Effects of GIS learning on high school students' spatial-cognitive abilities. A case study of three secondary schools in Johannesburg.

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Supervisor Dr Stefania Merlo

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DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the Master of Science in Geographical Information Systems and Remote Sensing at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University

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ABSTRACT

The purpose of this study was to analyze the effects of GIS learning on high school students' spatial abilities. 61 grade 11 learners, 31 doing Geography as a subject and 30 not doing geography, took part in the study. The learners, from three schools in Johannesburg, Parktown Boys High School, Parktown School for Girls and Marist Brothers Linmeyer, completed a pre and post spatial skills test during the first and third terms respectively, in 2017. Overall, the results showed a significant change from the pretest to the post tests of students who had done GIS learning. However, there were no significant differences between males and females. No significant differences were noted between students who spoke English as a first language and those who did not speak English as a first language. Different results obtained in the learners' test results were examined; revealing that the GIS course had a positive effect on students' spatial abilities, and that there was a positive relationship between the students' spatial abilities and the outcome of their spatial skills tests. The students' map drawing strategies did change for students who did GIS learning from landmark to route or survey, and not many changes were noticed for learners who did not do GIS learning. This showed that GIS learning had an effect on map drawing strategies.

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ABBREVATIONS AND ACRONYMS

ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
DoE	Department of Education
EdGIS	Education Applications of Geographic Information Systems
GIS	Geographic Information Systems
GPS	Global Positioning Systems
SAS	Statistical software
XLSTAT	Statistical software

CHAPTER 1: Introduction

1.1 Background

Geographic Information Systems (GIS) have been used extensively over the past 30 years. They have applications in fields such as agriculture, banking and business, environmental management, forestry, mining, education, real estate and in water supply industries (Manyatsi and Dube, 2000; DU, 2002) Put simply, a GIS is a system that allows users to capture, manipulate, analyze and store information so that maps can be generated as stated in Wieczorek and Delmerico (2009). The components of a GIS system include the hardware, which are the computers, software, people, as well as data in different formats (Rusko, Chovanec and Rošková, 2010). There are many ways of learning how to operate and apply GIS systems (Dempsey, 2018). Different definitions and classifications of GIS based on data models, platforms, cost and application areas have been put forward (Maguire, 1991). GIS is defined by Chrisman (2002) as an organized activity in which people measure different events and represent their findings as computer databases which highlighting aspects relationships and entities. Campbell. J and Shin M. (2012) define GIS as a unique based computer program that is able to store, edit, process and present geographic data and information in the form of maps. Early authors such as Koshkariov et al (1989) defined GIS as a system that comprise of geo-modelling capabilities, whilst Devine and Field (1986) defined it as a form of Management Information System (MIS), which allows general information to be displayed in a map. The following section explains GIS learning as used in this study.

1.1.1 GIS learning

GIS plays an important role in the training of geographers and is a valuable aspect in terms of thinking geographically within the environment we live in (Catling and Taylor, 2007). Over the last 20 years, GIS has been incorporated into secondary school and university geography curricula in many countries. In this study, 'GIS learning' indicates GIS as offered by the National curriculum high school geography. It entails learning what GIS is by looking at the definition of GIS, how to manipulate it, as well as when and where to apply it. There are however, many challenges in GIS learning in South African within secondary schools which make it difficult to implement in secondary schools (Scheepers, 2006). These include unclear curriculum demands, expensive software, which is not readily available in schools and lack of experienced trainers. Kidman and Palmer (2006) state that there are three main factors that can stall successful implementation of GIS in South Africa: 1) Lack of funds to purchase the required hardware such as computers, 2) lack of funds to acquire software. 3) Lack of financial support from government and private institutions to buy the necessary hardware and software. This study aimed to examine the effects of learning GIS on Johannesburg high school students' spatial cognitive abilities. Students in grade 11 were taught about the different elements of a GIS system, including how data is obtained, pre-processing of data, how to process data. In South Africa, paper-based GIS which is a manual technique, is used to teach the most basic concepts of GIS to high school students (Breetzke et al 2011). This technique makes use of topographical maps, orthophoto maps and tracing paper to identify point, lines and polygons (Breetzke et al 2011). It involves the employment of vector and raster models for spatial understanding of the environment by the application of scale, coordinates and map projections. Thus, to apply GIS effectively, three basic kinds knowledge are needed, and these are: declarative, procedural knowledge as well as conditional knowledge (Bednarz, 1997). Declarative knowledge is knowledge based on facts, concepts and ideas organized in different ways i.e. statements, lists or stories. Procedural knowledge allows one to perform a series of tasks in the correct sequence, and according Bednarz (1997), this is the knowledge that is used in the learning of GIS. The third type of knowledge is called conditional knowledge and is about knowing when and why to use a procedure (Lee and Bednarz, 2009). The three different types of knowledge are employed when establishing spatial relationships (Lee and Bednarz, 2009). The section below explains the spatial abilities that are employed in the learning of GIS, thereby giving an overview of the link between GIS learning and spatial abilities.

1.1.2 Spatial abilities in GIS use

GIS learning makes use of spatial abilities, and different spatial activities are employed when learning GIS, to establish the bond learning GIS and spatial abilities of learners (Bednarz 1995; Self et al 1992). McGee (1979), states that spatial abilities are categorized into three different categories and these are; spatial visualization, spatial orientation and spatial relations. He defines spatial visualization as the ability to use you mind to influence, twist and turn, and rotate visual stimuli. Coluccia and Louse (2004) defines spatial orientation as the ability of an individual to place him/her relative to a reference point. Spatial orientation is when one is focused and not disoriented by the changing patterns or arrangements of patterns within the environment but is able to position oneself (Baril, 2012). Spatial visualization is defined as the intrinsic ability to envision that human beings have before any formal training is given (Sorby, 2009). The last aspect of spatial abilities are spatial relations, defined as the ability to identify spatial patterns and distributions, correlate spatially distributed phenomena (Lee and Bednarz, 2009). GIS activities related to spatial relationships include interpolation, classing choropleth maps and dot maps, establishing patterns, analyzing spatial data, as well as drawing spatial features. Thus, GIS plays a role in improving spatial abilities.

1.2 Problem Statement

The GIS industry has expanded over the years and there is need for the education and training of GIS (Forer and Unwin 1999; Longley et al, 1999). According to Bednarz (1997), ongoing research focuses on what should be included in the GIS curriculum and how it should be taught. Little has been discussed in terms of students' spatial cognitive abilities and their link to GIS; however, there has been mention of spatial problem solving through the learning of GIS. This study assessed whether GIS learning improved spatial cognitive abilities of learners who did GIS learning by administering two spatial skills tests in term one and three respectively. A control group which did not do GIS learning also wrote the two tests in term one and three. Some studies have attempted to assess this link (Audet et al 1993; Barstow 1994; Salinger 1995). Lee and Bednarz (2009) developed a framework for this assessment based on psychometric tests. Their research questions and procedure were applied in this research report.

This research will generate new and relevant information which will be used to improve and enhance the teaching and training of GIS. This type of investigation has been carried out in developed countries but has not been used in developing countries, and in Johannesburg, South Africa, a similar study has never been carried out. Understanding the effects of GIS learning on students' spatial cognitive abilities will actually help high school GIS curriculum designers to take into account the effects of gender differences and language on spatial cognitive abilities, through GIS learning. In this research the effects of GIS learning on spatial cognitive skills were examined in terms of gender differences, and between those taking GIS and those not taking GIS in high school, by using spatial skills tests. In order to understand the differences students wrote two spatial skills test, one before being taught GIS during the first term and the other one after the teaching of GIS during the third term. The results provided an insight as to whether GIS improved spatial cognitive abilities and if there were significant gender differences to spatial cognitive abilities after GIS learning in South Africa.

1.2.1 Research Questions

1. Does GIS learning have an effect on students' spatial cognitive ability?

   a. Will completion of a GIS course affect the spatial cognitive ability of secondary school students?
   b. Will this effect be different for male and female students and for students whose mother tongue is different from English?

2. Will GIS learning affect students' spatial problem solving?

   a. Will completion of a GIS course affect the map-drawing strategy of students?
   b. Is there a relationship between students' map-drawing strategies and spatial cognitive ability?

1.2.2 Aim of the Study

The aim of this study was to examine whether the completion of a GIS course affected spatial cognitive abilities of high school students in Johannesburg. This research was based on a study carried out by Lee and Bednarz (2009) at Texas A and M University, involving undergraduate students. As such, the aim, objectives and research questions were governed by this study.

1.2.3 Study Objectives

The study was guided by the following objectives:

- To assess whether completion of a GIS course affects the spatial cognitive ability of high school students.
- To assess whether there are gender and language differences in spatial cognitive abilities before and after GIS learning.
- To assess whether GIS learning affects students' spatial problem solving.
- To assess whether there is a relationship between students' map-drawing strategies and spatial cognitive ability.

1.2.4 Limitations

Efforts were made to make the study applicable and relevant. The following were the limitations of this study.

1. Although eleven schools were approached, participation in the study was voluntary. The Human Research Council states that the researcher should respect the right of individuals to refuse participation in research and withdraw from research should they chose to do so at any stage of the research (Hsrc.ac.za, 2018). There was a general lack of interest from public schools, mostly from low income communities. Hence the sample is not representative of learners from diverse backgrounds.
2. Since the schools and the learners volunteered to participate, they were not randomly selected, and the sample is not representative of the greater population of the city of Johannesburg. This limits the conclusions from the sample.
3. Since this study was not part of the learners' assessments and did not have an effect on their grades, learners were not particularly motivated in carrying out the test.
4. The schools could not write the tests around the same time due to different school timetables which involved different extra curriculum activities. This might have influenced some outcomes.

Chapter 2: Literature Review

2.1 Introduction

This chapter provides a brief overview of current literature on GIS in relation to student's spatial abilities and cognitive skills. Although it did not fully exhaust all the existing literature on the subject since it has been a subject of much research, it laid an important foundation for the study. The literature however, provided it with an empirical foundation from which important issues were drawn that informed this study. This literature review is divided into four different sections, with the first section exploring spatial cognitive processes involved in GIS learning. The second section looks at spatial abilities in the context of GIS, and the third section looks at spatial problem solving. Finally, the link between spatial ability and spatial problem solving is explored in the last section of the literature review.

2.2 Spatial Cognition and GIS

Smelser and Baltes (2001) state that, cognition is about knowledge, its acquisition, storage, retrieval and manipulation. In humans, the cognitive structures and processes are part of the mind (Smelser and Baltes, 2001). Spatial cognition is concerned with the study of knowledge and beliefs about spatial properties of objects and events in the world (Smelser and Baltes, 2001). Spatial properties are identified as location and size; distance, direction, separation and connection; shape, as well as pattern and movement. Spatial cognition and spatial thinking are a collection of cognitive skills that enable learners to carry out spatial reasoning based on their conception of space and place (Liu, Bui, Chang, and Lossman (2010). Liu et al (2010) argue that spatial thinking is the cornerstone of GIS technology which, in turn, is an essential tool for supporting the development of spatial thinking skills.

The development and possession of critical spatial thinking and skills by students has for some time now been considered as critical in developing the skills of students (Bednarz, Acheson, and Bednarz 2006). It also allows them to interpret information, to have the ability to make decisions as citizens and to solve complex issues (Bednarz, Acheson, and Bednarz 2006). Milson and Curtis (2009) and Liu et al (2010), have argued that it is important to incorporate GIS into education for the purpose of developing students' spatial skills. Interest in the use of the GIS was given impetus by a question raised in 1994 at the National Conference on the Educational Applications of Geographic Information Systems (EdGIS) on 'what learning does using GIS allow that other ways do not' (Kerski, 2003). For Liu and Zhu (2008) GIS allows for the enhancement of learners spatial cognition and spatial perspectives. In the authors' view, activities such as making, using and interpreting maps; storing, collecting and using geo-spatial data and investigating geographic issues in the long term enhance the spatial and cognitive abilities of learners. In line with this thinking several studies, (Golledge and Stimson, 1997; Hart and Moore, 1973), have been undertaken which have been aimed at understanding the relationship between GIS and spatial thinking. These authors also carried out studies to understand the link between GIS and the development of spatial abilities among students and how it can be incorporated into educational activities. GIS can be used to develop student's abilities to reason spatially, solve spatial problems and to improve their map reading abilities (Albert and Golledge 1996). This argument has been empirically proven by Lee and Bednarz (2009) who managed to show that GIS can improve learner's spatial thinking ability.

Summerby-Murray (2001) showed that if given the chance students using GIS can learn scientific research procedures, conduct their own research, evaluate their project, cross check information and use their own data sources. In the study by Summerby-Murray (2001) students were required to map a heritage landscape using the GIS and to assess the accuracy of the database. The results showed that GIS uses and learning can greatly improve and enhance student's critical spatial thinking. To prove the importance of GIS in developing student's spatial learning Kim and Bednarz (2013) undertook a study in a large State university (name of university was not mentioned in the study), with their sample comprising of undergraduate students. The conclusion was that GIS learning was beneficial in enhancing students' critical spatial thinking, identified as the ability to assess data reliability, use sound spatial reasoning, and evaluate problem-solving validity.

Quantitative findings that indicated the development of these three components of critical spatial thinking were supported by qualitative thematic analyses (Kim and Bednarz 2013:362). For Kim and Bednarz (2013) the developments of the students' abilities were attributable to the nature of GIS learning. They saw it as developing the ability of students to think about data reliability, to read spatial imagery like maps and remote sensing imagery and to develop the ability to analyze spatial information and to reproduce spatial representations. Students through GIS learning were also able to develop reasoning skills, to learn and apply concepts and to undertake evaluations. This pointed out to the important contribution which GIS can be seen as making to the spatial and cognitive development of students. This observation is corroborated by Liu et al (2009) who argue that students who had been trained in GIS tend to develop 'high order thinking' in terms of their analytical and evaluation skills. They further state that students who learn the same content without GIS tend to develop 'lower order thinking skills' such as recalling information. Kerski (2000) stated that high school students using GIS scored significantly higher than students using traditional methods, on a spatial analysis test. The GIS group also demonstrated better abilities to synthesize, identify and describe human and physical patterns. A study carried out by Hagevik (2003) concluded that learning with GIS developed students' spatial- visual thinking skills.

However, some studies have shown no significant difference between students from an experimental GIS and those in a control group (Abbot, 2001). The study indicated that students showed improvement in integrating science process skills after a 2 week GIS course. No significant different where seen between those who did GIS and those who did not by Albert and Golledge (1999), in the map overlay activity.

2. 3 Spatial abilities and GIS

Spatial abilities consist of different but related factors (Hegarty et al., 2006). These are spatial visualization, spatial orientation and spatial relations. As stated earlier, spatial visualization involves as the ability to mentally manipulate, twist and turn, and mentally rotate and manipulate visual stimuli. Spatial orientation is the ability to remain focused and unconfused by the changing patterns or arrangements of patterns within a visual stimulus pattern (Baril, 2012). Spatial visualization and orientation is important GIS for example in the map overlay function where a new perspective on two or three dimensional representation is needed as well as to manipulate spatial features. Spatial thinking involves establishing relationships amongst entities (Sinton, D. S, 2014). This is through interpretation of relative location, distance between them, scale, correlation of distributed phenomena, direction and patterns as well as changes over time (Sinton, D. S, 2014).

Spatial thinking has been used to formulate meaning of spatial object arrangements. GIS aspects such a geometric transformation, map projections and map scale are directly linked to that aspect of spatial thinking that allows us to mentally manipulate, rotate, twist and turn diagrams that are presented to stimulate visual stimuli (Lee and Bednarz, 2009). Topology which falls under data management, classification of spatial data, spatial statistics, drawing maps, spatial data analysis and geo-referencing, are all related to a part of spatial thinking (Lee and Bednarz, 2009). This allows for establishing spatial data distribution and patterns, spatial hierarchies, map sketching, comparison as well as map overlay (Lee and Bednarz, 2009).

2.3.1 Spatial ability measurement

Psychometric tests developed by psychologists have been used to measure spatial abilities (Golledge and Stimson, 1997). However, authors such as Golledge (1993) and Self (1994) argue that these tests do not take into account certain aspects of spatial abilities such as distribution, process, association and structure which are essential in spatial activities. According to Newcombe and Dubas (1992), psychometric tests require manipulation of two dimensional and three dimensional diagrams, by mentally rotating diagrams and spatially manipulating them. However, psychometric tests fail to assess the spatial abilities needed to solve world problem situations (Montello et al 1999; Self et al 1992). Golledge (1993) argue that psychologists have neglected aspects such as elevation and relief when dealing with phenomena, yet spatial knowledge includes hierarchy, patterns, connectivity, surface and relationships. Psychometric tests are said to lack the depth that is needed to assess spatial abilities (Self et al 1992). Thus psychometric tests have got limitations since GIS had been designed to deal with spatial information on a wider and deeper scale making them inadequate to measure the effects of GIS learning on spatial ability. Kali et al (1997) propose a new set of assessment tool that measures spatial abilities that ordinary psychometric tests cannot. Different tests that measure spatial aspects have since been introduced i.e. a test focused on geologic spatial abilities developed by Kali et al (1997). Kerski (2000) created a test that required the mapping of a fast food restaurant within a hypothetical community based on different features such as traffic volume, existing fast food outlets, high schools as well as annual median income and zone. However, very few of these tests' reliability have been validated (Lee and Bednarz, 2009).

Research on individual spatial abilities has been inconsistent (Lee and Bednarz, 2009). Authors such as Bezzi (1991), Kali and Orion (1996), Kali et al. (1997), Saccuzzo et al. (1996) stated that there were improvements in students' spatial abilities with training. However, there has been debate as to whether gender differences exist. Saccuzzo (1996) states that men initially perform better than women but after training women show significant improvements. Kali and Orion (1996), states that men performed better than women, especially in visual spatial tasks. In terms of gender differences in GIS learning, there is still insufficient evidence that there are gender differences and hence results still remain inconclusive (Baker and White 2003; Self et al 1992).

2.3.2 Link between Spatial ability and GIS learning

The Board on Earth Sciences and Resources of the National Research Council (2006) states six reasons stipulating GIS as a support instruments to teach to think spatially in K-12 education (Chun, 2007).The Board explains that GIS can help in the process of scientific formulation and solution, thereby exemplifying discovery based student centered inquiry. They also stated that GIS can be used as a problem solving tool in real world context. It can also be used in interdisciplinary and multi-disciplinary learning by linking up different subjects. GIS allows students to make a spatial decision based on collection, organization, and store and analyze, as well as display data with better understanding (Chun, 2007). Liu and Zhu (2008) further reiterate that the use of GIS can help students develop higher order thinking by defining problems, creating and exploring different representations of the data and relevant information, analyze information, solve spatial problems as well as draw up relevant conclusions.

Albert and Golledge (1999) report a positive relationship between GIS and spatial ability. Their research was the first to connected GIS activities to the three aspects of spatial ability, namely spatial visualization, orientation and relationship (Lee et al, 2009). They stated that spatial visualization was important for activities such as map overlay which involved manipulation through a comparison between individual spatial components and performing a logical operation on the components. Spatial orientation is linked to oblique and vertical aerial photo interpretation, map orientation, geo-referencing as well as two dimensional and three dimensional transformations (Golledge and Stimson, 1997).

A study by Summerby-Murray (2001), demonstrated to students the crucial role played by data in research. In this research students were required to map a heritage landscape using GIS, and carry out an accuracy assessment of the database. This study required that they cross check information as well as consult various data sources. Students learnt scientific research procedures as well as to evaluate limitations within their projects. Liu et al (2010) reported that GIS learning developed students' higher order thinking like analytical skills as well as evaluation skills. A lower order thinking skill was observed in students who learnt the same content without GIS and only improved their ability to recall information. In summary GIS does play a role in improving spatial abilities.

2.4 Spatial problem solving and GIS

Cognitive mapping is defined as a mental process through which individuals comprehend and become aware of the world around them (Downs and Stea, 1977). Map drawing strategies in a cognitive mapping task are analyzed to measure their map drawing strategies (Lee and Bednarz, 2009). Stimson (1997) used cognitive maps to analyze differences in spatial abilities. Different methodologies have used to analyze the various aspects of cognitive maps and mapping (Kitchin, 2001). These methodologies include mechanical approaches which is about counting items and evaluating accuracy based on their distance estimation. Golledge and Stimson (1997) pointed out that maps are always distorted based on their Euclidean geometry and factors such as age of individual, way of thinking, environmental experience and style of training all have an influence. Other authors such as Antes (1988) state that individuals preference of certain routes, familiarity of landmarks also have an influence on their cognitive maps. The second approach is the structural approach which classifies cognitive maps based on spatial abilities developmental level required to produce those (Lee and Bednarz, 2009).

The third methodology is the process oriented approach which aide in focusing on spatial problem solving as a part of problem solving than the map as a finished product (Lee and Bednarz, 2009). Nyerges (1995) suggest that the information that a user of GIS has is based on knowledge of two aspects; problem domain knowledge and tool domain. The problem domain is based on sets of concepts about theoretical space related to a particular discipline which involve everyday knowledge, whilst tool domain knowledge is based on based on problem solving abilities with the GIS context. An example is the map overlay process (Albert and Golledge, 2010).In the map overlay operation is a fundamental GIS operation which makes use of spatial cognitive abilities to mentally visualize and manipulate spatial objects. This involves the use of a series of operations to achieve certain results (cognitive tasks), and visually authenticate a map overlay process as well as choosing the precise map layers to overlay.

2.5 Map drawing styles and cognitive ability

Downs and Stea (1973) define cognitive mapping as a procedure of psychological changes whereby an individual, recalls and convert acquired information based on location and attributes within well-known spatial areas. According to Olson and Bialystok (2014) spatial relations and concepts are fundamental in all levels of the cognitive structure, from interpretation of objects to interpretation of geometry. A cognitive map is used to answer two basic questions: how valued things are and how to get to where they are, from where an individual currently is (Downs and Stea, 1973).

The drawing of cognitive maps involves selection of information from a spatial environment, which is then placed in an organized representation and translated from large scale to a small scale space, which is a piece of paper (Downs and Stea 1973; Siegel 1981). This process makes use of spatial problem solving i.e. decisions on the type of information that is going to be stored, how the information is going to be represented, how it is going to be displayed and ordered, as well as how to attach relative value and importance to it (Down and Stea, 1997). Cognitive mapping also helps in terms of measuring spatial ability and problem solving since spatial skills are used in defining spatial relationships such as distribution and patterns formed (Lee and Bednarz, 2009).It also helps with connecting locations, identifying related spatial phenomenon and establishing hierarchy and regions (Lee and Bednarz, 2009).

2.5.1Map drawing strategies

According to MacEachren (1992) evidence exist that acquisition of environmental information of unfamiliar surroundings of environments is a gradual development process that start with fragmented selective information, which build up over time until an individual achieves an integrated cognitive representation of the place. (Albert and Golledge, 1996) proposed a model that explains three different types of spatial knowledge, known as the Spatial Geographic Knowledge model. The first type of knowledge is known as Geographic facts or landmarks, and these include individual features recorded from a spatial point of view. As a person travels through different or familiar environments, his cognitive map or knowledge of large-scale environments is said to build up from observations acquired as he/she travels through the environment (Kuipers, 1978). This knowledge is also said to be acquired through the studying of cartographic maps and the outcome is usually referred to as survey knowledge. Kuipers (1978) goes to explain that this will act as a problem solver in terms of finding routes and relative positions, as well as giving a description of the current location. Couclelis et al (1987) further states that this knowledge is represented in discrete spatial units, hierarchically. The second type of knowledge if known as route knowledge which links together geographical facts between two points The third type of knowledge is known as configuration knowledge which combines routes and geographic facts and forms a network between several places (Golledge et al, 1997). Werner et al (1997) propose a hierarchy in attainment of spatial knowledge from landmark to route, the survey. They describe it as forms and representations of spatial data that can be identified in systems navigating in complex environments (Werner et al (1997). Landmarks are defined as distinctive items at fixed locations; routes as fixed sequences of locations, whilst survey knowledge had to do with integrate information from different sources into a single model

(Gieseking, 2013). Ruddle et al (1997) suggest that map learning provide more direct access to survey knowledge than navigation, and they further state that survey is the highest order in the hierarchical steps of spatial knowledge acquisition.

Cognitive maps are said to be organized based on reference points known as anchors (Lee and Bednarz, 2009). These are closely related to landmarks from Lynch's (1960) landmarks. Landmarks have been used to describe different things including features of a region, features along a route that allow for navigation, information within a memory disk, as well as rivers and roads (Lee and Bednarz, 2009). Ferguson and Hegarty (1994) pointed out that linear and marks are better recalled than point features due to the space they occupy. Authors such as Anderson 1990; Kitchin 1997 suggest that anchors are used as starting points when creating cognitive maps. The anchors and relationship between them provide a hierarchical structure that is used in the creation of cognitive maps (Lee and Bednarz, 2009). This gives rise to spatial relationships of objects within space (Lee and Bednarz, 2009).

The orders in which individuals include anchors within a cognitive representation indicate hierarchy (Lee and Bednarz, 2009). For high school students a map is meant to tell a story, to reveal something meaningful and interesting and this is achieved by manipulating and displaying results about geographic features, attributes and phenomena that they represent (Buckley and Fields, 2011). (Lee and Bednarz, 2009) state that different people use different strategies when drawing maps, and this is due to differences in cognitive styles and spatial abilities. In several studies map drawing strategies have been linked to aptitude, and three types of aptitude strategies relationships have been identified (Lohman and Kyllonen, 1983). The first one is limited by aptitude because the use of strategies requires certain skills. The second strategy choice, strategy is relevant only to understand how to perform a task and not aptitude. The last strategy which is choice, takes into account first and second strategy choices, and establishes a relationship between the two.

