A METHODOLOGY FOR ASSESSING GEOGRAPHICAL INFORMATION SCIENCE PROFESSIONALS AND PROGRAMMES IN SOUTH AFRICA

HENDRIK JACOBUS DU PLESSIS

Dissertation presented for the degree of Doctor of Philosophy in the Faculty of Arts and Social Sciences at Stellenbosch University.

Supervisor: Prof A van Niekerk

Pectora roborant cultus recti

April 2015

DECLARATION

By submitting this research dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

With regard to Chapters 3, 4 and 5 the nature and scope of my contribution were as follows:

Chapter	Nature of contribution	Extent of contribution (%)
Chapter 3	This chapter was published as a journal article (Du Plessis and Van Niekerk 2012) and was co-authored by my supervisor who helped in the conceptualization and writing of the manuscript. I carried out the literature review, data collection and analysis components and produced the first draft of the manuscript.	HJ Du Plessis 85% A Van Niekerk 15%
Chapter 4	This chapter was published as a journal article (Du Plessis and Van Niekerk 2013) and was co-authored by my supervisor who helped in the conceptualization and writing of the manuscript. I carried out the literature review, data collection and analysis and produced the first draft of the manuscript.	HJ Du Plessis 85% A Van Niekerk 15%
Chapter 5	This chapter was published as a journal article (Du Plessis and Van Niekerk 2014) and was co-authored by my supervisor who helped in the conceptualization and writing of the manuscript. I carried out the literature review, data collection and analysis components and produced the first draft of the manuscript.	HJ Du Plessis 85% A Van Niekerk 15%

Signature of candidate: Declaration with signature in possession of candidate and Supervisor

Signature of supervisor: Declaration with signature in possession of candidate and Supervisor

Date: 19 August 2014

SUMMARY

There is a growing demand worldwide for geographical information science (GISc) practitioners. Government agencies and the private sector are competing to find and employ practitioners in the GISc field who are suitably qualified and competent in the practice of the relevant technologies and sciences. Little research exists in South Africa on what GISc professionals should know or be able to do. A set of competencies, knowledge and skills required by professionals in the workplace is needed to design appropriate programmes and to guide those responsible for controlling quality in the profession (through registration) as well as in educational institutions (through accreditation).

This research developed a new GISc academic framework with an embedded competency set to serve as a standard for the training of professional GISc practitioners. The format of this GISc framework is based on the structure of the University Consortium of Geographical Information Science (UCGIS) geographical information science and technology (GI S&T) body of knowledge (BoK) as the most frequently used framework internationally, but incorporates content from two existing South African competency sets. The new framework represents the South African, the USA and European perspectives of the knowledge and skills regarded as essential for the GISc profession. An easy-to-use and accessible web-based GISc self-assessment tool (SAT) was developed to facilitate the implementation and adoption of the new framework. Based on feedback from the GISc community the tool is proving to be a valuable labour- and time-saving resource with significant benefits to the GISc society and academia.

The new GISc framework, which consists of 14 knowledge areas, 6 fundamental and 32 core units, was developed using a combination of qualitative and quantitative procedures to compare three different existing competency sets. This methodology is unique and lends itself for application in similar studies regardless of the discipline. Through the literature studied, no other GISc web-based SAT was discovered, making the concept of a web-based and database driven SAT unique. The SAT can be modified for use in other disciplines and countries.

KEYWORDS

Academic framework, accreditation, registration, competencies, training, knowledge, skills, education, geographical information science, GISc, self-assessment tool, web-base, database

OPSOMMING

Daar is ’n groeiende vraag wêreldwyd na geografiese inligtingswetenskap (GIW) praktisyns. Regeringsagentskappe en die privaatsektor kompeteer om GIW praktisyns, wat in die toepassing van die relevante tegnologie en wetenskappe voldoende gekwalifiseerd en kundig is, te vind en in diens te neem. Min navorsing is in Suid-Afrika gedoen oor wat ŉ GIW professionele persoon moet weet en kan doen. ŉ Stel vaardighede en kennis wat van professionele persone in die werksomgewing vereis word, word benodig om gepaste opleidingsprogramme te ontwerp en om diegene wie verantwoordelik is vir die kwaliteitskontrolering van die beroep (deur registrasie) en opvoedkundige instansies (deur akkreditasie) te lei.

