findings in this study confirmed that students with a combination of prior knowledge and experience as well as the abilities to fuse these components between 2D and 3D are most likely to produce accurate solutions. Therefore, findings showed that retention of the fundamentals of 2D to 3D drawing, that is knowledge of among other factors, orthographic and isometric, was not sufficient enough during the 2D to 3D visualisation process. Thus, during 2D to 3D learning activities, greater emphasis must be placed on integration through comparing, contrasting and synthesising.

5.5.3 Construct

The ability to mentally construct a 3D image of an object in the brain and then sketching the image on paper was the final stage of the 2D to 3D visualisation process. Consistent with Piaget’s spatial development theory, a summary of spatial visualisation skills, which were necessary to imagine 3D objects from 2D views were; (1) the ability to imagine an object from a different point of, (2) the ability to imagine the rotation of depicted objects in 2D or 3D and, (3) the ability to manipulate an object in an imaginary 3D space and create a representation of the object from a new viewpoint (Linn & Petersen, 1985; Olkun, 2003; Rodriguez & Rodriguez, 2016; Sorby et al., 2017; Kösa & Karakuş, 2017). According to Pillay (1998), *construction* was required if information is not directly displayed graphically in the given information. Pillay (1998) contested that if information was presented in orthographic projection there were elements of the object that was obscured, which the observer was expected to mentally construct in order to fully comprehend the nature of the object. Thus, during the process of mentally constructing a 3D representation from a 2D orthographic drawing, Pillay (1998) suggested that a person may begin either by encoding and constructing 3D mental representations of various components and then, use these representations to construct a 3D representation of the complete object. Alternatively, a 3D representation of the overall object may be constructed with limited detail and held in memory to then be elaborated on gradually as the 3D representation of components becomes meaningful (Pillay, 1998).

The conceptual framework of the current study provided the structure for the processes of creating a 3D mental image from the 2D views of an object (cf. Annexure E). The construct stage, of the conceptual framework for the current study, was thought of as a cyclic process varying between creating a 3D mental image, modifying the image and using sketching to keep track of the development of the process. To begin with, attention was placed on the mental processes that students used to create an image and, this was followed by an analysis of how students used sketching activities during the 2D to 3D visualisation process.

Amid the semi-structured interviews, which was conducted to elicit responses from students regarding their mental processess during 2D to 3D visualisation, they were asked to explain how they created 3D image(s) of the three orthographic views and what that image looked like. The discourse proceeded as follows:

> *Researcher: How do you create the 3D image of the object in your mind?*
>
> *Ra: No its not familiar but I can see it has steps that goes like this ...(gesture with her hands making steps) (silence as she continues drawing the isometric) (After some time have passed she gets confused.)... I am confused right now.*
>
> *Rb: In your mind as … as … you are given the three views … in your mind you must construct and put the different views together and visualise what this thing is going to look like.*

Both students’ *Ra* an *Rb* visualised the 3D image of the three views through an object visualising process by focussing on the shape. Student *Ra* also made use of hand gestures by placing the hands at different levels to illustrate steps as in a staircase. However, *Rb* mentioned that the object should be visualised from the three different orthographic views, but is not able to say what the object looks like. On the same question, a more detailed image was provided by student *Rc* (cf. Annexure H, Figure viii).

> *Rc: What I do to make the image is to tell myself that there are three separate blocks which are then standing together. I try to imagine where these blocks are standing... in front or the back or the side.*

Student *Rc* recognised that the object consisted of three separate blocks. This indicated that *Rc* not only recognised shape, but also the location of the three blocks in space. *Rc* thus combined object and spatial visualisation processes. The researcher felt it needed further investigation:

> *Researcher: Could you imagine the 3D object from a different point of view?*

> *Rc: Yes, if I see it from the right side then this part (pointing to the front view, the block marked a,* (cf. Figure 17) *is hidden but from the left side it will be seen.* (cf. Annexure H, Figure viii, the student produced two sketches of visualising the object).

Student *Rc* showed the ability to mentally construct a 3D image through rotating and viewing a 3D object from different positions. This was an indication of well-developed spatial visualisation skills, coupled with substantial prior knowledge and experience. On further questioning, it emerged that *Rc* did do Engineering Graphics Design as a subject at school and this fact supported the quantitative component of this study's research question 1 which investigated the relation between academic-type prior spatial experience and spatial visualisation skills.

In contrast to forming 3D mental images of the object, student *Re* said:

> *It is difficult for me to imagine this shape in my mind. What confuse me is the many blocks… maybe there are three… I first have to start with the axis in isometric and fit the sizes on the axis.*

Student *Re* (cf. Annexure H, Figure x) could not narrate the formation of a 3D mental image and from the onset wanted to follow a procedure or method for producing 3D pictorial drawing in isometric, as Re said; "*I first have to start with the axis in isometric*."

The urge to follow a procedure or method was consistent with what Halpern et al. (2016, p. 56) called "a schema-driven" processes. Once the schema was activated, the knowledge contained in the schema provided the general steps and procedures to follow in order to solve the problem (Halpern et al., 2016). However, as Halpern et al. (2016) explained, unlike novices, experts were able to work forward immediately by choosing appropriate steps that led them to their goal as they recognized the problem from previous experiences and already know the next moves to solve it. In the end, *Re* produced a solution which was almost entirely incorrect. Therefore, it could be argued that *Re* was aware of a specified method, however, the shortcoming of spatial visualisation skills negatively influenced the production of an accurate 3D solution. Thus, the researcher probed deeper.

> *Researcher: So, are you going to follow a method of drawing isometric without visualising the object?*
>
> *Re: Yes, I follow a method by first drawing the axes and then I draw the front view on the axis and then the top. (cf. Annexure H, Figure v).*

According to procedure, student *Re* (cf. Annexure H, Figure x) drew the isometric axis, then placed the front view in the front face and the side view on the left face. However, by the time the student wanted to place the top view it was evident that there was no concept of "location in space." Hence, the parts of the object were placed in incorrect positions and the left side view was rotated back to front. Student *Re* ended up producing an inaccurate solution.

Thus, during the construct stage of the 2D to 3D visualisation process it would be expected that a mental 3D image was created by using a combination of object visualisation and spatial visualisation processes. Object visualisation focusses on colour, texture, shape and patterns while spatial visualisation focusses on location, relation, rotation and transformation (Blazhenkova & Kozhevnikov, 2009). Moreover, spatial visualisation was homogenous to Piaget's projective representation stage where cognitive faculties such as object orientation, viewer perspective and similar advanced spatial visualisation abilities were developed (Fleisig et al., 2011). Furthermore, Piaget's projective stage began in adolescence and development continued throughout university, therefore it could be argued that students in the current study should have had the abilities to develop spatial skills (Fleisig et al., 2011). Moreover, substantial knowledge of drawing conventions and methods do not necessarily transform into the visualisation and production of accurate 3D solutions. However, findings from the current study hinted at prior spatial experience and well-developed spatial visualisation skills to be more apportioned to 2D and 3D visualisation processes.

5.5.4 Sub research question 4.1

The current study endeavored to determine how students used sketching as an extention of the visualisation process when they have to create the 3D images of an object's 2D views. Ullman et al. (1990, p. 263) described sketching as "free hand drawings, usually not to scale and which was used for amongst others, to act as an extention to the draftsmans' short term memory to remember ideas that they might otherwise forget". Gagnier et al. (2017) stated that sketching was often used as a pedagogical tool to help students reason about 3D structures and Fish and Scrivener (2007) suggested that the necessity to sketch, derived from the need to envisage the outcome of the synthesis of objects. Typically, during the process of 2D to 3D visualisation, sketching would be utilised in stages to externalise the mentally created object. Fish and Scrivener (2007) argued that the importance of sketching increased in proportion to the degree of abstraction or dificulty involved in manipulating the object and therefore a system was needed for representing the object to be easily stored and manipulated. Asserting from the conceptual framework of the current study, sketching was a fundamental stage in the process of visualising, constructing and remembering a 3D mental image from the 2D views of the object, especially in the case of a multifaceted object, such as represented in Figure 17.

As part of the semi-structured interviews, students were asked to show the sequence of sketches which they followed during the 2D to 3D visualisation process, much like the isometric sequence drawings as shown in Annexure I. Students were allowed to erase a sketch if it conflicted with their visualisation process. Since the interviews were video recorded, the sequence of sketches were reproduced by the researcher (cf. Annexure H, Figures vi to x). The sequence drawings allowed the researcher to analyse how sketching was used as part of the 2D to 3D visualisation process, and how it contributed towards the production of a 3D pictorial image.

Thus, guided by this study’s conceptual framework regarding sketching as an extention of the 2D to 3D visualisation process, students were asked to give reasons why they sketch, and why they modified sketches during drawing activities.

The analysis of the sequence drawings showed that students employed an assortment of sketching strategies to visualise the 3D pictorial object from the given 2D orthographic views (cf. Annexure H, Figures vi to x). Most distinctly, the results indicated sketching activities related to procedural–strategies, modification and spatial transformation (cf. Table 26). In addition to the various sketching strategies employed by each student, Table 26 also shows the researchers’ final rating for the 3D solution produced by each student. Procedural–strategies had two sub–categories, Blocking and Crating methods. Hence the different categories of sketching that was observed from students’ work will be discussed.

Table 26: *Sketching strategies used by students during 2D to 3D visualisation*

Participants	Procedural–strategies		Modification	Spatial transformation	Final rating
	Blocking	Crating			
Ra	X	X			20
Rb					1
Rc		X	X	X	10
Rd	X	X	X	X	20
Re	X		X		1

5.5.4.1 Procedural – sketching strategies used by students

Procedural–strategies are a fixed, step-by-step sequence of activities or course of action that must be followed in the same order to correctly perform a task (Benade & van den Heever, 1993). Two common procedural–strategies to solve 2D to 3D problems are the “Blocking Method” and the “Crating Method” as illustrated in Annexure I. In this study, four students followed a procedural–strategy to produce the 3D pictorial drawings. Out of these four students, one exclusively used the Blocking Method, one exclusively used the Crating Method and two students used a combination of both methods (cf. Table 26). For instance, *Ra* said; “*I like to make the sketch of the entire shape first to see how it will fit… and I need to change the isometric again to see if isometric fits to the front view.* Student *Ra* proceeded to draw using the

Blocking method. Student *Ra* continued to draw the shapes of the three views onto the three faces of the isometric block (cf. Annexure H, Figure. vi). In addition, student Rd indicated:

> *Yes, I sketch what I am thinking of… for me it's better because I can match the image with my method… which I use the block method and*

student *Re* noted:

> *I'm following the block method but there's something that doesn't add up here with my boxes … they are six instead of four, also*

student *Rc said:*

> *I mean that I think of the object as building it up from the ground… as if I have to put it together… so I sketch it… but I can keep on changing my sketch.*

The sequence drawings for student *Rc* is shown in Figure 20. Student *Rc* first placed the overall base of the object in the top view where after the individual components which made up the object were located. Note however that *Rc* made one error by placing the smallest component in the incorrect position (cf. Figure 20).

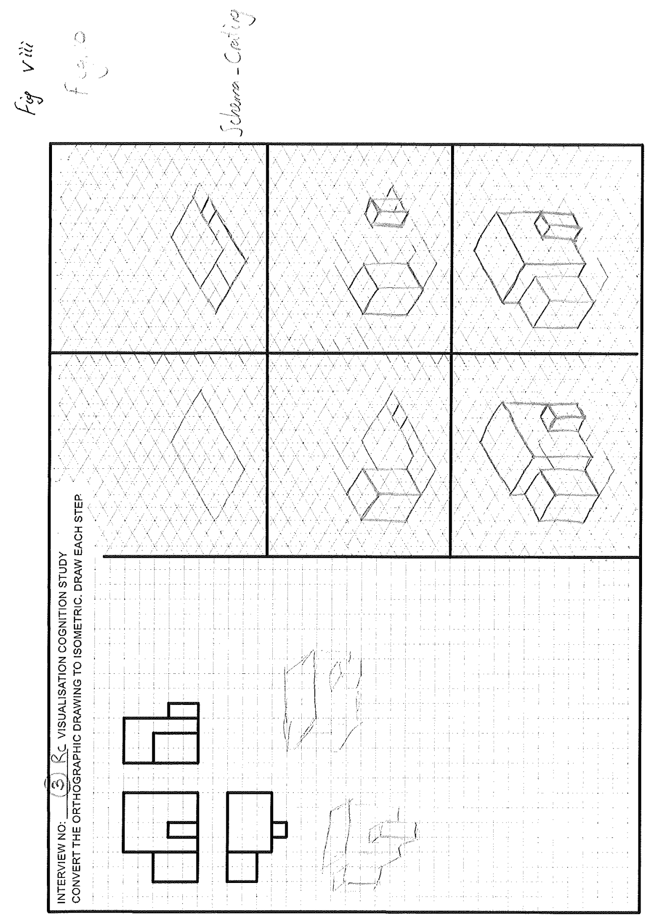


Figure 20: Student Rc's sequence drawings.

Notably, only students' *Ra* and *Rd* produced what can be considered accurate 3D solutions for the given problem (cf. Annexure H, Figures I and iv). This finding was interesting seen in the light that both students used a combination of the Blocking and Crating methods. However, even though student *Re* used a procedural strategy, the final solution was not at all accurate.

5.5.4.2 Modification sketching strategies used by students

Modification in this study referred to sketching as a system for representing and storing information of the object in order to be manipulated and modified in accordance with new information that was received. For example student *Rc* said:

> *I also can easily erase the parts of the sketch if it does not match with the three views that I see”* and student *Rd* indicated; “*I think some people they have a problem with … I can say drawing the object in their mind before drawing the object down on paper …. and if you are struggling with that the best thing a person could do is to firstly roughly sketch the object and they will have an idea ... a basic idea of what it’s going to look like ... then they can come back and re-draw the object.*

The observation here was that two students *(Rc and Rd),* kept on sketching and modifying the 3D drawing until they were satisfied that the drawing corresponded with the 2D orthographic views as well as the mental images they had (cf. Annexure H, Figures ii and iv). Additionally, both students *Rc* and *Rd* produced two separate sketches from different view–points in an effort to imagine the 3D object from a different perspective. However, only student *Rd* ended up producing a completely accurate 3D drawing, while *Rc* made a slight error in the spatial orientation of one feature of the object. In contrast, student *Re* said:

> *I mean to say I change my image and drawing I have... maybe trial and error until the measurements fits.*

Even though student *Re* (cf. Annexure H, Figure v) did use a strategy for modifying the object, to the student’s own admission, it was a trial and error effort which either could or could not achieve the desired outcome. Notably, student *Re* failed to produce an accurate 3D solution to the problem.

5.5.4.3 Spatial transformation sketching strategies used by students

The current study considered spatial transformation as the ability to visualise and externalise the location, relation, rotation and transformation of the different components of an object. Guided by Piaget’s theory on the development of spatial relations, investigations have already established a strong link between spatial visualisation skills and success in 2D to 3D drawing (Leblanc, 2015). Furthermore, research showed that spatial visualisation skills can be enhanced through activities such as sketching (Sorby & Baartmans, 2000). In this study, only two students (*Rc* and *Rd*), showed some intimation of utilising sketching activities to make sense of the 3D object from different perspectives. For example, student *Rc* noted that:

> *I also try to think of the block from another side… so that I can see it better than before"* and *Rd said; "I rotated it (the object) because I could not see this block (cf. Figure 17, block a) from that side. Now I can see it clearly.*

Both students externalised their thoughts by producing sketches of the 3D object imagined from a different point of view. However, student *Rc's* sketches (cf. Annexure H, Figure viii) was in one direction only, while student *Rd* rotated the 3D object in two different points of view (cf. Annexure H, Figure ix). Student *Rd* first exposed the right side view of the object that was hidden and in the second sketch the left side view was exposed. Student *Rd* demonstrated by way of sketches, tangible evidence of the ability to mentally rotate and then sketch the 3D image.

5.6 SUMMARY

Guided by Piaget's theory on the development of perception and mental imagery, this study investigated the relationship and impact of prior spatial experience, gender, 3D solid computer modelling and different cognition styles on students' spatial visualisation skills at a rural–university. The nature of this study's research questions compelled the application of a mixed methods sequential research design (QUAN→QUAL). Therefore, this study used distinct research instruments to collect data viz. a biographical questionnaire (see Annexure A), a spatial experience questionnaire (SEQ; see Annexure B), the Purdue Spatial Visualisation Test: Rotation (PSVT: R; see Annexure C) and semi-structured interviews (see Annexure E).

Research question 1 investigated the relation and impact of students' prior spatial activities on their spatial visualisation skills. To comprehensively answer research question 1, it was structured into 4 sub-research questions. Extensively, this study found no significant relation between academic-type prior spatial experiences (Research Question–1.1), non-academic-type prior spatial experiences (Research Question–1.2), and spatial visualisation skills. However, within the construct of academic-type prior spatial experience, the fullfilment of a mathematics module was found to be a significant predictor for spatial visualisation skills (Research Question–1.2). Specifically, this study found that the completion of an engineering school subject had no significant relation on students' spatial visualisation skills (Research Question–1.3). Furthemore, findings showed that the sub-constructs, sketching and driving a car, which were categorised as non-academic-type spatial activities, were significant predictors of spatial visualisation skills, however, using computers, playing sport and traditional games and building lego blocks had no significant impact on students' spatial visualisation skills in this study (Research Question–1.4).

Furthermore, with regard to the relation between gender and spatial visualisation skills, findings showed no statistically significant difference in spatial visualisation post-test scores between the genders (Research Question–2).

However, findings made after a 3D solid computer modelling intervention showed a statistically significant difference, with a moderate effect, in students' spatial visualisation skills between the experimental group and the control group in this study (Research Question-3).

Also, students in this study demonstrated fundamental knowledge and understanding of relevant 2D to 3D procedural strategies, however, it was observed that those students who managed to assimilate object imagery processes with spatial imagery processes, produced better 3D drawing results (Research Question–4). These findings were contrary to Piaget's theory on spatial development, which alluded to the projective representation stage where cognitive faculties such as object orientation, viewer perspective and similar advanced spatial visualisation abilities were developed. Findings showed that this anomaly could be attributed to inadequacies of a proper developed spatial imagery systems within the students in the current study (Research Question–4). In addition, findings in this study confirmed that students using a combination of prior knowledge and experience as well as the abilities to fuse the components between 2D and 3D were most likely to produce accurate solutions. Findings also showed that retention of the fundamentals of 2D to 3D drawing as well as knowledge of drawing conventions was not sufficient enough for success during the 2D to 3D visualisation process, however, previous spatial experience and well-developed spatial visualisation skills were more apportioned to 2D and 3D visualisation processes (Research Question–4). Additionally, the study found that students employed a variety of sketching activities during 2D to 3D visualisation including; procedural–strategies, modification, and spatial transformation (Research Question–4.1). Notably however, students who made extensive use of sketching activities during the 2D to 3D visualisation process produced consistently better results than their counterparts (Research Question– 4.1).

CHAPTER 6: DISCUSSION

6.1 INTRODUCTION

In the current study the researcher's observation was that graphic design students at a rural-based South African university often experienced difficulties to convert 2D views of an object into a 3D pictorial drawing. Research within urban contexts, by Duffy et al. (2016), Friess et al. (2016), Rodriguez an Rodriguez (2016) and Kösa and Karakuş (2017), established that the ability to perform successfully in engineering graphics activities were to a great extent depended on spatial visualisation skills. However, the current study did not find any research which investigated the relations and impact of spatial visualisation skills on students' ability to complete 2D to 3D drawing at a rural–university. What research by Nkomo and Sehoole (2007), Modisaotsile (2012), Evans and Le Roux (2016) and Mabusela and Adams (2017), have demonstrated though, was that students at a rural–university experienced unique educational drawbacks including factors such as, low levels of literacy skills, insufficient computer literacy skills, inadequate resources and the dire effects of poverty. Following, but not limited to the aforementioned drawbacks, the purpose of this study was to investigate the relationship and impact of students' spatial visualisation skills. This study also endeavored to establish how prior spatial experience, gender, 3D solid computer modelling and different cognitive styles influenced students' spatial visualisation skills at a rural–university. In part, this research sought to develop a context-specific instructional and learning model for 2D to 3D drawing.

Guided by Piaget's theory on the development of perception and spatial relations, this study explored the differences in relationship between students with well-developed spatial abilities and those with less-developed spatial abilities when they have to produce 2D to 3D drawings. The focal point of this study on 2D to 3D drawing was located within a constructivist/interpretivist paradigm in order to understand the impact of students' experiences. It also placed emphasis on understanding the individual and their interpretation and application of visualisation processes. The nature of the research questions in the current study necessitated the use of mixed methods sequential research which included a correlational design. Additionally, the pretest-posttest control-group quasi experimental design, and a systematic interactive interpretivist paradigm with a phenomenological design structure were applied. Forthcoming is a discussion on the findings of this study's research questions.