Several studies (Schultz, 1991; Snow, 1980) showed that there was a relationship between strategy choice and spatial abilities (Lee and Bednarz, 2009). However, Bruin et al (2000) did not find any link among aptitude, strategy choice and performance of individuals. Lawton (1994) did not find any relationship between mental rotation and way finding strategy which is a cognitive mapping-based behavior. In conclusion, there is a link between individual spatial strategies and spatial performance, however, understanding strategy choice and its relationship to spatial performance is essential to further understand variations in spatial abilities (Schultz, 1991).

2. 6 Conclusion

The aim of the literature review was to provide background information and context on the effect of GIS learning on student's spatial cognitive abilities. Emphasis on spatial analysis and visualization make GIS different from other information processing systems (Goodchild, 1987; Maguire, 1991). Hall-Barstow (1994) and Thompson et al (1997,) stated that logical methods in GIS, which include spatial measurements, calculations and spatial queries as well as statistics, improved students' analytical skills as well as spatial reasoning. These spatial abilities are linked to performance on spatial aptitude tests and to spatial visualization and orientation, with spatial relation as the third component of spatial abilities (Golledge and Stimson, 1997; Golledge, 1993). Thus, GIS affect individuals' spatial problem solving since cognitive mapping and GIS make use of normal mental processes (Lee and Bednarz, 2009).

Chapter 3: Methodology

3.1 Study area

The city of Johannesburg covers approximately 1 648.0 square kilometers and has a total population of approximately 4.949 million people (Cs2016.statssa.gov.za, 2018). It is divided into 109 wards (Municipalities.co.za, 2018), which are part of the 420 wards in the Gauteng province (De Wet et al., 2008).

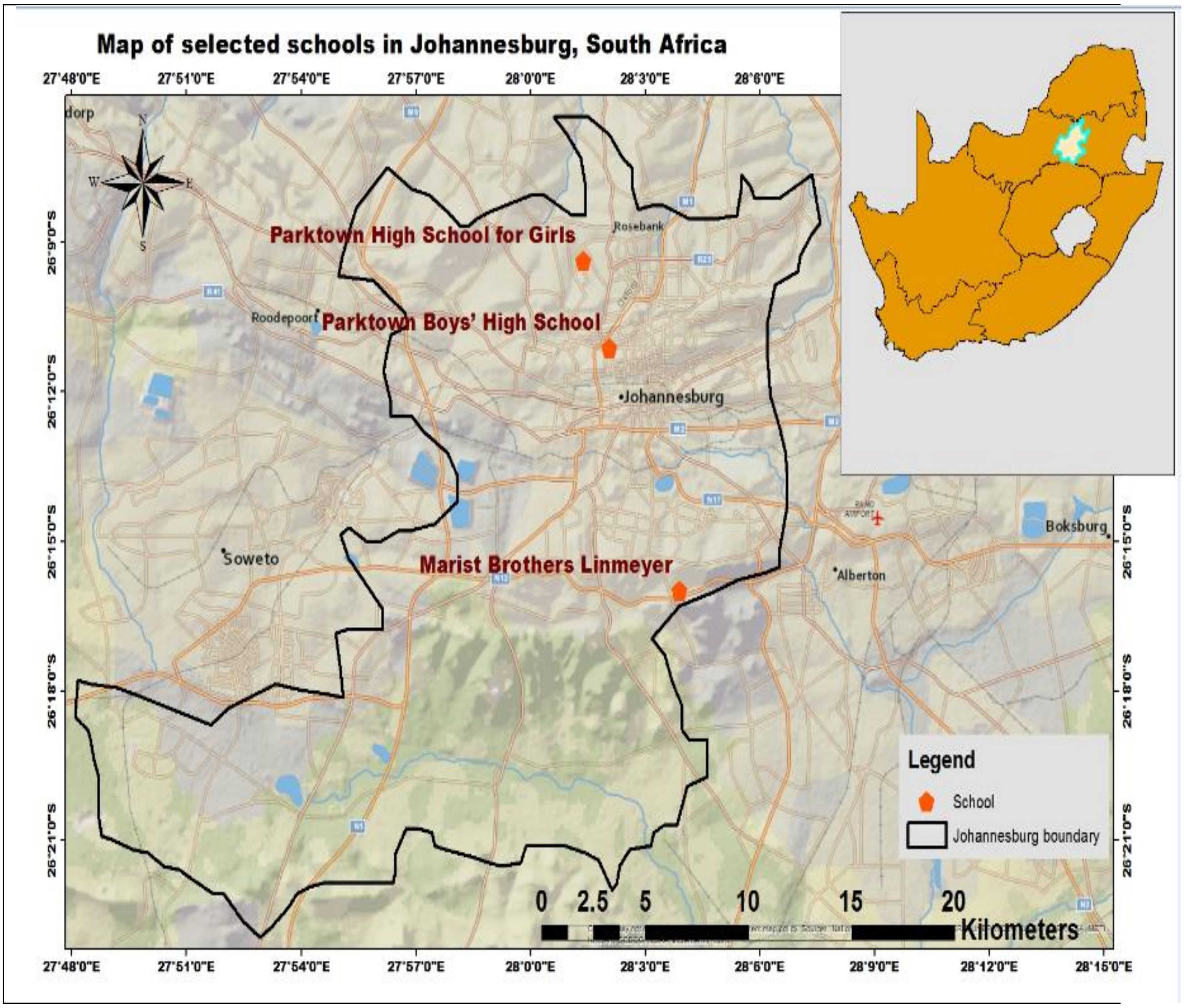


Figure 1: Map showing study area

3.1.1 Demographics

Statistics South Africa, 2004, reported that ethnic compositions within the city of Johannesburg accounted for 73% black population, 16% white population, 6% colored population and the Asian population group at 4%. Of the local languages spoken 32% of the population in Johannesburg spoke Nguni languages, whilst 24% spoke Sotho and 18% English. 7% spoke Afrikaans with the remaining 6% speaking Tshivenda (Statistics South Africa, 2004). This study took into consideration three high schools located in Parktown, Parkhurst and Linmeyer (figure 1). Parktown is a suburb in Ward 67 of Johannesburg, in South Africa, the first suburb on the northern part of the CBD. It is well known as one of the Parks, and includes Parkview, Parkwood, Westcliff, Parktown North, Parkhurst as well as Forest Town. Parktown is considered an affluent suburb within the city of Johannesburg (Sa-venues.com, 2018). It has a population of approximately 21 592 (Wazimaps, 2018). The average annual house hold income is approximately R57 300 which is double that of Gauteng (Wazimaps, 2018).

Parktown is a suburb that has a lot of businesses, huge mansions, churches, schools and also has hospitals and medical centers. It is an old suburb whereby there are no new developments taking place (Privateproperty.co.za, 2018). Although Parktown boys high school, which is located in Parktown, is considered to be in an affluent area, it also caters for learners from less affluent area such as Hillbrow, Berea, Johannesburg CBD, Braamfontein Yeoville and Soweto(Parktownboys.com, 2017.Parktown is one of Johannesburg's largest suburbs, and is located next to Hillbrow, Braamfontein and Milpark on the southern part; Berea and Houghton on the eastern part; Killarney on the northern, as well as Westcliff, Melville and Richmond on the western part. It was originally established by the Randlords in the 1890s, Parktown is now home to many businesses, hospitals, schools, churches and restaurants, whilst still maintaining quiet residential areas. Parktown contains primary and secondary schools, as well as public and private schools. Parkhurst is a small but densely populated suburb located in northern Johannesburg (It has got approximately 4000 residents (Wazimaps, 2018). It is located next to Parktown, and that is where Parktown School for girls is located. It is a very affluent suburb (Wazimaps, 2018). Most people run businesses very home and average household income per annum is approximately R230 700 (Wazimaps, 2018). Two secondary schools are in Parkhurst, as well as one primary school and a lot of nursery schools.

Linmeyer is a suburb located in Region 9 on the southern border of Johannesburg. It is ward 56 with an average population of 31 096 people (Wazimap, 2017). It overlooks the Klipriversburg Mountains to the south. It is a fairly new suburb with an average income of approximately R57 300 (Wazimaps, 2018). Linmeyer has got one main private school, for both boys and girls, which has got a primary and secondary school. A lot of nursery schools are located in this area as well. It is considered a middle income residential although there are some areas which are seen as upper class.

The three schools involved in this study included Parktown Boys' High school, Parktown School for girls and Marist Brothers Linmeyer. Parktown Boys' High school is a public boys' school located in Parktown Johannesburg. It started as a co-ed school in 1920, and was joined with Parktown school for girls, which is now located in Parkview. Both schools are government schools which follow the National Curriculum for the General Education and Training (GET) for grades 8s and 9s, and the National Curriculum for the National Senior Certificate, grades 10s to 12.Parktown boys high school has got an average of 850 boys and a staff compliment of 50 full time teachers (Parktownboys.com, 2017) whereas Parktown school for girls has over 1 000 students and a staff compliment of over 60 teachers(Parktowngirls.co.za, 2017). Both schools are composed of diverse population groups, which include whites, blacks, colored and Asians. Marist Brothers Linmeyer is an independent mixed (containing both boys and girls), Catholic school, situated in Linmeyer, a suburb in southern Johannesburg, and has got grades 0 to 12. The school is registered with the Independent Examination Board (IEB) and also follows the National Senior certificate for the grades 10s to 12s, as well as the GET for grades 8s and 9s. Marist Brothers Linmeyer has approximately 566 learners and 44 teachers for the secondary school (Marist Brothers Linmeyer, 2018).

3.2. Methodology

This section outlines the methodology used in the study. Psychometric tests have been administered extensively to analyze spatial abilities for instance spatial visualization along with spatial orientation (Goldstein et al, 1990; McGlone, 1981; Newcombe and Dubas 1992).It was with this in mind that a research methodology which was holistic and contextual in understanding the use of spatial cognitive abilities in GIS learning was developed. Two spatial skills tests were administered to gauge changes in spatial ability plus spatial problem solving of grade 11 students, before and after they concluded GIS learning. It should be noted that comparisons done were for entire groups and not based on comparisons between schools. This section gives an overview of the research design and methods involved in these two assessments.

3.2.1. Data collection and Sampling techniques

In the research, the purposive sampling technique was used to get information from respondents. This is a technique that is applied in qualitative studies for the purposes of selecting individuals or groups within an organization based on specific characteristics that relate to that particular study (Yu, 2007). In this instance, settings, persons or events are selected for the important information they can provide that cannot be obtained from others (Maxwell 1997: 87cited in Teddlie and Yu 2007:77).

3.2.1.1 Participants

The schools that took part in the study were Parktown boys' high school situated in Parktown, Parktown School for girls located in Parkview and Marist brothers Linmeyer located in Linmeyer. These schools volunteered to take part in the study. Overall, more than 10 schools were approached to take part in the study and there was a general unwillingness amongst the schools to take part in the study. Several schools located in the less influential suburbs, such as Soweto and Tembisa, citied time constraints as a reason for not taking part in this study. There was also a lack of interest amongst the students to take part in the study since the scores obtained in this study were not going to be used as report marks. A total of 80 grade 11 students were initially chosen from the three different schools around Johannesburg using the stratified sampling method. The grade 11 group was chosen based on the fact that they would benefit more from the study since the grade 12s will be focused on the matric exams and will not have time. 40 of these students were supposed to be geography students and 40 students were supposed to be students not doing geography, and these were supposed to make up the control group. However, only a total of 61 students eventually took part in the study, 31 geography students and 30 none geography students. Of these students, 31 were girls and 30 were boys.

3.2.1.2 GIS Learning

In this study, 'GIS learning' is GIS offered by the National curriculum as part of high school Geography. In this study, paper-based GIS and no software was used. This entailed learning what GIS is by looking at the definition of GIS, how to use it, and when and where to use it. Learners are going to be drawing spatially referenced maps by using 1:50,000 topographic maps, a 1:10,000 orthophoto map and tracing paper to create layers. Learners also looked at spatial and spectral resolution by analyzing and assessing different satellite images. They looked at different data types such as points, lines, area and attribute data, as well as learn about raster and vector data models. Different satellite images, including false colour images were also analyzed and assessed. Identification and drawing of contour lines were covered as part of the curriculum. Applications of GIS covered in class included climate, oceanography and meteorology.

3.2.1.3 Spatial skills tests

Spatial skills tests (Appendix 1) were constructed as a slight variation of Lee's (2005) tests and slightly modified for the purpose of this research. Permission to use the tests was obtained from Professor Bednarz (Emeritus Professor of Geography, Texas A and M) and Professor Lee, via email in April 2017, on condition that the researcher shares the findings of the research with them. Permission to use material from Psychometric success spatial ability, for the spatial skills test was also obtained from Paul Newton (Owner and copyright holder www.psychometric-success.com), was obtained via e-mail in May 2016. The possible answers to the two tests were also provided. The spatial skills test included seven types of question items. These were: a) overlaying and dissolving a map. This required spatial cognitive abilities to visualize, mentally, spatial features as well as manipulate them. The map overlay was a basic GIS operation that required spatial abilities to be meaningful. b) Choosing the best location based on several spatial factors, orienting to a real world frame of reference, imagining maps from verbal descriptions. c) Correlating spatially distributed maps. This involved the use of spatial cognitive abilities to compare and match certain phenomenon given maps. d) Constructing contours based on point data. This was done to assess what is known as Boolean logic, which is used in GIS spatial analysis in which all values are either reduced to true, or false (Lee and Bednarz, 2009). In this study the Boolean operator 'XOR' was used in question 1 and 2 of the first spatial skills test. This research was based on a study carried out by Lee and Bednarz (2009) at Texas A and M University thus boolean 'XOR' operator is interpreted according to their study. However, it should be noted that the boolean operator 'XOR' is not the opposite of the boolean operator 'OR'. e) This activity involved converting 2D shapes using 3D shapes. In this case several spatial abilities were used to come up with the different shapes and to identify spatial data types such as points, lines, or polygons/ area). F) The last item was for the learners to identify different spatial data types. The spatial skills test included multiple choice questions and short structured questions. Learners were asked if they were taking Geography or not. Qualitative information such as gender, name of school, grade age, first language as well as population group were included in both the pre and posttests. Learners had to give information on whether they had a mobile device, and whether it was an ordinary phone or smartphone. They also had to provide information on whether they also had a computer and/or tablet, and provide their uses. It was important to ask if the learners had ordinary phones or smartphones due to the fact that applications such as GPS might influence the drawing of the maps. The digital age has brought in technology that might have an influence on spatial cognition. According to Spence and Feng (2010), research has shown that taking part in action games will lead to changes in a number of sensory and attentional abilities that are essential for carrying out various spatial cognitive activities. Other studies show that playing an action video game removes the gender differences in spatial consideration and all the while lessen the gender exclusivity in mental hinge capacity, which is part of spatial cognition, (Feng, Spence and Pratt, 2007).

Most of these studies have been done in western countries and there are gaps in terms of effects of GIS learning in Africa, as well as between English first language speakers and non-speakers. Questions on the modes of transport, area where they are staying, and if they were staying in hostel were also asked. For the purposes of anonymity, they were also asked to provide their favorite color and house number. The effects of the variables related to the participants' background such as gender and whether they did GIS learning or not, were examined. The other component that was analyzed was the correlation between the participants' average scores on the spatial skills test before and after GIS learning. This information was used in two ways. Through it, individuals from test 1 and 2 could be uniquely linked, anonymously. Moreover, this information was included in the analysis of the performance results.

Spatial skills tests 1 and 2 were administered to the grade 11 learners during the second term and third term respectively. Each test had duration of 30 minutes. The tests were written outside school hours after 15:00 pm, as per GDE requirements. The tests were written on the school premises, in classrooms. The first test was written in the last week of May, 2017 by all schools.

The general atmospheric conditions during that time were low temperature and no rainfall. Parktown Boys' High School and Marist Brothers Linmyer, wrote the second test during the second week of September 2017, after school. The general weather during that week was fine. Parktown girls wrote the second test during the last week of September, and there weather was similar to the weather experienced during the second week of September. There was need to take note of the general atmospheric conditions because according to Cheema and Patrick (2012) too much ambient warmth can have effects on the most basic cognitive tasks. The main challenge in terms of administering the tests to the learners was finding suitable time when all learners did not have other commitments i.e. sports and extra lessons particularly for Parktown boys and Marist Brothers. It was also a challenge to administer the second the tests to

Parktown girls in September as they were writing tests during that week. Students were not required to write down their names on the test, but to indicate their house number as well as favorite colour. Some students were however unwilling to indicate their house number, with some students putting down their phone numbers. The purpose of writing down their house number and favorite colour was to enable the researcher to track the learners from pre test to post test. However, some learners changed their favorite colour from what they wrote in the pre test to the post test. An indication of their home language had to be included for the purpose of analyzing the results, as well as an indication of their population group. The spatial skills tests measured changes in spatial ability, before and after completion of GIS learning.

3. 3 Data Analysis and Interpretation Plan

The data gathered during the research was grouped into three main data sets comprising of data gathered from the three different schools. Performance on the spatial skills test was measured based on the total number of questions answered correctly. Results were coded using analytical codes which are representative of the main issues that have been raised in the research questions. Grouping the data using analytical codes allowed for the researcher to manage data while at the same time identifying relationships and patterns.

In order to achieve the research objectives, the following statistical analysis methods were used:

- Shapiro-Wilk test to test for normality in samples.
- Paired sample t-test: Was used to assess paired sample scores between pre- and post-test as well as to show that both the males and the females increased their spatial abilities significantly.
- Bartlett's test was used to verify equal variance.
- Analysis of variance (ANOVA): test statistic that was used to analyze differences among groups' means as well as variations within and amongst groups.
- Linear regression: Was done for the pre and post test before running ANCOVA to establish the linear relationship. One of the assumptions of ANCOVA is that x and y variables must have a linear relationship.
- Analysis of Covariance (ANCOVA): Was used to determine significant differences in score improvements between the different groups i.e. GIS and non-GIS.
- Post-hoc Test: Tukey's method was performed after the ANOVA method and Bonferroni method after ANCOVA to see where the differences had occurred.

The analysis started with descriptive statistics. The average score for each student group was analyzed using analysis of variance (ANOVA), analysis of covariance (ANCOVA) as well as a paired sample t-test. A t-test is a statistical test that is used when comparing the means of two groups (Kim, 2015). A paired sample t-test is a test that is used to determine whether the means of two of observations is zero. In this test each observation was measured twice resulting in pairs of observations. The sample formed two different groups, where each score in one group was paired with a score in the other group. The null hypothesis (H0) assumed that the average pair differences were not significantly different to zero. Bartlett's test is a test that was used to verify if populations had equal variances (Snedecor and Cochran, 1989). This is known as homoscedasticity or homogeneity of variances. Analysis of Variance (ANOVA) is a test statistic that was used to analyze differences among groups' means as well as variations within and amongst groups, while Analysis of Covariance (ANCOVA) analyzed whether the means of the dependent variable were equal across levels of a categorical independent variable, while controlling covariates which might not be of interest (Miller and Chapman, 2001).

An alpha level of 0.05 was used to assess differences and to see significant differences amongst the groups, the Bonferroni and Tukey's test were carried out to see where these differences occurred. The Tukey's test was done after the ANOVA analysis to compare all possible pairs of means and was based on the t-distribution. It assumed that observations were independent within and between groups, and that the data followed a normal distribution (Montgomery, 2013). It also assumed homogeneity. A write up of all the findings was done and presented in a report containing frequency tables, histograms and tables, all making up the research results in the final research report.

3.4 Map drawing strategies

Students were asked to draw a map based on the following scenarios: Pretest-"A relative of yours has come to pick visit your school. Unfortunately you are busy with sporting activities and cannot show her/him around. Draw a map to help your relative find some useful places. Your map should include the main administration block (including the principal's office), the staffroom, the tuck-shop, the toilets and the main hall. Also add a place that you particularly like at the school and one that you do not like. Show as much detail as you can." Posttest had the following scenario; "Create a map from your house to your school. Include prominent landmarks such as an event marking, an important stage of development or a turning point in history."The Spatial Geographic Knowledge model (Golledge et al, 1997) was used to classify the maps (see 2.5.1). Mapping strategies are said to bring out cognitive processes individuals use when creating a map (Lee and Bednarz, 2009).

Students' map drawing strategies were analyzed using a map sketching exercise. In the pretest, the students were asked to create a map of their school to help a relative who has come to visit the school. In the post test students were asked to create a map from their house to their school. Mental mapping are considered a depiction of an individual's cognitive map, which can be sketched by hand or is computerized, in drafting as well as labeling an already existing map. Thus this affords an insight into the way in which individuals produce and experience space, spatial aptitude as well as the dynamics of human-environment relationships (Gieseking, 2013). Kuiper states that survey maps are the final stage of the hierarchical steps in acquisition of spatial knowledge whilst Noordzij et al, 2006, suggest that cartographic map provide a way into survey knowledge, although it is more related to landmarks. However, Zhange et al (2012), states that route and cartographic map learning are not substantially different in the representation of features, meaning that they can produce comparable cognitive maps. Thus for this study the maps were classified according to the Spatial Geographic Knowledge model which contains three different components which are Landmark, Route and Survey (see 2.4.2), based on the classification method used in Tolhurst (2006). Landmarks are defined as distinctive items at fixed locations; routes as fixed sequences of locations, whilst survey knowledge had to do with integrating information from different sources into a single model (Gieseking, 2013).Fig 2 shows descriptions of each strategy.