Hierdie navorsing het ’n nuwe raamwerk en stel vaardighede vir GIW ontwikkel, wat kan dien as ŉ standaard vir die opleiding van professionele praktisyns in GIW. Die formaat van hierdie GIW-raamwerk is op die University Consortium of Geographical Information Science (UCGIS) geographical information science and technology (GI S&T) body of knowledge (BoK) gebaseer wat tans internasionaal as die mees gebruikte raamwerk aangewend word. Die nuwe raamwerk is ’n kombinasie van twee Suid-Afrikaanse kundigheidstelle en die GI S&T BoK. Dit verteenwoordig die Suid-Afrikaanse sowel as die Amerikaanse en Europese perspektiewe oor watter kennis en vaardighede vir die GIW professie belangrik geag word. ’n Webgebaseerde selfevalueringsinstrument (SEI) is ontwikkel om die implementering en aanvaarding van die raamwerk te bevorder. Die SEI is gebruikersvriendelik en toeganklik vir potensiële gebruikers. Terugvoering vanaf die GIW gemeenskap het bevestig dat die SEI (GISc SAT) ‘n waardevolle arbeid- en tydbesparende hulpbron is wat aansienlike voordele vir die GIW-gemeenskap en akademiese wêreld bied.

Die nuwe GIW raamwerk bestaande uit 14 kennisgebiede, 6 fundamentele eenhede en 32 kern eenhede, is ontwikkel deur van kwalitatiewe en kwantitatiewe metodes gebruik te maak om verskillende GIW-raamwerke te vergelyk. Hierdie metodologie is uniek en kan ook in ander velde aangewend word. Tydens die literatuurstudie is geen ander GIW SEI opgespoor nie, wat die konsep van ŉ webgebaseerde en databasisgedrewe SEI uniek maak. Die SEI kan aangepas word vir gebruik in ander dissiplines en lande.

TREFWOORDE

Akademiese raamwerk, akkreditering, registrasie, vaardighede, opleiding, kennis, kundigheid, opvoeding, geografiese inligtingswetenskap, GIW, selfevalueringsinstrument, webwerf, databasis

ACKNOWLEDGEMENTS

I sincerely thank:

- Leslie, my wife, for her support, understanding and patience throughout this project.
- Michelle, my daughter, and Richard Michael, son-in-law, for their support.
- Andre, my son, and Taryn du Plessis, daughter-in-law, for their support.
- Senior management and colleagues in the Department of Rural Development and Land reform, for their support.
- President and members of the South African Council for Professional and Technical surveyors (PLATO), for their support.
- President and members of the South African Geomatics Institute, for their support.
- National chairperson and members of the Geographical Information Society of South Africa, for their support.
- Prof Adriaan van Niekerk, my supervisor, for his continued motivation, support and timely suggestions.
- Friends and relatives who supported me throughout this project.
- Dr Pieter de Necker, for editorial work, insightful suggestions and for keeping me motivated.
- Mr Storm van der Merwe for his support during the website development of the GISc self-assessment tool.

CONTENTS

TABLES

FIGURES

ACRONYMS AND ABBREVIATIONS

3D	Three dimensional
3NF	Third normal form
AGILE	Association of Geographic Information Laboratories for Europe
ASP	Active server pages
ATM	Automatic teller machine
BoK	Body of knowledge
BSc	Bachelor of Science
CDNGI	Chief Directorate National Geospatial Information
CHE	Council on Higher Education
COGTA	Co-operative Government and Traditional Affairs
COTS	Commercial off-the-shelf
CPD	Continuous professional development
CPUT	Cape Peninsula University of Technology
DACUM	Develop a curriculum
DEM	Digital elevation model
DHET	Department of Higher Education and Training
DOLETA	Department of Labor, Employment and Training Administration

DPSA	Department of Public Service Administration
DST	Department Science and Technology
EAC	Education Advisory Committee
ER	Entity-relationship
ERD	Entity-relationship diagram
ESKOM	Electricity Supply Commission
ESRI	Environmental Systems Research Institute
EUGISES	European GIS in Education Seminar
GI S&T	Geographical information science and technology
GI S&T BOK	Geographical information science and technology body of knowledge
GIS	Geographical / geographic / geospatial information system
GISc	Geographical information science
GISc AF	Geographical information science academic framework
GISc SAT	Geographical information science self-assessment tool
GISSA	Geographical Information Society of South Africa
GITA	Geospatial Information and Technology Association
GNSS	Global navigation satellite system
GPS	Global positioning system

GPSSBC	General Public Service Sector Bargaining Council
GTCM	Geospatial technology competency model
GUI	Graphical user interface
GWDC	Geospatial Workforce Development Centre
HEQF	Higher Education Qualifications Framework
HR	Human resource
HTML	Hypertext markup language
HTTP	Hypertext transfer protocol
ICT	Information communication and technology
ID	Identification
IP	Internet protocol
ISO	International Organization for Standardization
IT	Information technology
KA	Knowledge area
LDM	Logical data model
LDMD	Logical data model diagram
MISA	Municipal Infrastructure Support Agent
NASA	National Aeronautics and Space Administration