6.2 RESEARCH QUESTION 1

Research question 1 investigated the relation and impact of students' prior spatial experiences and their spatial visualisation skills. To comprehensively answer research question 1, it was structured into four sub-research questions.

Sub-research question 1.1 investigated the relation between academic-type prior spatial experience and students' spatial visualisation skills. Data from the current study revealed that there was no significant correlation ($p > .05$) between academic-type prior spatial experience and spatial visualisation skills of rural–university graphics design students. In support of this finding, Strong and Smith (2002) reported that in engineering graphics literature, prior experience has often been found to not have a statistically significant correlation with spatial abilities. In contrast to the finding of the current study, investigations into the effectiveness of spatial training on science, technology, engineering and mathematics (STEM) disciplines, by Stieff and Uttal (2015), found the correlation between academic-type prior spatial experience and spatial visualisation skills to be "moderate." In addition to this finding, Rafi and Samsudin (2007) studied the factors that could have affected the perceived ability of secondary students to learn engineering drawing and the authors reported a "moderate" correlation, $r(222) = .45$, $p \leq .002$, between perceived spatial ability and spatial experience. Furthermore, Salthouse et al. (1990) investigated the correlation between spatial visualisation accuracy and two groups of adults with different levels of spatial experience. The study by Salthouse et al. (1990) reported a significant difference ($p < .05$) between the two groups, with the higher spatial experience group outperforming their counterparts on all spatial visualisation tasks. In addition, related work by Farrell and Harding (2015) has noted that there was a moderately strong correlation between secondary school academic-type prior spatial experience and spatial visualisation skills. However, it should be noted that the studies by Salthouse et al. (1990), Farrell and Harding (2015), and Stieff and Uttal (2015) were not positioned in rural-based settings but, in urban contexts in Europe and the United States of America respectively.

Sub-research question 1.2 investigated the relation between non-academic-type prior spatial experience and students' spatial visualisation skills. The current study did not find a significant relationship between non-academic-type prior spatial experience and spatial visualisation skills. One plausible explanation for this finding, and supported by Newcombe and Baenninger (1989, p. 335), could be that spatial activities which people engage in changes over a person's lifetime and recalling activities in retrospect could have some inaccuracies. In other words, underpinned by Piaget's (1976) constructivist theory, which argued that people produced knowledge and formed meaning based upon their experiences, it could be presumed that an individuals' spatial visualisation skills were not constant, but could change and improve through gaining more experience. However, related work by Quaiser-Pohl and Lehmann (2002) has noted that there was a correlation between non-academic-type prior spatial experience and spatial visualisation skills. Quaiser-Pohl and Lehmann (2002) reported that actual experiences, for example computer and technical experience, revealed to be of importance for spatial visualisation. However, the study by Quaiser-Pohl and Lehmann (2002) was not set in a rural-based context and it could be speculated that individuals who grew up in a different context to have varied more rich experiences because of access to resources.

Sub-research question 1.3 investigated the impact of having previously completed and engineering orientated school subject on spatial visualisation skills. It must however be noted that in the current study's sample, only 10.0% of students did an engineering orientated subject (for example EGD, Electrical, Mechanical, and Civil technology) at school. The reasons for so few students doing an engineering-type subject at school were many folds, however, Pretorius (1999) mentioned that unqualified teachers and lack of facilities and resources to be the main factors for schools not to offer engineering subjects in South African schools. The current study found no significant correlation between having completed previous engineering-type school subjects and spatial visualisation skills. In support of this finding, Strong and Smith (2002) studied spatial visualisation against the fundamentals and trends in engineering graphics courses. According to Strong and Smith (2002), neither previous high school drafting nor Computer Assisted Design (CAD) courses was significantly correlated to scores on measures of spatial visualisation. However, in contrast to the findings of this study, work by Michau (2012), Pedrosa et al. (2014) and Kösa and Karakuş (2017) reported statistically significant correlations between previous engineering activities and spatial visualisation. Of note was Kösa and Karakuş (2017) who reported a significant difference of spatial visualisation skills in favour of students having completed related engineering drawing content to those students who have not completed such content ($p < .05$). However, findings in this study was that students entering the university with engineering-type content had no significant advantage over their counterparts in terms of their spatial visualisation skills to perform 2D to 3D activities.

Sub-research question 1.4 investigated the various constructs of spatial visualisation skills in order to determine the best predictor for spatial visualisation skills. There was insufficient evidence from literature about which spatial activity construct(s) were the best predictor for spatial visualisation skills in a rural education context. The finding made by the current study was, that amongst the sub-constructs of prior spatial activities (academic and non-academic), the prior completion of a mathematics first semester module to be a statistically significant predictor for spatial visualisation skills. This finding was supported in a study by Yenilmez and Kakmaci (2015, p. 7) who suggested that, “a branch which was included in mathematics and which was effective in visualisation processes was geometry, the purpose of geometry was generally expressed as the recognition of the properties of geometrical shapes and objects.” Additionally, Pedrosa et al. (2014, p. 144) reported that “traditionally, engineering drawing courses have included a strong component of descriptive geometry and sketching.” In support of the finding of the current study, Yenilmez and Kakmaci (2015) studied the difference in achievement in spatial visualisation by mathematics and report that there were significant differences in terms of spatial visualisation achievements between mathematics achievement groups ($p < .001$). In addition, Rafi and Samsudin (2007), investigated the relationship between previous mathematics achievement and ability to learn engineering drawing and found the relationship between spatial experience and previous mathematics achievement to be statistically significant ($p = .040$).

A further finding in the current study revealed that prior spatial activities such as sketching and driving a car to be significant predictors for spatial visualisation skills. Studies by Sorby (1999), Alias et al. (2002) and Sorby et al. (2017) confirmed the positive correlation between sketching activities and spatial visualisation skills. Of note was Alias et al. (2002, p. 172) who reported a statistically significant correlation between sketching activities and spatial visualisation ability ($p < .05$).

The finding in the current study that driving a car had a significant impact ($p < .05$) on spatial visualisation skills was surprising however, the reasons for this finding was not in the scope of the current study and hence was discussed as recommendation for further research. Ultimately, the current study resonated with Piaget's theory on perception and mental imagery in as far as the notion that perception and mental symbolism derived from activity and that amongst others, sketching formed the basis for the development of visual imagery.

6.3 RESEARCH QUESTION 2

Research question 2 examined the relation between gender and spatial visualisation skills. Findings in the current study showed no statistically significant difference in spatial visualisation post-test scores, as measured by PSVT: R, between the genders. It must be noted that although every effort was made to find rural-based studies on gender and visualisation, as far as could be determined, studies on the effects of gender on spatial visualisation skills were conducted mostly at schools and universities in the United States of America and Europe and within urban settings. Contradictory to the current study's finding, was that several studies demonstrated that gender was a significant predictor for spatial visualisation ability (Battista, 1990; Sorby, 1999; Strong & Smith, 2002; Terlecki, Necombe, & Little, 2007 and Farrell & Harding, 2015). Additionally, the main factors between females and males, which impacted the slant towards male dominance in spatial visualisation included, but was not limited to, students' field of study (Strong & Smith, 2002), boys have more computer and videogame experience (Terlecki et al., 2007), socio-cultural factors such as gender-typed socialisation where male children have more opportunities to engage in spatial activities at an early age (Rafi et al., 2006), and environmental factors (Sorby, 1999). Consequently, the finding of this study must be depicted within a rural-based context where the prior spatial experiences of females and males were not sufficiently disparate to actualise in differences in spatial visualisation skills.

6.4 RESEARCH QUESTION 3

Research question 3 investigated whether 3D solid computer modelling instruction had the potential to improve the spatial visualisation skills of first year graphics design education students at a rural–university. Students were randomly assigned to a control group and an experimental group. The control group and experimental group were randomly selected from 250 students enrolled for a graphics design module at a rural–university. The control group and the experimental group were enrolled for the same graphics design module. Moreover, the two groups entered the university with the same entry requirements. Additionally, as discussed in section 5.4, the data met the assumptions of reliability of the covariate, linearity and normality, and homogeneity of regression slopes. Thus, there were no statistically significant difference between the control group and the experimental group at the start of this study. Consequently, this study used a pretest-posttest control group design to measure students' spatial visualisation skills with the Purdue Spatial Visualisation Test: Visualisations through Rotations (PSVT: R) before and after a 4-week 3D solid computer modelling intervention.

6.4.1 Meeting Assumptions

To meet the assumption of reliability of the covariate, the Cronbach Alpha was computed to estimate internal consistency and resulted in a coefficient of .816 for the PSVT: R. Pallant (2010) suggested that Cronbach alpha values of above .7 were considered to be reliable. Among others, studies by Yue (2006), Fleisig et al. (2011), Rodriguez and Rodriguez (2016) and Kösa and Karakuş (2017), which used the PSVT: R test during investigations into spatial visualisation skills of students, reported reliability coefficients of between .80 and .86. After computing the Shapiro-Wilk test of normality, the pre-test data was found to be normally distributed with results of .052 for the experimental group and .089 for the control group. According to Pallant (2010, p. 57), if the dependent variable for the specified level was non-statistically significant ($p > .05$) the data would be considered to be normally distributed. The significance of the interaction between the PSVT: R pre-test and the PSVT: R post-test for the experimental group and the control group was computed and found to be .148. The finding of the interaction between the pre-test and post-test was significant, because at an alpha level of .05, the assumption of homogeneity of regression slopes was violated (Pallant, 2010, p.293). For this violation, the Levene's test for equality of variance was found to be statistically non-significant at p = .219 which did not violate the assumption of equality of variance. The data in the current study therefore met the assumptions of reliability of the covariate, linearity and normality, and homogeneity of regression slopes, and could therefore be analysed using parametric statistics as suggested by Pallant (2010, p. 109).

An independent samples t-test was performed to determine if any differences in terms of performance of students' PSVT: R pre-test scores existed between the control group and the experimental group before the 3D solid computer modelling intervention. Findings showed that there was no significant difference in PSVT: R pre-test scores between the experimental group (*M* = 40.8, SD = 18.5) and the control group (*M* = 41.9, SD = 18.8); t(198) = -.40, p = .69 (two-tailed). The magnitude of the differences in the means (mean difference = -1.06, 95% CI: -6.3 to 4.14) was very small (eta squared = .0008). This indicated that there were no statistically significant differences between the spatial visualisation skills of graphics design students in the experimental and control groups before the 3D solid computer modelling intervention. After the 3D solid computer modelling intervention was administered to the experimental group, both the experimental and control groups took the same PSVT: R test again. Findings showed that the means of the PSVT: R post-test for both the experimental group (*M* = 54.7) and the control group (*M* = 47.9) increased which led to the conclusion that both traditional instructional methodology, as followed by the control group, and 3D solid computer modelling software, as followed by the experimental group had a positive impact on students' spatial visualisation skills.

This finding affirmed the results of previous studies which concluded that students' spatial visualisation skills could be improved by among others, sketching, mentored sketching, engineering drawing tasks, using hand held models, and virtual environments (Rafi et al., 2005; Rodriguez & Rodriguez, 2016). Of note, studies by Sorby (1999), Mohler and Miller (2008) and Marunic and Glazar (2014), found that sketching activities had a moderate positive impact on students' spatial visualisation skills, Rafi et al. (2006) found that engineering drawing tasks had a moderate positive impact on students’ spatial visualisation skills while Rafi et al. (2005) and Pedrosa et al. (2014) found that web-based virtual environments had a positive impact on students’ spatial visualisation skills.

However, to determine if the increase in the mean scores between the experimental and control groups in the current study were statistically significant, an ANCOVA was performed. The independent variable was a 4-week 3D solid computer modelling intervention which only the experimental group underwent. The dependent variable consisted of spatial visualisation scores on the PSVT: R test administered to both the experimental and control groups after the intervention was completed. Students’ scores on the pre-intervention administration of the PSVT: R test were used as the covariate in the Analysis of covariance. Findings revealed that there was a statistically significant difference between the experimental group and the control group on the post-intervention PSVT: R scores, $F_{(1, 197)} = 13.14$, $p = .000$, partial eta squared = .063. The current study used the guidelines for interpreting the eta squared statistics as proposed by Cohen (2013, p. 284); .01 denoted a small effect; .06 a moderate effect, and .14 a large effect. The effect of the 3D solid computer modelling intervention on the students’ spatial visualisation skills in the current study was moderate which accords with previous studies by Kurtuluş and Uygan (2010); Ligocki, (2011), and Kösa and Karakuş (2017). Furthermore, findings showed a strong relationship between the pre-intervention PSVT: R scores and the post-intervention PSVT: R scores as indicated by the partial eta squared value of .365. The ANCOVA results showed that there was a statistically significant difference with a moderate positive effect in the spatial visualisation skills between the students in the experimental group and the students in the control group. Therefore, the use of 3D solid computer modelling software could be considered as an effective instructional methodology in a graphics design module at a rural-university.

6.5 RESEARCH QUESTION 4

Research question 4 investigated, in line with the 2D to 3D spatial visualisation conceptual framework of the study (cf. Annexure E), if students had the ability to encode, integrate and construct information from orthographic projections in order to mentally visualise and draw an object. The study was guided by Piaget's theory on perception, imagery and spatial relations which signified that it was projective spatial abilities that allowed for the understanding of spatial relationships of objects. Therefore, to accomplish the objective of analysing the different cognitive styles which students employed during 2D to 3D drawing, the current study utilised semi-structured interviews. During these interviews, students were shown a first angle orthographic drawing (cf. Annexure D) consisting of three views of a multi-faceted object, and they had to produce the 3D representation of the object in isometric projection. The resulting narrative of the interviews as well as the 3D solutions that students produced were analysed in light of the three stages of the conceptual framework viz. encode information, integrate knowledge, and experience and construct 3D drawings.

Findings revealed that students possessed previous knowledge of orthographic projection and isometric projection, however, not all students could identify the correct layout of the orthographic views, which were considered fundamental for 3D visualisation. From the interviews with students on encoding of information, it was evident that they did not have the same level of prior knowledge and understanding necessary to produce 3D projections from 2D views. This was evident when some students incorrectly identified the different views and dimensions from the given orthographic projection. However, difficulties with encoding information from 2D views was not unique to this study's rural-based students. For example, Accascina and Rogora (2006) suggested that, loss of information due to projection was a common error made by students. Furthermore, findings of the current study revealed that students initially relied on object imagery processes to visualise the 3D object from the 2D views. In doing so, students focussed on the shape of the object by referring to geometrical shapes which they visualised, such as "rectangle" and "block". In addition, students used colour as a way of making sense of the 2D views, although this was not as evident as shape. Based on the object imagery system, students also associated the three orthographic views with "familiar" objects, which they retrieved from the brain, such as "a house", "a door", "a veranda" and "a brick". The association of these objects with the three orthographic views showed that students associated the shape of these objects with a 3D image that they created in their minds. Further observation and document analysis revealed that only some students traversed from an object imagery system to a spatial imagery system. The spatial imagery students focussed on the location and positioning of different parts of the object in 3D space by mentioning, “different levels in height”, “not the same position”, “in front of” and “where it stands”. A meaningful finding from the current study was that students who traversed from an object imagery system to a spatial imagery system successfully produced answers which were closely related to the expected answer of the study. A congruent argument was forwarded by Blazhenkova and Kozhevnikov (2009, p. 640) that “spatial imagery was not limited to spatial locations or relations between objects in spatial array, but could refer to spatial relation between parts of the object and also, it could refer to the object’s movement and to the dynamic spatial transformations of different elements of the object.” Therefore, students who did not have sufficient spatial visualisation skills did not perform well in activities which required them to convert multifaceted 2D views of an object into the 3D representation of the object. Moreover, the spatial imagery system was closely related and dependent on the skills required for spatial visualisation (Blazhenkova & Kozhevnikov, 2009). Therefore, it could be argued that graphics design instructional material should include activities and exercises which are focussed on the development of spatial visualisation skills. However, it was important to note that none of the 2D and 3D instructional sources investigated in this study had sufficient activities and exercises to improve the spatial visualisation skills of students before they attempted the activities which required them to convert 2D views into 3D representations.

Another finding in the current study was that students who did well in the 3D activity did not necessarily have greater theoretical knowledge than their counterparts. In fact, the current study found that in certain cases, students with sufficient knowledge and understanding of 2D and 3D drawing produced answers which were inaccurate. The reason for this anomaly became clear, after intensive study of the narrative and 3D solutions, and revealed that students’ poor performance was due to their inability to spatially visualise the different components of the object in relation to location and position in space.

Furthermore, findings from the current study revealed that students were in agreement that the object must first be visualised before it can be drawn on paper however, not all students could initially accurately describe the 3D mental image of the object from the 2D views. Some students did however associate the 2D views with familiar objects in their environment such as “a house”, “a door” and “a building with a flat roof” in order to try and make sense of what they see. Compelling findings were made by the current study with regard to the importance of spatial visualisation skills when converting 2D views into 3D representations. The study found that students who did have the ability to imagine an object from a different point of view, or the ability to imagine the rotation of the object in space, produced answers of acceptable standard, and, in contrast, students who did not manage to exhibit these spatial skills did not produce the required answer.

Sub-research question 4.1 investigated how students use sketching as an extention of the visualisation process when they had to create the 3D image of an object from its 2D views. Discourse and document analysis found that students employed an assortment of sketching strategies to visualise the 3D pictorial object from the given 2D orthographic views. Most distinctly, the results indicated sketching activities related to procedural–strategies, modification and spatial transformation. The importance of sketching in graphics design was highlighted by researchers who indicated that, sketching acted as an extention to the draftsmans' short term memory to remember ideas Ullman et al. (1990), sketching was used as a pedagogical tool to help students reason about 3D structures Gagnier et al. (2017), and to sketch derived from the need to envisage the outcome of the synthesis of objects Fish and Scrivener (2007). Observations and analysis of 3D solutions from the current study revealed that students who mentally modified the 3D image used sketching as a tool to externalise their internal thoughts. For example, students externalised their thoughts by adding or removing features, by locating and positioning different parts of the object in space or by sketching the object from another point of view (cf. Annexure H, Figure ix). Similarly, in a recent STEM study, which sought to find if sketching supported spatial reasoning, Gagnier et al. (2017, p. 895) found compelling evidence that "sketching a prediction created a permanent representation of the students' mental prediction that could be compared to the expected answer and the act of sketching forced the learner to form a conceptual model, which could be used to make a prediction". A unique finding in the current study was that one student indicated the use of a "trial and error" method to mentally modify the 3D image. This finding was supported in a study by Garmendia et al. (2007), who examined the visualisation difficulties of students during drawing tasks, and found that students eventually reached the final correct solution however, they committed numerous errors during the solution process, so they resorted to trial and error. However, the student in the current study which resorted to trial and error did not produce an accurate solution.

Significantly, no research could be found which supported the view that sketching was not beneficial in the visualisation process. In the current study, students who employed sketching proceeded to create answers which were closely related to the expected answer. In contrast to findings in the current study that sketching was beneficial in the visualisation process, it was found that students who did not sketch their mental images produced answers which did not represent the expected answer at all (cf. Annexure H, Figure x). There was thus compelling evidence from the current study that sketching assisted the visualisation process to translate orthographic 2D information into depictive 3D representation and notably sketching was used by students as an extension of their short-term memory to remember and modify what they were thinking.

6.6 A PROPOSED INSTRUCTIONAL AND LEARNING MODEL FOR 2D TO 3D DRAWING

6.6.1 Introduction

The current study, which was conducted at a rural–university, often encountered that students entered the university unprepared for tertiary studies. This unpreparedness for tertiary study was due to factors such as poverty, gender inequality, inadequacy of educational resources, shortcomings in prior spatial experiences and lack of qualified teachers. The essence of this study was to investigate the impact of graphic design students' prior spatial experience, gender differences, 3D solid computer modelling intervention and different cognitive styles on spatial visualisation skills. Based on the findings of the aforementioned constructs, the study endeavoured to develop an instructional and learning model for 2D to 3D drawing at a rural–university.

Henceforth, guided by Piaget's theory on the development of perception and mental imagery, and vindicated by the significant findings of the current study, as well as compelling depositions from literature, a proposed instructional and learning model for 2D to 3D drawing was developed for learning at a rural–university. The contributing factors which guided the development of the proposed 2D to 3D model are illustrated in Figure 21.

6.6.2 Contributing factors to a proposed 2D to 3D model

Literature reviewed for the current study examined the elements which researchers acknowledged and examined as influential contributors for 2D to 3D cognitive processes. These contributing factors included but was not limited to; spatial visualisation, prior spatial experience, 3D solid computer modelling and PCK. PCK included representations, curricular saliency, assessment and topic specific instructional strategies. It was important to identify the contextual factors which needed to be considered for developing a 2D to 3D instructional model to benefit the characteristics of a typical graphics design student at a rural–university. Therefore, guided by Piaget's theory on the development of perception and mental imagery, informed by a constructivist research paradigm and placed within the context of a rural–university the contributing factors for the proposed 2D to 3D model are discussed.