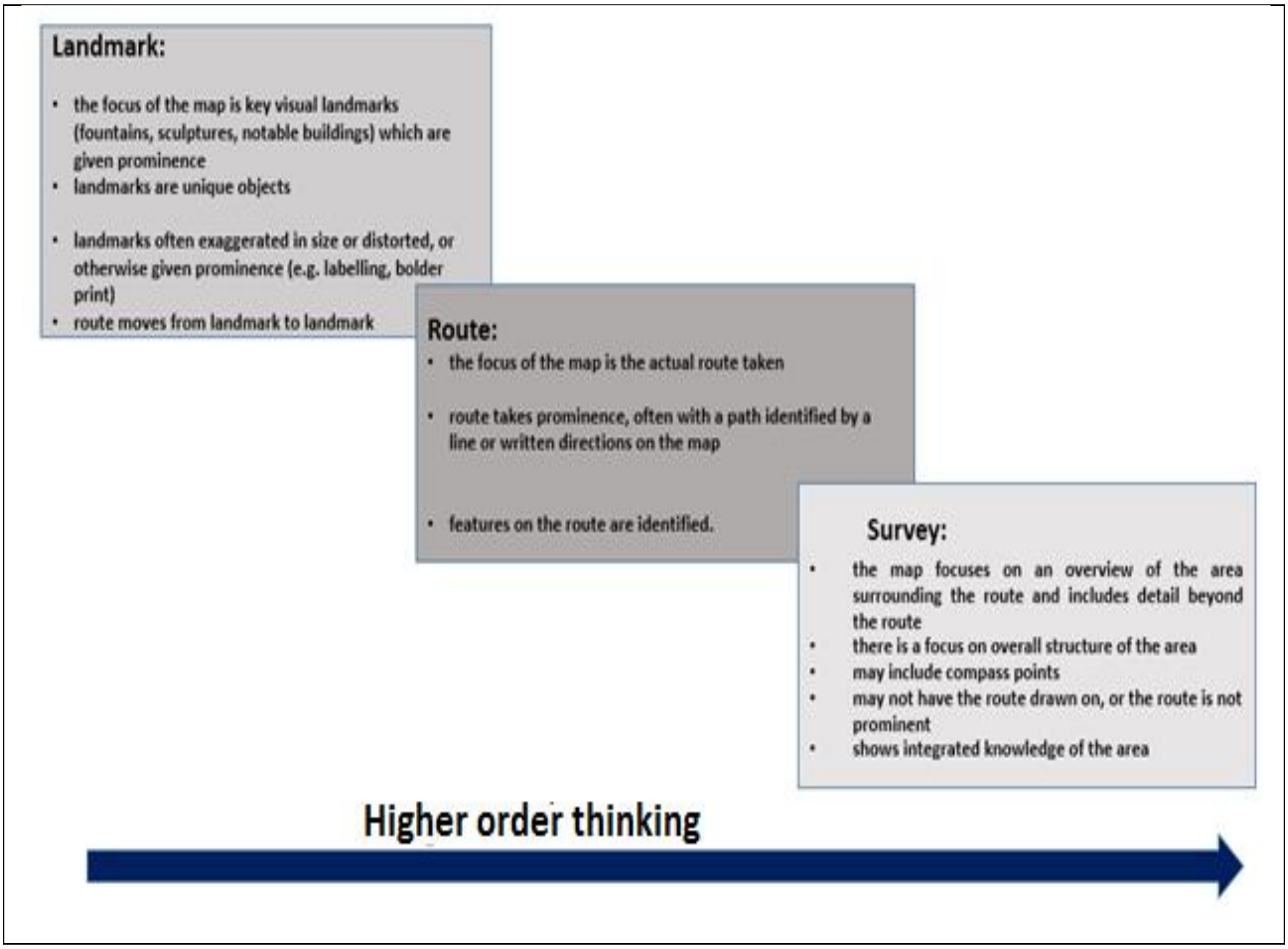
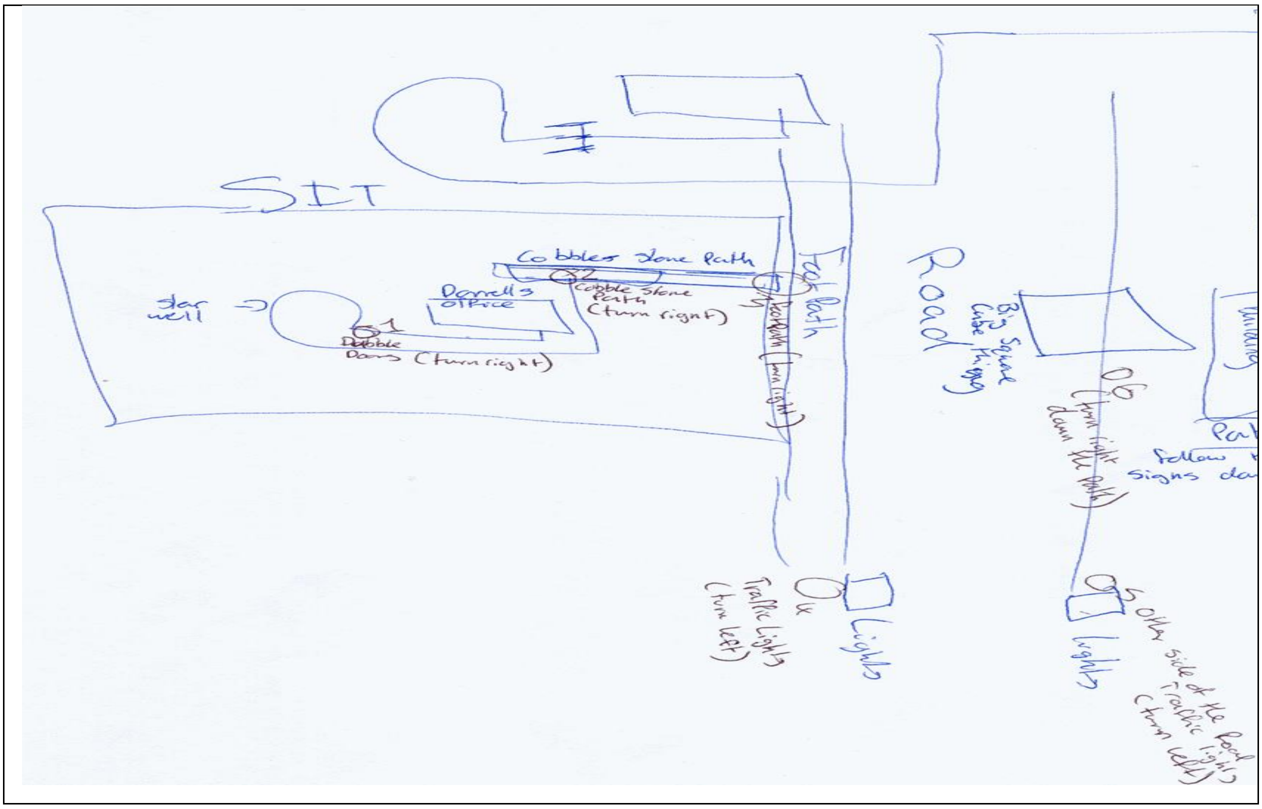


Figure 2: Descriptions and characteristics of map drawing strategies

(Gieseking, 2013)

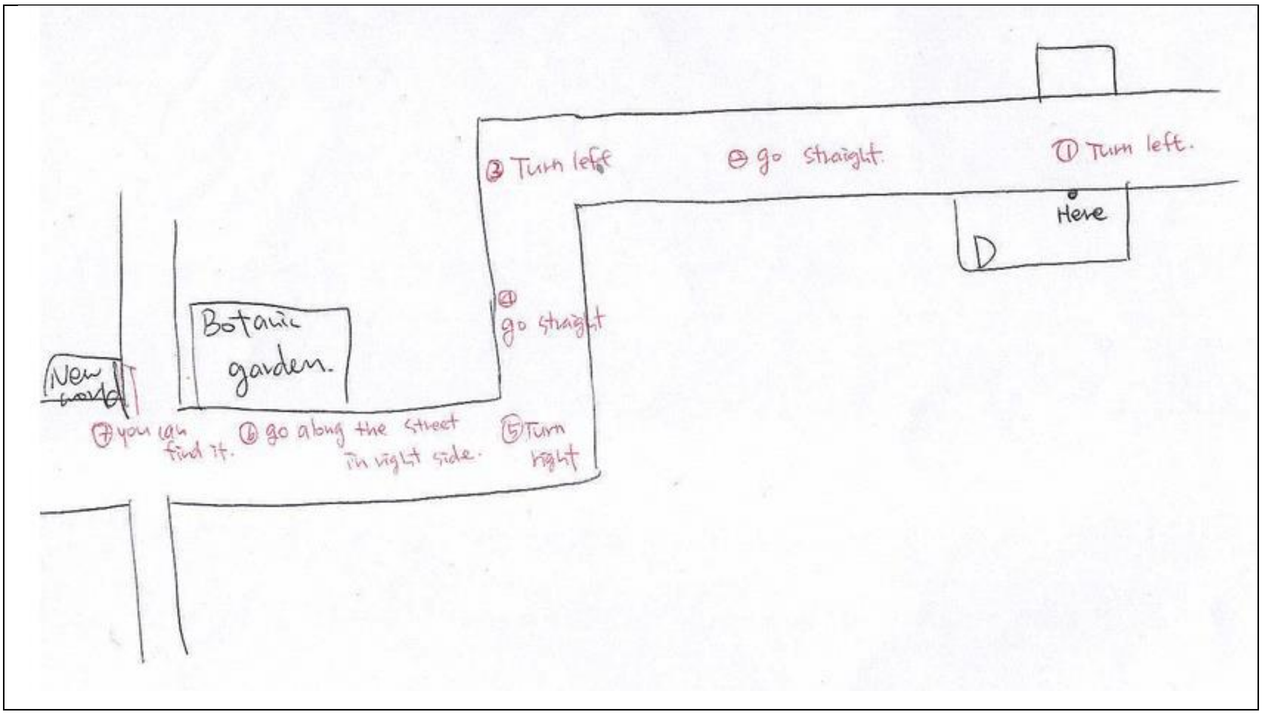
Figure 3 below show examples of the three map drawing strategies as indicate in Tolhurst, 2006.

Figure 3: Examples of landmark, route and survey maps



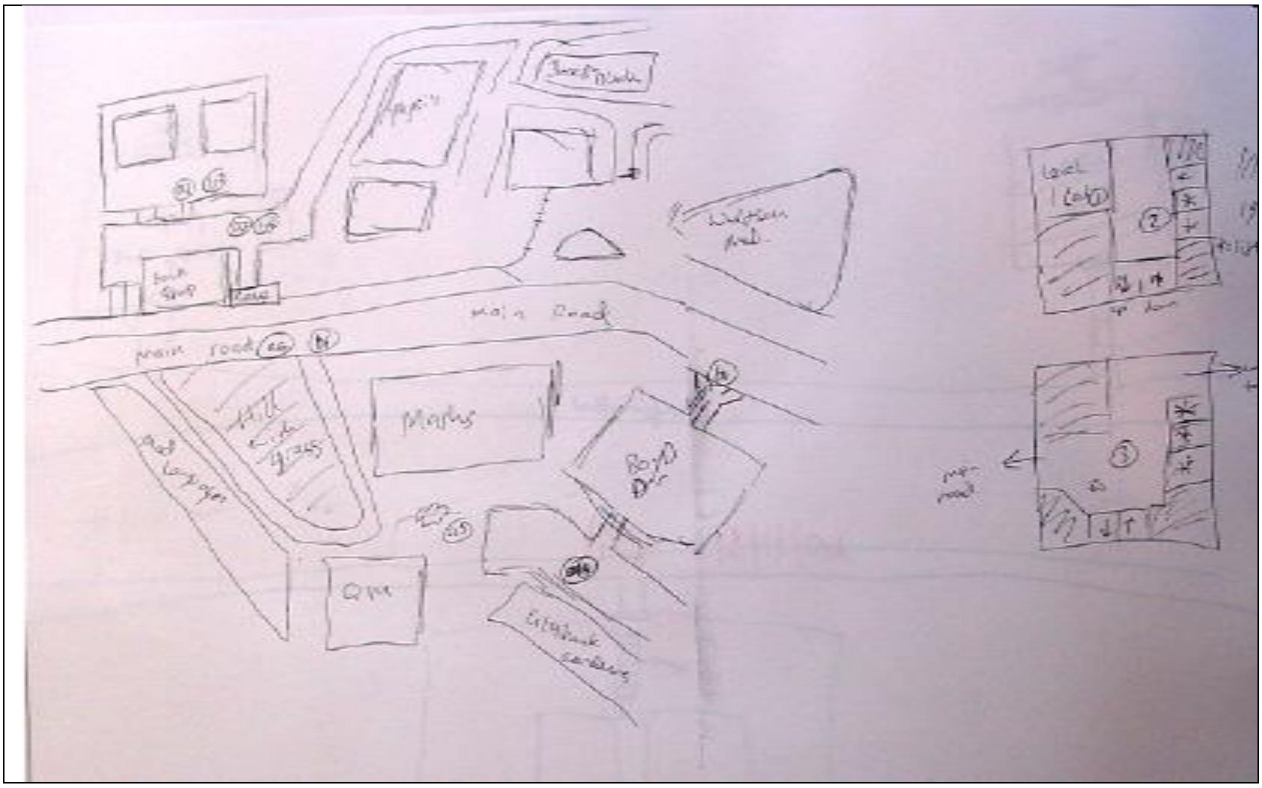
Landmark map

(Source: Tolhurst 2006)



Route map

(Source: Tolhurst 2006)



Survey map

(Source: Tolhurst 2006)

The students' map drawing strategies were classified as landmark, route and survey and any changes between the pre and posttest was analyzed. Identification of the following features under each category enabled the learners' maps to be classified: Landmark maps contained key visual landmarks such as notable buildings and prominent structures, and were often distorted in size and given prominence. A route map focused on the actual route taken to navigate from a certain point to the desired destination. The route map clearly highlighted directions given. Survey maps gave a detailed overview of the area surrounding, as well as details of features surrounding the proposed routes. This map included map features such as the scale, legend and north arrow. Students' abilities to link spatial features as well as inclusion of relevant land marks were analyzed.

3.5 Data analysis assumptions

1. This study assumed the learners' spatial abilities were measurable and that the spatial skills tests were valid.

2. This study assumed that learners' mapping drawing strategy were representative of their spatial problem-solving strategy.

3. This study assumed that GIS learning is a treatment that brings about differences in results between the pre- and post-tests.

4. Assumed that learners taught GIS achieve the learning objectives.

3.6 Research Ethics

Ethics are concerned with what is right and wrong hence the researcher carried out the research ethically in line with the University of Witwatersrand, Gauteng Department of Education (GDE) and South Africa rules and guideline, since learners who are minors were involved. The researcher overcame ethical dilemmas by protecting respondents, giving them dignity, and ensuring that the research is transparent; of high quality and that there was integrity in the research process. The researcher ensured informed consent from parents during the research, ascent from students, permission from the GDE, schools, School governing bodies (SGB) and all relevant stakeholders involved, and respected anonymity and confidentiality. Data will be retained for a period of five years. Feedback will be given on research outcome.

Chapter 4: Results

4.1 Introduction

Three schools, Parktown Boys' High School, Parktown School for Girls and Marist Brothers Linmeyer, located in the city of Johannesburg (Gauteng), took part in this study. This chapter gives an overview of all statistical and qualitative research outcomes obtained in this study. This includes an analysis of participants' test scores in the two tests to establish whether there were significant differences between the control and experimental groups. Table 1 below gives an overview of the overall statistics and parameters used in this study.

Table 1: Schools statistics and parameters

Schools	Population	Sample											
				Pre-test				Post-test				English 1st language speakers	
		Boys	Girls	GIS		None GIS		GIS		None GIS			
				male	female	male	female	male	female	male	female	yes	no
A	566	10	10	5	6	5	4	5	6	5	4	15	5
B	800	20	-	10	-	10	-	10	-	10	-	15	5
C	1000	-	21	-	11	-	10	-	11	-	10	17	4
TOTAL	**2366**	**30**	**31**	**15**	**17**	**15**	**14**	**15**	**17**	**15**	**14**	**47**	**14**

The table above show the overall statistics of the three schools involved in this study. An overall total of 61 students took part in the study. There were 31 females and 30 males, and of these 15 males and 17 females did Geography hence they completed GIS learning, and 15 and 14 females and males did not do Geography hence did not complete any GIS learning. School A had a total of 566 students, and total of twenty three grade 11 learners did Geography in 2017. A total of10females and 10 males respectively took part in both the pre and post tests respectively. School B had an overall population of approximately 800 learners and of these 78 did Geography. Of the 78 students doing Geography, only 10 students doing Geography and 10 no Geography students took part in the study. School C had a total population of over 1000 learners. The total number of grade 11 learners doing Geography was given as approximately 120.

However, only 11 Geography and 10 non Geography students took part respectively. A large number of English first language speakers took part in this study compared to none speakers which might have resulted in biased results. A total of 47 English first language speakers took part in the study and only 14 non speakers took part in the study. A variety of different languages including Afrikaans, isiZulu, Xhosa, Shona, Ndebele, Urdu, Sotho, Tswana, French and Greek were given as first languages.

4.2 Test Reliability

According to Baker and White (2003), the reliability is generally of concern when it comes to performance assessment. The reliability of these spatial skills test was done based on the internal consistency reliability method. This is a method requires neither does not allow for the splitting of items into halves (Walsh and Betz 2001). A high score indicate that the same variable is being measured (Walsh and Betz 2001).Table 2 below shows internal consistency and the range of Cronbach's alpha. The acceptable range is above 0.7.

Table 2: Cronbach's alpha and internal consistency

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

(Source: www.statisticshowto.com)

In this study, the reliability analysis of the spatial skills tests was done using Microsoft Excel software XLSTAT. A Cronbach's estimate of 0.714 was obtained, showing that the tests were reliable. Fig 4 below shows the XLSTAT outputs.

Cronbach's alpha	Standardized Cronbach's alpha
0.714	0.714

COVARIANCE MATRIX		
Variables	Pretest	Posttest
Pretest	25.333	13.517
Posttest	13.517	23.36339

Figure 4: Cronbach's alpha and covariance matrix

4.2Comparisons of group tests scores

Comparisons in test scores of the different groups were analyzed. Fig 4below shows the overall statistics of the pre and post test scores for the different groups. Fig 5 below shows a comparison of test marks between students who did GIS and students who did not do GIS, English first language speakers and those who do not have English as their first language, as well as test score differences between males and females. The Shapiro-Wilk test was carried out for the different samples to test for normality of samples.

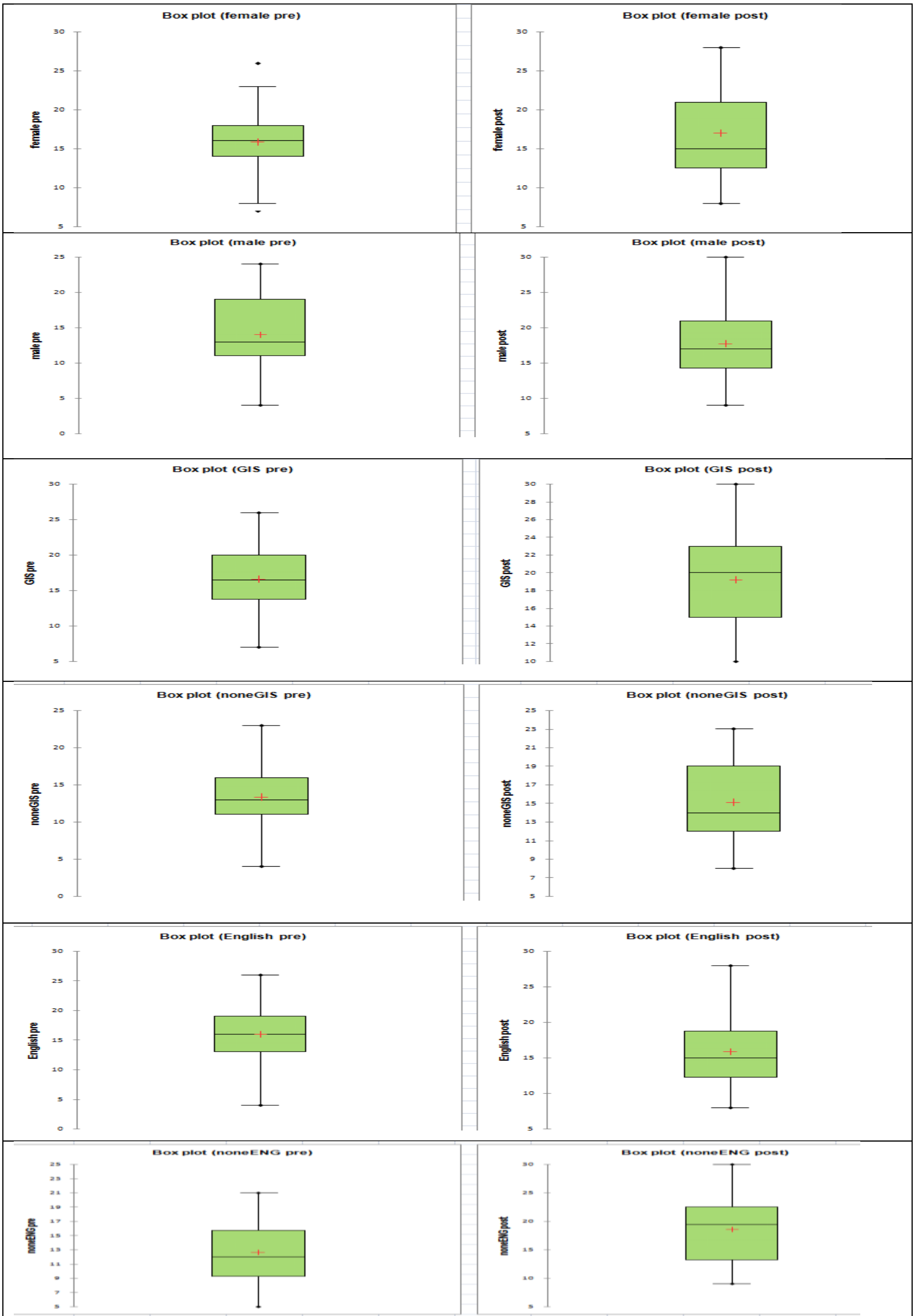


Figure 5: A comparison of pre and post test scores by groups

Table 3 below show the p-values obtained when the Shapiro- Wilk test was carried out for the different groups. The null hypothesis states that the sample follows a normal distribution. The test was carried out at 5% significance level. The higher the p-value obtained the more it follows a normal distribution (Thulin, 2014)

Table 3: Shapiro- Wilk test p-values for the different groups

Group	**p-value**
Male pre-test score	0.1433
Male post test score	0.693
Female pre-test score	0.244
Female post test score	0.0933
GIS pre test score	0.8621
GIS post test score	0.360
None GIS pre test score	0.7448
None GIS post test score	0.18177

All groups had a p-value greater that 0.05 indicating that the samples followed a normal distribution. The overall scores showed an improvement in post test scores for female students compared to the male students who showed an overall decrease in the post test scores. A wider range of scores distribution was also observed for the students who did not take GIS showed a marked improvement in their test scores from the pre test to the post test. English first language speakers did not show any significant improvement in their score marks, from the pre test to the post test, however, there was a significant improvement in the score marks for students who did not do GIS, however overally the scores were not higher than the scores of the students who did GIS learning. However, the sample size for the students who are English first language speakers was much higher than that of non speakers. This might have influenced the outcome of the results.

4.2.1 Analysis of variance (ANOVA)

This is a test statistic used to analyze differences among groups' means as well as variations within and amongst groups. This makes a comparison of the variability to the random variability, to see if there are significant differences. SAS 9.3 EG software was used for this analysis. A comparison of pre-test scores amongst the groups was able to determine learners' spatial abilities before GIS learning. Analysis of Variance (ANOVA) was applied to the pre test scores of the different groups. These were gender, males and females, English first language speakers and none speakers, as well as students who did GIS and those who did not do GIS. The table below shows an overall p-value of 0.16, which is greater than 5% significance level. This shows that there were no significant differences amongst the means of the different groups.

Table 4: ANOVA pre test p-value

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	2	201.262	100.631	4.4260.016	
Error	58	1318.738	22.737		

Table 5 below shows the ANOVA p- values of the different groups, as well as the interaction of the different groups. It shows the groups which had means which were not significantly different (highlighted in blue) and groups which had mean which were significantly different. The values highlighted in blue show the groups that showed no significant differences of the means in the pre test scores. A p-value of 0.1132, which is greater than 5% significance level, was obtained for gender, indicating that there were no significant differences within the gender groups. No significant differences of the means were also found between the interaction of English first language speakers and none speakers, gender and the GIS and none GIS groups, as well the gender and language groups. Significant difference of the means was obtained for the GIS and none GIS groups in the pre test scores which had scores of less than 0.05.

Table 5: ANOVA pre test scores by groups

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Gender	1	51.4236559	51.4236559	2.59	0.1132
GIS/ none GIS	1	149.5683384	149.5683384	7.54	0.0082
English none	1	23.6979327	23.6979327	1.19	0.2793
Gender*GIS/ none GIS	1	14.4953058	14.4953058	0.73	0.3964
Gender*English/ noneEng	1	12.2511548	12.2511548	0.62	0.4354
GIS none*English /none Eng	1	197.3335470	197.3335470	9.95	0.0026

Tukey's method was then used as a post-hoc to see which groups were significantly different and which was not. The Tukey's test is done after the ANOVA analysis to compare all possible pairs of means and is based on the t-distribution. It assumes that observations are independent within and between group, and that the data follows a normal distribution (Montgomery, 2013). It also assumes homogeneity. Null hypothesis (H_0) is that all means are from the same population. Table 6 below shows the post-hoc results using the Tukey's method. There were significant differences between the means of the gender group and the English first language speakers and none speakers' group.

Table 6: Tukey's method outputs

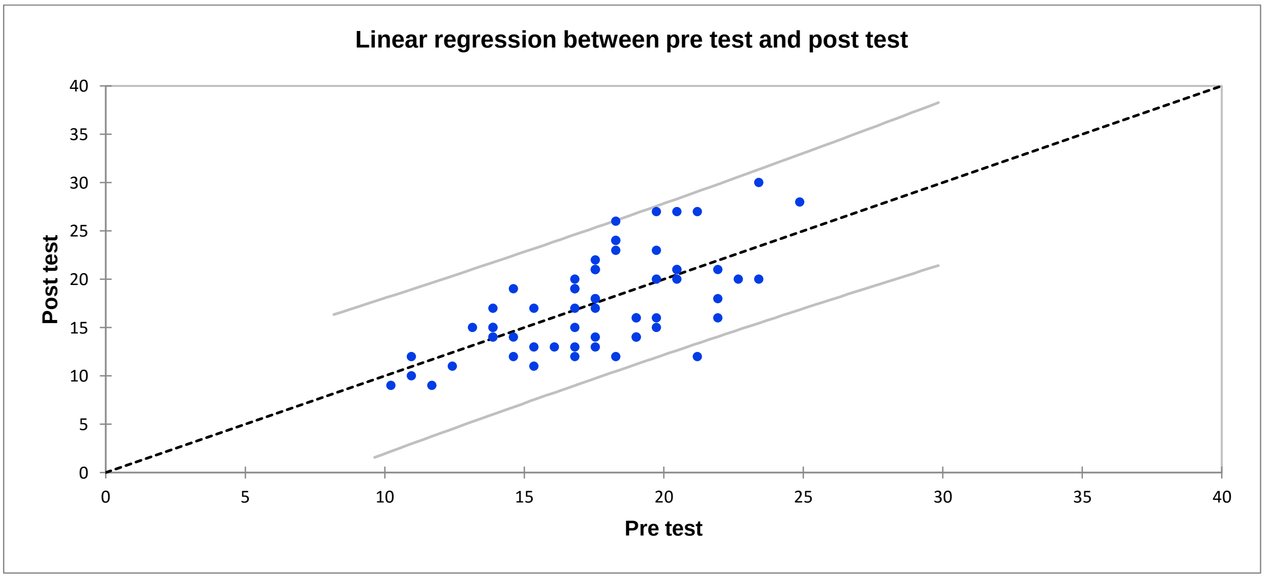
Comparisons significant at the 0.05 level are indicated by ***.				
Gender*English/ non Eng	Difference Between Means	Simultaneous 95% Confidence Limits		
1 - 2	3.364	0.908	5.820	***
2 - 1	-3.364	-5.820	-0.908	***

The ANOVA test showed significant differences within most groups in the pre-test scores, greater significance was observed between the GIS and non-GIS groups. This means that the differences in the means were greater between these groups.