NCGIA	National Center for Geographical Information and Analysis
NDRDLR	National Department of Rural Development and Land Reform
NF	Normal form
NQF	National Qualifications Framework
NSIF	National Spatial Information Framework
O*NET	Occupation new and emerging technologies
OGC	Open geospatial consortium
OSD	Occupation specific dispensation
PHP	Hypertext pre-processor
PICC	Presidential infrastructure co-ordinating committee
PLATO	South African Council for Professional and Technical Surveyors
RDBMS	Relational database management system
RPL	Recognition of prior learning
SA	South Africa
SAGI	South African Geomatics Institute
SAQA	South African Qualifications Authority
SAT	Self-assessment tool
SDI	Spatial data infrastructure

SGB	Standards generating body
SQL	Structured query language
TIN	Triangular irregular network
UCGIS	University Consortium of Geographical Information Science
URL	Uniform resource locator
US	United States
USA	United States of America
USBQ	Unit standards-based qualification
UT	University of Technology
UTM	Universal transverse Mercator
WIL	Work integrated learning
WPLI	Workplace learning and performance institute
WWW	World Wide Web

CHAPTER 1 A METHODOLOGY FOR DEVELOPING A SELF-ASSESSMENT TOOL FOR GEOGRAPHICAL INFORMATION SCIENCE PROGRAMMES IN SOUTH AFRICA

> "Graduates of many existing academic programs find themselves ill-equipped when they seek employment in one of the many public and private sector activities making substantial use of geographic information systems (GIS). Among the difficulties that they encounter are: inadequate knowledge of the critical computer science/information technology basis of GIS; a weak understanding of the special characteristics of spatial data; insufficient knowledge pertaining to both the current theoretical and practical status of spatial analysis and the capabilities of the technology available to implement spatial analysis approaches; and insufficient training in identification of the spatial components of problems and in the specification of potential solutions to these problems" (Kemp 2003: 47).

Technological advances such as geographical information systems (GIS), global navigation satellite systems (GNSS) and the World Wide Web (WWW), along with the integration of various kinds of spatial information (e.g. satellite imagery, aerial photography, GNSS-derived data) into devices such as computers, mobile phones and navigation systems, continue to change our social lifestyle patterns (Levy 2004; Morrison 2006). Geographical information science (GISc) is a relatively new discipline that encompasses all of these technologies and sources of information. It involves skills and knowledge beyond the GIS, remote sensing and GNSS training that have traditionally been offered at universities as part of geography, civil engineering, computer science and surveying courses because GISc practitioners must have insights into and understanding of the critical linkages among these related disciplines.

The demand for GISc practitioners is growing worldwide. Government agencies in the United States of America (USA) are competing with the private sector to find and employ GISc practitioners who are suitably qualified and competent (Gewin 2004; U.S. Department of Labor 2004; 2006). European countries are experiencing similar demands (Johnson 2006; Toppen & Reinhardt 2009). Verfaillie et al. (2012), for example, evaluated the GISc job market in Flanders, Belguim, and found that most (64%) respondents agreed that there are not enough skilled graduates available. In South Africa, GISc has been identified as a scarce skill essential for executing the country's National Development Plan (NDP) (DST 2006; DPSA 2009; SA News 2013). As in the USA, South African government agencies and the private sector are competing to find and employ qualified and competent GISc practitioners. This growing demand for GISc skills to address infrastructural development and capacity building (particularly in rural municipalities) led to a number of initiatives by the Presidential Infrastructure Co-ordinating Committee (PICC) – chaired by the President and represented by heads of departments such as the National Treasury, Co-operative Government and Traditional Affairs (COGTA) and Higher Education and Training (DHET). One such initiative is the provision of student bursaries and internships to prepare individuals for professional registration (DPSA 2009; DHET 2013; MISA 2013; National Treasury 2014). This, combined with the growing awareness that the introduction of GISc at secondary-school level has created (Geomatics Education Meeting 2007), will place increasing pressure on universities to provide adequate training and be held accountable for the quality of their academic output. However, few international and local guidelines are available on the content of academic GISc programmes. Kemp & Wiggins (2003) have suggested that a set of competencies, knowledge and skills required by professionals in the workplace is needed to design appropriate educational programmes and to guide those responsible for controlling quality in the profession (through registration) as well as in educational institutions (through accreditation).