6.6.2.1 Spatial visualisation

In essence, spatial visualisation referred to the ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus and was characterised by a number of features which included but was not limited to skills in representing, transforming, generating and recalling non-linguistic information (Rafi & Samsudin, 2007; Rodriguez & Rodriguez, 2016). Additionally, literature was in agreement that spatial visualisation skills were fundamentally important in producing accurate graphics design content, such as the focus of 2D to 3D drawing in this study (Friess et al., 2016). Moreover, studies have reported that spatial visualisation can be enhanced through activities such as; sketching, computer assisted design, virtual environments, 3D solid computer modelling and using concrete visual objects (Kösa & Karakuş, 2018; Rafi et al., 2005). In line with Piaget's perception and imagery theory, research has established that perception and imagery were figurative processes which could be trained and were developed through action, and these actions increased spatial visualisation skills (Potter & Van der Merwe, 2001).

However, findings in the current study showed that graphics design students entering the university had poor spatial visualisation skills which was attributed to environmental factors including prior spatial experience, inadequate schooling and lack of fundamental literacy skills. Furthermore, the study on available graphics design learning resources by Benade and Van den Heever (1993), Maguire and Simmons (1998), Morling (2010), Reddy (2008) and Wilson (1991) showed a prominent focus on procedural understanding of concepts and absence of activities which targeted the development of spatial visualisation. Hence, the proposed instructional and learning model for 2D to 3D drawing (cf. Figure 21) included activities to develop the cognitive functions of spatial visualisation. Moreover, these spatial visualisation activities aimed to develop both object imagery processes through the visual appearance of objects and scenes in terms of their shape, vividness, colour, and texture as well as spatial imagery processes through location, movement, spatial relations and transformations.

6.6.2.2 Prior spatial experience

The study found that prior spatial experience consisted of two distinct components namely academic-type spatial activities which were acquired through formal training sessions, and non-academic-type spatial activities which was acquired through life experiences such as playing games, partaking in sport and playing with toys that require manipulation in space (Newcombe et al., 1983; Sorby, 1999; Uttal et al., 2014). Furthermore, there was general agreement in literature that prior spatial experience was a determining factor in the development of spatial visualisation skills (Rafi et al., 2005).

However, the current study investigated prior spatial experiences of rural–university students and found two constructs which were significant predictors for spatial visualisation skills, viz. mathematics and sketching. Therefore, the proposed model for 2D to 3D learning (cf. Figure 21) included mathematics content and sketching activities. Fortunately, the curriculum in which the current study was situated included mathematics as a compulsory module. This situation however allowed for the lecturers in the curriculum to work together for the purpose of curricular saliency as proposed by theories surrounding PCK. Moreover, the 2D to 3D learning model included abundant opportunities for students to be engaged in 2D and 3D sketching activities.

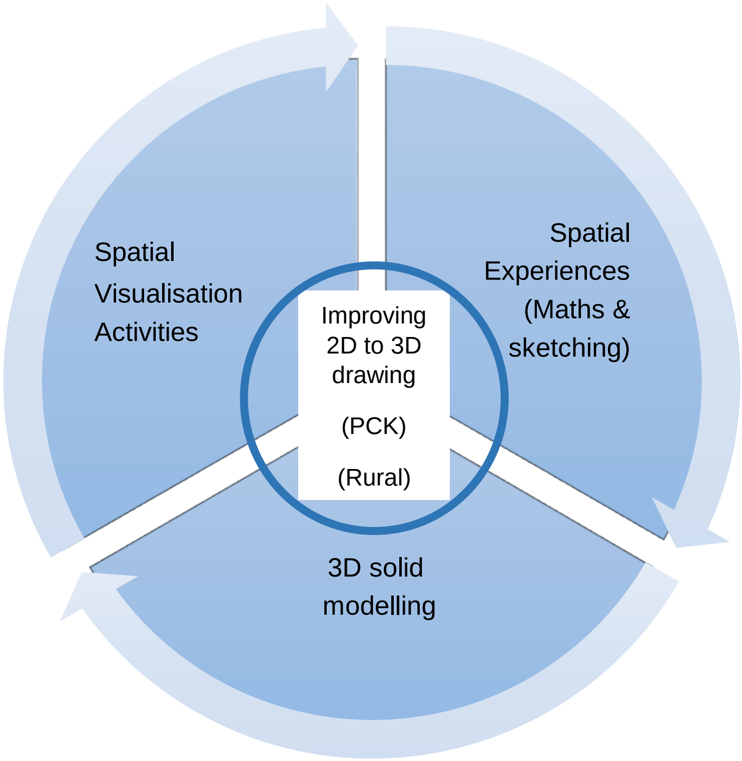


Figure 21: Proposed instructional and learning model for 2D to 3D drawing.

6.6.2.3 3D solid computer modelling

From literature, it was predicated that 3D computer solid modelling was the most advanced method of representing the solid parts of an object on a computer (Hsu, 2010). Moreover, research reported on the positive impact that the application of 3D solid computer modelling has had on the improvement of students' spatial visualisation skills (Rodriguez & Rodriguez, 2016). However, as far as could be determined, no studies on 3D solid computer modelling interventions on spatial visualisation were rooted in rural-based contexts. Notwithstanding, studies at the same university as the one in which this study was completed suggested that the majority of students learned more efficiently through the use of computers (Mabusela & Adams, 2017). Therefore, this study searched for a suitable platform that could be used to apply 3D solid computer modelling activities. Investigations revealed that “SketchUp” software to be a good option to use in a graphics design course for improving spatial skills because of advantages such as, being freely downloadable from the internet, easy to learn and it combined a simple, yet robust tool-set with an intelligent drawing system. Therefore, the proposed model for learning 2D to 3D drawing (cf. Figure 21) included an assortment of 3D solid computer modelling activities including, 3D modelling from isometric, 3D modelling from physical objects, 3D modelling from orthographic views and 3D modelling creative design.

6.6.2.4 Pedagogical Content Knowledge (PCK)

In literature, a distinction was made between General Pedagogical Knowledge (GPK) and PCK (Etkina, 2010). GPK was defined in literature as follows; “teachers should know how people learn, how memory operates, and how a brain develops with age” (Davidowitz & Rollnick, 2011, p. 134). However, most importantly, teachers of a specific subject should possess special understandings and abilities that integrated their knowledge of the subject’s content and students’ learning of the content. This special knowledge was referred to as PCK and was what distinguished the science knowledge of teachers from that of scientists (Shulman, 2000). Moreover, a PCK model (cf. Figure 8) was developed by Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) to understand and explain the nuances of PCK. An important constituent, that was considered for the development of the current study’s 2D to 3D learning model, immerged from Rollnick’s PCK model, namely manifestations of teacher knowledge. Rollnick et al., (2008) intimated that manifestations of teacher knowledge referred to observable teaching practices in the classroom, such as representations, curricular saliency, assessment and topic specific instructional strategies. Hence, the manifestations as observable practices for the current study's 2D to 3D instructional and learning model (cf. Figure 21) was formulated and are presented.

6.6.2.4.1 Representations

Shulman (2000) indicated that a teacher should be able to construct or provide alternative representations in the form of examples, illustrations, analogies or explanations that will enable students to understand the topic being taught. In the current study, 2D to 3D simulations, sketching and demonstrations of concrete objects were considered to be effective instructional representations for 2D to 3D drawing. Findings of the current study showed the effectiveness of 3D solid computer modelling software and sketching on enhancing students' spatial visualisation skills. Therefore, the proposed 2D to 3D learning model (cf. Figure 21) included a variety of 3D modelling and sketching activities. It was critical to include a variety of presentations in the development of a 2D to 3D drawing model for the current study. These representations included, but was not limited to simulations, video, concrete object demonstrations and 3D solid computer modelling. Moreover, the instruction of 2D to 3D drawing included concrete demonstrations of real objects to give students' the opportunity to apply object visualising (shape, colour, texture) as well as spatial visualising (location, relation, rotation, transformation, movement) processes.

6.6.2.4.2 Curricular saliency

Davidowitz and Rollnick (2011) referred to curricular saliency as the teachers' understanding of the place and purpose of a topic in the curriculum, and may be observed in teachers' decisions to leave out certain aspects of the topic, and in teachers' awareness of how a topic fits into the curriculum. In the current study, findings that mathematics was a strong predictor for spatial visualisation skills necessitated that lecturers in the mathematics, science and technology curriculum work within a co-operative strategy to provide students with opportunities to develop and enhance their spatial visualisation skills. Within the proposed model (cf. Figure

21) mathematics content such as descriptive geometry was included to enhance the spatial visualisation skills of students. Similarly, the current study focussed on the development of 2D to 3D drawing with an emphasis on developing students' spatial visualisation through 3D solid computer modelling instead of the narrow focus on multiple exercises with increased difficulty as often found in graphics design instructional material.

6.6.2.4.3 Assessment

The instructional and learning model of the current study was guided by Piaget's constructivist theory on spatial perception and imagery development. In the current study, Piaget's perception and imagery theory was brought to bear in the assessment of students' spatial visualisation skills which were found to be inadequate for effective 2D to 3D drawing. According to Bhattacharjee (2015), the purpose of learning was to construct your own meaning and not just to memorize and regurgitate the "right" answers of someone else's meaning. Additionally, constructivist views held that assessment was authentic and interwoven with teaching and manifested via student works, observations, points of view as well as tests in which process was as important as product (Bhattacharjee, 2015).

The present study's 2D to 3D learning model (cf. Figure 21) therefore included formative assessment activities during which students worked either individually or corroborated to solve 2D to 3D problems, where students were allowed to be creative and design their own solutions, where students were allowed to participate in peer-assessment and reflective practices and where students and lecturers could openly engage in discussions. Thus, responding to the objective of the development of a 2D to 3D learning model, baseline assessment of students' spatial visualisation skills and regular assessment of students' progress in spatial skills (formative assessment) and content knowledge were included.

6.6.2.4.4 Topic specific instructional strategies

Magnusson et al. (1999) pointed out that topic specific instructional strategies, which were considered an aspect of a teachers' PCK, where the specific strategies which were useful for assisting students to understand concepts in the topic being taught. Findings by the current study alluded to a statistically significant impact of 3D solid computer modelling activities on students' spatial visualisation skills. For this reason, the current study employed 3D solid computer modelling in order to enhance students' spatial visualisation skills. These 3D solid computer modelling activities included modelling 3D objects from isometric, modelling 3D objects by measuring concrete objects, modelling 3D objects from 2D views and modelling 3D objects based on design and creativity. The 3D solid computer modelling activities were hosted on the university's learning management system (LMS) which made it possible for students to effectively engage in group-work, peer-assessment, discussions and reflection. 3D solid computer modelling could therefore be considered successful to enhance spatial visualisation skills at a rural–university.

6.7 SUMMARY

Piaget's theory on the development of perception and mental imagery guided this study's investigations into the relation and impact of prior spatial experience, gender, 3D solid computer modelling and different cognition styles on students' spatial visualisation skills at a rural–university. The study investigated prior spatial experiences on two fronts, namely academic-type prior spatial experiences and non-academic-type prior spatial experiences. This study found no significant relation between academic-type prior spatial experiences, non-academic-type prior spatial experiences and spatial visualisation skills. However, within academic-type prior spatial experience constructs, mathematics stood out as a significant predictor for spatial visualisation skills. What's more, this study found no significant relation between engineering school subject learning and students' spatial visualisation skills. Furthemore, findings showed that sketching and driving a car to be significant predictors for spatial visualisation skills, however, using computers, playing sport and building lego blocks showed no significant impact on students'spatial visualisation skills at a rural–university.

Furthermore, this study did not find a significant difference between the pre-test spatial visualisation scores and gender differences which showed that females and males entered the university on the same footing. Also, the mean scores for both females and males showed poor spatial visualisation skills on the pre-test PSVT. Moreover, findings showed no statistically significant difference in spatial visualisation post-test scores between the genders which indicate that females and males responded equally to the 3D solid computer modelling intervention.

However, it was revealed that a statistically significant difference, with a moderate effect, existed between an experimental group's spatial visualisation skills and spatial visualisation skills of a control group. This finding pointed to 3D solid computer modelling as an effective tool for enhancing spatial visualisation skills at a rural–university.

What's more, during semi-structured interviews, students in this study demonstrated fundamental knowledge of 2D to 3D procedural strategies, however, students did not manage to assimilate object imagery processes with spatial imagery processes. These findings were contrary to Piaget's theory on spatial development and indicated that students in this study were not at the appropriate cognitive developmental stage for spatial visualisation. In addition, findings confirmed that students who combined prior knowledge and experience with the ability to decipher 2D drawings were more likely to produce accurate 3D solutions. Furthermore, findings showed that substantial knowledge of 2D to 3D drawings and conventions were not sufficient for success in 2D to 3D visualisation processes. However, previous spatial experience and well-developed spatial visualisation skills were more apportioned to 2D and 3D visualisation processes. Additionally, findings revealed that students employed a variety of sketching activities during 2D to 3D visualisation including; procedural–strategies, modification and spatial transformation. However, students who made ample use of sketching activities during 2D to 3D visualisation processes produced consistently superior results compared to students who did not engage in sketching.

Ultimately, this study's findings articulated in the development of a proposed model for learning 2D to 3D drawing at a rural–university. Guided by Piaget's theory on the development of perception and imagery, set within a rural-based context and substantiated by literature, several contributing factors emanated viz. spatial visualisation, prior spatial experience, 3D solid computer modelling, PCK and 2D to 3D visualisation. Therefore, situated in a constructivist paradigm, the proposed 2D to 3D instructional and learning model comprised activities for the enhancing of spatial visualisation skills including, sketching, descriptive geometry, co-operative learning, creative design and 3D solid computer modelling.

CHAPTER 7: SUMMARY, CONCLUSION AND RECCOMMENDATIONS

7.1 INTRODUCTION

The purpose of the current study was to investigate the relationship and impact of factors such as; prior spatial experience, gender, 3D solid computer modelling and different cognitive styles on rural students' spatial visualisation skills. This chapter presents the summary, conclusions, recommendations, limitations and suggestions for future research.

7.2 SUMMARY

The current study, which took place at a rural–university in South Africa, undertook to investigate the difficulties which first year graphics design students experienced with regard to 2D to 3D drawing. 2D to 3D drawing was considered a fundamental skill to master within graphics design programmes. During 2D to 3D drawing a student was required to mentally visualise and then draw the 3D pictorial drawing of an object from the 2D views of the same object. Within the current study, students used the isometric technique to draw 3D pictorial drawing. On the other hand, 2D views were presented using first angle orthographic projection. A review of available literature divulged that a strong relationship existed between spatial visualisation skills and the effective performance in graphics design subjects. In addition, literature also pointed to various factors which had an impact on the development of spatial visualisation skills. These factors included, but was not limited to prior experience, gender, cognitive styles and instructional interventions. Research reported on instructional interventions such as 3D solid computer modelling, physical objects, sketching, virtual environments and computer assisted design programmes to enhance spatial visualisation. Moreover, the cognitive development of spatial visualisation skills was guided by Piaget's theory surrounding the development of perception and mental imagery. Piaget's perception and imagery theory suggested that spatial visualisation was the ability to mentally represent visual appearances of objects and these abilities were developed through relevant experiences. Therefore, guided by Piaget's theory, the purpose of this study was to investigate the relationship and impact of graphic design students' prior spatial experiences, gender differences, 3D solid computer modelling and different cognitive styles on spatial visualisation skills at a rural–university in South Africa. The findings of these research questions led to the development of a model for learning 2d to 3D drawing. The proposed model was informed by the findings of the interactions between spatial visualisation skills and prior experiences, gender, 3D solid computer modelling and cognitive styles.

Considering that this study was positioned within a rural–university context, consideration had to be afforded to elements which impacted students' learning such as lack of reliable resources, large classes, low levels of spatial visualisation skills, poor academic and computer literacy and general under-preparedness for university education.

Furthermore, the nature of this study's research questions necessitated the use of a mixed method sequential research design with the application of non-experimental correlation, pretest-posttest control group and discourse analysis as relevant methods. Therefore, data was collected and analysed through quantitative and qualitative methods. By virtue of the demand for quantitative data within a positivist paradigm, the ontological stance was that there is a single reality or truth and the epistemological view was that reality can be measured with reliable and valid tools. Hence, the quantitative component of this study investigated a random sample of students by using the PSVT: R test to measure spatial visualisation skills and the SEQ to measure prior spatial experiences. Both these instruments were considered and reported to be reliable and valid. The qualitative component of this study was based on a constructivist/interpretivist paradigm. The ontological view was that there was no single reality or truth and the epistemological stance was that reality needed to be interpreted. Therefore, this study used descriptive discourse to evaluate a purposive sample of students' cognitive styles during 2D to 3D visualisation. The data for the qualitative component in this study was collected through semi-structured interviews. The structure of the interviews was based in a 2D to 3D conceptual framework with three stages of making meaning of 2D drawings that was, encoding information, integrating information with existing knowledge and finally, constructing a 3D image.

Quantitatively, this study's non-experimental correlational findings revealed no significant relation between students' academic-type prior spatial experiences, non-academic-type prior spatial experiences and spatial visualisation skills. However, within the construct of academic-type prior spatial experience, the fullfilment of a mathematics module was a significant predictor for spatial visualisation skills. Contrary to the findings of related studies, this study found that the completion of an engineering school subject had no significant relation on students' spatial visualisation skills. Furthemore, this studys' findings showed that the sub-constructs, sketching and driving a car, which were categorised as non-academic-type spatial activities, were significant predictors of spatial visualisation skills, however, using computers, playing sport and building lego blocks had no significant impact on students' spatial visualisation skills in this study.

Furthermore, with regard to the relation between gender and spatial visualisation skills, findings in the current study showed that both females and males entered the university with low levels of spatial visualisation skills. Importantly, no statistically significant difference in spatial visualisation post-test scores could be found between the genders after the 3D solid computer modelling intervention. The impact of a 3D solid computer modelling programme therefore, did not favour either females or males within the context of the current study. However, pretest-posttest control group findings made after the 3D solid computer modelling intervention showed a statistically significant difference, with a moderate effect, in students' spatial visualisation skills. The 3D solid computer modelling intervention for the enhancement of students' spatial visualisation skills thus had merit for inclusion in a proposed 2D to 3D learning model.

Results of the qualitative component in this study displayed students' fundamental knowledge and understanding of relevant 2D to 3D procedural strategies. However, it was observed that students who managed to assimilate object imagery processes with spatial imagery processes produced better 3D drawing results. These findings were contrary to Piaget's theory on spatial development. Piaget's theory alluded to the projective representation stage where cognitive faculties such as object orientation, viewer perspective and similar advanced spatial visualisation abilities are developed.

Findings in this study showed that students' difficulties with 2D to 3D drawing could be attributed to inadequacies of proper developed spatial imagery systems. In addition, findings in this study confirmed that students who employed a combination of prior knowledge and experience as well as the abilities to fuse the components between 2D and 3D were most likely to produce accurate solutions. Findings also showed that retention of the fundamentals of 2D to 3D drawing as well as knowledge of drawing conventions was not sufficient enough for success during the 2D to 3D visualisation. However, previous spatial experience and well-developed spatial visualisation skills were more apportioned to 2D and 3D visualisation processes. Additionally, the study found that students employed a variety of sketching activities during 2D to 3D visualisation including, procedural–strategies, modification and spatial transformation. Notably however, students who made extensive use of sketching activities during the 2D to 3D visualisation process produced consistently better results than their counterparts.

Consequently, the meaningful findings of this study's quantitative and qualitative research questions were integrated and combined with features of PCK for the development of an instructional and learning model for 2D to 3D drawing. This study's 2D to 3D model, illustrated in Figure 21, stand on three pillars that is spatial visualisation skills, 3D solid computer modelling activities and spatial experiences. This study's 2D to 3D instructional and learning model proposed that spatial visualisation skills were fundamental in 2D to 3D drawing and therefore the students must be provided with sufficient opportunities to develop their spatial visualisation skills. Furthermore, this study's 2D to 3D model advanced that 3D solid computer modelling to be an efficient strategy to enhance students' spatial visualisation skills. Finally, this study's 2D to 3D model recommended that students, must be provided with sufficient graphics design representations, must get opportunities to integrate appropriate mathematics content, must partake in a variety of different assessment strategies and should be exposed to specific 2D to 3D instructional strategies and experiences, in order to bring about accurate 3D solutions.