4.2.2 Analysis of covariance (ANCOVA)

ANCOVA analyses whether the means of the dependent variable are equal across levels of a categorical independent variable, while controlling covariates which might not be of interest (Miller and Chapman, 2001). Assumptions of ANCOVA are that the covariate and dependent variable are independent, and that the covariate and independent variable have a linear relationship. Linear regression using Xlstat was carried out for the pre and post tests for the GIS and none GIS user groups. The pretest was used as a covariate because it correlates with the posttest. Stevens (2002), states that the rule when choosing a covariate is to look for measures that correlate with the outcome and have little inter-correlation. Fig 6 below shows a positive relationship between the pre-test scores and the post test scores. This fulfills the assumption of the ANCOVA test that there should be a linear relationship between the independent variable which was the pretest and the dependent variable, the post test.

Fig 6: Linear regression between pre and post test



ANCOVA was then carried out using SAS 9.4 software. ANCOVA was carried for both males and female doing GIS as well as the none-GIS group. There was a difference in the test scores for all groups during the experimental period. Analysis of covariance (ANCOVA) was used to see if there were significant differences between the test scores of the groups. ANCOVA was applied to the post-tests of the different groups and the pre-test was used as a covariate and the posttest as the dependent variable. The pretest score acts as a control group. The F statistic value of 2.28 (p-value 0.0723), indicated that no significant differences existed between the post test scores of the different groups (see Table 7 below).

Table 7: ANCOVA results using the pre test score as the quantitative variable and post test score as the dependent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	236.982354	59.245588	2.28	0.0723
Error	56	1457.247155	26.022271		
Corrected Total	60	1694.229508			

After performing the ANCOVA test, a post-hoc was done using the Bonferroni method. This was done to further analyze differences within the groups. The Bonferroni method showed female and male students showed no significant differences in their test scores from the pre test to the post test scores. A p-value of 0.6070 was obtained showing that there were no significant differences in the test scores of the different genders. The SAS output is shown in table 8 below.

Table 8: Bonferroni method outputs

GIS/ non-GIS	posttest LSMEAN	H0:LSMean1=LSMean2 Pr > |t|
Gender	Post LSMEAN	H0:LSMean1=LSMean2
		Pr > |t|
female	16.8556248	0.6070
male	17.5445829	

4.2.3 Paired-sample t-test for the GIS and none GIS students

A t test is a statistical test that is used when comparing the means of two groups (Kim, 2015). A paired sample t-test is a test that is used to determine whether the difference of the means of the two different sets of observations is zero. In this test each observation is measured twice resulting in pairs of observations. The sample forms two different groups, where each score in one group is paired with a score in the other group. In this study the paired sample t-test was used to do a comparison of the pre and posttests. Students who did GIS learning did increased their test significantly (p-value = 0.0457 at 5% significance level), and their scores were generally higher than the scores of the students who did not do

GIS learning. On the other hand, learners who did not do GIS learning showed an increase in their scores from the pretest to the post test, although they obtained a p-value of 0.1824 which not statistically significant. The p-values are shown in tables 9 and 10 below respectively.

Table 9: Paired sample t test GIS group

N	Mean	Std Dev	Std Err	Minimum	Maximum
32	2.6563	7.2183	1.2760	-12.0000	16.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
2.6563	0.0538	5.2587	7.2183	5.7869	9.5966

DF	t Value	Pr > |t|
31	2.08	0.0457

Table 10: Paired sample t test none GIS group

N	Mean	Std Dev	Std Err	Minimum	Maximum
29	1.7931	7.0629	1.3115	-10.0000	16.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
1.7931	-0.8935	4.4797	7.0629	5.6050	9.5522

DF	t Value	Pr > |t|
28	1.37	0.1824

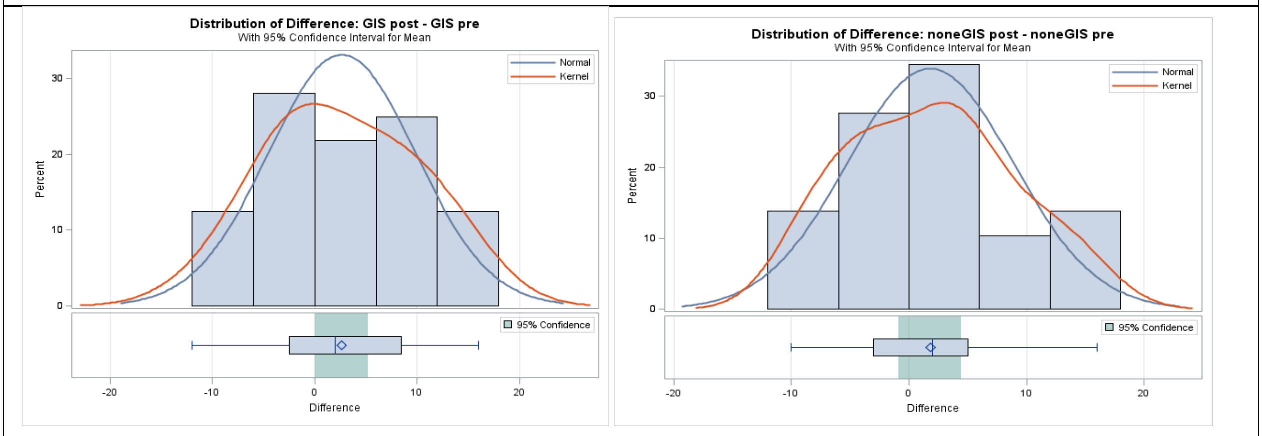


Figure 7: Comparisons of the distribution of t test scores for GIS and none GIS differences

The general trends in the distribution of the scores showed a left skewed distribution for none- GIS group and a more normal distribution for the GIS group in the score differences for the pre and posttests. To see if some components of the spatial skills test had a larger impact than others, average scores between the group that did GIS learning and the group that did not do GIS learning were observed and compared. The different questions types were grouped into a total of thirteen questions. These included map overlay, finding the best location, references, imagining maps from oral descriptions, identification of spatial data as well as creating a contour map. However, only four questions which had a huge impact were analyzed in this study. The GIS group showed a marked improvement in finding best location, referencing maps, identifying of spatial maps as well as creation of contour maps. Table 11 shows the score differences for selected pre and posttest items.

Table 3: Pre and posttest differences for selected items

Item type		Pre test	Post test	Differences in scores
		mean	mean	
Verbal map description	GIS	0.375	0.5	0.125
	None GIS	0.25	0.2413	-0.008
Best location	GIS	0.5	0.637	0.137
	None GIS	0.517	0.557	0.4
Spatial correlations	GIS	0.4375	1	0.5625
	None GIS	0.48	0.862	0.382
Spatial data type identification	GIS	1.437	0.965	-0.471
	None GIS	1.103	0.6555	-0.44

From this observation a conclusion can be reached that GIS learning can aid students find the best location taking into account spatial effects, connect environments which are spatially correlated, as well as create maps from verbal descriptions. However, negative differences were obtained in identification of spatial data types by both GIS and none GIS students, as well as creating maps form verbal descriptions from by none GIS students. Most students who did not do GIS learning did not attempt the question of contour maps as well as identification of spatial data, indicating a general lack of understanding. Physical geography which is part of the geography curriculum taken by GIS learners might have contributed to the students' spatial abilities (Lee and Bednarz, 2009).

4.3 Score comparison by gender

Another objective was to see determine if gender had an effect on the students' scores for the spatial skills test. Table 11 summarizes the average scores in the pre- and post-test respectively, and these scores distribution by gender.

Table 4: A comparison of pre and post test by gender

		Pre- test		Post- test		**Score difference**	p(paired sample t-test
	Number of learners	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**		
Male	30	14.2	5.822	17.66	8.0498	3.4	0.0206
female	31	16.194	3.872	17.00	5.453	3.3	0.3613

Table 11 shows that males did show significant differences in the means of their pre and posttests. Males had a p-value of 0.0206. On the other hand, females had a p-value which was more than the 5% significance (p-value 0.3613) indicating that there were no significant differences. Overall, males scored slightly higher than females in both the pretest and the post test. Fig 7 shows the distribution of the score differences for males and females, for both the pre and posttests.

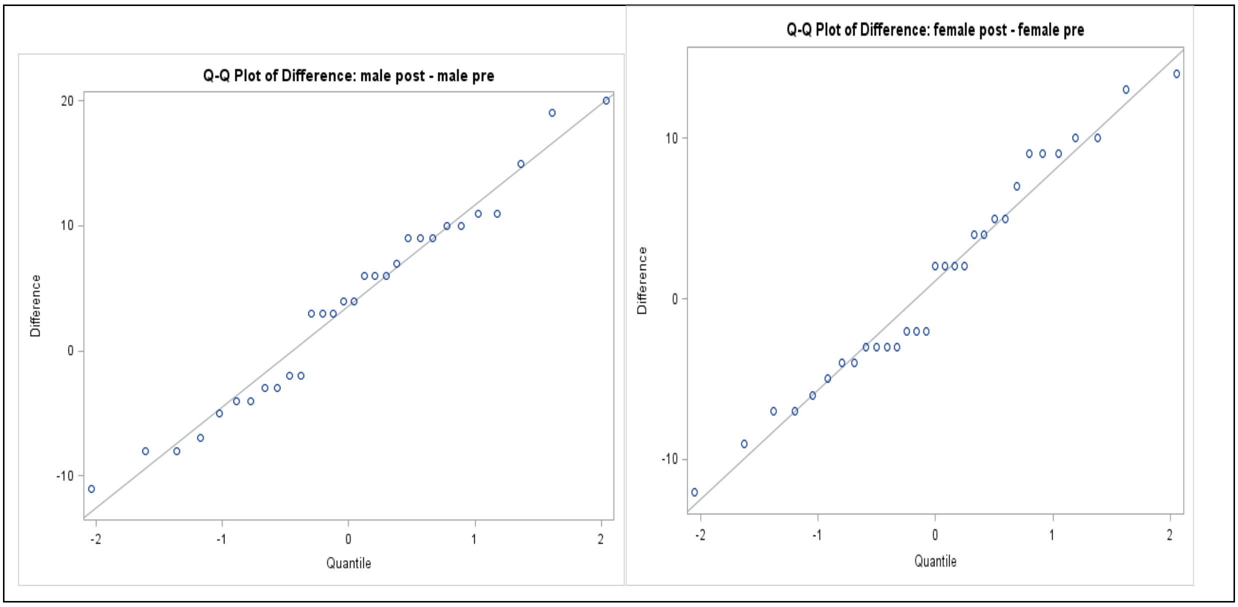


Figure 7: Q-Q plots showing a comparison of score differences between the genders

Fig 8 shows scattergrams of the range of scores for the males and the females, for the pretest and the post test, as well as the mean and median. Not much difference was observed between the differences in the average scores of the males and females for the pre and posts tests. Fig 89 further shows the general distribution of the tests scores for the different genders.

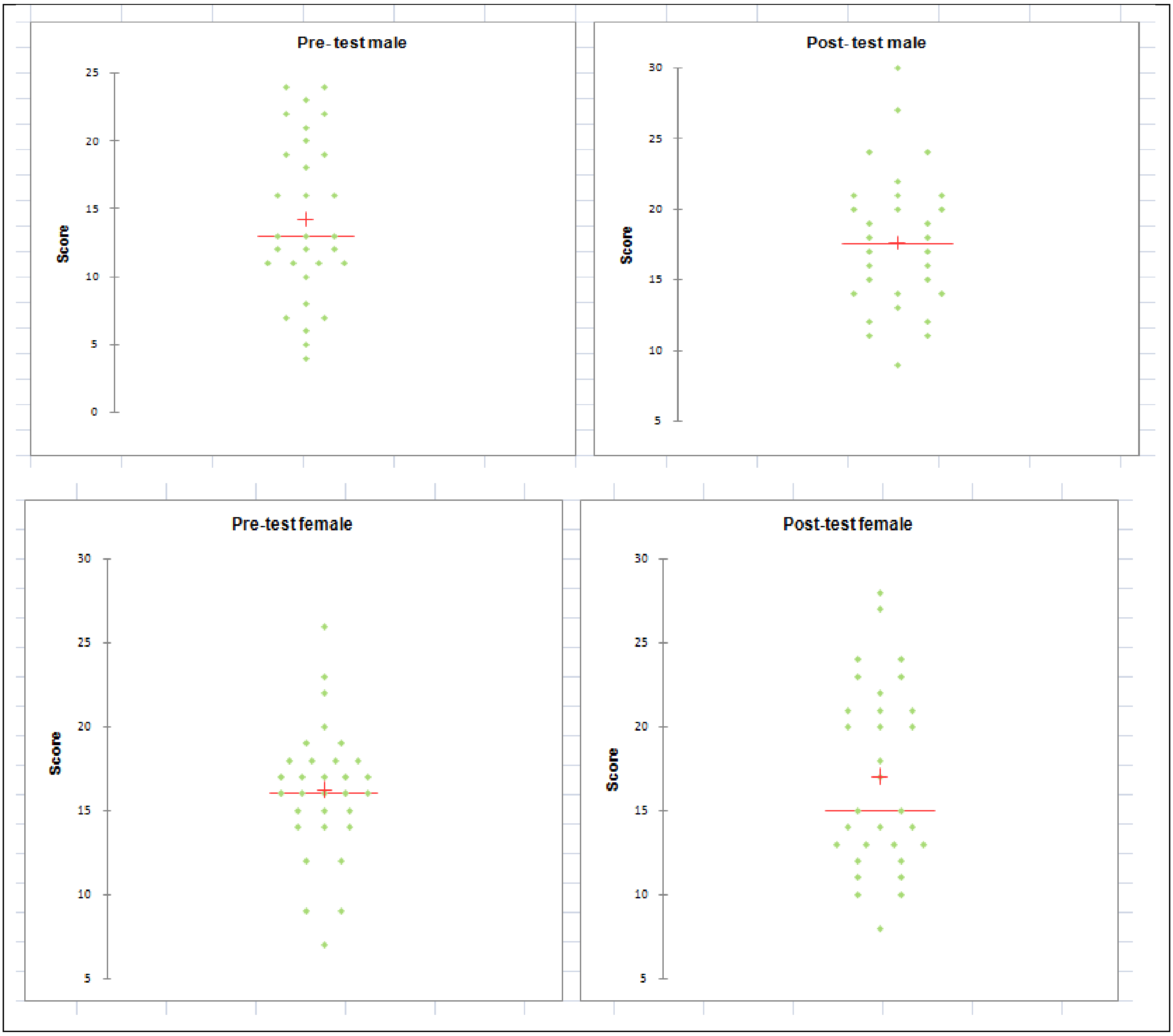


Figure 8: Scattergrams showing distribution of pre and post test scores based on gender

4.4 Score comparison by Language

A paired sample t-test was also carried out to see if there were significant differences between the English first language speakers and none speakers. There were no significant differences in the means of the pre and post tests scores for the English first language speakers as seen in table 12 below. A p-value of 0.4302 was obtained which is greater than 0.05.

Table 5: Paired sample t test output for English first language speakers and none speakers

English first language speakers

N	Mean	Std Dev	Std Err	Minimum	Maximum
42	0.8571	6.9723	1.0759	-12.0000	15.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
0.8571	-1.3156	3.0299	6.9723	5.7369	8.8909

DF	t Value	Pr > |t|
41	0.80	0.4302

None speakers

N	Mean	Std Dev	Std Err	Minimum	Maximum
18	-5.9444	9.2893	2.1895	-20.0000	8.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
-5.9444	-10.5639	-1.3250	9.2893	6.9706	13.9260

DF	t Value	Pr > |t|
17	-2.71	0.0147

However, for none speaker group there were significant difference between the means of the pre and post tests scores. The smaller sample size of the English first language non speakers could have had an effect on the outcome, since the sample size was half the number of learners in the English first language speakers group. Hence caution had to be taken when interpreting the results.

4.5 Analysis of the Map drawing skills

Students' map drawing strategies were analyzed using a map sketching exercise. In the pretest, the students were asked to create a map of their school to help a relative who has come to visit the school. In the post test students were asked to create a map from their house to their school. Mental mapping is considered a representation of an individual's cognitive map, hand sketched or computerized, in drafting as well as labeling an already existing map. Lee (2005) states that mapping strategies show insight into the cognitive processes individuals use to operate in their environment. Thus, this affords an insight into the way in which individuals produce and experience space, spatial intelligence as well as the dynamics of human-environment relationships (Gieseking, 2013). An analysis of the maps based on the method used by Tolhurst et al (2014) was applied.

4.5.1 Classification of Map-drawing Strategy

The researcher and two other individuals worked individually to classify the maps into landmark, route and survey, based on the Spatial Geographic knowledge model. Information given in fig 8 was used to place the maps into different categories. A comparison was done and an overall accuracy percentage of approximately 82% was obtained. This was obtained by calculation the percentage of a total of 51 maps agreed on by all three individuals, divided by the total number of pre and posttests. Although most maps were easy to classify, some learners' maps fell into more than one category and were difficult somehow difficult to classify. There were also many cases of missing maps, whereby some students did not draw the maps.

This section takes into account only the students who answered the map drawing questions. A total of 43 out of 61 drew a map in the pretest, and a total of 35 students out of 61 drew maps in the post tests. A reason for the decrease could have been the busy schedule during the time when the test was written, with some students pre-occupied with class tests which were being written during that week, as well as sporting fixtures that some learners had to attend after the test. Examples of the different maps are given below. It should also be noted that the map drawing scenario in the pretest, whereby students had to direct a relative to places around the school, would be biased towards the landmark strategy since it was focused around the school. The posttest question which involved drawing a map from the students' house to the school would in fact favor the route strategy. The table below summarizes the map drawing statistics for the pre and post tests for the different schools.

Table 6: Number of maps in different categories

School		**Map Strategy**											
		Pre test						**Post test**					
		Landmark		**Route**		**Survey**		**Landmark**		**Route**		**Survey**	
		***G**	***nG**	**G**	**nG**	**G**	**nG**	**G**	**nG**	**G**	**nG**	**G**	**nG**
A	Male	2	2	1		2		1	1	1		-	
	Female	3	2	1			1	1	3	1	1	-	
	*missing	6						11					
B	male												
	female	13	7					1	3	3	2	3	1
	missing	1						6					
C	male	3	1	1	1	3		4		7		2	
	female												
	missing	11						6					
TOTAL (excluding missing maps)		**21**	**12**	**3**	**1**	**5**	**1**	**7**	**7**	**12**	**3**	**5**	**1**

**missing – for missing maps*
**G- GIS*
**nG-non GIS*

Examples of the different maps in these categories are illustrated below.Fig 8 below shows an example of a landmark map. The main focus of these maps is the prominent features which are highlighted and sometimes exaggerated in size.

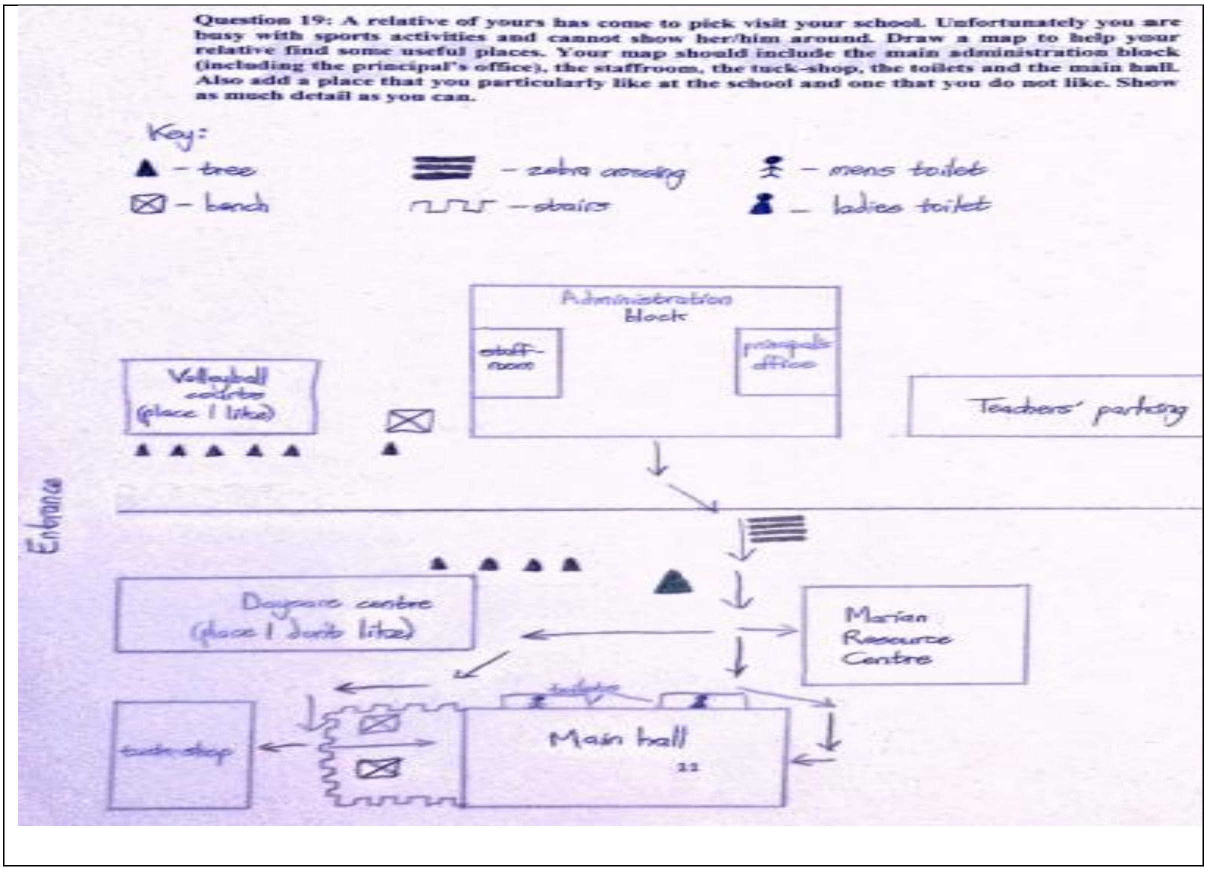


Figure 3: Landmark mapping strategy

The route map

The main focus of this map is the route very little information is provided about the surroundings. Some land marks can be included but the main focus is the route.

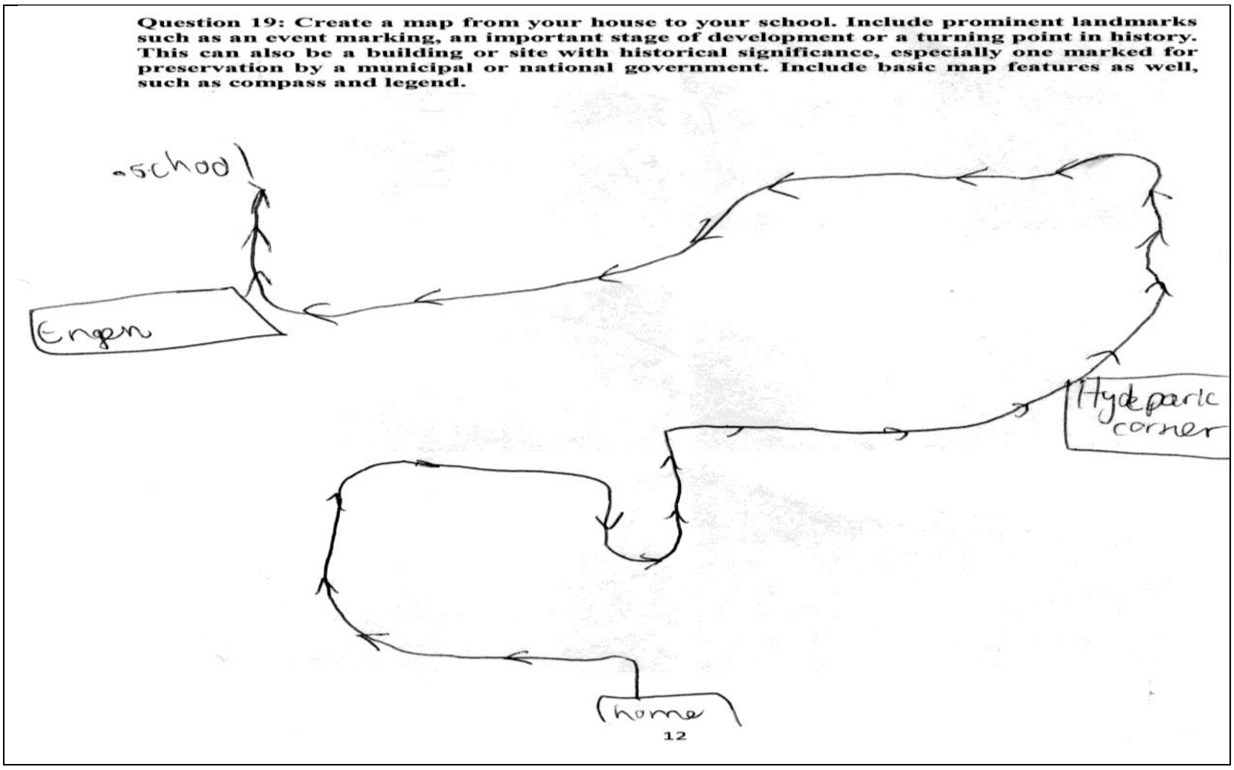


Figure 4: Route mapping strategy

The survey map

This map includes detailed information about the surroundings as well as the route. It gives survey information.