1.1 RATIONALE

The demand for GISc professionals prompted the South African Department of Science and Technology (DST) to include GISc (geomatics) as one of the five technology focus areas for the Information Communication and Technology (ICT) roadmap (Nadasen & Salojee 1998; DST 2006). This created a legitimate and insistent demand from the GISc industry that universities be held more accountable for the quality and relevance of their academic output. Much of the early design of GISc education was generated by academics at various universities (Kemp & Wiggins 2003). Consequently, the content, outcomes and quality of the qualifications vary significantly and shortcomings in competencies that should have been developed during formal training are often only revealed to employers once candidates are appointed. As with their counterparts in the USA, employers of GISc practitioners in South Africa seek assurance that the employees they hire are competent in the tangible and intangible skills necessary to excel in GISc (Kemp 2003; Prager & Plewe 2009). Without a well-developed set of criteria for GISc programmes in South Africa, universities will not be able to meet the demands set by the GISc community. Consequently, employers continue to be frustrated by deficiencies in the competency levels of the employees they hire.

In 2001 the GISc community in South Africa reconstituted the dormant Geographical Information Society of South Africa (GISSA) with the purpose of promoting professionalism in GISc (PLATO 2002). An immediate objective of GISSA was to develop educational standards in GISc that meet the registration requirements of the South African Council for Professional and Technical Surveyors (PLATO) (South Africa 1984). A task group, namely the GISc Standards

Generating Body (SGB), was nominated by industry and appointed by the Minister of Education to generate and register unit standards-based qualifications (USBQs) in GISc. A unit standard was defined as a composition of learning outcomes and assessment criteria which determine the knowledge, skills and abilities students are required to attain to be assessed as competent (Bruniquel & Associates 2009). A set of GISc USBQs was subsequently registered with the South African Qualifications Authority (SAQA), decision number 0012/08, in February 2009 (SAQA 2012).

GISc USBQ inputs, outputs and outcomes were frequently used (during 2004 to 2011) as measures to assess the competencies of candidates applying for professional registration with PLATO. The assessment process is essentially a comparison of candidates' qualifications and work experience with the USBQs to determine their knowledge (inputs and outputs) and competencies (outcomes). Consequently, applicants' competence as GISc practitioners is related to their knowledge and understanding of GISc concepts and experience in applying geospatial technologies, in particular GIS, to support decision making. At the end of January 2010, 360 applications had been approved by the Registrar of PLATO (PLATO 2010, Pers com) and this number increased to 505 registered persons in GISc by July 2012 (PLATO 2012). Because the Office of the Registrar of PLATO does not have the capacity to assess applications for registration, all assessments are done voluntarily by persons employed in the profession. This places intense pressure on assessors who are expected to evaluate each application objectively and thoroughly. This burden will become heavier with the expected influx of applications following the introduction of legislation prepared by the Department of Rural Development and Land Reform, i.e. the Geomatics Act (Act 19 of 2013), which aims to regulate the geomatics profession and introduce work reservations for different levels of registration. The Geomatics Act defines a geomatics practitioner as a "person who exercises skills and competencies in the science of measurement, the collection and assessment of geographic information and the application of that information in the efficient administration of land, the sea and structures thereon or therein ... and who is registered in one or more of the branches of geomatics ..." (South Africa 2013: 6). The definition applies to land surveying, engineering surveying, mine surveying, photogrammetry and GISc.

The evaluation of individuals' knowledge and understanding of GISc concepts and practical skills can be simplified significantly by accrediting university programmes for training professional GISc practitioners. However, the accreditation of GISc programmes is complicated by the greatly varying content, outcomes and quality of programmes, variations attributable to the way the programmes have been developed. Some universities based their programme content on existing international programmes and guidelines, while those of others evolved haphazardly. Many of the programmes are in constant flux due to staff and capacity dynamics. Because much of the early design of GIS education was initiated and done by university academics, GISc emerged as a new profession with little concomitant research being done on what GISc professionals should know or be able to do.