7.3 CONCLUSIONS OF THIS STUDY

This study was located within a rural–university context where students experienced unique circumstances towards learning graphics design content. Therefore, caution must be applied when generalising the results of this study to other contexts because it was composed of randomly assigned graphics design education students from a rural-based university rather than the largely based urban and peri-urban contexts. The sample was 200 graphics design students, randomly selected from a population of 250 students. Moreover, students at a rural–university experienced problems such as being under–prepared for university education in terms of low levels of academic and computer literacy, difficulties of adapting to higher level learning as well as cultural and socio-economic problems.

The study did not find any positive relation between either academic-type, nor non-academic-type prior spatial experiences. The conclusion was that the type of non-academic activities which the students in this study engaged in, for females and males, had no impact on their spatial visualisation skills. This finding was in contrast to studies from urban contexts, which did report significant relations between non-academic prior spatial activities and spatial visualisation skills. Thus, it was concluded that students in the current study did not often partake in what literature referred to as *prior spatial activities* such as video games, computers, Lego blocks, erector sets, orienteering and playing sport. However, it must be noted that students in this study were not selected into the graphics design programme based on their spatial visualisation skills. Therefore, students in the graphics design programme could benefit if they partook in spatial activities as extra-curricular events in order to improve or enhance their success in graphics design content. These non-academic spatial activities which students could be engaged in were for example, traditional games, sketching, sport and activities involving hand-eye co-ordination. Moreover, further analysis of the constructs of prior spatial activities, for instance, completion of a previous mathematics module and sketching activities were found to be statistically significant and was incorporated in the development of the proposed learning model for 2D to 3D drawing for the current study.

A compelling result in this study showed a statistically significant difference with a moderate positive effect in the spatial visualisation skills between the experimental group and the control group. Thus, 3D solid computer modelling as an instructional method has definite merit and was included as one of the pillars on which this study's 2D to 3D learning model was based. In the current study, 3D solid computer modelling presented unique opportunities to counter some of the inhibiting factors towards learning at a rural–university such as, lack of sufficient resources, physical infrastructure and space and the effect of large classes. Furthermore, the use of 3D solid computer modelling eliminated the conventional dependency on making concrete physical objects to enhance spatial visualisation skills. By its very nature, making physical models in a large class was considered to be resource intensive, required a lot of time and was relatively expensive whereas, 3D solid computer modelling required an initial investment in computer infrastructure after which the number of models that students could model was infinite.

Furthermore, this study endeavoured to determine the mental processes that students engaged in when constructing meaning from 2D views to produce 3D images. Literature suggested that there were two distinct processes of visualising an object that is object visualisers and spatial visualisers. This study did not set out to determine whether a student was either predominantly an object visualiser or predominantly a spatial visualiser. However, this study did show that students initially used object imagery processes to mentally create a 3D image until a stage was reached when students traversed from object imagery processes to spatial imagery processes. In contrast, not all students in this study could make the transition between object imagery processes and spatial imagery processes successfully. Traversing between the two imagery systems mentioned here, proved vital in this study such that the students who did not manage the traverse between these processes managed to produce the desired expectations. This study showed that the ability to use spatial imagery processes was closely linked to a students' spatial visualisation skills which in turn was fundamentally important in converting 2D views of an object into the 3D representation of the object. In support of the notion that spatial visualisation skills were fundamentally important to accurately produce 3D images, this study found that current instructional material in engineering graphics design did not provide sufficient activities or exercises for students to enhance their spatial visualisation skills. It was also revealed that the level of a students' prior graphics design procedural knowledge was not paramount in producing isometric drawings from orthographic views. As a matter of fact, this study found that in certain cases students with higher levels of prior graphics design knowledge achieved worse results due their inability to spatially visualise a 3D object. Moreover, the current study found that students who did possess the ability to imagine an object from a different point of view and the ability to imagine the rotation of the object in space produced acceptable 3D answers. The finding that students who have the spatial abilities to mentally rotate and imagine objects from different viewpoints necessitated the inclusion of spatial activities in this study's proposed 2D to 3D learning model. Furthermore, this study showed evidence that students used sketching during the visualisation process but, more importantly students who did use sketching as a tool to externalise their internal thoughts produced significantly better results than the students who did not use sketching effectively. Additionally, this study advanced the suggestion that sketching was an important tool to manage and supplement the short-term memory because during the visualisation of complex multifaceted objects, thought processes fluctuated from an initial image to one where features are added or removed, where parts are positioned and located in 3D space and where objects are rotated or viewed from a different viewpoint. Sketching thus kept track of all the changes students made during the visualisation process and was therefore included as a vital component in this study's proposed model for 2D to 3D drawing.

7.4 PRACTICAL IMPLICATIONS

The results of this study suggested that prior spatial experience did not significantly contribute to rural–university students' spatial visualisation skills. However, the construct of completing a mathematics module had a significant impact on the model of spatial visualisation. Although this study did not delve deeper into the construct of mathematics, it could be suggested that interventional programmes for struggling students should include aspects of geometry that is, figures and shapes and descriptive geometry.

The current study recommends that rural–schools and rural–universities which offer subjects or courses in STEM (Science, Technology, Engineering and Mathematics) should include spatial visualisation activities and exercises in their instructional material. The conventional reliance on procedural strategies for producing isometric drawings from orthographic projections must be augmented with spatial visualisation exercises such as translations, rotations, alternative views, folding and unfolding and mental cutting. Recommendations for authors who develop instructional material for engineering graphics and design programmes are to add colour in the graphics and to add activities and exercises where learners can practice their skills of locating and positioning objects within 3D space.

The study also highlighted a shortcoming when assessing non-academic-type prior spatial experience. Prior spatial experience, which a person accumulates over a lifetime, is by nature reported as a retrospective measure. Future work should therefore develop alternate constructs for measuring non-academic-type prior spatial experience in line with Piaget’s perception and imagery theory. A person may have forgotten what type of activities s/he was involved in during the crucial sensori-motor and preoperational stages of mental imagery development.

The following recommendations are offered to graphics design instructors and researchers:

- Prior spatial experience activities which could enhance spatial visualisation skills should be included in graphics design courses. These prior spatial experiences include sketching and descriptive geometry.
- As far as offering graphics design courses at a rural–university it is not necessary to make a clear distinction between the spatial visualisation instructional material offered to females and males.
- 3D solid computer modelling software such as SketchUp could be used effectively in a graphics design module to improve spatial visualisation skills of students. Again, both females and males could enhance their spatial visualisation skills using the same 3D solid computer modelling activities.

- Before attempting to employ 3D solid computer modelling software such as SketchUp, students must first develop the necessary computer skills such as, using the different functions of the mouse and learning the different drawing tools.
- 3D solid computer modelling software should be used during the initial stages of spatial reasoning where students can manipulate 3D models to view objects from different positions.
- In the current study, the use of 3D solid computer modelling software was only used for a period of four weeks however, it should be used in other content areas where spatial visualisation skills are vital such as mechanical drawing, sectioning, solid geometry, and intersection of solids.
- 3D solid computer modelling software should not replace the foundational methods used in graphics design courses. Students should still learn the fundamental rules and conventions of drawing.
- Students should understand the fundamentals of orthographic and isometric projection which 3D solid computer modelling software cannot teach them.
- Sketching activities combined with physical concrete models and 3D solid computer modelling software would provide the best results to improve students' spatial visualisation skills. However, with limitations of workshop space, materials and tools to make physical models, 3D solid computer modelling is a viable option.
- The nature of the 3D solid computer modelling software, such as SketchUp, by building 3D models with the "push/pull" tool would lead to the reinforcement of using the "crating method" when sketching or drawing 3D objects. The "crating method" starts with the base of an object and is then expanded vertically upwards to form the shape, much like constructing a house. This is a more realistic method for producing 3D objects through sketching and drawing.

7.5 LIMITATIONS

The research was conducted at a rural–university where the majority of students enter the university with poor computer and academic literacy skills. Although students in the current study did complete a prior computer literacy module in their first semester of study, some students found it challenging to learn the basics of the SketchUp 3D solid computer modelling software which was used as the intervention for this study. The challenges which students faced with learning the 3D solid computer modelling software were mostly related to the use of the mouse for example, to navigate by orbit and pan functions where the keyboard's controls are used in synchronise with the mouse's buttons. Since the purpose of the 3D solid computer modelling intervention was to improve students' spatial visualisation skills it would be considered fundamental that they know how to use the software efficiently. Therefore, more time must be allotted for students to become familiar with the computer programme before they attempt the activities which are designed to develop spatial visualisation skills.

Moreover, this study did not find a positive relation between students' spatial visualisation skills and playing traditional games as determined by the spatial experience questionnaire (SEQ). Playing traditional games was one overarching construct on the SEQ. However, the SEQ did not delve deeper into the specifics of the individual traditional games with spatial visualisation attributes which constitute this construct. Therefore, the SEQ, which was the instrument for collecting prior spatial experience data, was limited to the overarching construct of "traditional games" and not specific to the individual traditional games. Hence, the SEQ could include a list of traditional games which has a spatial visualisation impact.

7.6 FUTURE RESEARCH

There are very little qualitative STEM studies which explore the mental processes that students engage in when constructing and presenting 3D images in isometric projection from the 2D views in orthographic projection. Future research should focus on how students in STEM subjects apply their cognitive processes during visualisation activities.

It is also recommended that future research focusses more on specific constructs within broader academic-type activities such as the sub-topics within mathematics content. This could highlight with more accuracy which sub-topics have a more significant impact on students’ spatial visualisation skills.

In addition, to determine the impact of spatial visualisation skills on engineering graphics and design content, future work should focus on specific sub-topics within engineering graphics design content. This could provide better insight into how remedial graphics design programmes should be developed to improve spatial visualisation skills.

Furthermore, future research should be conducted to establish if spatial visualisation skills are retained after the completion of a graphics design course. Additionally, future research should investigate the specific traditional spatial–orientated games and activities which learners partake in and the relation of these games to spatial visualisation skills. The possible impact of playing specific traditional games on spatial visualisation skills could be used as strategy to enrich and complement a classroom environment.

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Appendix 1: Candidate's originality declaration

ORIGINALITY DECLARATION

Full Names and Surname	Kok, Petrus Jacobus
Student Number	20045438
Title of dissertation/thesis	Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University

I acknowledge that I have read and understood the University's policies and rules applicable to postgraduate research, and I certify that I have, to the best of my knowledge and belief, complied with their requirements.

In particular, I confirm that I had obtained an ethical clearance certificate for my research (Certificate Number UZREC 171110-030 PGD 2017/192) and that I have complied with the conditions set out in that certificate.

I further certify that this thesis is original, and that the material has not been published elsewhere, or submitted, either in whole or in part, for a degree at this or any other university, except as follows:

a. A paper titled; Evaluating Spatial Visualisation via 3D solid computer modelling: Application in a First Year Graphics Design Module, based on research question 3 of the current thesis, has been submitted for review with the African Journal of Research in Mathematics, Science and Technology Education. The part constitutes 25% of the current thesis. This paper evaluated graphics design students' spatial visualisation skills before and after a 3D solid computer modelling intervention programme.

I declare that this thesis is, save for the supervisory guidance received, the product of my own work and effort. I have, to the best of my knowledge and belief, complied with the University's Plagiarism Policy and acknowledged all sources of information in line with normal academic conventions.

I have/have not subjected the document to the University’s text-matching and/or similarity-checking procedures. (*One could indicate that this process applied only to some chapters or that it occurred during the course of the research and not in respect of the final product.*)

Candidate’s signature	
Date	7 December 2018

Appendix 2 : Supervisor's consent, with HOD and Dean's endorsements

CONSENT TO SUBMIT A MANUSCRIPT FOR EXAMINATION

(To be completed separately by supervisors and co-supervisors)

I hereby confirm that the manuscript of the following candidate has been submitted for examination

- With my consent
- Without my consent, for the reasons indicated in the attached document
  (D*elete that which is not applicable, and attach document if the second option is selected*)

My consent implies that I believe that

- The candidate has complied with institutional policies, in particular the Research Ethics Policy, and the conditions, if any, specified by the University's Research Ethics Committee
- The manuscript meets the required standards and is ready for assessment

My consent does not imply or guarantee that the examiners will hold a similar view and that the examination process will be successful.

Full Names and Surname	Petrus Jacobus Kok
Student Number	20045438
Degree	Doctor in Education
Name of Supervisor	Professor Anass Bayaga
Supervisor e-mail address	bayagaa@unizulu.ac.za
Name of Co-supervisor	
Co-supervisor e-mail address	
Title of thesis	Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University
Supervisor's signature	
Date	

HEAD OF DEPARTMENT AND DEAN'S ENDORSEMENT

To the best of my knowledge, the University Rules and the procedures stipulated in the Postgraduate Assessment Guide have been adhered to in respect of the above-mentioned candidate.

Name of HoD/Dean	**Department/Faculty**	**Signature**	**Date**
HOD: Dr B.G. Ndawonde	MSTE		
Dean: Prof M.C. Maphalala	Education		

D

Appendix 3: Permission to conduct research

University of Zululand
PO Box X1001
KwaDlangezwa
3886

The Dean
Faculty of Education
University of Zululand

Date: 21 August 2017

Dear Professor Maphalala

REQUEST FOR PERMISSION TO CONDUCT RESEARCH

I am a registered Doctoral student in the Department of Mathematics, Science and Technology Education (MSTE) at the University of Zululand. My supervisor is Professor A. Bayaga.

The proposed topic of my research is: **Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University**

The objectives of the study are to:

- evaluate the students' level of prior spatial experience (PSE) and the impact thereof on spatial visualisation skills.
- determine to what extent relation(s) exist/s amongst the factors of PSE, gender and prior learning of a Technology school subject/s (for example EGD, Civil, Mechanical or Electrical Technology) and their spatial visualisation ability.
- examine if the application of 3D solid computer modelling software offsets any differences in low spatial visualisation skills.
- analyse the cognitive styles in terms of 3D drawings from 2D cognition.

I am hereby seeking your consent to conduct research in the MSTE department at the university. The participants will be year level one students enrolled for a graphics design course in semester 2. To assist you in reaching a decision, I have attached to this letter:

(a) A copy of an ethical clearance certificate issued by the University
(b) A copy of the research instruments which I intend using in my research

Should you require any further information, please do not hesitate to contact me or my supervisor. Our contact details are as follows:

- Candidate - Mr. PJ Kok 035 9026242 kokp@unizulu.ac.za
- Supervisor – Prof A Bayaga 035 9026809 bayagaa@unizulu.ac.za

Upon completion of the study, I undertake to provide you with a bound copy of the dissertation.

Your permission to conduct this study will be greatly appreciated.

Yours sincerely,

Kok.

Mr. PJ Kok

Annexure A: Questionnaire – Biographical information

UNIVERSITY OF ZULULAND

Research Title: Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University

NOTE: This research instrument will be answered online. Participants will have to login using their own passwords to complete it. This is an example.

Purpose of the study: The purpose of this study is to investigate the relationship and impact of prior spatial experience, gender and cognition styles on students' spatial visualisation skills and the enhancement of these skills through the application of 3D solid computer modelling.

Dear Participant

There are four instruments in this study. The purpose of these instruments are to determine your biographical information, your spatial visualisation experiences, your spatial visualisation skills and your mental processes during 2D to 3D drawing. Please answer truthfully. The results are confidential and will only be used for this research. Please do not enter your name, surname or student number anywhere on any document.

Biographical information and school experience

Please answer all the questions by either entering text or selecting only one option.

1. What is your age? *Enter your age:* ____
2. What is your gender? *Select one:* Female ○ Male ○
3. Did you do any of the following subjects at school: EGD, Civil Technology, Mechanical Technology or Electrical Technology?

   Select one: No ○ Yes ○

Annexure B: Spatial Experience Questionnaire (SEQ)

Please indicate which of the following activities you have participated in regularly. It could have been at school or in everyday life.

1 Sketching	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
2 Measuring	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
3 Designing	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
4 Using computers	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
5 Building or making things	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
6 Reading a map	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
7 Playing chess	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
8 Cycling	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
9 Using tools	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
10 Driving a car	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
11 Playing sport	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
12 Dancing	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
13 Playing board games	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
14 Playing traditional games	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
15 Playing video games	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
16 Knitting	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
17 Repairing things	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
18 Lego or building blocks	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
19 Interior decorating	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○
20 Photography	1 Never ○	2 Occasionally ○	3 Often ○	4 Very Often ○

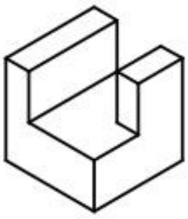
Annexure C: Purdue Spatial Visualisation Test

Roland B. Guay

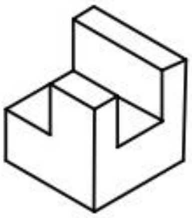
A: VISUALISATION OF ROTATIONS

Directions: This instrument is designed to measure how well you can visualise the rotation of three-dimensional objects. There are 20 questions in this section. Shown below is an example of the type of question. You are to:

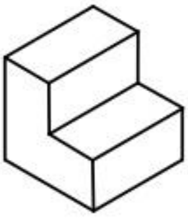
1. Study how the object in the top line of the question is rotated;
2. Picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner;
3. Select from among the five drawings (A, B, C, D or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.



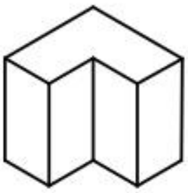
IS ROTATED TO



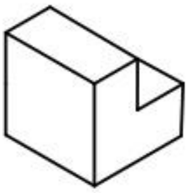
AS



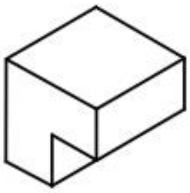
IS ROTATED TO



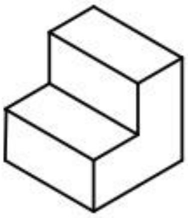
A



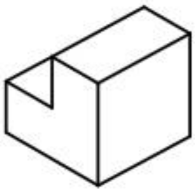
B



C



D



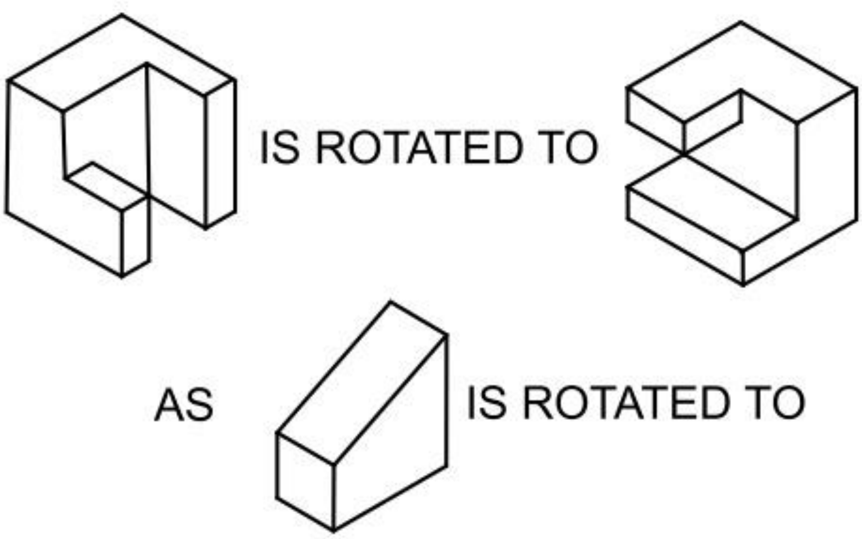
E

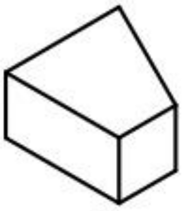
What is the correct answer to the example shown above?

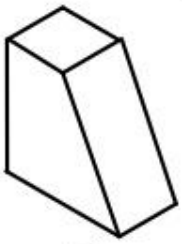
Answers A, B, C, and E are wrong. Only drawing D looks like the object rotated according to the given rotation.

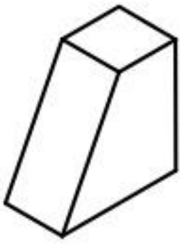
Remember that each question has only one correct answer.

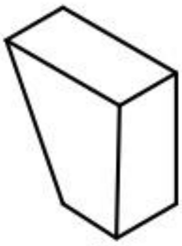
Now look at the next example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied.

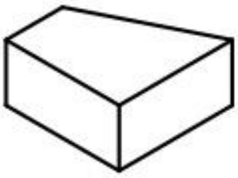



A


B


C


D


E

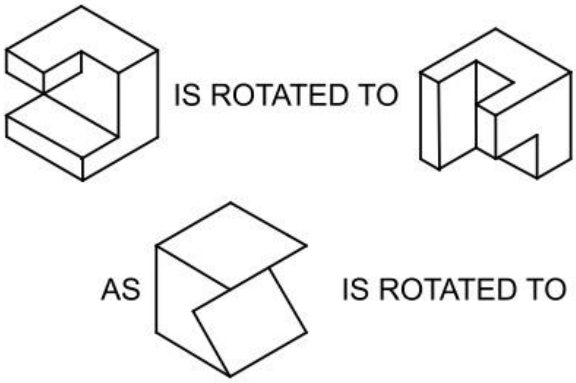
Notice that the given rotation in this example is more complex.