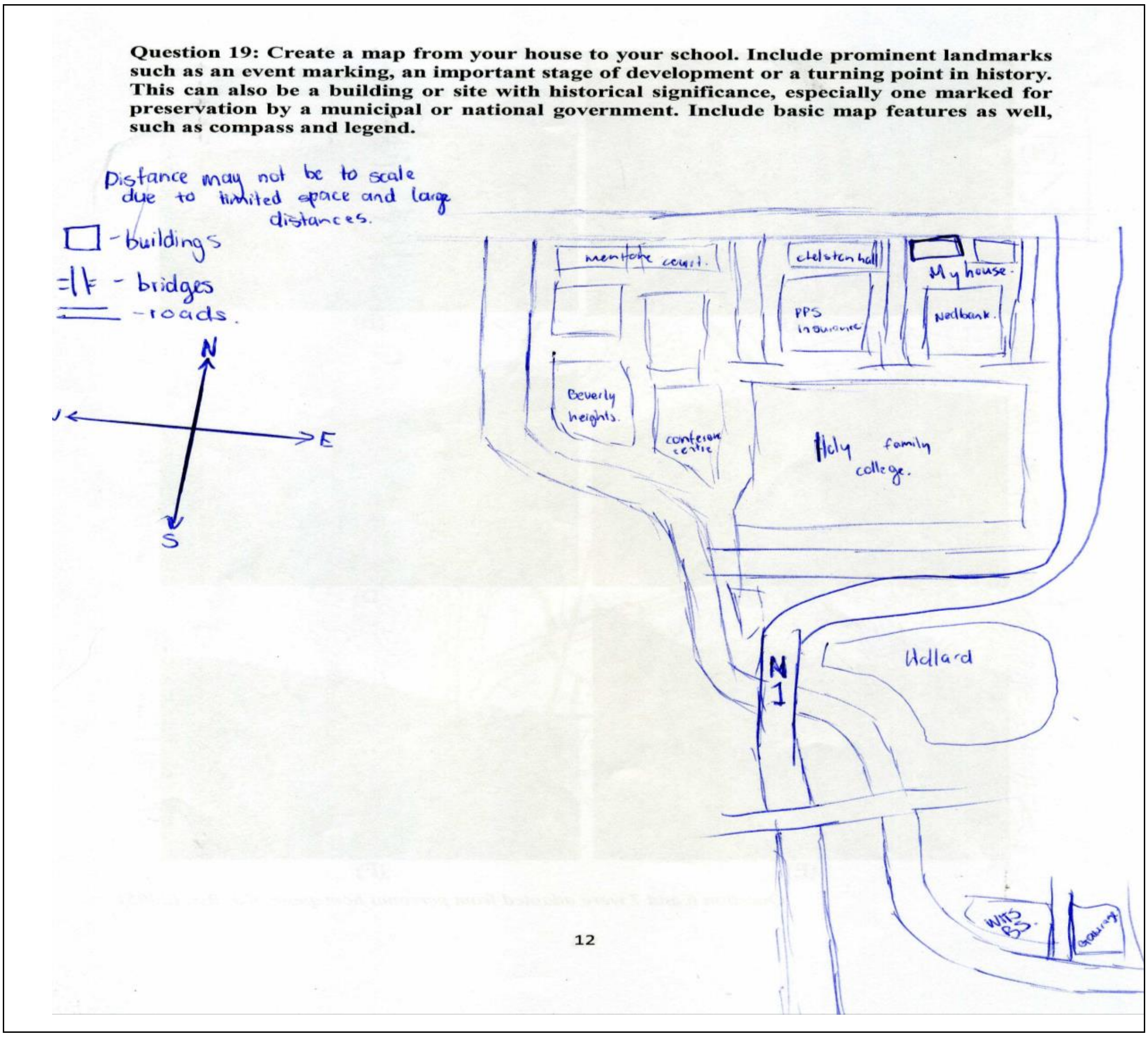


Figure 5: Survey mapping strategy

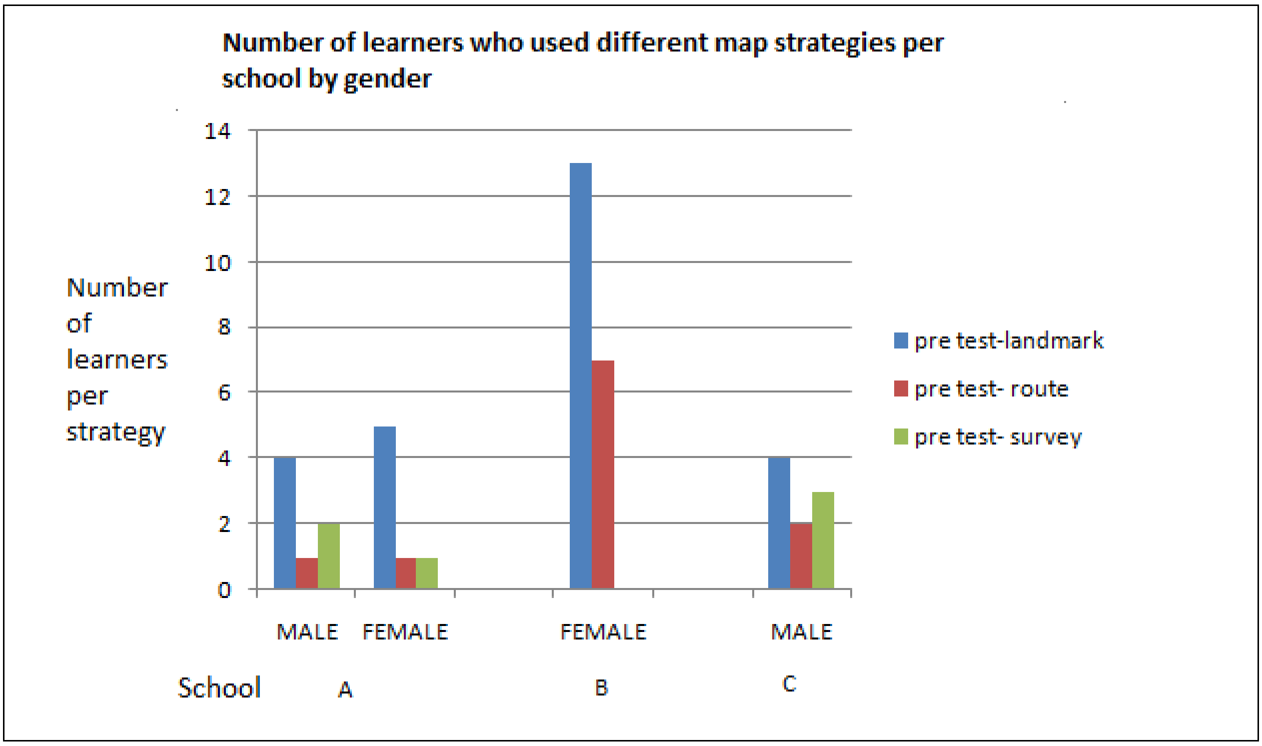
4.5.2 Comparisons of the different map drawing strategies

The different strategies noted could have resulted from different spatial cognitive abilities. Qualitative data given at the beginning of the test showed the land mark method preference amongst the females and the route method amongst the males. Students who travelled by car used mostly the route method, whilst those who walked or used the bus also used mostly the route method. No differences were seen between English first language speakers and none speakers in terms of map drawing strategies, hence no further analysis was done. o significant differences were noted between the findings of the map drawing strategies are contrary to research by Lee and Bednarz (2009) and Bruin et al (2000), who did not find significant differences in make drawing strategies for the different genders, as well as the GIS and none GIS groups.

Not much difference was noted between the GIS group and none GIS group in terms of choice of strategy. However, landmark strategy was mostly used for both the pre and posts test although the post test was more related to the route strategy since it involved movement from home to school. The survey method was used mostly by the GIS group, and most maps drawn during the post test showed much more detail in terms of map features and landmarks. This could have been as a result of cartography learning in Geography by the GIS as most of the maps drawn in the post tests indicated the features of maps which include the north arrow, legend and compass. The map given below illustrates this.

4.5.3 Change of map drawing strategy from pre to post test.

A total of 35 learners completed the map drawing task in the post test. A total of 74% (26 out of 35) learners changed their map drawing strategies from the pre test to the post test. It is assumed that GIS learning can change map drawing strategies from landmark which is considered a low order strategy (Gieseking, 2013), to route then survey which is considered higher order spatial knowledge. This trend was observed in the GIS group which shifted from landmark to route strategy. However, not a lot of changes were observed in the none-GIS groups. The maps below show changes in map drawing strategies. Some learners changed from survey to landmark, whilst most students who did GIS learning added map features in their posttests. The reason for this could be the teaching of map work which is part of the Geography curriculum. Fig 11 shows a comparison of the changes in map drawing strategies of the different genders on the different schools.



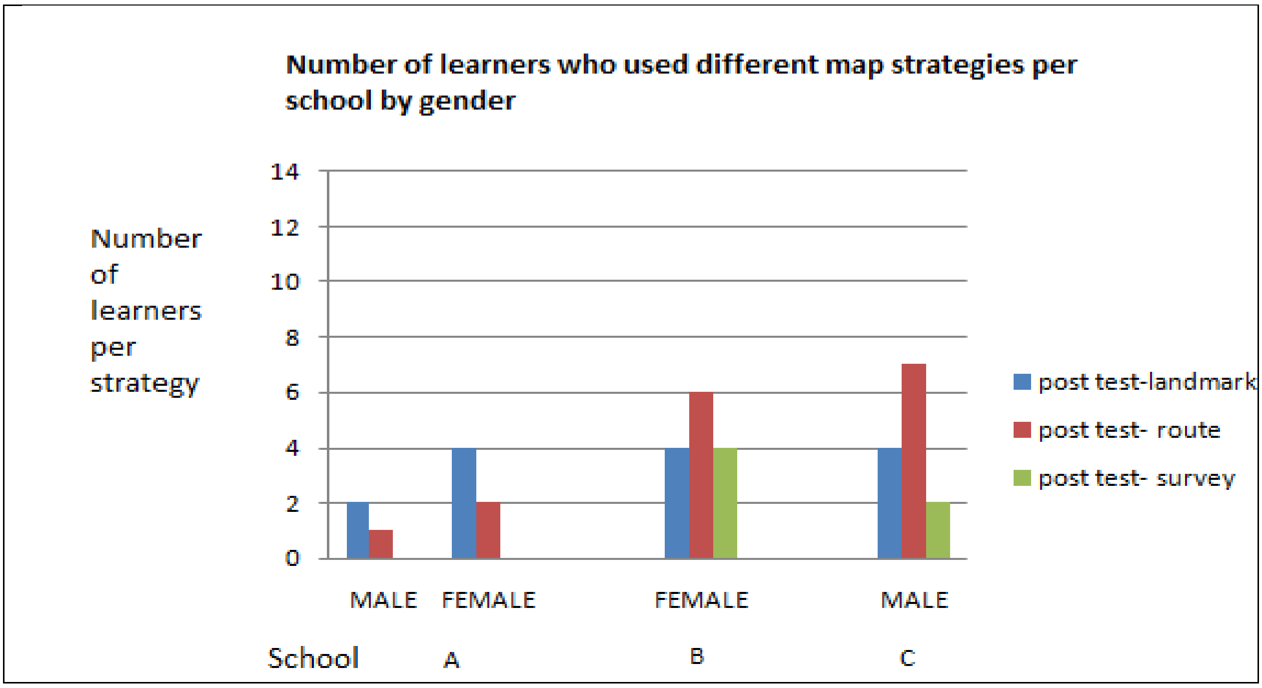
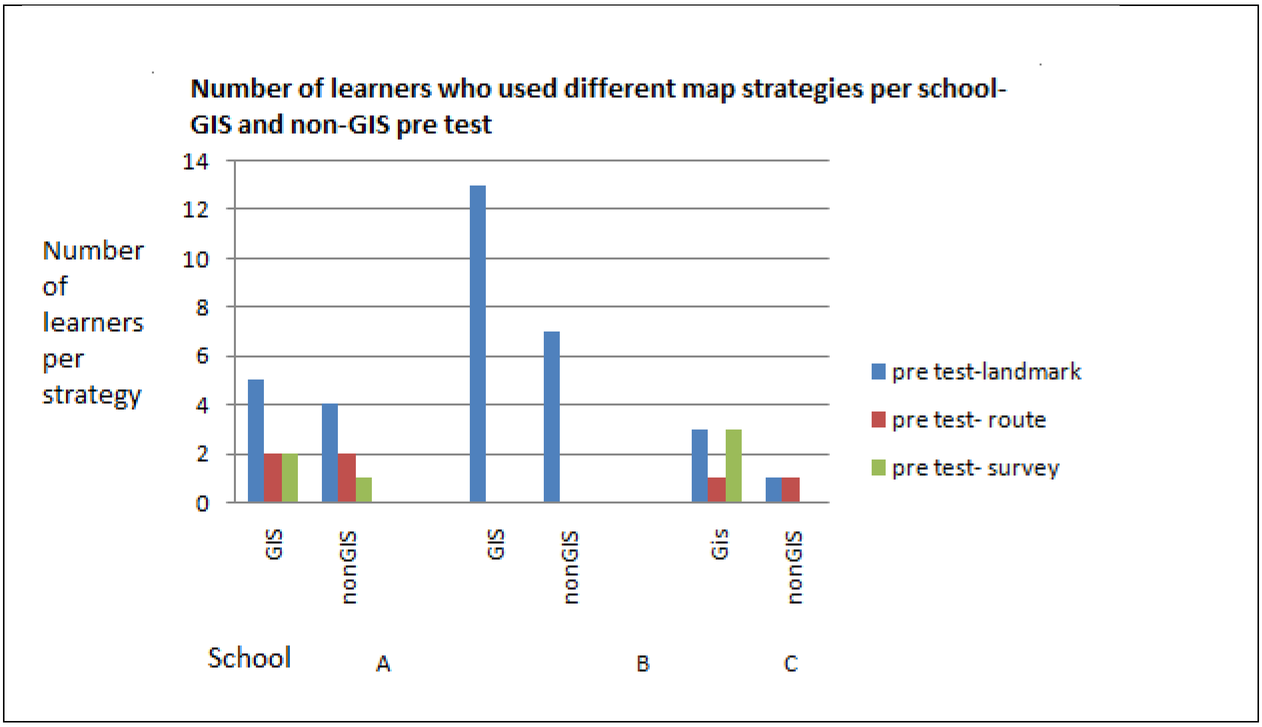


Figure 6: Changes in map drawing strategies for the males and females

From the graphs it can be seen that most females used the land mark strategy for both the pre and post tests, although there were some who changes to the route and survey strategies. For the males, route strategy dominated as the strategy of choice for the map drawing strategy in the post test. The reasons for these differences might be that males view the maps from a global perspective, which is the route pattern, whist the females are said to focus on local features, thus use the land mark strategy (Coluccia et al. 2007). This hypothesis is further supported by Colucia et al. (2006), who state that roads for part of a whole global configuration and that map learning and real world spatial orientation strategies would involve a network of road interlinked than single isolated road detached from the surroundings. The observations in this are also supported by several researchers (Brown et al., 1998; Dabbs et al., 1998; Saucier et al. 2002), who observed that males prefer configurational strategies (route methods), whilst females would rather procedural strategies since they pay more detail to their surroundings.



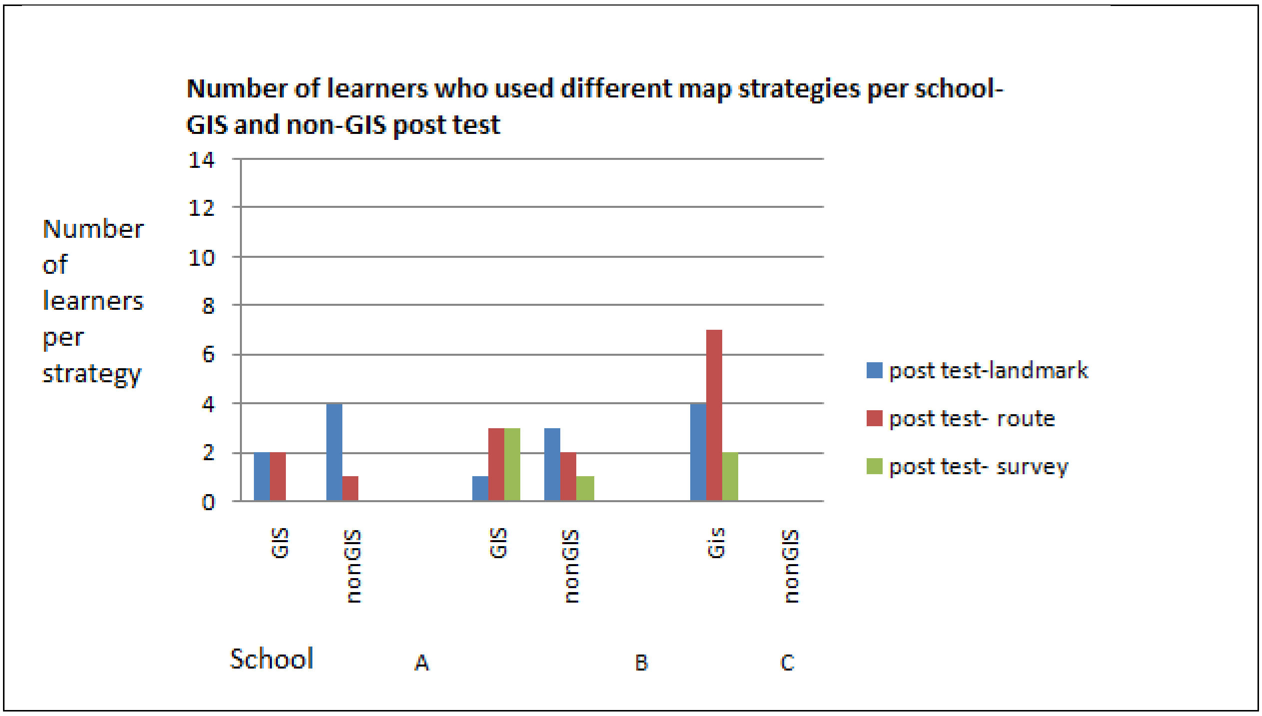
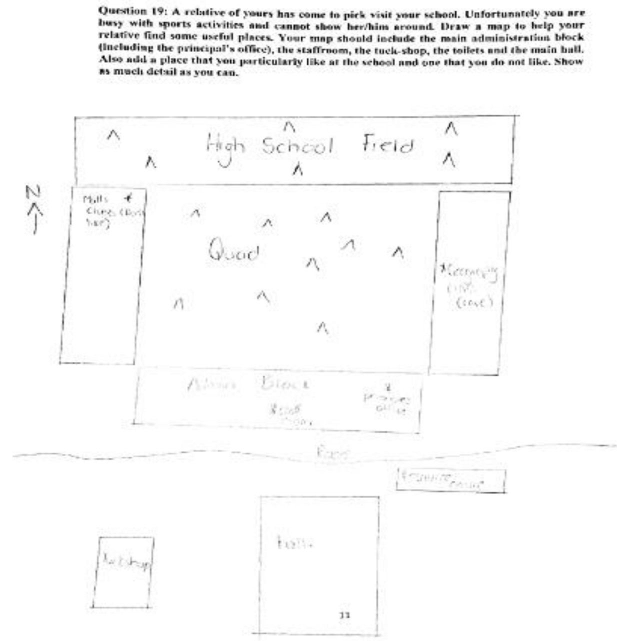
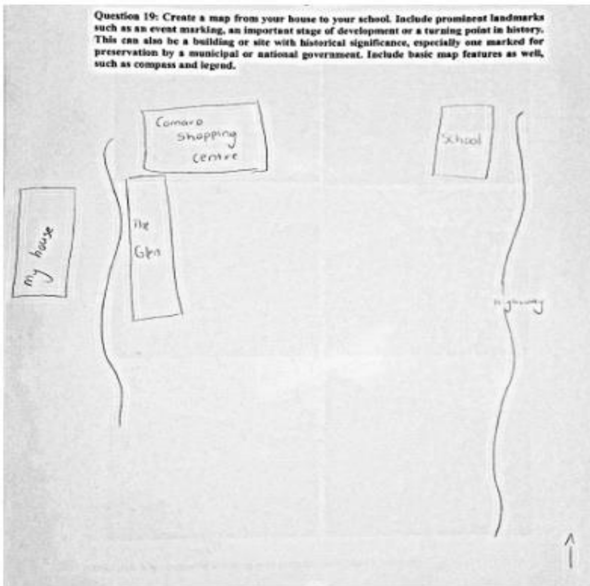


Figure 7: Changes in map drawing strategies for the GIS and none GIS groups

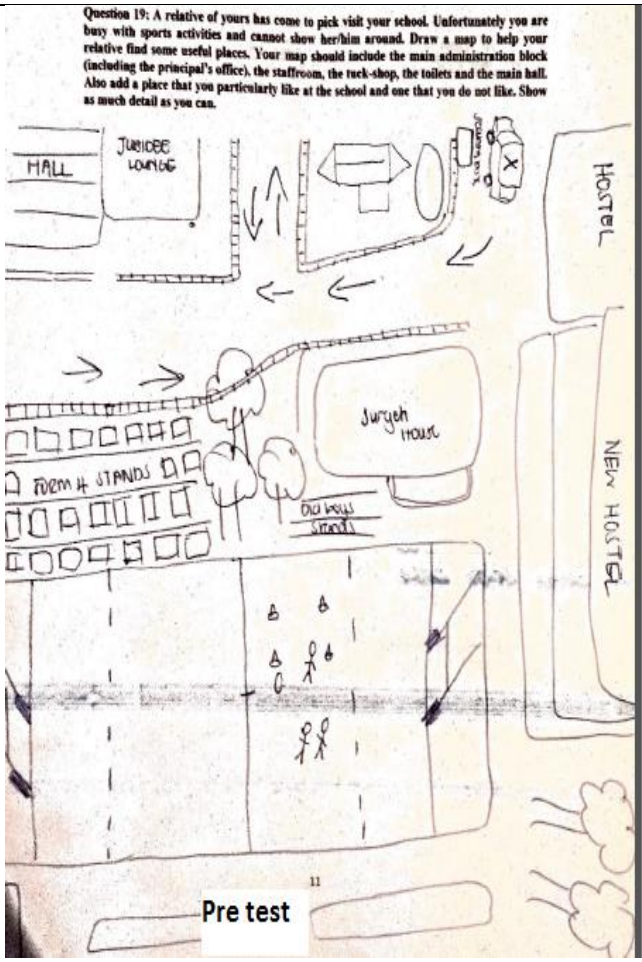
The GIS group significantly changed their map drawing strategies as seen in fig 13 above. Changes were from the landmark strategy to route and survey. The non GIS group used mostly the landmark strategy with very few learners changing to the survey method. This observation is supported by Lee (2005) study that GIS learning does inmprove spatial abilities. Fig 13 a to are illustrations of maps of the changes by some learners from one strategy to another, from pre to post test.