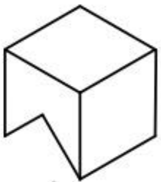
The correct answer for this example is B.

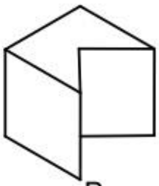
To proceed with the test, click on **Attempt Quiz now**.

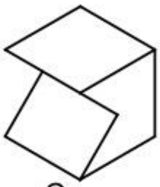
You have 20 minutes.

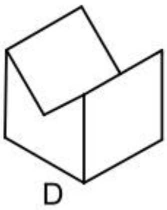
1

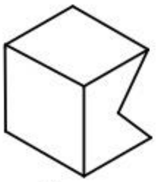



A


B

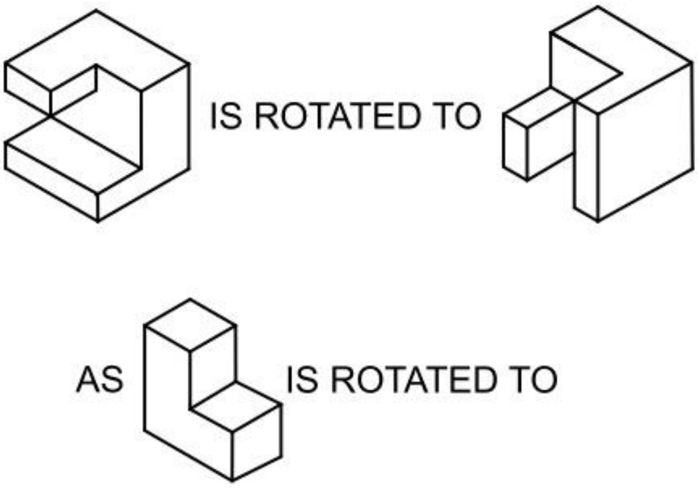

C

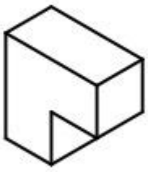

D

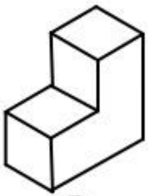

E

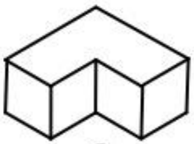
Select one: ○A ○B ○C ○D ○E

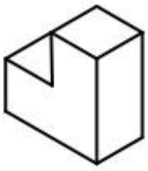
2

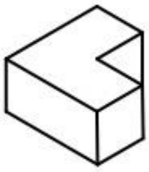



A


B

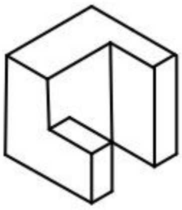

C


D

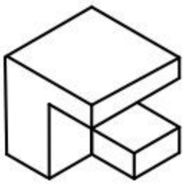

E

Select one: ○A ○B ○C ○D ○E

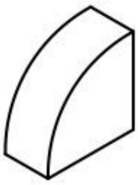
3



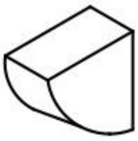
IS ROTATED TO



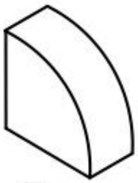
AS



IS ROTATED TO

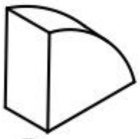


A

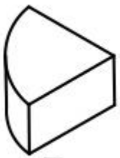


B

C



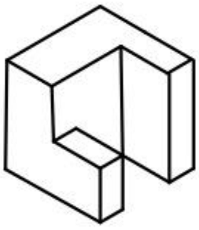
D



E

Select one: ○A ○B ○C ○D ○E

4



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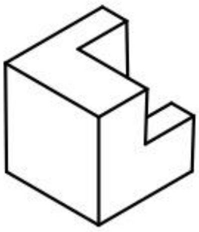
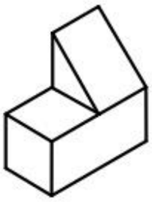


AS



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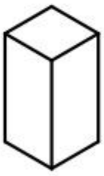
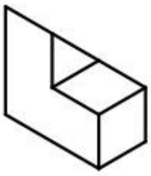


A



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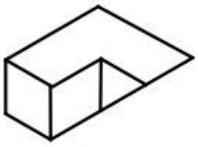

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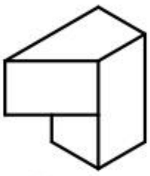
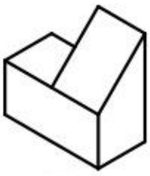


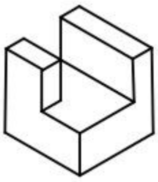
D



E

Select one: ○A ○B ○C ○D ○E

5



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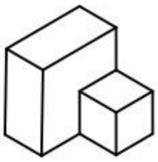

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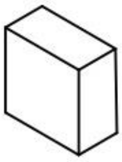
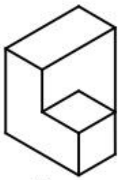


A



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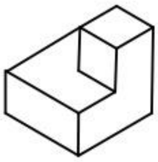

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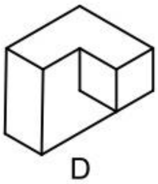

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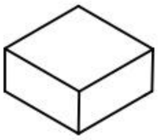
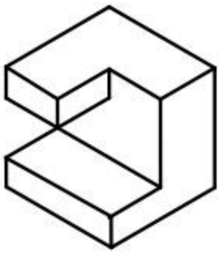


E

Select one: ○A ○B ○C ○D ○E

6



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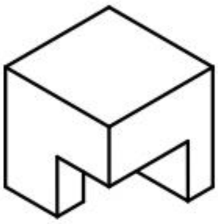

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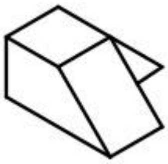
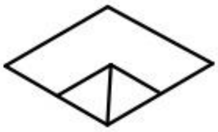
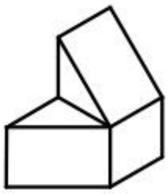


A

B



C

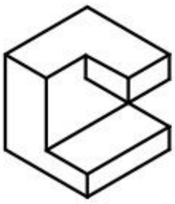


D

E

Select one: ○A ○B ○C ○D ○E

7



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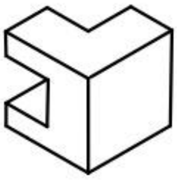

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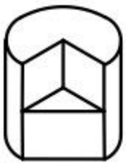
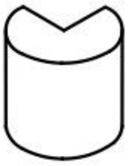


A

B

C

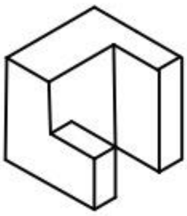


D

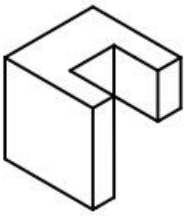
E

Select one: ○A ○B ○C ○D ○E

8



IS ROTATED TO



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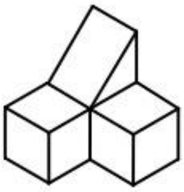

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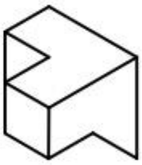
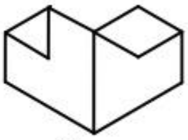


A

B



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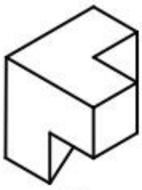
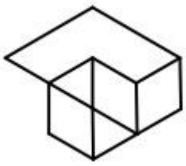


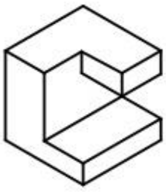
D



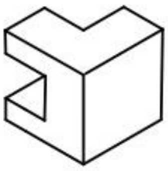
E

Select one: ○A ○B ○C ○D ○E

9



IS ROTATED TO



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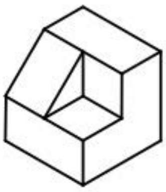

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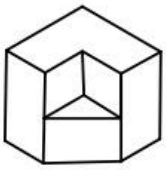
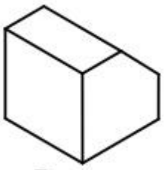
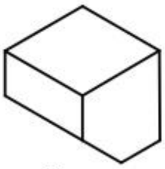


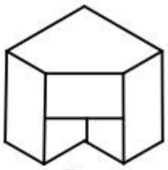
A



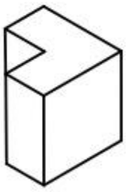
B



C



D

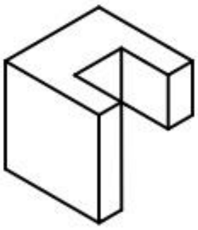


E

Select one: ○A ○B ○C ○D ○E

10

IS ROTATED TO



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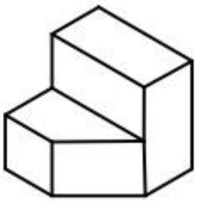
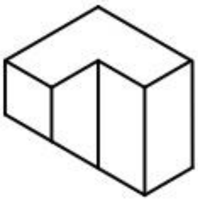
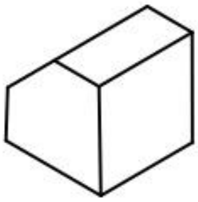


IS ROTATED TO



A



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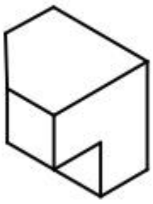

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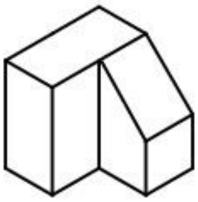

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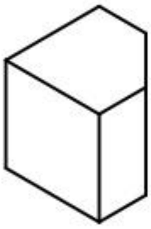
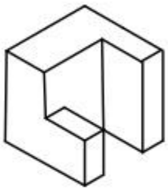


E

Select one: ○A ○B ○C ○D ○E

11



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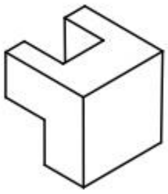

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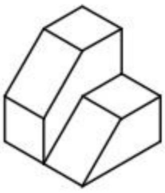

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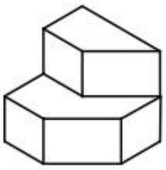

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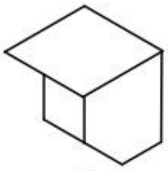

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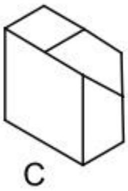

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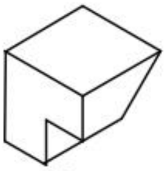

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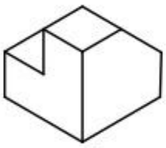

E

Select one: ○A ○B ○C ○D ○E

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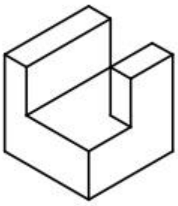

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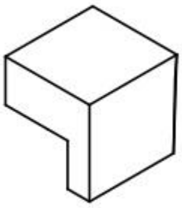

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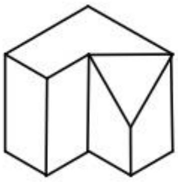

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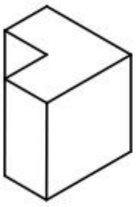

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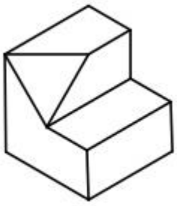

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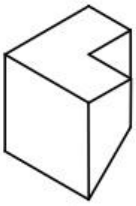

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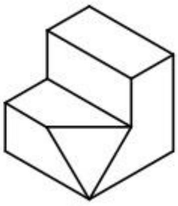

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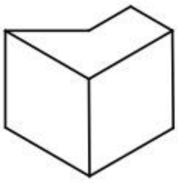

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Select one: ○A ○B ○C ○D ○E

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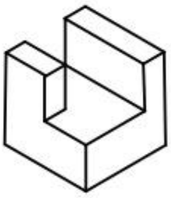

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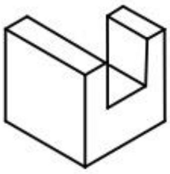

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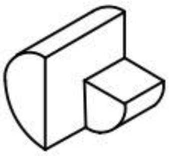

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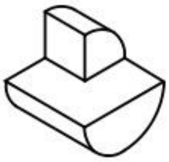

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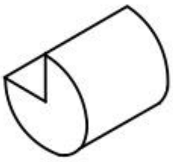

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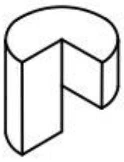

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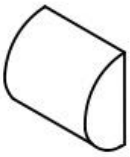

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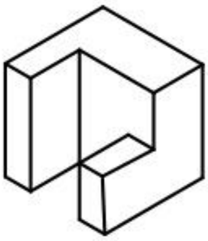

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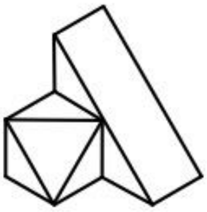

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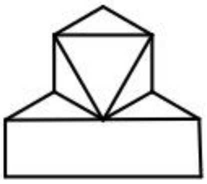

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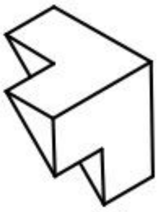

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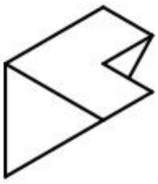

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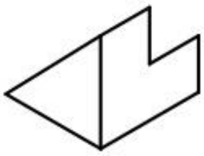

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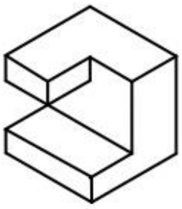

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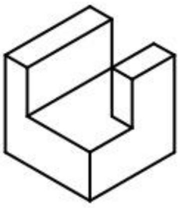

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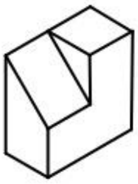

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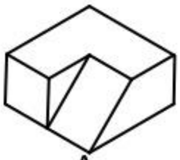

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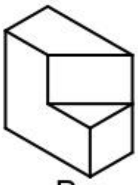

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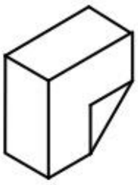

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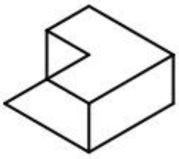

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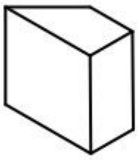

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Select one: ○A ○B ○C ○D ○E

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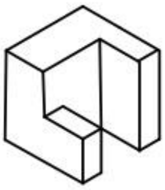

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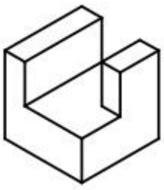

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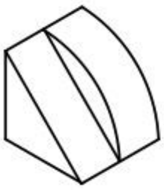

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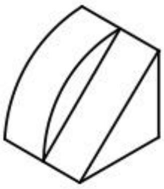

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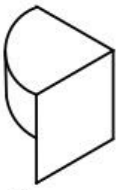

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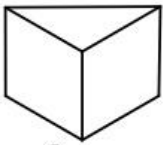

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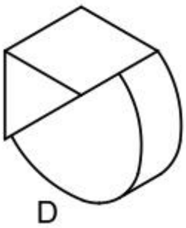

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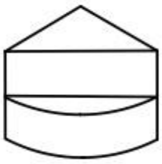

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Select one: ○A ○B ○C ○D ○E

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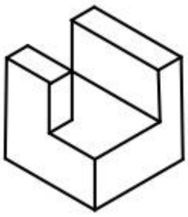

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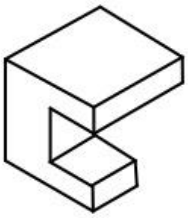

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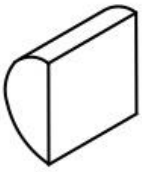

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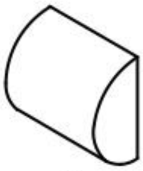

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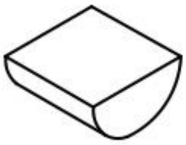

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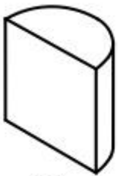

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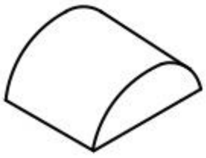

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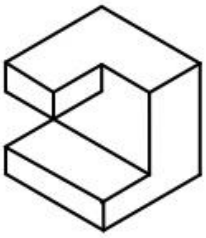

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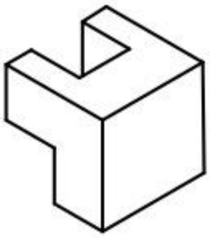

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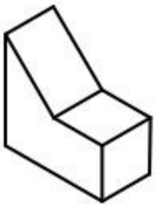

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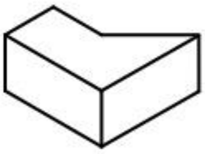

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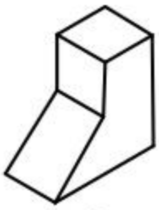

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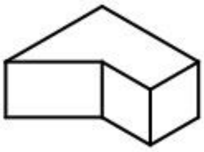

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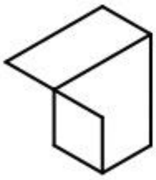

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Select one: ○A ○B ○C ○D ○E

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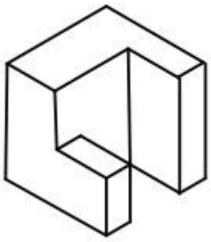

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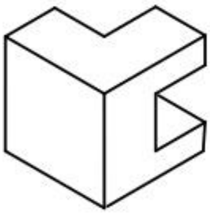

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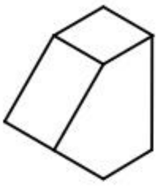

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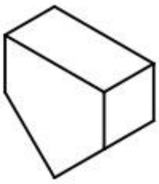

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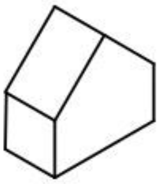

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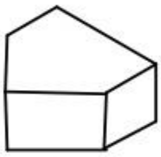

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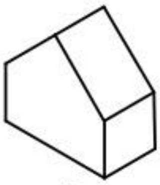

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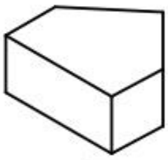

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Select one: ○A ○B ○C ○D ○E

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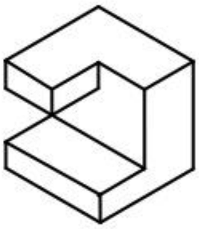

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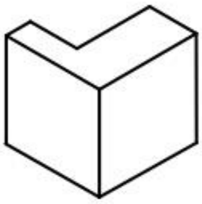

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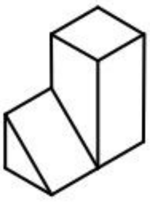

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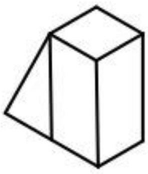

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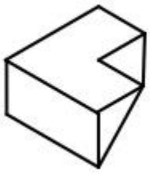

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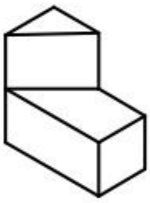

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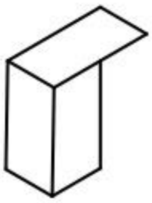

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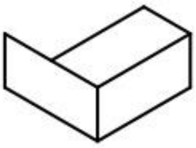


E

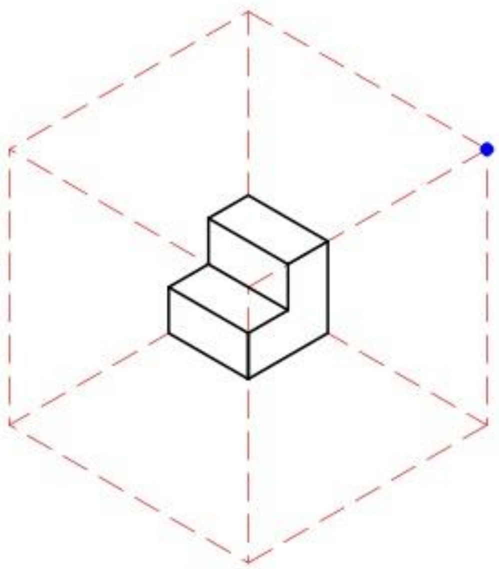
Select one: ○A ○B ○C ○D ○E

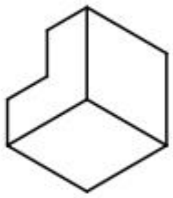
B: VISUALISATION BY ISOMETRIC VIEWS

This instrument wants to know how well you can visualise what three-dimensional objects look like from various viewing positions. There are 10 questions in this section. Shown below is an example of the type of question included in this section.

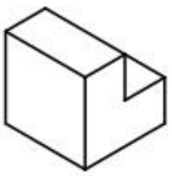
Directions: The example shows an object positioned in the middle of a "glass box" and five drawings representing what the same object looks like when seen from different viewing positions. The dot in the top right corner of the 'glass box' identifies the desired position for this example. You are to:

1. Imagine yourself moving around the 'glass box" until the dot is located directly between you and the object.
2. From this viewing position picture in your mind what the object in the "glass box" looks like.
3. Select from among the five drawings (A, B, C, D or E) the one that looks like the object as seen from the viewing position.





A



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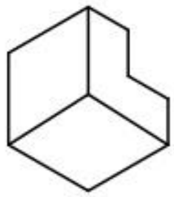
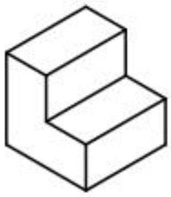


C



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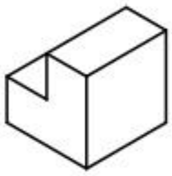


E

What is the correct answer to this example shown here?

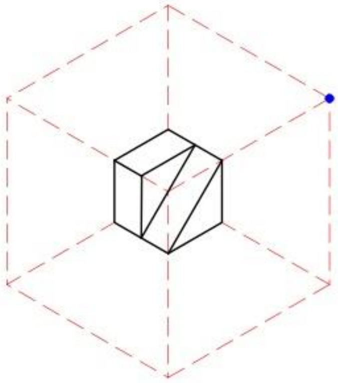
Answers A, B, C and D are wrong. Only E looks like the object as seen from the given viewing position.

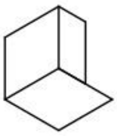
Remember that each question has only one correct answer.

To proceed click on: Attempt Quiz now.

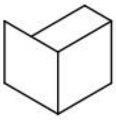
You have 10 minutes.

1



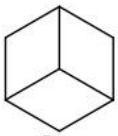


A



B

C



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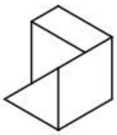
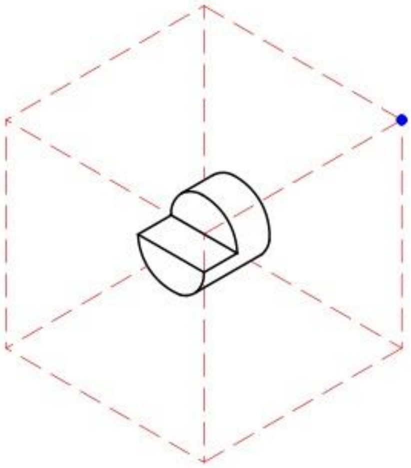


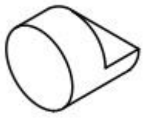
E

Select one: ○A ○B ○C ○D ○E

2

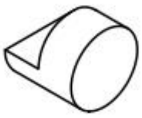


A



B

C

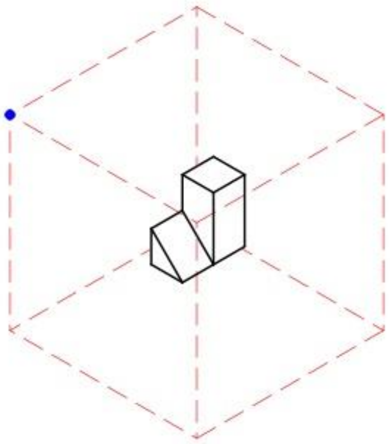


D

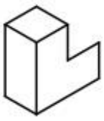
E

Select one: ○A ○B ○C ○D ○E

3



A



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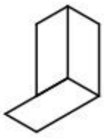
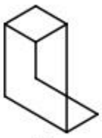


C

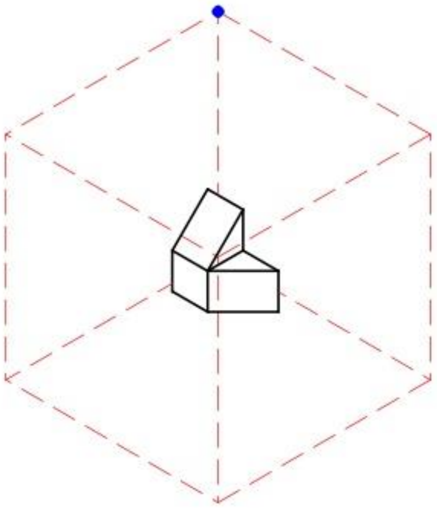
D



E

Select one: ○A ○B ○C ○D ○E

4



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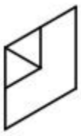

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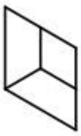

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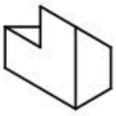

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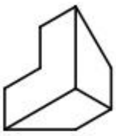
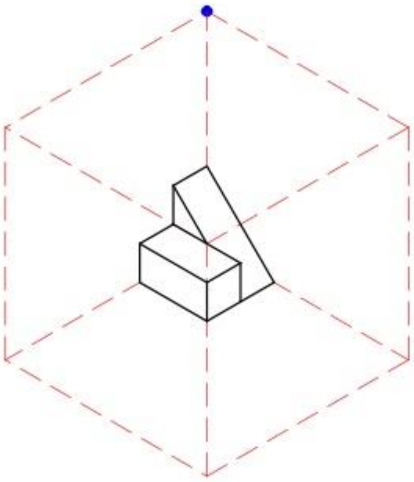
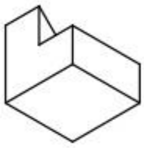


E

Select one: ○A ○B ○C ○D ○E

5

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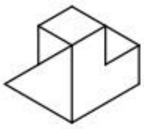
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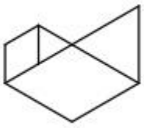
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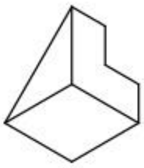
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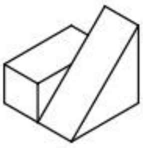
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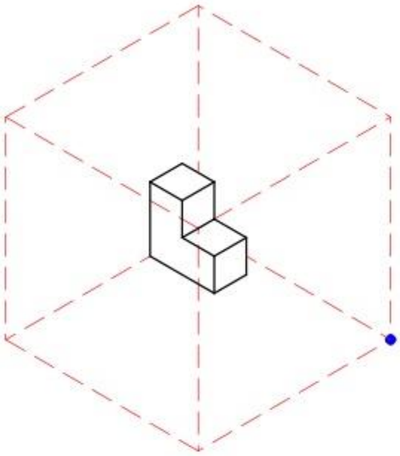
6

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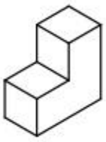
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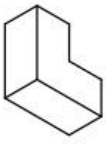
C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E

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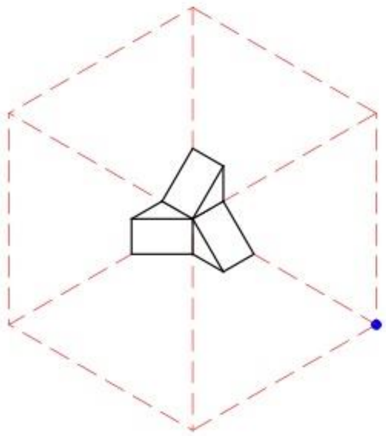


A


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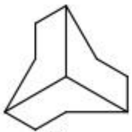
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E

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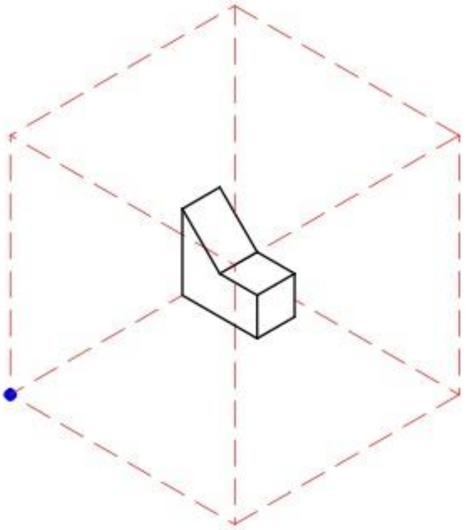

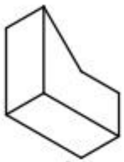
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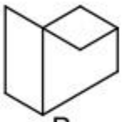
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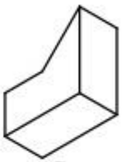
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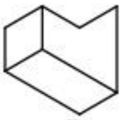
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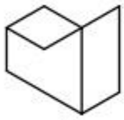
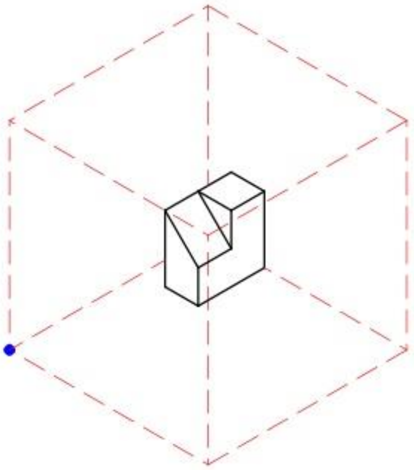
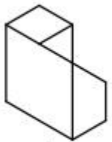

E

Select one: ○A ○B ○C ○D ○E

t

9

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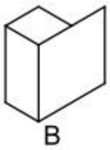
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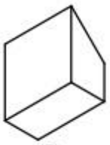
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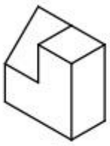
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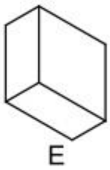
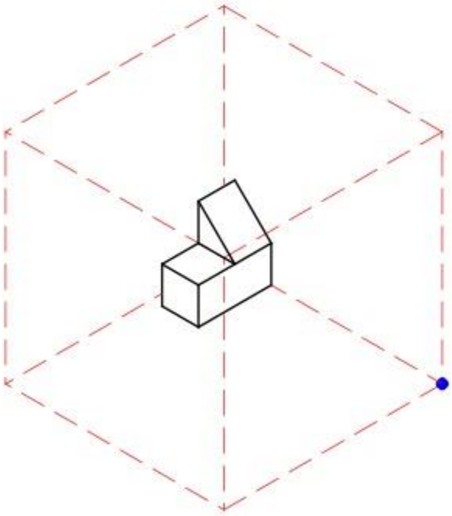

E

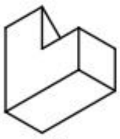
Select one: ○A ○B ○C ○D ○E

10




A


B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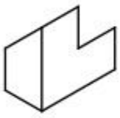
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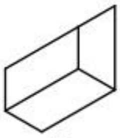

E

Select one: ○A ○B ○C ○D ○E

Annexure D: Interview schedule

UNIVERSITY OF ZULULAND

INTERVIEW SCHEDULE: SEMI-STRUCTURED

Research Title: Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University

Purpose of the study: The purpose of this study is to investigate the relationship and impact of prior spatial experience, gender and cognition styles on students' spatial visualisation skills and the enhancement of these skills through the application of 3D solid computer modelling.

Research Question

What are the mental processes students engage in, when constructing meaning from 2D views to produce 3D representations?

1. Figure 1 shows three views of an object and the 3D representation of the object in isometric. Similar to the given example refer to the three orthographic views and draw a 3D representation of the object on the Isometric grid. As you are drawing I want you to think allowed and tell me how you go about to visualise the object. I will also be asking you questions as you proceed.

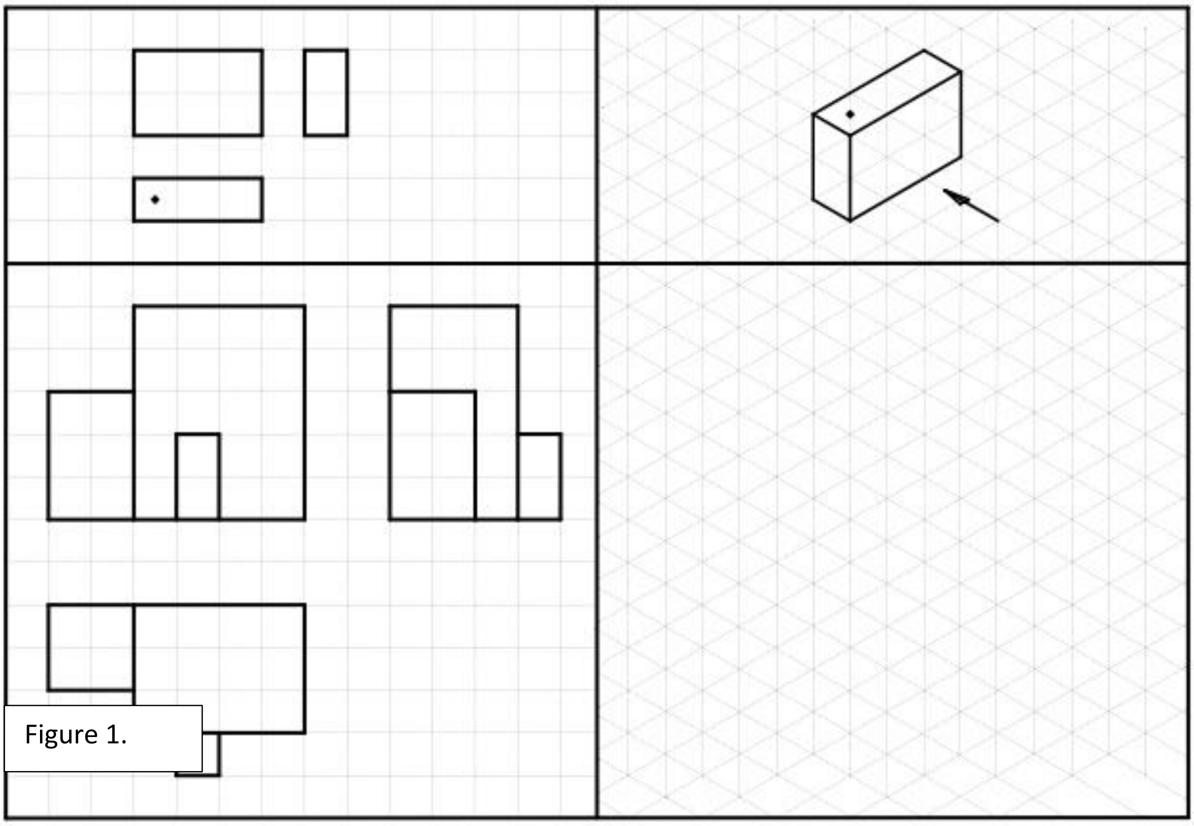


Figure 1.

Semi-Structured Interview Schedule

2. Questions are based on the conceptual framework for 2D to 3D drawing. **Encode** information from the 3 different views
- **Integrate** the information with existing knowledge
- **Construct** a 3D mental representation of the object either/or combined, (1) bottom-up process – individual components are visualised, (2) top-down process – the complete object is visualised.

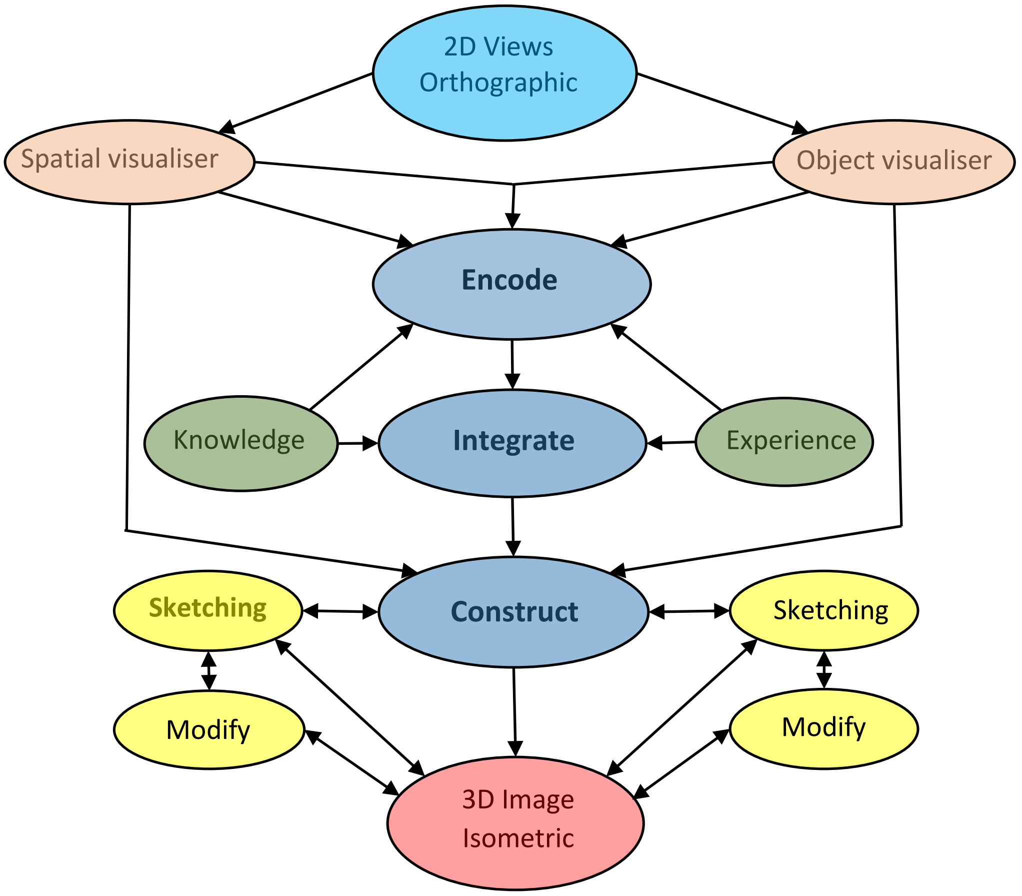
Semi-Structured Interview Questions *(Questions are not necessarily asked in this order)*

ENCODE	INTEGRATE	CONSTRUCT
1. What information do the 3 views show you?	1. What do you know about 3D drawing? 2. Can you relate the 3 views with what you know?	1. What mental image do you have of these 3 views? 2. Which view/s do you consider when

	3. Do you know a method/s of drawing 3D?	constructing the mental image? 3. Do you visualise the image in parts or as a complete object?

CASE		**ANSWERS**	**COMMENTS**
		Questions: Encoding information	
	1		
B		**Questions: Integrating information**	
	1		
	2		
	3		
C		**Questions: Constructing a 3D mental representation**	
	1		
	2		
	3		

Annexure E: Conceptual Framework for 2D to 3D Drawing



Annexure F: Informed Consent Form

PARTICIPANT INFORMED CONSENT DECLARATION

Project Title: **Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University**

Mr. PJ KOK from the Department of MSTE, University of Zululand has requested my permission to participate in the above-mentioned research project. The nature and the purpose of the research project, and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to determine whether or not the use of computer based solid modelling software will have an effect on students' success in spatial visualisation activities.

2. The University of Zululand has given ethical clearance to this research project and I have seen/ may request to see the clearance certificate.

3. By participating in this research project I will be contributing towards knowledge creation to be able to better visualise graphic design and improve spatial visualisation skills when designing with 3D solid computer modelling software.

4. I will participate in the project by completing an online spatial visualisation test (pre-test). I will be answering questions giving biographical data and my experiences in drawing. I will be attending 4 hours of classes where I will learn how to use a 3-Dimensional modelling computer programme to design objects. I will be completing a spatial visualisation post-test.

5. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.

6. I will not be compensated for participating in the research.

7. There may be risks associated with my participation in the project. I am aware that:

    a. the information I provide in the online tests will be treated confidentially; that the classes I attend will be for my own benefit and have no direct influence on my academic record.
    b. in order to complete the online tests, I have to login using a password only known by me.
    c. there is a 0 % chance of the risk materializing if my password is kept safe.

8. The researcher intends publishing the research results in the form of a research

paper. However, confidentiality and anonymity of records will be maintained and that my name and identity will not be revealed to anyone who has not been involved in the conduct of the research.

9. I will receive feedback in the form of an online report regarding the results obtained during the study and this information is only accessible by me using my login password.

10. Any further questions that I might have concerning the research or my participation will be answered by the researcher.

11. By signing this informed consent declaration, I am not waiving any legal claims, rights or remedies.

12. A copy of this informed consent declaration will be given to me, and the original will be kept on record.

I, ………………………………………………………………………….. have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of me during the research. I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

…………………………………. ………………………………….

Participant's signature **Date**

Annexure G: Permission to use PSVT

RESEARCH INSTRUMENT PERMISSION

Purdue Spatial Visualisation Test   (1976)

By: Roland B. Guay

Webcite: https://www.lib.purdue.edu/uco/ForResearchers/works.html

What exceptions apply?