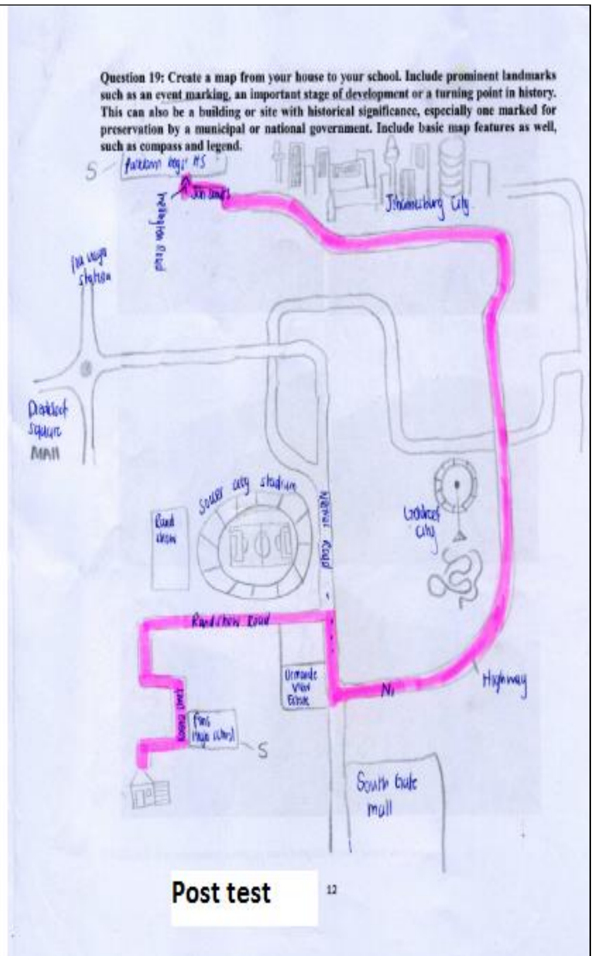
Pre test



Post test



Pre test



Post test

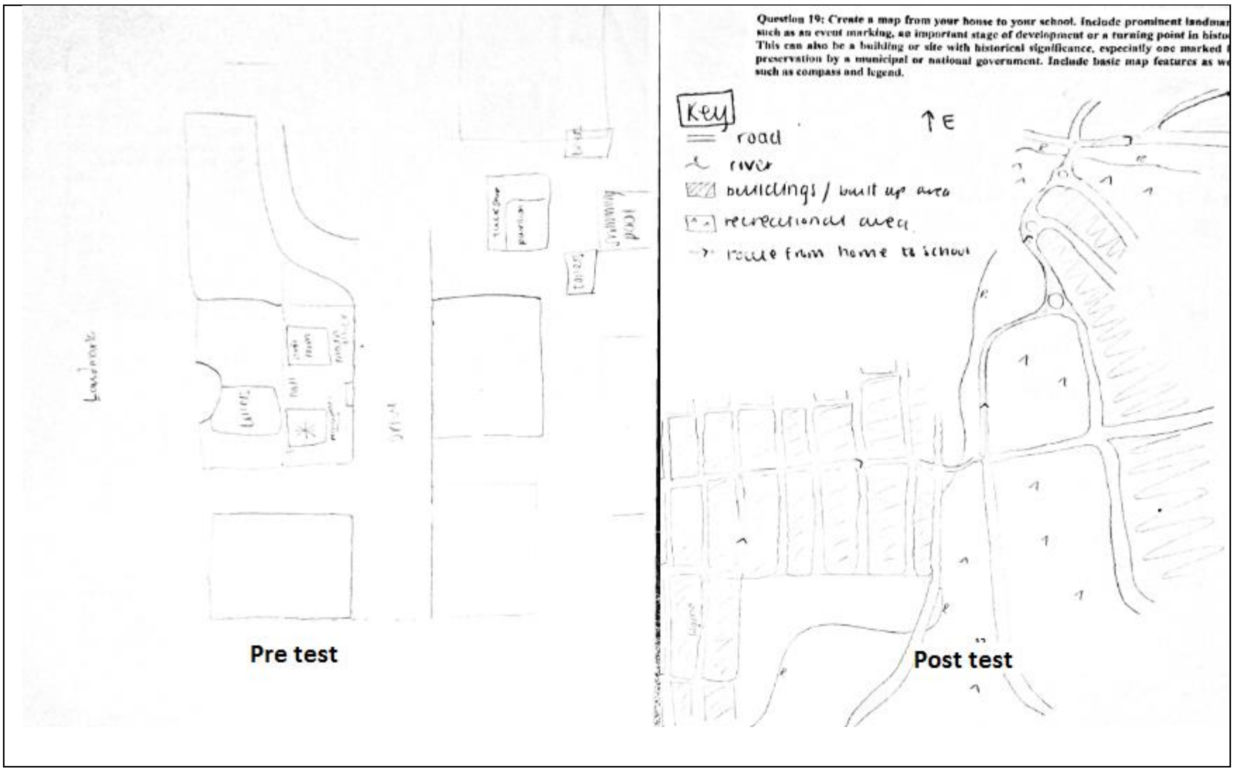


Figure 8: Changes in map drawing strategies by the learners

The were no significant differences between the English first language speakers and none speakers in terms of changes in the map drawing strategies hence no further analysis was done. It should be noted that the map drawing strategy in the pre test was biased towards landmark stategy because it asked for a map of a local area which was the school, whilst the post test question was biased towards the route strategy because it asked to a map showing how to get to school from the learners place of residence. The mapwork learning in the Geography curriculum could have contributed to learners coming up with maps that fell into the survey strategy. This involves learning about cartographic information wgen dealing with maps, such as legend, north arrow, scale and co-ordinates.

4.6 Relationship between map-drawing Strategies and spatial ability

A total of 35 students completed both the spatial skills tests the map drawing question in the post tests. The relationship between the spatial skills test and the map drawing strategy was investigated. The students were placed in different categories based on map drawing strategy and an average score for each group was computed. Table 14 and 15 below show the summary statistics for the three different strategies using the post test scores.

Table 7: Comparison of post test scores by map drawing strategies

Level of Strategy	N	Posttestscore	
		Mean	StdDev
Landmark	14	16.0000000	6.17687997
Route	15	18.3333333	5.94818900
Survey	6	18.1666667	4.87510684

Table 8: ANOVA statistics of post test scores by different map drawing strategies

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Between groups	2	44.004762	22.002381	0.63	0.5369
Within groups	32	1110.166667	34.692708		
Corrected Total	34	1154.171429			

There was not much difference between students who used the route strategy and the survey strategy in terms of scores obtained in the post test. However, students who used the landmark strategy had lower scores than those who used the route and survey strategies. ANOVA was used to assess score differences and a p-value of 0.5369 was obtained for the three different strategies using the post test scores. This showed that the score differences were not statistically significant. A reason for this could have been the small sample size (35) which was used.

5 Discussion

In this chapter the findings of this research are going to be discussed in the context of the research questions. The discussion will also link up with the literature review given in chapter two, followed by a summary and conclusion. Below are the research questions that governed this research. The discussion will be based each question in the same order they were given

1. Does GIS learning have an effect on students' spatial cognitive ability?

   a. Will completion of a GIS course affect the spatial cognitive ability of secondary school students?
   b. Will this effect be different for male and female students and for students whose mother tongue is different from English?

2. Will GIS learning affect students' spatial problem solving?

   a. Will completion of a GIS course affect the map-drawing strategy of students?
   b. Is there a relationship between students' map-drawing strategies and spatial cognitive ability?

Research question 1 a and b

Does GIS learning have an effect on students' spatial cognitive ability?

1a. Will completion of a GIS course affect the spatial cognitive ability of secondary school students?

In this study, there was a significant difference in spatial abilities between students who did GIS learning and the none GIS group. ANCOVA statistics followed by a post hoc Bonferroni method indicated significant different between the learners who did GIS learning and those who did not do GIS learning. There were slight improvements in the post test scores of the students who did GIS learning compared to those who did not do GIS learning. Exposure to map work and possibly physical georaphy for the Geography students who did GIS learning might have had an influence in the scores. Thus this research concluded that completion of a GIS course in secondary school does have affect spatial cognitive abilities. This finding is supported authors such as Orion et al. (1997) and Hall-Wallace and McAuliffe (2002) who found a positive relationship between GIS learning and the students' spatial abilities. There was a direct link between certain items contained in the spatial skills tests and GIS learning. The main focus of the test was spatial relations which is something that GIS students improved on.

However, there was a decrease in scores for all students in spatial relation questions particularly identification of spatial patterns. There were, marked improvements in certain item types for GIS learners' i.e. spatial correlations components and verbal map descriptions. Both groups however increased their scores for choosing the best location item. It should however be noted that other subjects and their effects were not taken into account hence there is need for further research to establish if doing other subjects together with GIS will have an effect.

B Will this effect be different for male and female students and for students whose mother tongue is different from English?

There were no significant differences between males and females from the pretest to the post test, with an ANCOVA p-value of 0.6070. Males scored slightly higher in their test scores than females. There were no significant differences between male and female pre and post test scores indicating that GIS learning did not affect students' spatial abilities based on gender. Vincent (2004), found no differences between the males and the females, however males had higher scores. These findings are supported by Connor et al. (1977) and Goldstein and Chance (1965), who concluded that males tend to get very high scores compared to females. Overall, males performed better than the females particularly in the post test.

No patterns or trends were observed in terms of scores for the different items as there was a mixture of scores for the males and females. Significant differences were not found for the English first language speakers for the pretest score and the posttests score, however, significant differences were found in the pre and post test scores for the none english speakers. This could be attributed to the very small sample size however further studies would need to be carried out to support such differences. However, no further analysis was carried out due to the huge differences in the two groups in terms of size which would have resulted in a bias of the results. The lack of significant in the english language speakers can be attributed to the fact that english is a language of instruction these schools thus it made no difference if the learners were not English first language speakers.

Research question 2a and b

2. Will GIS learning affect students' spatial problem solving?

a. Will completion of a GIS course affect the map-drawing strategy of students?

The students' spatial problem solving was examined in the spatial skills test by completing a map drawing task. The purposed was to see if the individual map drawing strategies would reveal the processes individuals use in spatial environments. The Spatial Knowledge Geography model was used to categorize the maps into landmarks, routes and survey which is said to involve higher order thinking (Golledge, 1997). This study assumed that students doing GIS learning would improve their spatial problem solving since GIS is said to be a tool for spatial problem solving. Students who did GIS changed their strategy from land mark to either route or survey indicating that GIS learning did affect students' map drawing strategy. However, the outcome might have been influenced by map work learning which involves cartography. The findings in this study are consistent with findings by Gluck et al (2002), that completion of GIS learning does affect map drawing strategies. The use of smartphones might have had an influence in the post test map drawing task as most learners make use of the GPS system as indicated in the qualitative data provided at the beginning of the tests.

b. Is there a relationship between students' map-drawing strategies and spatial cognitive ability?

Another objective of this study was to correlate the students map drawing strategies and their spatial abilities. The assumption was that students who used the higher order strategies would get higher scores than students who used the lesser strategies. Results obtained in this study showed that students who used the route and survey scored slightly higher than the students who used landmark strategies, although this was not statistically significant (ANCOVA p-value obtained was 0.5369). There were not many differences between scores of students who used the route strategy and students who used the survey strategy. Thus in light of these findings, this study concluded that there is no relationship between students' map-drawing strategies and spatial cognitive ability.

9 Conclusions and recommendations

GIS learning does affect secondary students' spatial abilities. There are other factors which also need to be taken into account when analyzing spatial abilities after GIS learning such as other subjects students are taking, time frame for the teaching of GIS and whether the use of software is involved. In South Africa, GIS as part of the Geography curriculum, thus there is limited time allocated to GIS learning. There are limited spatial activities that are done within the classroom, thus limiting the students in terms of applying acquired skills to a wide range of contexts. The type of GIS learning that took place in this study is paper based GIS which might not have been sufficient to not difference amongst the different groups. This means that the learners' problem solving abilities were limited. It should be noted, however, that so many factors could have influenced the outcomes of these results.

No comparison was carried out for the individual schools to see the dynamics in the score results. The socio-economic background might have had an influence on the test results. The general atmospheric conditions on the days the tests were written would have had an effect on thinking abilities. These are areas which might warrant further investigation in future. On the other hand, the map drawing skills strategies changed for the students who had done GIS learning. However, this could have been due to the fact that they were taught cartography in mapwork, and cartography which falls under the survey strategy (Golledge, 1997).

More research is needed to understand the changes in the students' map drawing strategies, although is this particular study the pretest map drawing strategy which was more localized thereby biased towards the landmark strategy, and the posttest map drawing task which was biased towards the route strategy. An interesting finding is the lack of significant differences between English first language speakers and none speakers in their test scores for the pre and posttests. This study would have benefited more if schools from less affluent suburbs taken part in the study.

The effect of the use of paper-based GIS verses the use of software was no tested in this research. There is need to revisit the Geography curriculum and improve on the GIS learning that is offered to high school learners and perhaps make use of open source software, such as Quantum GIS, to teach GIS in class. Enough time should be given so that learners can have an opportunity to engage in spatial activities that promote problem solving. Open access GIS software should be made available in schools and related equipment and hardware provided. In a technologically advancing world, there is need to change the teaching strategy which is paper based GIS and start using exciting and innovate ways that appeal to the younger generation. Another recommendation would be to start using GIS to teach geography especially the mapwork sections thus making it relevant to today world as a 21st skill.

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Appendix 1: Spatial skills tests

SPATIAL SKILLS TEST

Pre-Test

Personal Information

Duration- 30 minutes

Favorite colour	
House number – NOT address	
Age	
Gender	
Name of school	
Grade	
Year	
Population group	African □ White □ Coloured □ Indian/Asian □Other □

Please tick appropriate.(✓)

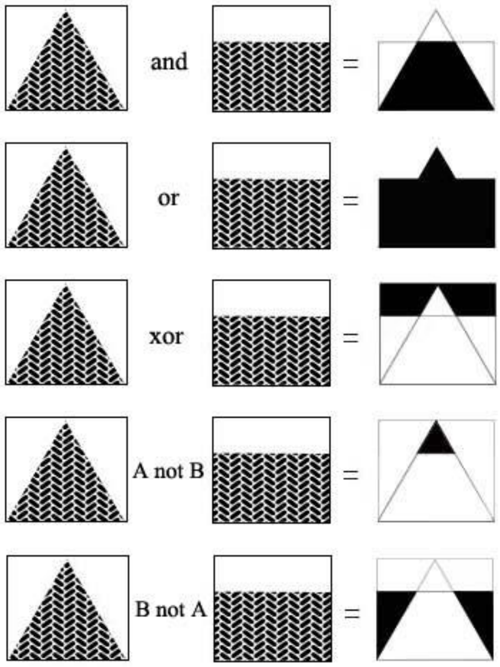
- Are you currently doing Geography? Yes□ No□
- Are you an English first language speaker? Yes □ No □
- If no to question above, what is your home language? ________________
- Do you have a mobile phone? Yes □ No □
- I f yes to above question, which phone do you have? Ordinary □Smartphone □
- Do you have a computer or tablet? None □ Computer □ Tablet □
- If yes to above questions, what do you use it for?

____

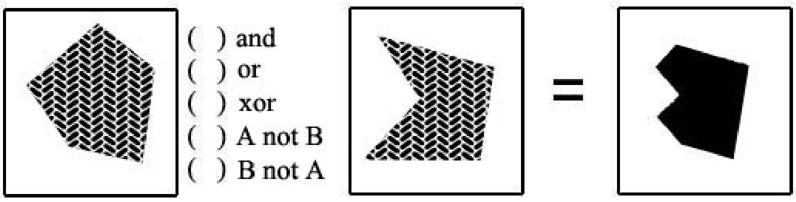
- Are you staying in hostel? Yes □ No □
- If no to above question, where do you stay? __________________________
- What is your usual mode of transport? You can check more than one.
- Car □ Bus □ Taxi □ Walk □

Question 1and 2: Solve the following questions based on the example below. Please tick (√) the correct answer in the space below the shape.

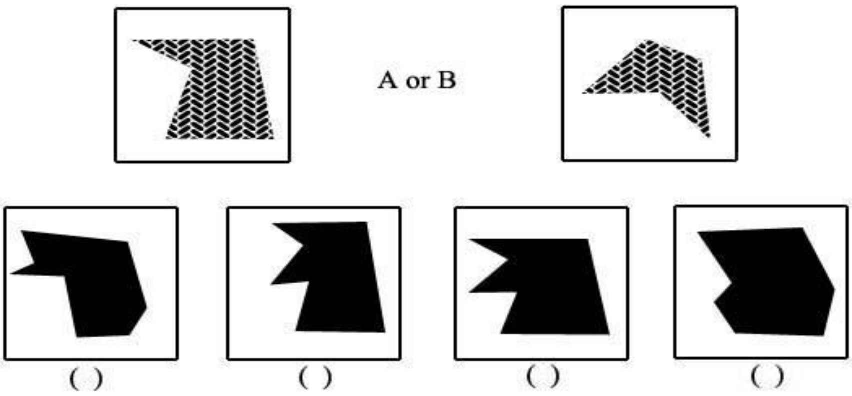
(Example)



1.



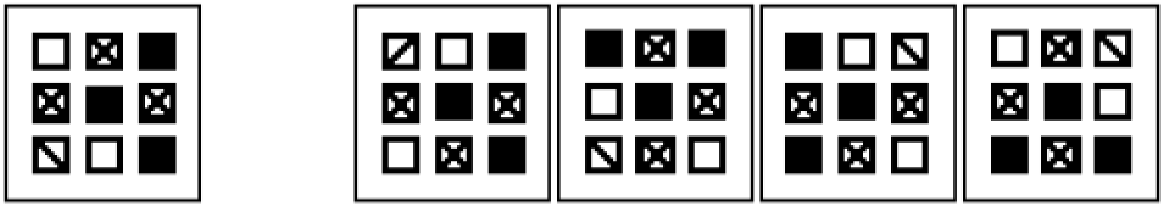
2.



*(**Question** 1 and 2 were adapted from Albert and Golledge (1999))*

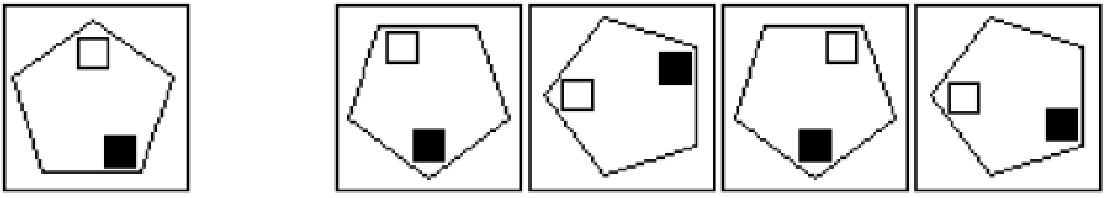
Question 3 and 4: In the figures below, one of the shapes (A-D) is identical to the first figure on the left but has been rotated. Please tick (√) the correct answer in the space below the letter.

3. Which figure is identical to the first?



A	B	C	D
( )	( )	( )	( )

4. Which figure is identical to the first?



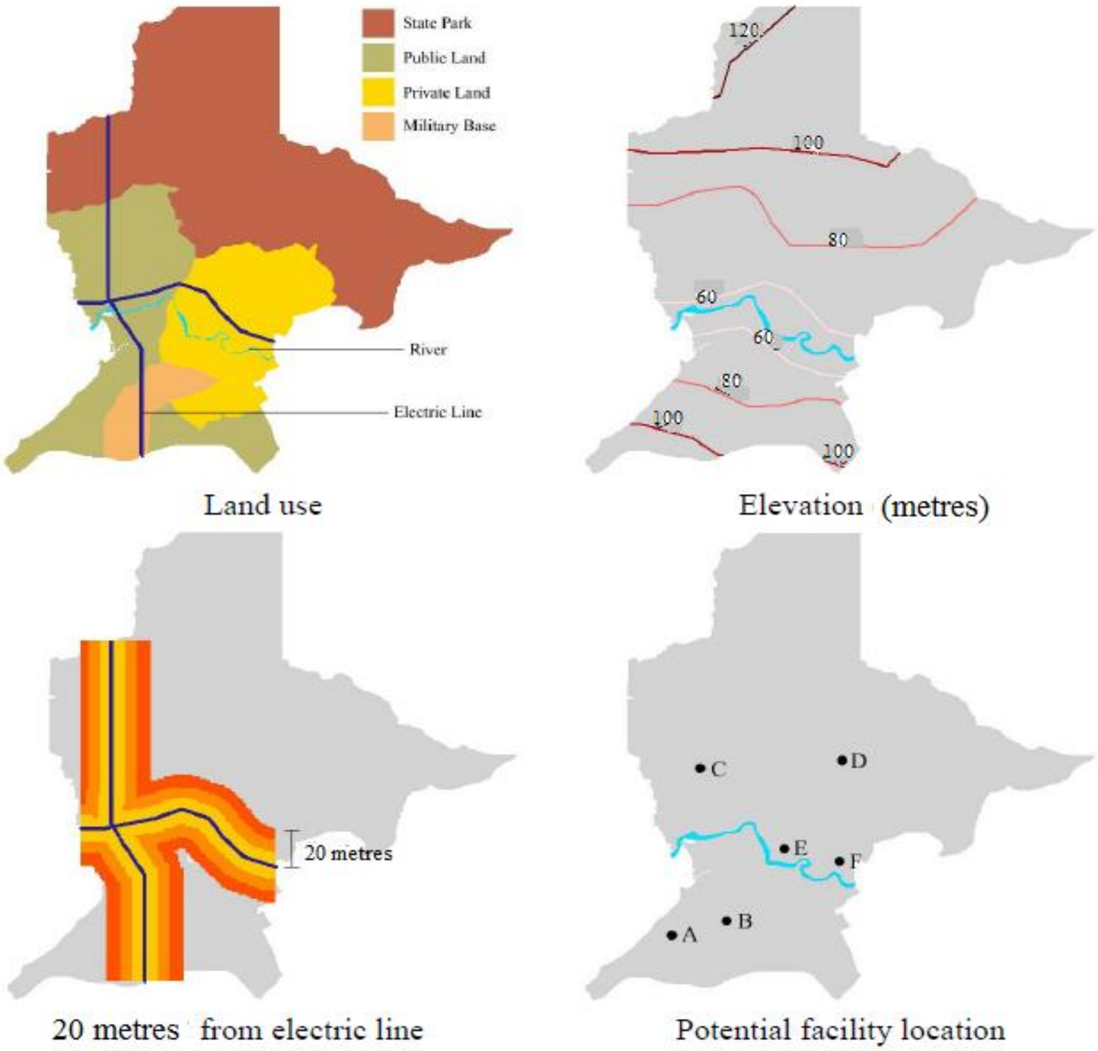
A	B	C	D
( )	( )	( )	( )

(Question3 and 4 were adapted from Newman and Bristoll (2016))

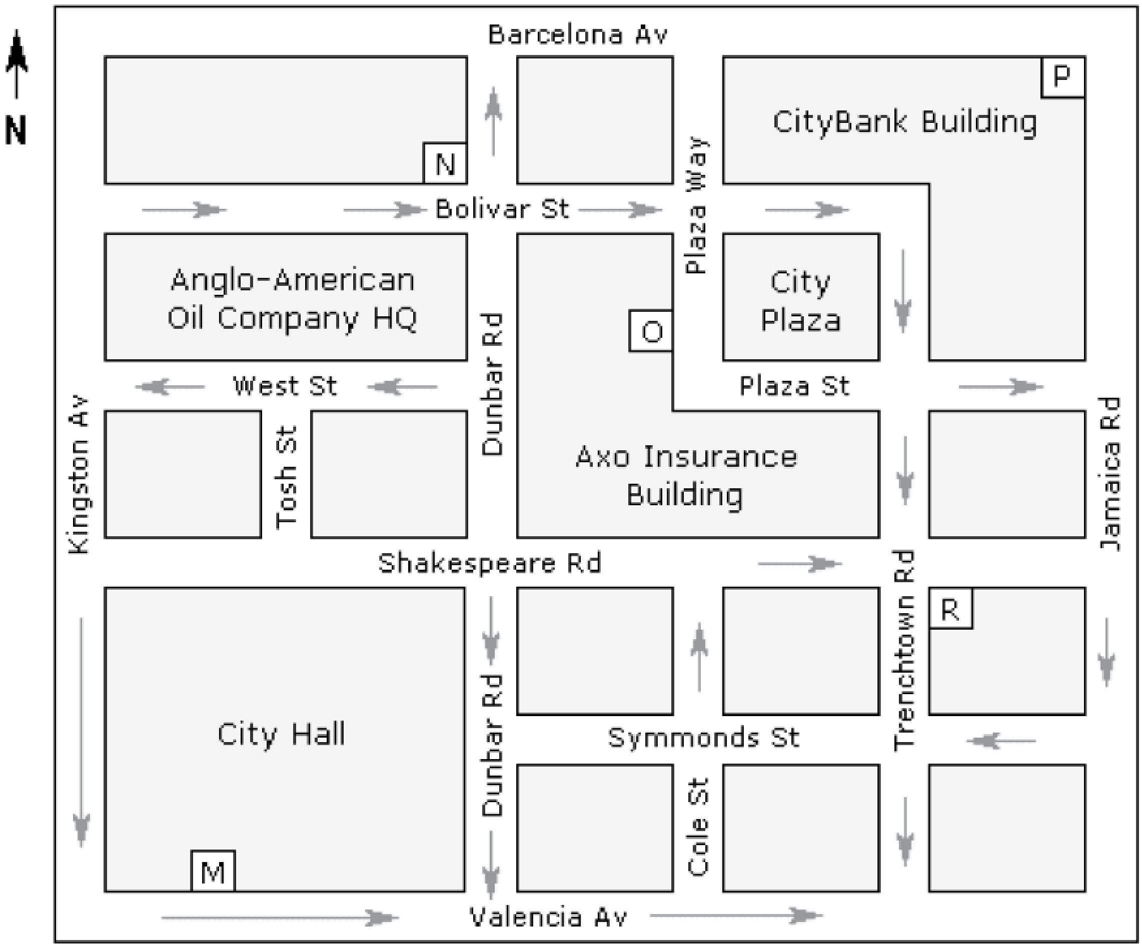
Question 5:Find the best location for a flood management facility based on the following conditions.

- Possible site for a flood management facility should be within 20m of an existing electric line.
- Possible site for a flood management facility should be located less than 80m elevation level.
- Possible site for a flood management facility should be located in State Park or Public Land

Mark [√] on the best site for flood management facility on the map below (Potential facility location).



Question 6, 7, 8: Study the map below and answer questions 6, 7 and 8



6. Officer Johns is in Tosh with City Hall to her right. What direction is she facing?Please tick (√) the correct answer.

A	B	C	D
North	South	East	West

7. She turns and walks to the junction with West St. She then turns and walks to the next junction before turning left. Where is 'O' in relation to her position?

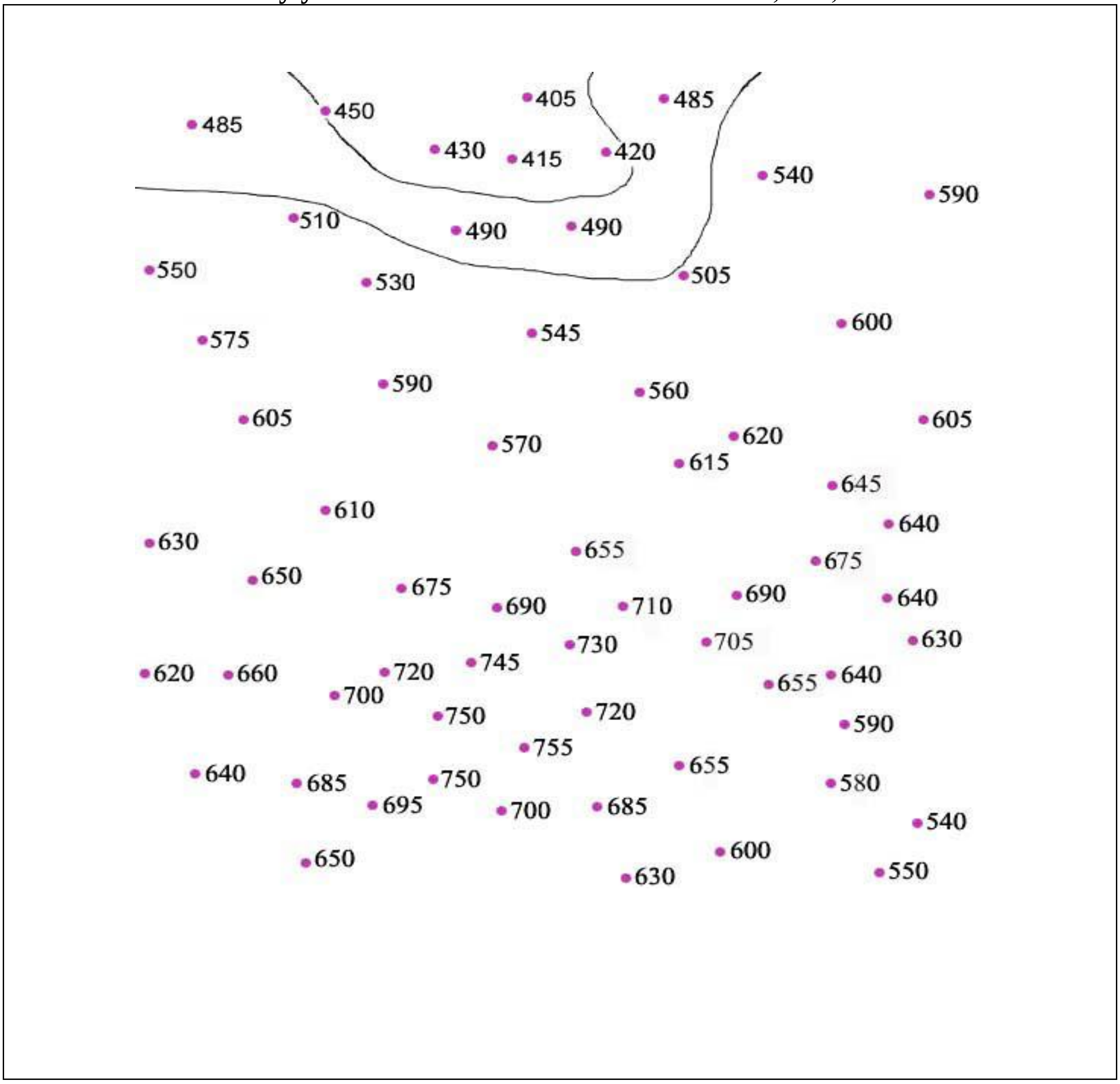
A	B	C	D
North	South	East	West

8. Officer Lawrence starts from location 'M' and proceeds as follows: left onto Valencia Av-heading east, second left- heading north, second right – heading East, second left – heading North. He proceeds north for two blocks. What is his location?

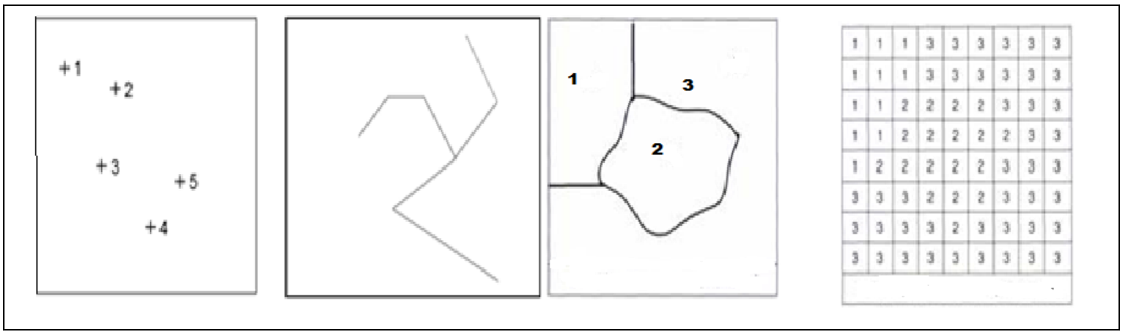
A	B	C	D
N	O	R	P

(Question6, 7and 8 were adapted from Newman and Bristoll (2016))

Question 9: The values below are indicating elevation of each point. Based on the elevation data, create contour lines. The contour interval should be 50 meters. The lowest contour line is 400 meters. In this way your contour intervals should run 400, 450, 500…

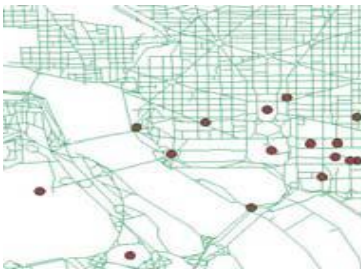


Questions10 -15:Spatial information can be displayed based on Point, Line (Arc), Area (Polygon), and Raster (lattice). Based on the sample question below, classify the following spatial data.



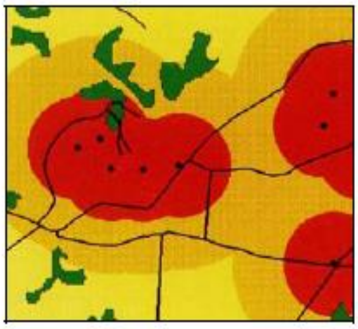
Point **Line (Arc)** **Area (Polygon)** **Raster (lattice)**

Example

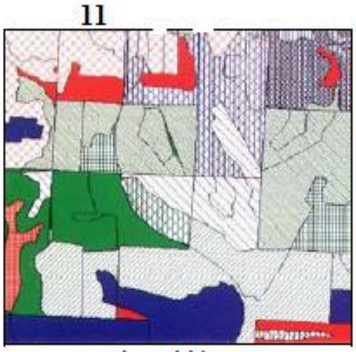


(√) Point (√) Line ( ) Area ( ) Raster

10

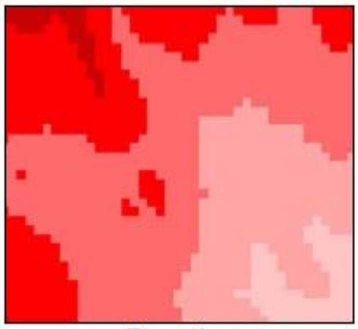


11



Land Use

12



Elevation

13. River channels and their basins in Gauteng.

14. Rea vaya bus route in Johannesburg.

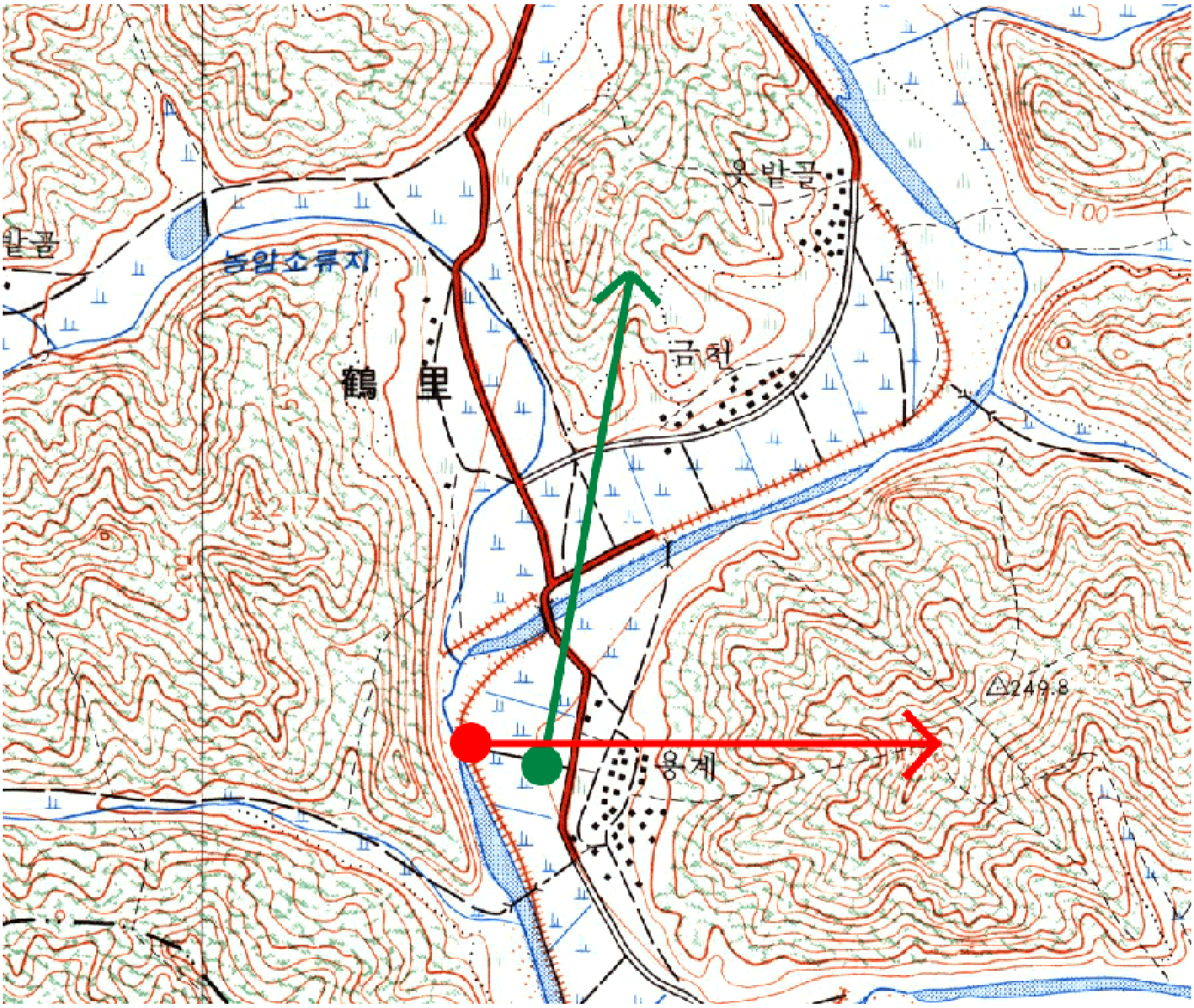
15. Surface elevation recorded on a 30- meter horizontal grid.

Please mark (√) on your answer

	Point	Line	Area	Raster
10	[ ]	[ ]	[ ]	[ ]
11	[ ]	[ ]	[ ]	[ ]
12	[ ]	[ ]	[ ]	[ ]
13	[ ]	[ ]	[ ]	[ ]
14	[ ]	[ ]	[ ]	[ ]
15	[ ]	[ ]	[ ]	[ ]

Question 16 and 17:Imagine that you are standing and looking in the direction of the red (or green) arrow. Among 6 photos (A~F) on the next page, which photo most closely represents what you would see? Mark (√)on your answer.

	(A)	(B)	(C)	(D)	(E)	(F)
16 - Red Arrow						
17- Green Arrow						



(A)

(B)

(C)

(D)

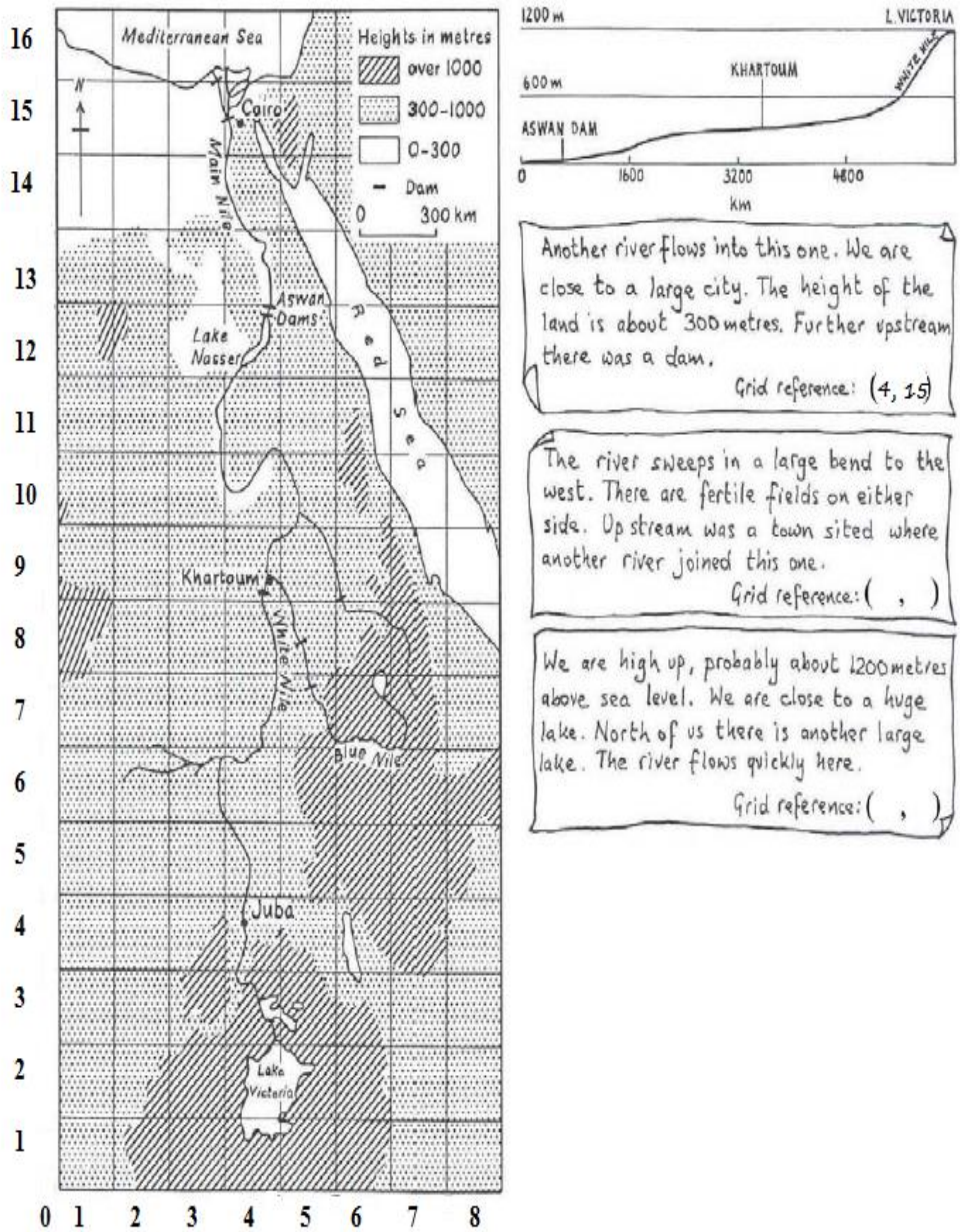
(E)

(F)

Question 16 and 17 were adapted from personal homepage of J. Ryu (2005)

Question 18: A group of young travelers is making a journey down the White Nile. They make notes as they travel. Below are three pages from their notebook. They are not in order. Based

on information below, find the place each note indicates and write grid reference as (X, Y) format.



Question 19: A relative of yours has come to pick visit your school. Unfortunately you are busy with sports activities and cannot show her/him around. Draw a map to help your relative find some useful places. Your map should include the main administration block (including the principal's office), the staffroom, the tuck-shop, the toilets and the main hall. Also add a place that you particularly like at the school and one that you do not like. Show as much detail as you can.

SPATIAL SKILLS TEST 2

Post-test

Personal Information

Duration- 30 minutes

Favorite colour	
House number – NOT address	
Age	
Gender	
Name of school	
Grade	
Year	
Population group	African □ White □ Coloured □ Indian/Asian □Other □

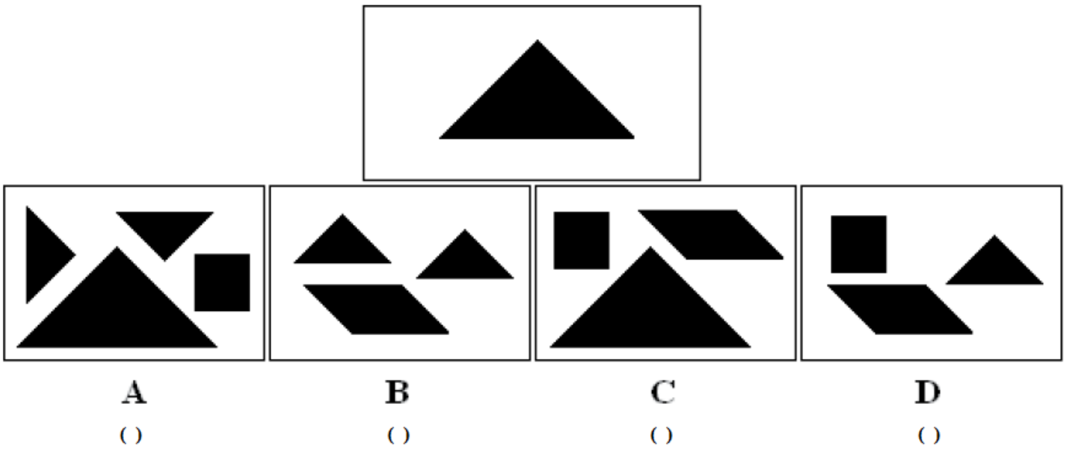
Please tick appropriate.(✓)

- Are you currently doing Geography? Yes□ No□
- Are you an English first language speaker? Yes □ No □
- If no to question above, what is your home language? _________________
- Do you have a mobile phone? Yes □ No □
- I f yes to above question, which phone do you have? Ordinary □Smartphone □
- Do you have a computer or tablet? None □ Computer □ Tablet □
- If yes to above questions, what do you use it for?

____

- Are you staying in hostel? Yes □ No □
- If no to above question, where do you stay? ___________________________
- What is your usual mode of transport? You can check more than one.
- Car □ Bus □ Taxi □ Walk □

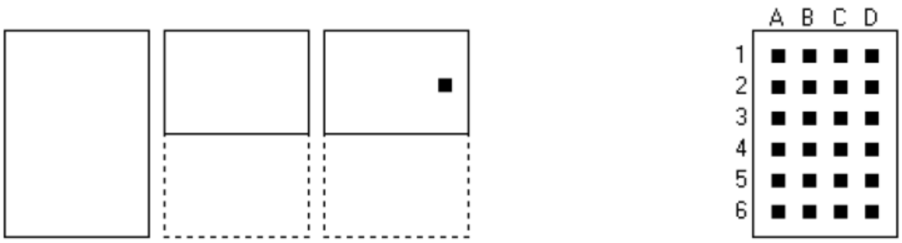
Question 1:Which group of shapes can be assembled to make the shape shown below? Please tick (✓) the correct answer in the space below the shape.



(Question1 was adapted from Newman and Bristoll (2016))

Question 2, 3 and 4: The drawing below show a sheet of paper which has been folded. The dashed lines indicate the whole sheet, each drawing represent a single fold. The black square shows where a hole was punched. Where do the holes appear when the sheet is unfolded? Please tick (✓) the correct answer in the space below the correct letter.

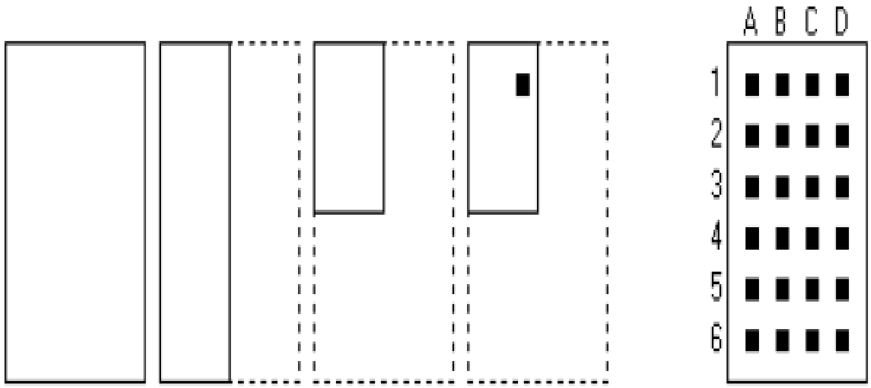
2.



A	B	C	D
2C,5C	2D,5D	3D,3D	2C,2D

( ) ( ) ( ) ( )

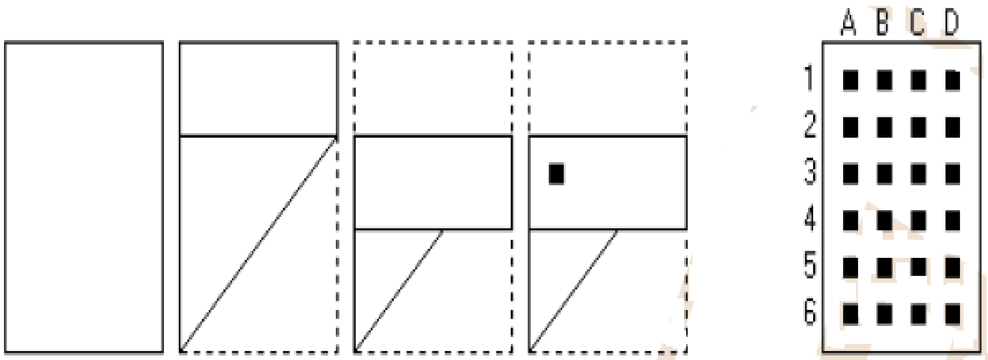
3.



A	B	C	D
1B,1C,5B,5C	2B,2C,5B,5C	1B,2C,6B,6C	1B,1C,6B,6C

( ) ( ) ( ) ( )

4.

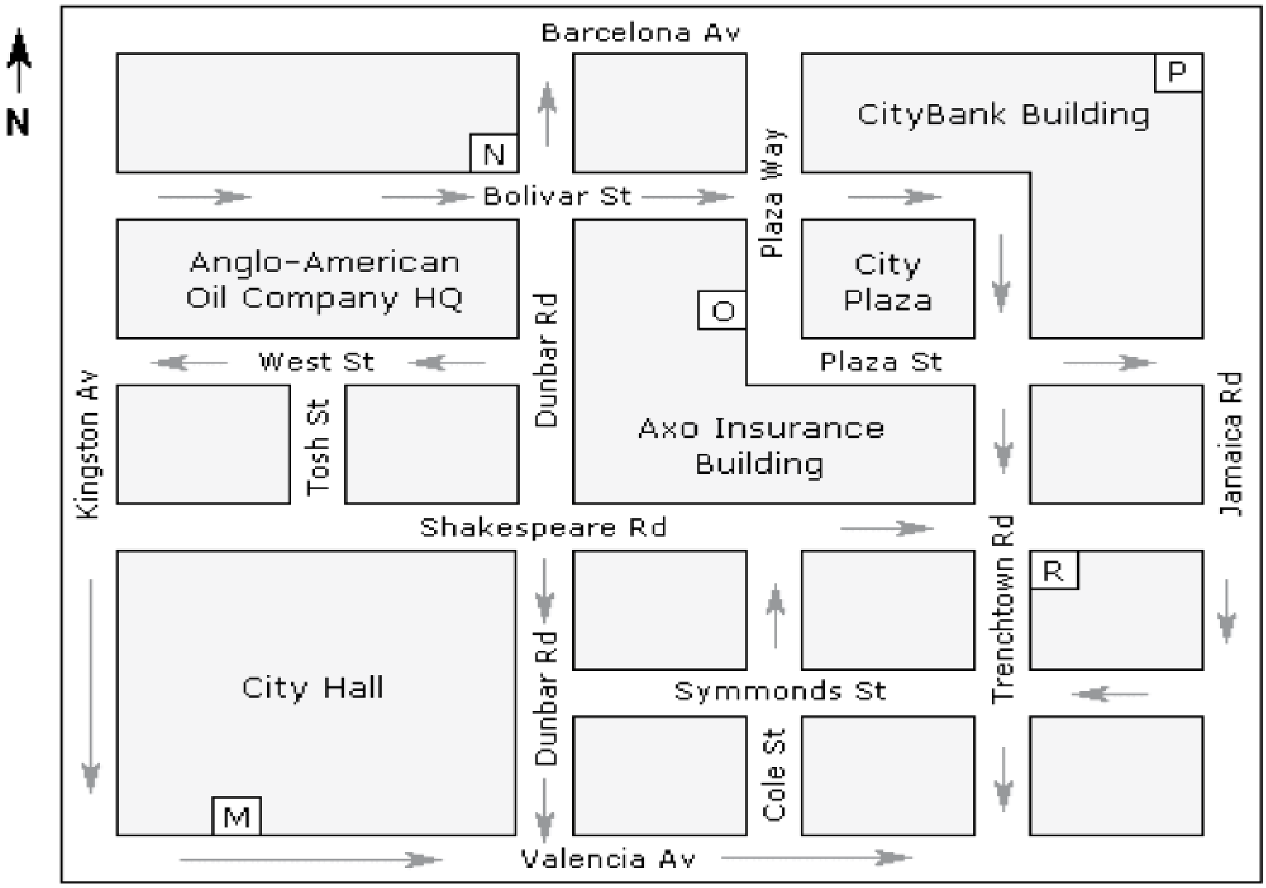


A	B	C	D
3A,2A,6D	3A,5A,6D	3A,5A,3D	3A,2A

( ) ( ) ( ) ( )

(Question2, 3 and 4 were adapted from Newman and Bristoll (2016))

Question 5, 6,7, Study the map below and answer questions 5, 6 and 7



5. Officer Johns is in Cole Street with City Hall to her left. What direction is she facing?Please tick (√) the correct answer.