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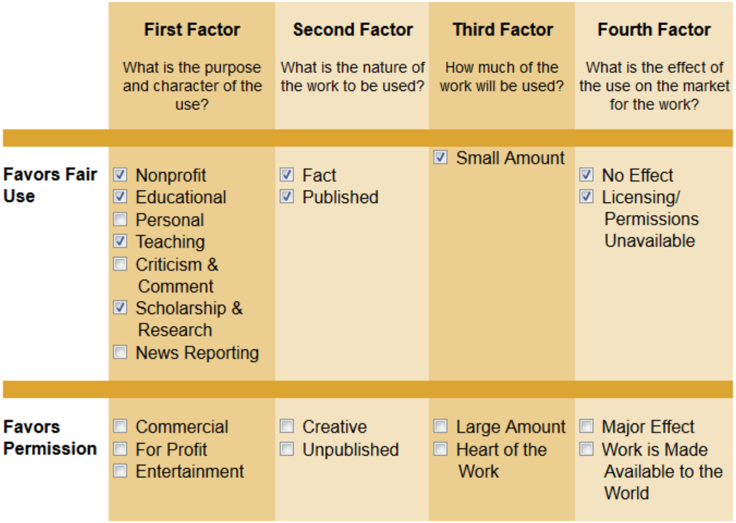


	First Factor What is the purpose and character of the use?	**Second Factor** What is the nature of the work to be used?	**Third Factor** How much of the work will be used?	**Fourth Factor** What is the effect of the use on the market for the work?
Favors Fair Use	☑ Nonprofit ☑ Educational ☐ Personal ☑ Teaching ☐ Criticism & Comment ☑ Scholarship & Research ☐ News Reporting	☑ Fact ☑ Published	☑ Small Amount	☑ No Effect ☑ Licensing/ Permissions Unavailable
Favors Permission	☐ Commercial ☐ For Profit ☐ Entertainment	☐ Creative ☐ Unpublished	☐ Large Amount ☐ Heart of the Work	☐ Major Effect ☐ Work is Made Available to the World

Fair use analysis May 2017 for Doctoral study with title:

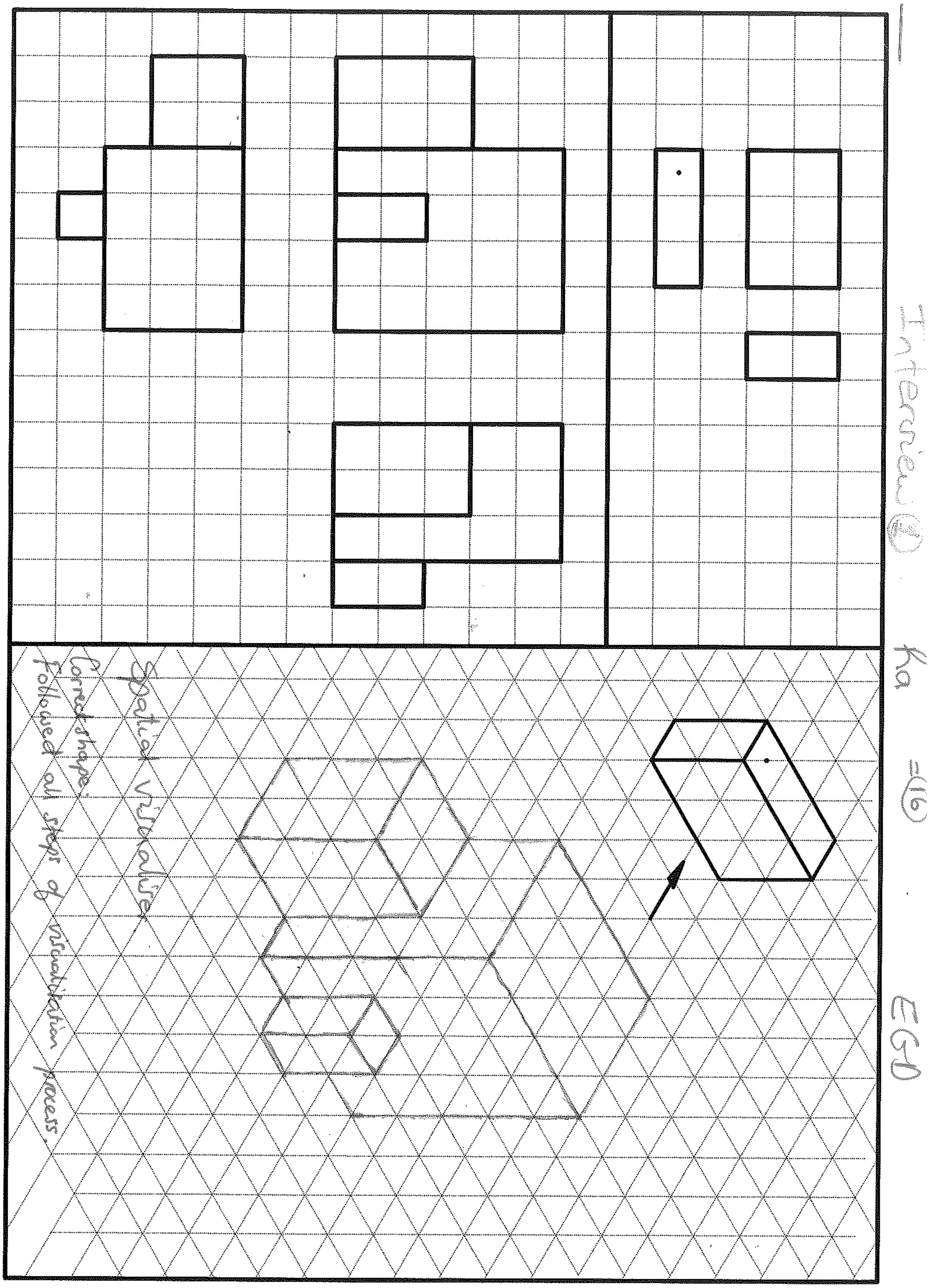
Effects of Prior Spatial Experience, Gender, 3D Solid Computer Modelling and Different Cognitive Styles on Spatial Visualisation Skills of Graphic Design Students at a Rural-Based South African University

If the balance weighs in favour of fair use, then the work can be used without permission. However, if the balance weighs against fair use and other exceptions do not apply, then permission must be obtained to use the work.

Researcher: Kok.   Date: 06/09/2017

Mr. PJ Kok

Annexure H: Students' answers on 2D to 3D drawing.



Spatial visualise.
Correct shape.
Followed all steps of visualisation process.

Interview ②

Ra =16

EGD

Figure i. Student Ra'

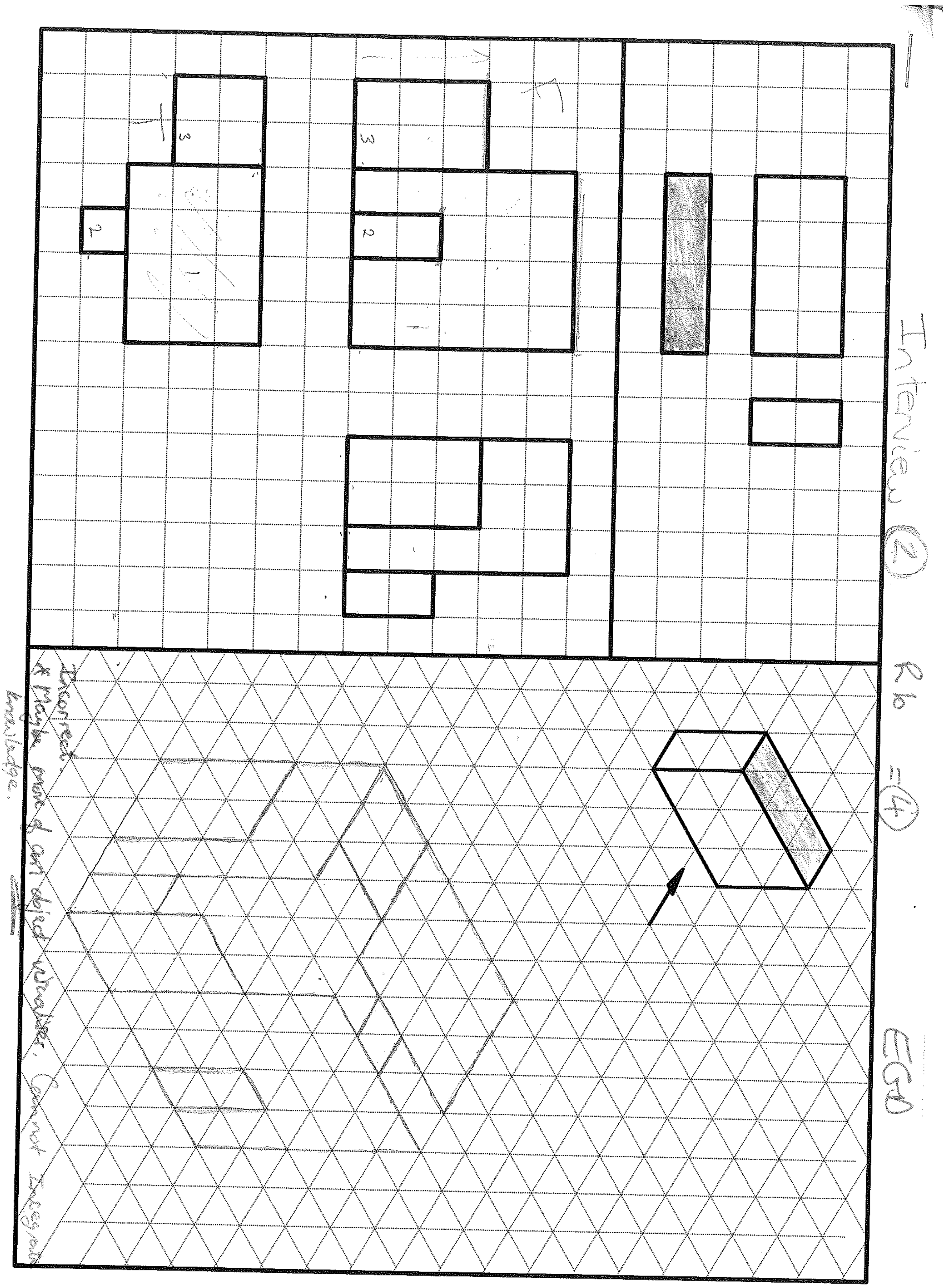
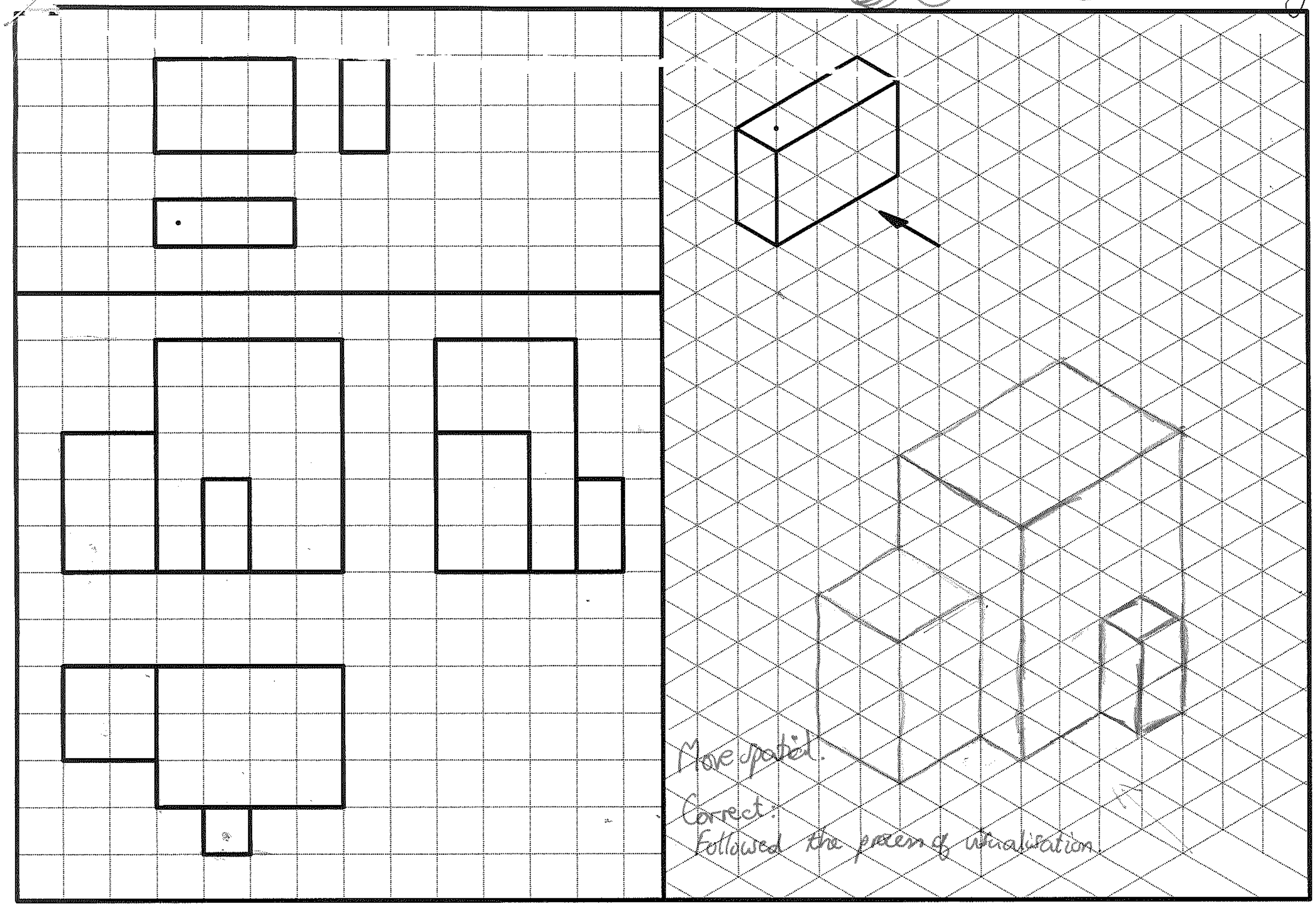


Figure ii. Student Rb' answer

Interview ③ Rc =⑤=⑩ EGD Fig iii



More spatial.

Correct.

Followed the process of visualisation.