A	B	C	D
North	South	East	West

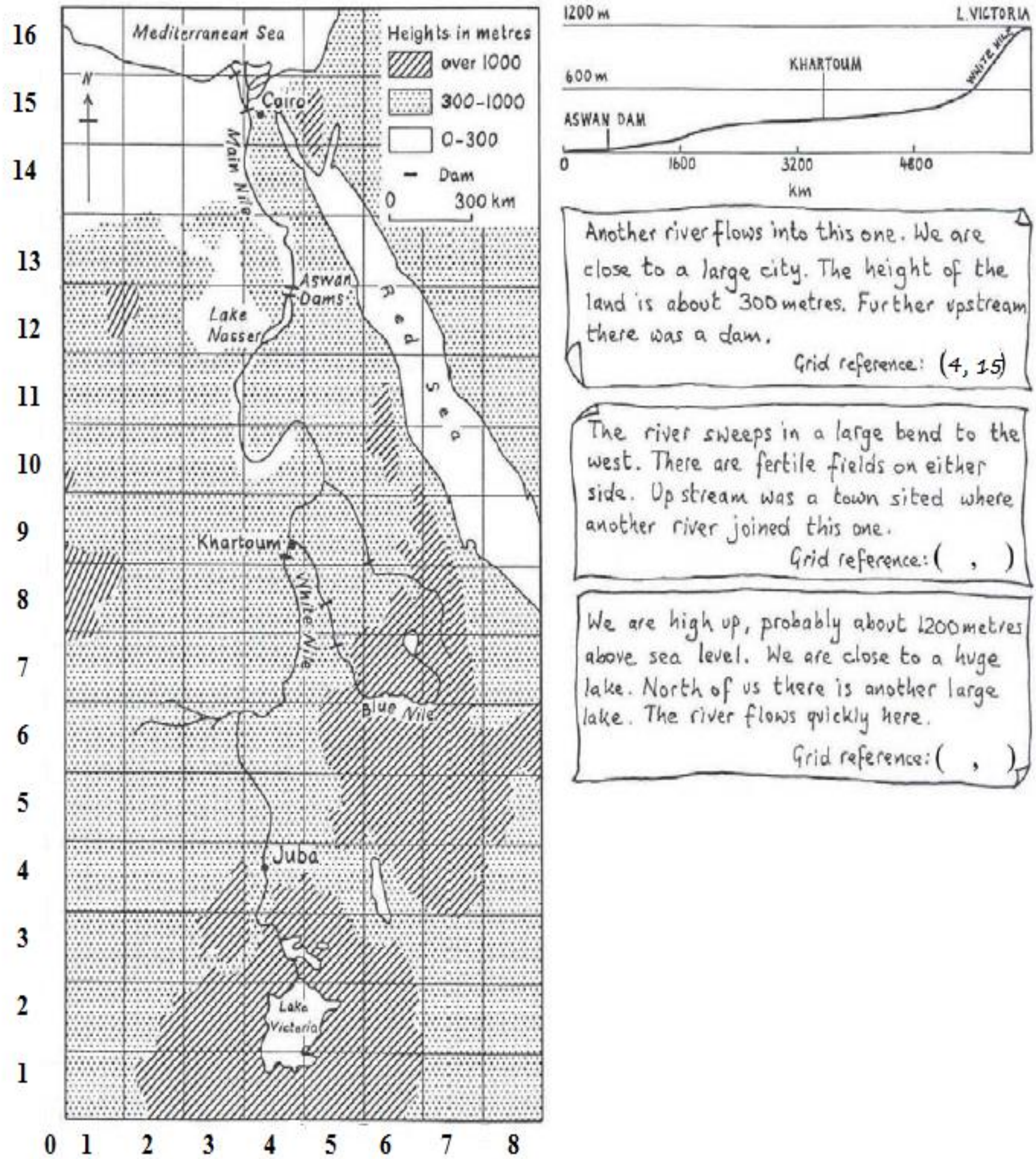
6. She turns and walks to the junction with West St. She then turns right and walks to the next junction before turning left. Where is 'R' in relation to her position?

A	B	C	D
North	South	East	West

7. Officer Lawrence starts from location 'N' and proceeds as follows: right onto Dunbar rd- heading south, second left- heading east, second right – heading North, second left – heading North. What is his location?

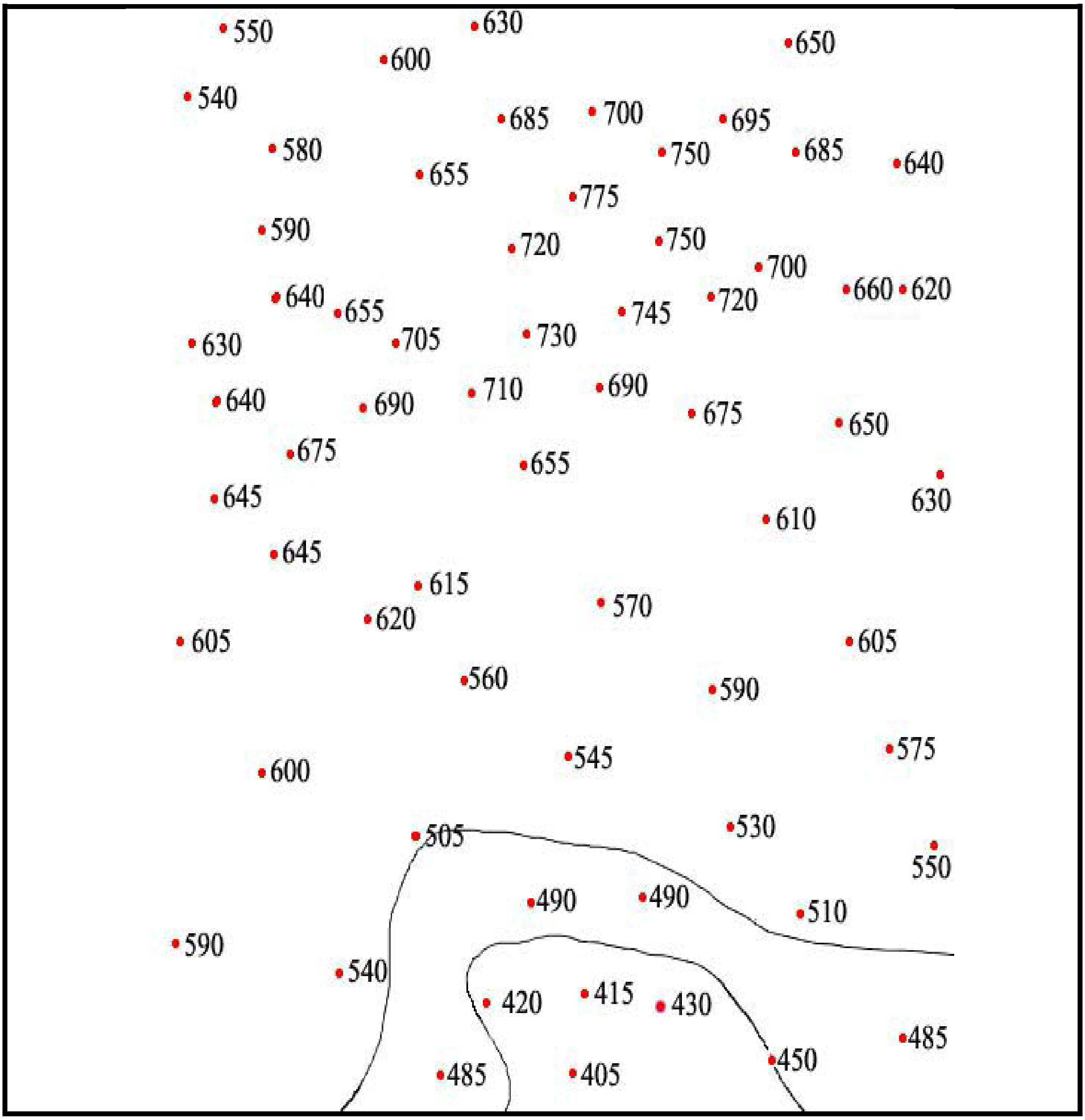
A	B	C	D
N	O	R	P

Question 8 and 9: A group of young travelers is making a journey down the White Nile. They make notes as they travel. Below are three pages from their notebook. They are not in order. Based on information below, find the place each note indicates and write grid reference as (X, Y)



(Question 6 and 7were adapted from Lee JW (2005))

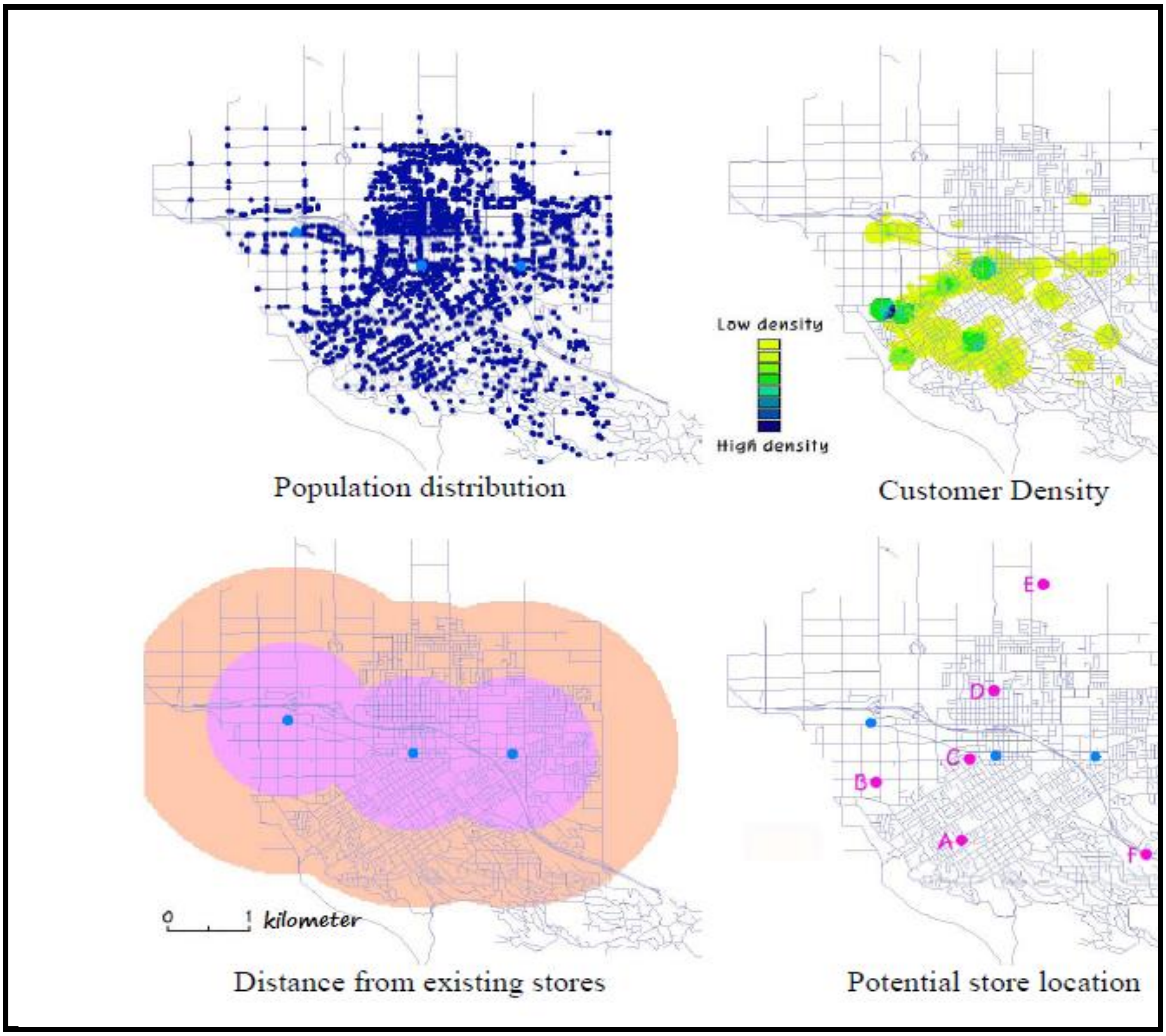
Question 10: The values below are indicating elevation of each point. Based on the elevation data, create contour lines. The contour interval should be 20 meters. The lowest contour line is 400 meters. In this way your contour intervals should run 400, 420, 440…


550
630
600
650
540
685
700
695
580
750
685
640
655
775
590
720
750
700
640
655
745
720
660
620
630
705
730
640
690
710
690
675
650
675
655
645
630
610
645
615
570
620
605
605
560
590
575
600
545
505
530
550
490
490
510
590
540
420
415
430
485
450
485
405

Question 11: Find a new best site for a coffee shop based on the following conditions.

• Possible site for a new store should be more than 1 kilometer from any existing stores. If any stores are closer than 1 kilometer, they may compete with each other for customers.
• Possible site for a new store should be easy for potential customers to access. 'Customer density' shows the density of coffee drinkers who have visited the three stores over the last year.

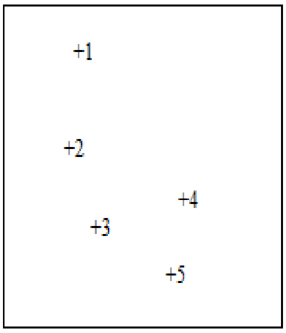
Mark (✓) on the best site for a potential coffee shop on the map above.



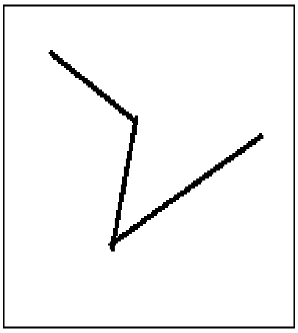
Population distribution
Customer Density
Distance from existing stores
Potential store location

(Question 9 was adapted from Lee JW (2005))

Questions 12-17:Spatial information can be displayed based on Point, Line (Arc), Area (Polygon), and Raster (lattice). Based on the sample question below, classify the following spatial data.



points



lines

polygon

1	1	1	3	3	3	3	3	3
1	1	1	3	3	3	3	3	3
1	1	2	2	2	2	3	3	3
1	1	2	2	2	2	2	3	3
1	2	2	2	2	2	3	3	3
3	3	3	2	2	2	3	3	3
3	3	3	3	2	3	3	3	3
3	3	3	3	3	3	3	3	3

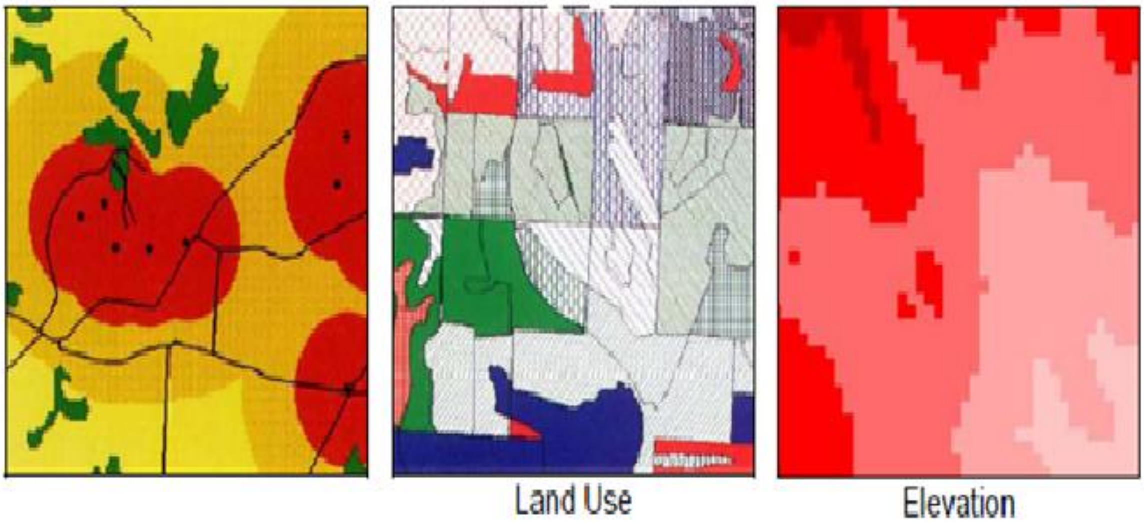
1 Residential 2 Water 3 Farmland

Raster

Example of answer below:

(√) Point (√) Line ( ) Area ( ) Raster

12 13 14



15. River channels and their basins in Gauteng.

16. Rea vaya bus route in Johannesburg.

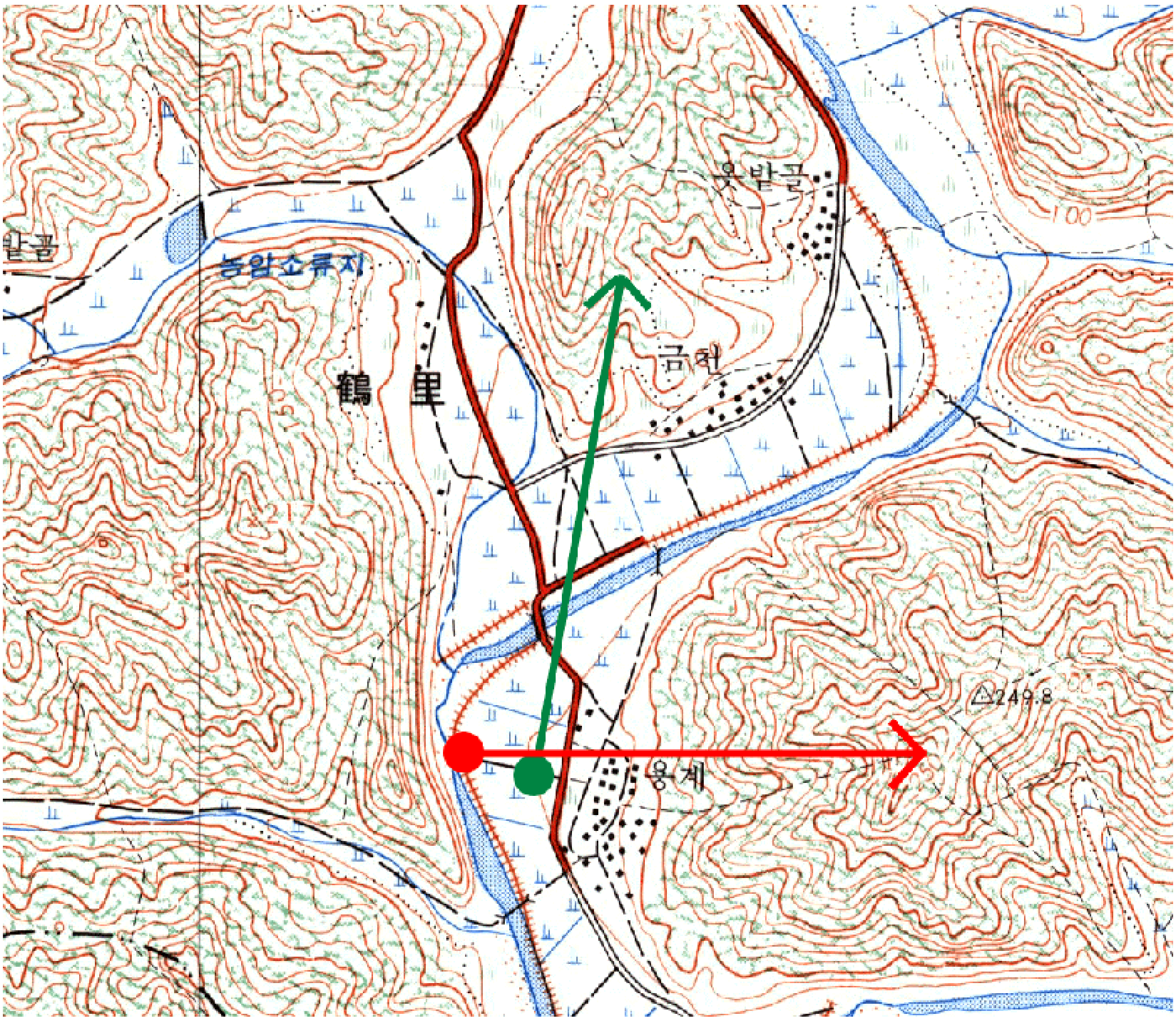
17. Surface elevation recorded on a 30- meter horizontal grid.

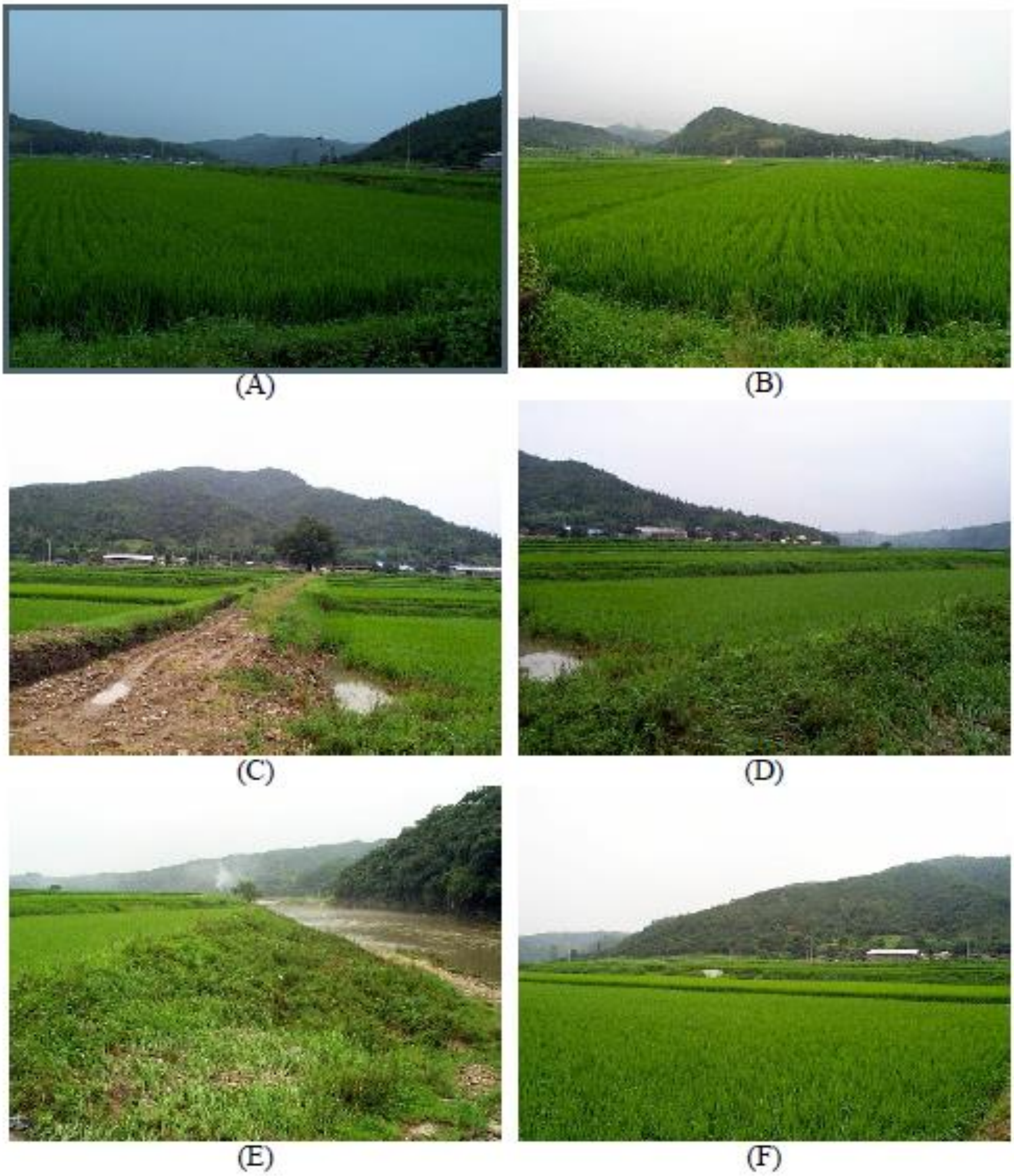
Please mark (✓) on your answer

12	Point	Line	Area	Raster
13	[ ]	[ ]	[ ]	[ ]
14	[ ]	[ ]	[ ]	[ ]
15	[ ]	[ ]	[ ]	[ ]
16	[ ]	[ ]	[ ]	[ ]
17	[ ]	[ ]	[ ]	[ ]

Question 18: Imagine that you are standing and looking in the direction of the red (or green) arrow. Among 6 photos (A~F) on the next page, which photo most closely represents what you would see? Use(✓) on your answer.

	(A)	(B)	(C)	(D)	(E)	(F)
Red Arrow						
Green Arrow						





Question 6 and 7 were adapted from personal homepage of J. Ryu (2005)

Question 19: Create a map from your house to your school. Include prominent landmarks such as an event marking, an important stage of development or a turning point in history. This can also be a building or site with historical significance, especially one marked for preservation by a municipal or national government. Include basic map features as well, such as compass and legend.