Figure iii. Student Rc's answer

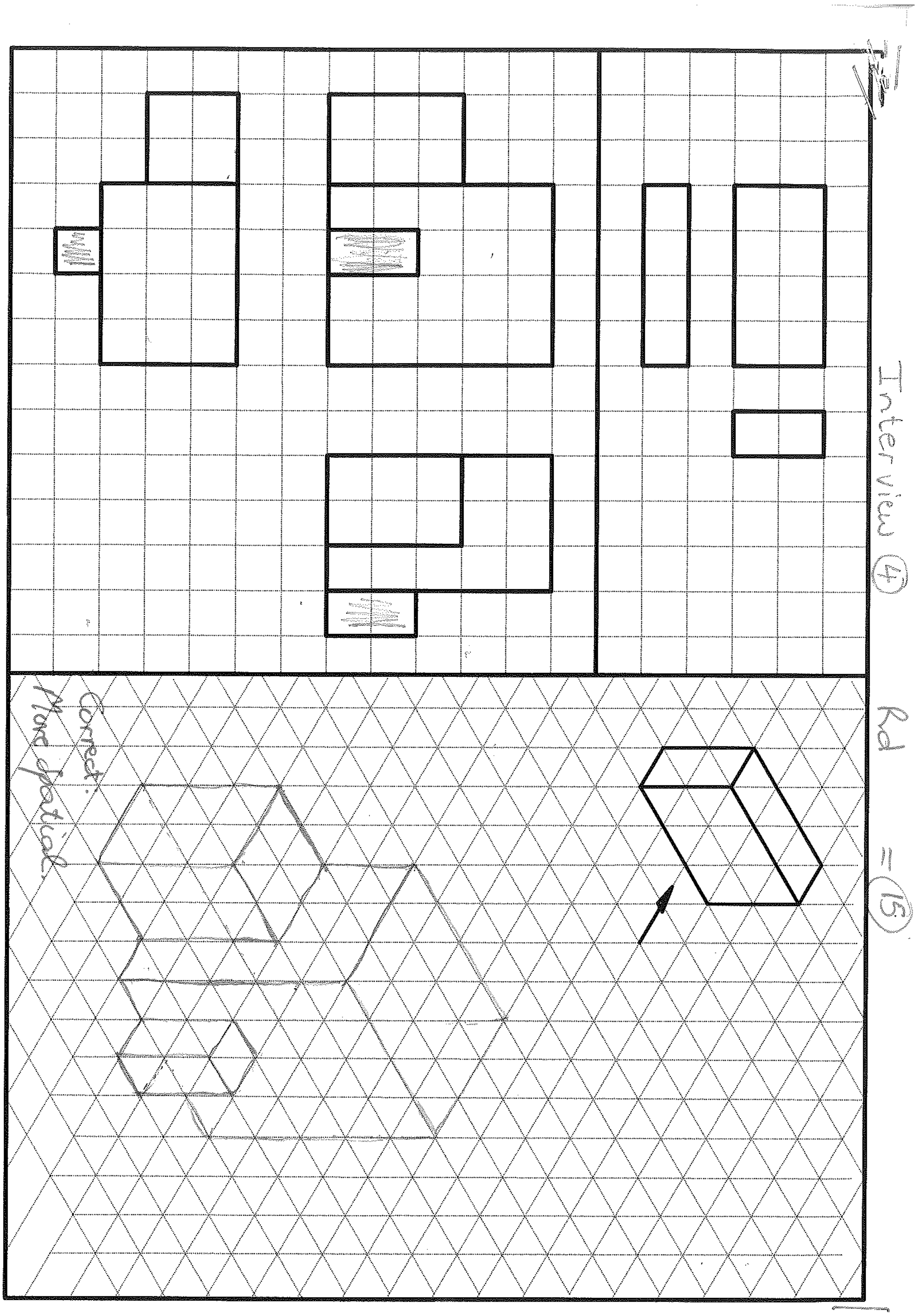


Figure iv. Student Rd's answer

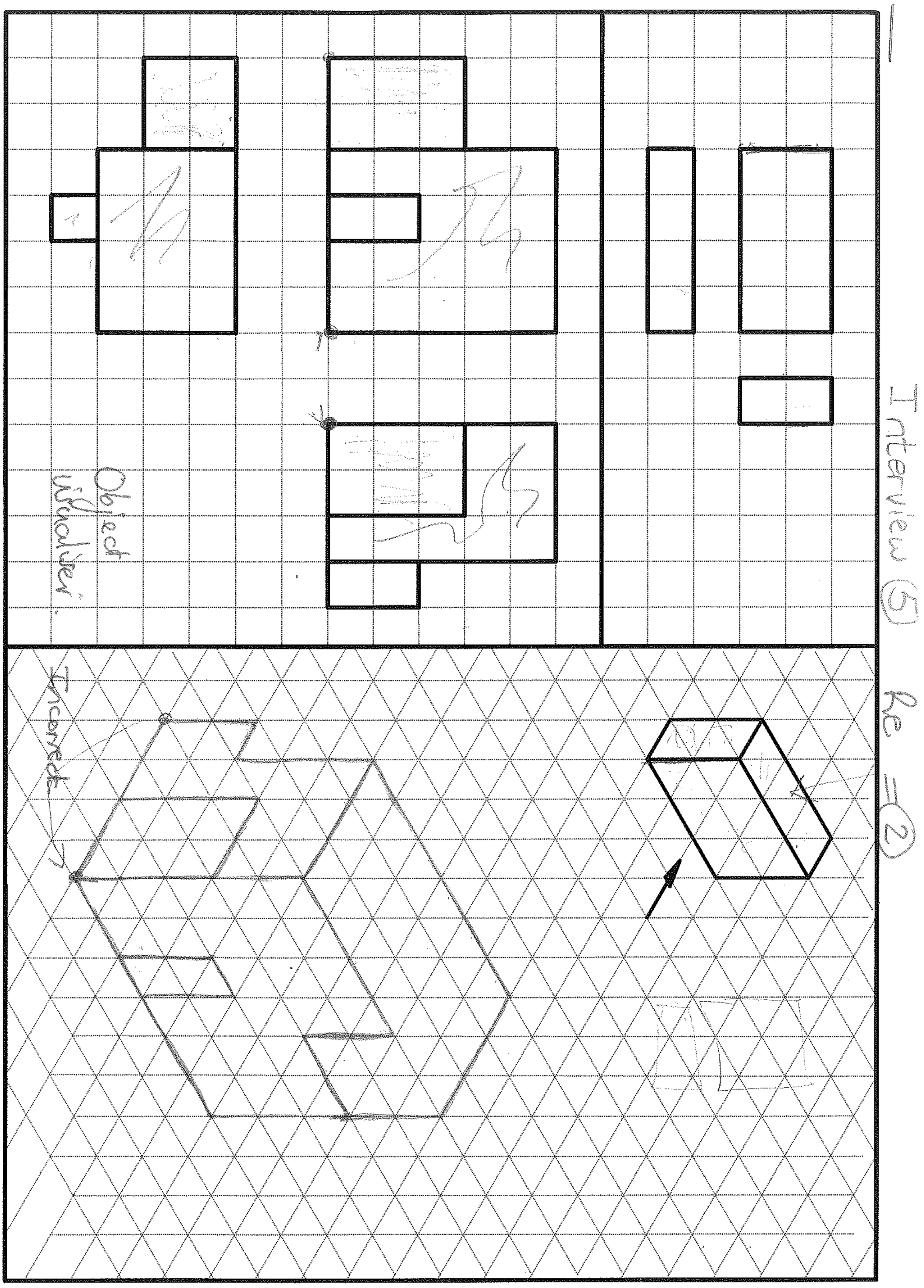


Figure v. Student Re’s answer

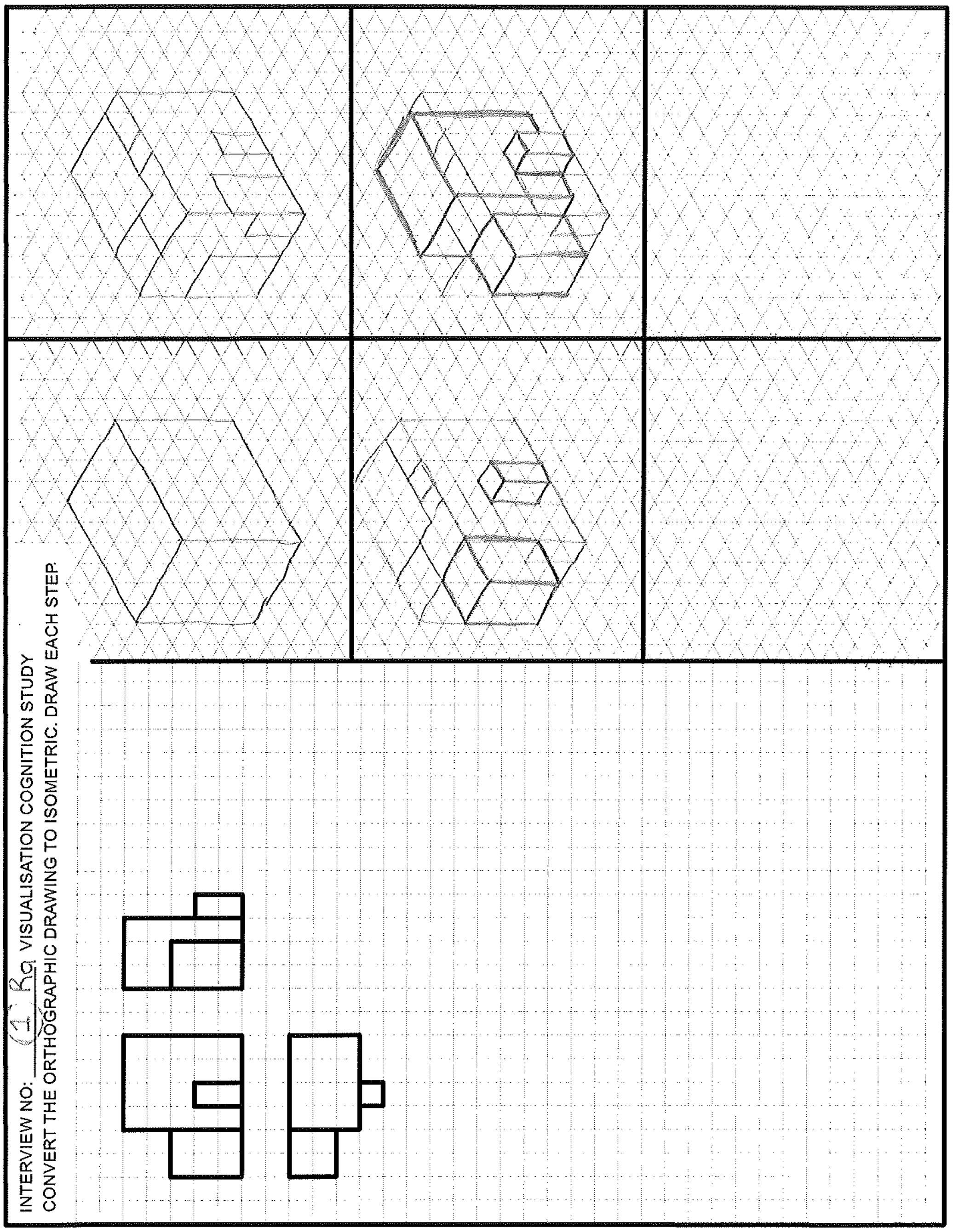


Figure vi. Student Ra’s sequence drawings

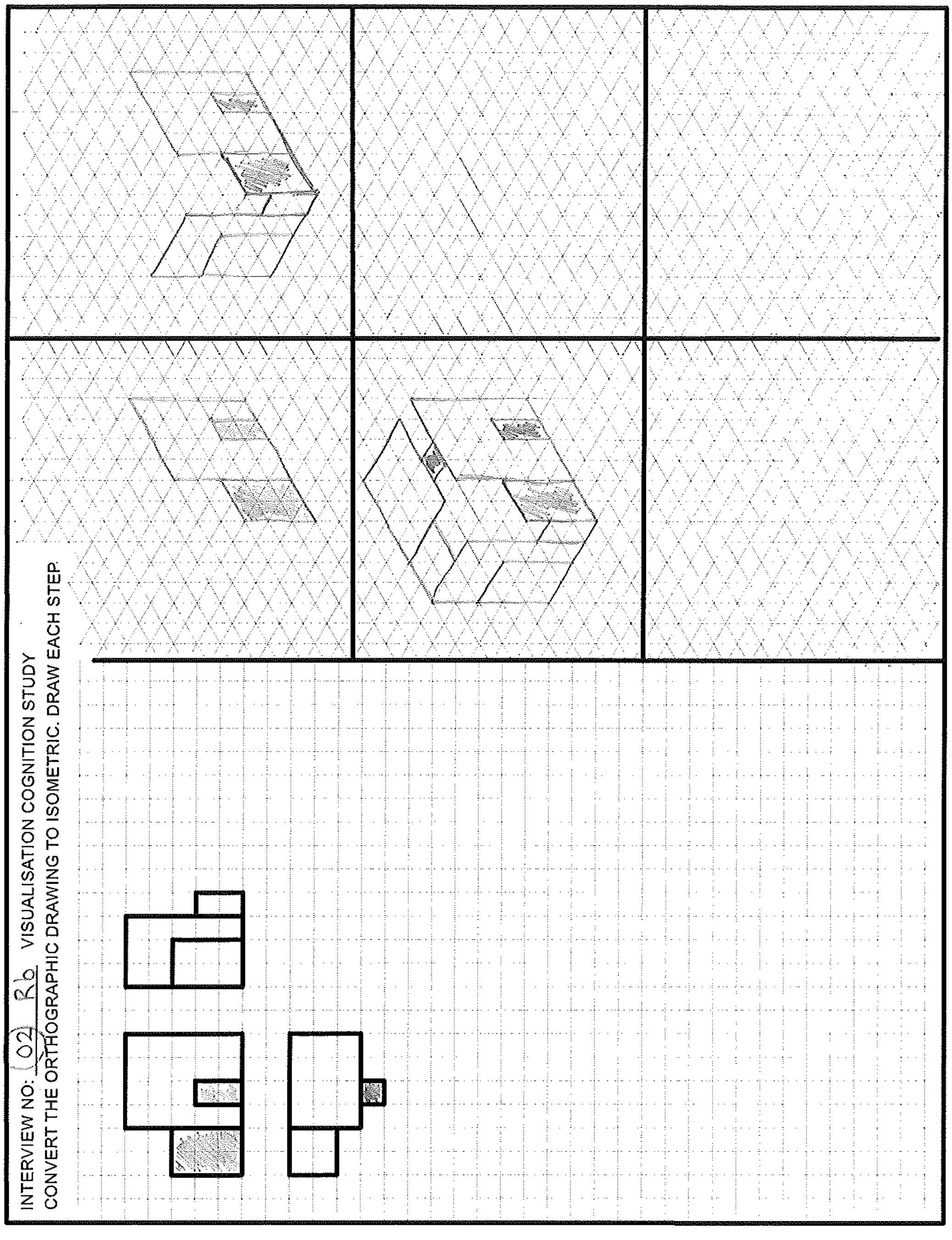
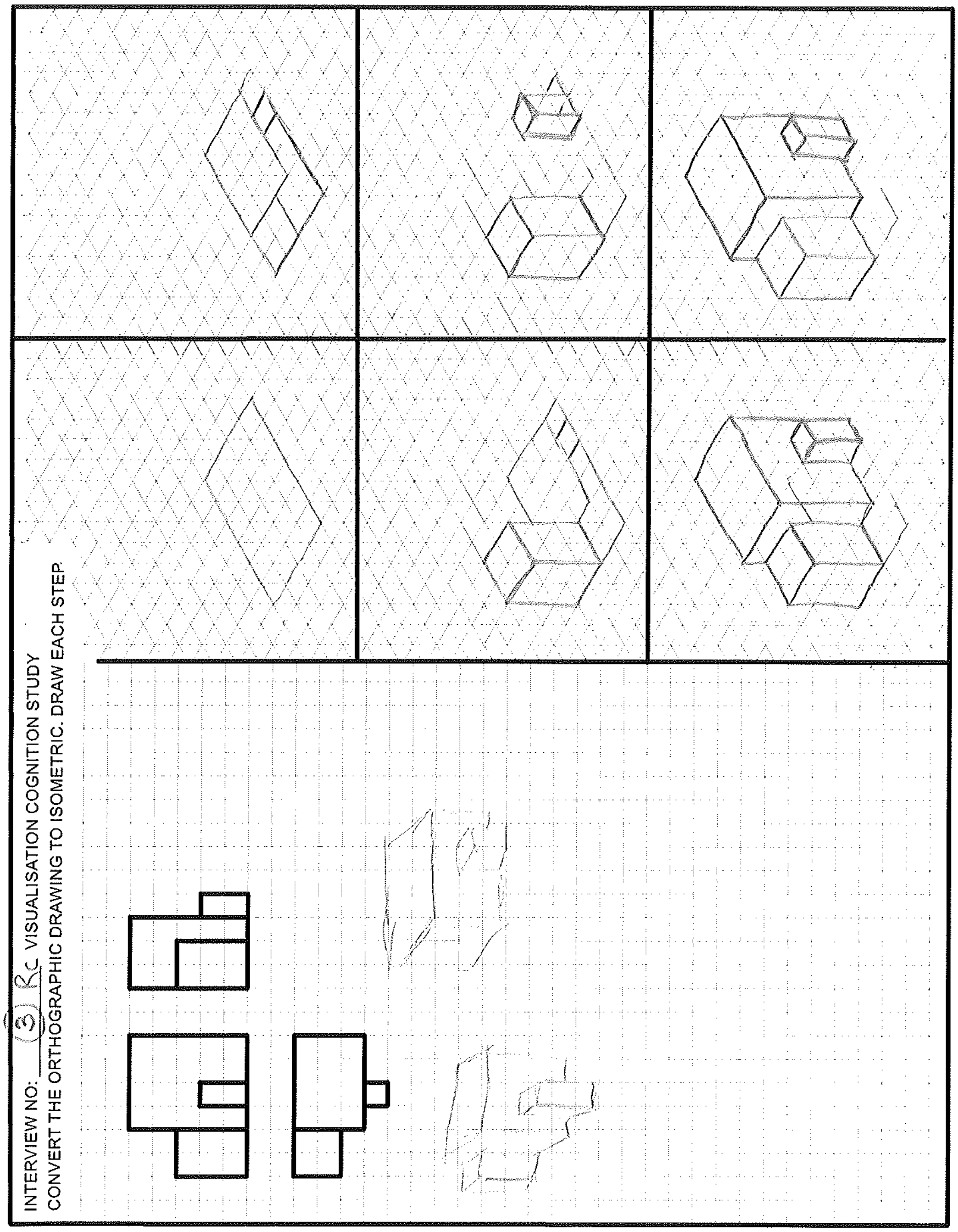


Figure vii. Student Rb’s sequence drawings

Fig viii

Fig 10

Schema - Coding



INTERVIEW NO: ③ Rc VISUALISATION COGNITION STUDY
CONVERT THE ORTHOGRAPHIC DRAWING TO ISOMETRIC. DRAW EACH STEP.

Figure viii. Student Rc's sequence drawings

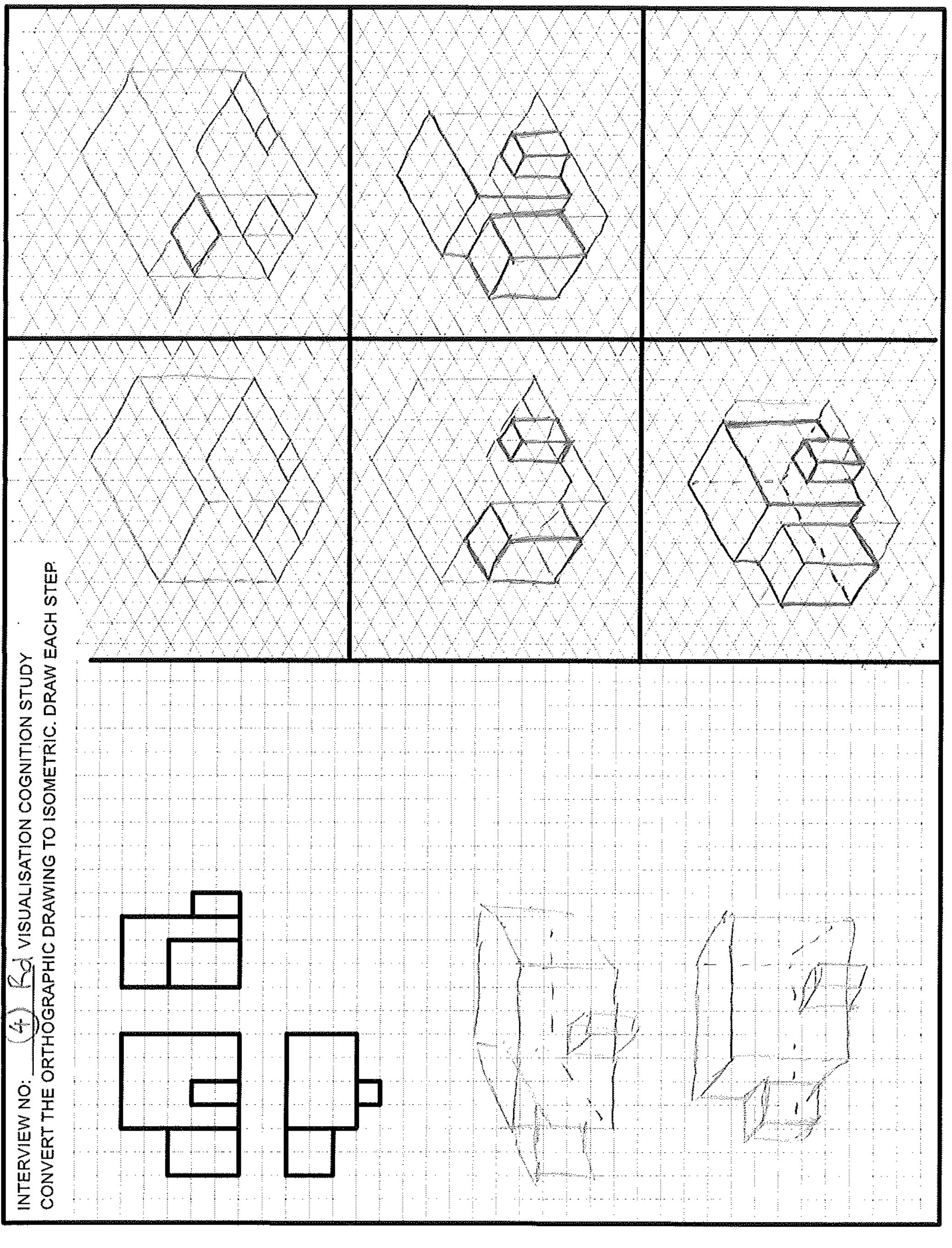


Figure ix. Student Rd’s sequence drawings

Fig. 11

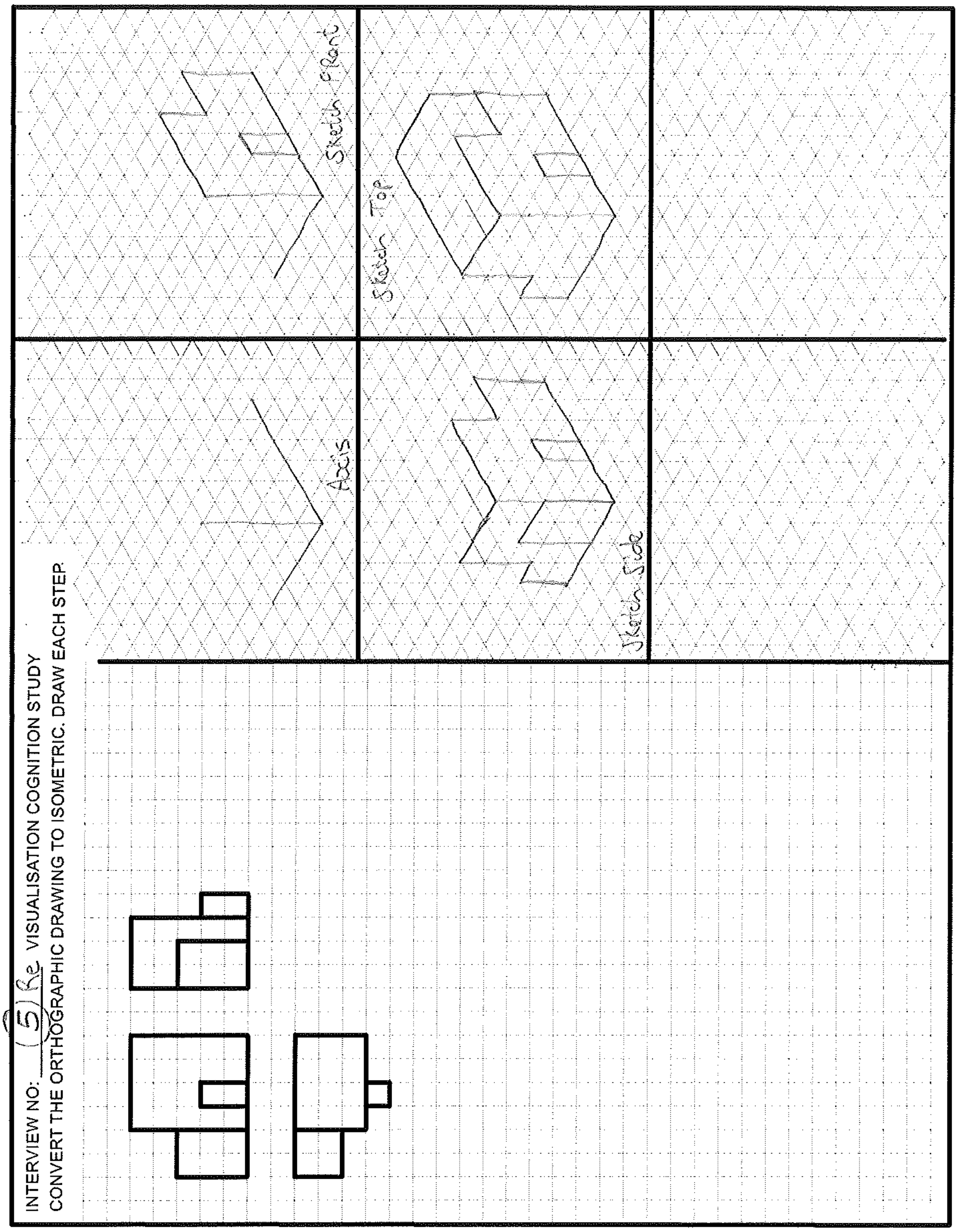
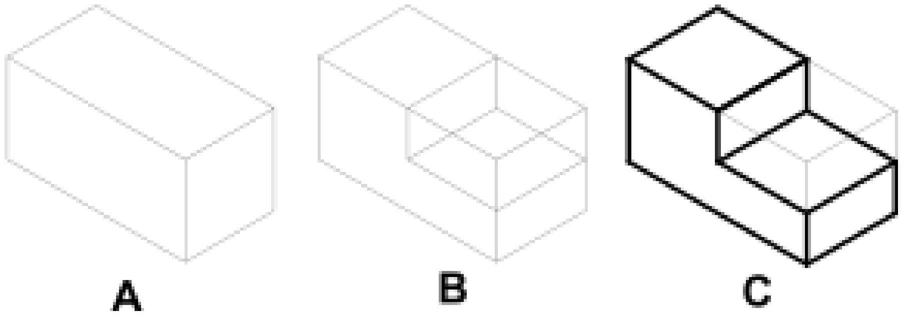


Figure x. Student Re's sequence drawings

mm

Annexure I: Isometric sequence drawings

BLOCKING METHOD



CRATING METHOD