GISc courses at South African universities are offered as part of geography, earth science, surveying, town planning, environmental and computer science programmes, so that the content, outcomes and quality of training and education vary considerably. Many of the programmes only require students to take one or two introductory GIS courses to be able to produce simple maps and carry out basic spatial operations. Programmes fail to consider in-depth knowledge of geospatial concepts and theories as prerequisites for competence. Many students who complete the programmes seek employment as professional GIS practitioners for which they are often ill-prepared. This predicament has been noted internationally with graduates often finding themselves ill-equipped when seeking employment in the many public and private sector organizations that make substantial use of GISc (Kemp 2003). According to Gaudet, Annulis & Carr (2003: 22) “... [in] the absence of recognized standards or industry certification, it is no surprise that organizations equipped with increased geospatial technology capabilities for decision support are questioning the kind of people to hire.” PLATO assessors experienced similar difficulties when considering the competency levels of individuals for registration in GISc (PLATO 2008). The application of the USBQ set of competencies for programme evaluation was found to be problematic as the USBQ focusses on technical skills, whereas many science programmes in which GISc is taught include generic scientific modules like chemistry, physics and biology. Because these generic subjects are not represented in the USBQs, comparisons of the latter’s competency set with the content of existing academic programmes are difficult, if at all workable. Consequently, a GISc competency set (GISc PLATO model) was adopted during the 2011 PLATO Council meeting to replace the USBQ. The GISc PLATO model aimed to align the GISc competency set with the same structure used for other geomatics streams, i.e. land surveying, engineering surveying, mine surveying and photogrammetry, all of which shared common subject areas offered at different levels of complexity. However, during the 2012 and 2013 accreditation visits to universities it became evident that the decision to replace the USBQ with the GISc PLATO model increased the problems experienced by assessors, university programme coordinators, students and employers. Matching the credits and outcomes of modules to the lecture hours and content specified by the PLATO model was particularly difficult. This is mainly due to the generalized nature of the PLATO model which consists of twelve broadly defined and sometimes overlapping themes. Such a structure is also problematic for curriculum development as the model does not provide sufficient guidance on how the skills and competencies within each theme should be prioritized. A number of GISc practitioners and academics have also raised concern about the applicability of using a model that attempts to align GISc competencies to those required for land surveying, engineering surveying, mine surveying and photogrammetry. Although there is some overlap between these fields, GISc has a much wider range of application making the definition of core competencies more difficult and programmes offered at universities more diverse. Universities that offer training in surveying also have the advantage that they can incorporate existing modules for building a GISc programme, while other universities need to develop and offer modules that are only of interest to GISc students. Clearly, a new approach to assessing GISc practitioners and for guiding curriculum development in South Africa is needed.

1.2 RESEARCH PROBLEM

Three inherent problems exist regarding the professional registration of GISc practitioners in South Africa: 1) the inconsistencies found in the knowledge and skills development of GISc professionals; 2) the lack of a standard set of competency requirements to assess individuals and accredit academic programmes; and 3) the challenges faced by universities to prepare students for professional registration with the PLATO Council. This unsatisfactory situation is unlikely to change unless a set of GISc competencies is developed to guide the design of new university curricula and support the accreditation of existing programmes.

Although the USBQ and the PLATO models were developed as guidelines for the development and accreditation of programmes in South Africa, they both have a number of shortcomings. For instance, the USBQ is too focussed on technical skills, making comparisons with the content of existing academic programmes difficult. The GISc PLATO model is deemed by many to be biased toward the surveying profession, so complicating comparisons with existing GISc programmes and international standards such as the University Consortium of Geographical Information Science (UCGIS) geographical information science and technology (GI S&T) body of knowledge (BoK) (DiBiase et al. 2006). Another concern is that the USBQ and the PLATO models differ considerably, so raising questions about their application as a standard.

The USBQ and the PLATO models also differ from the BoK which is the most comprehensive competency set and guideline used by many international universities for GISc curriculum development and assessment (Gaudet, Annulis & Carr 2003). It is vital that the competency sets used for professional GISc assessments and curriculum development in South Africa conform to international academic requirements as this will facilitate opportunities for entering into reciprocal agreements with international universities and registration bodies (Unwin 1997; DiBiase 2003; DeMers 2009). The current version (2006) of the BoK includes more than 330 topics organized into 73 units and ten knowledge areas (KAs) (DiBiase et al. 2006). A new version of the BoK is being developed that will likely include some changes to accommodate the needs of the broader global GISc community, such as the European perspective (Toppen & Reinhardt 2009; EUGISES 2012; Reinhardt 2012). According to Johnson (2006) and DiBiase et al. (2006), assessment and curriculum evaluation are the primary uses of the BoK which includes Marble's (1998) six-tier competency pyramid. Gaudet, Annulis & Carr (2003) have for example identified 39 competency abilities (i.e. the knowledge and skills individuals need to do their jobs) required of the geospatial technology workforce.

Although it is clear that USBQ and the PLATO models differ from the BoK, it is uncertain which international requirements are absent from the South African models and, moreover, whether any of the South African requirements are absent from the BoK. A clear and complete identification of the discrepancies between the various frameworks will ensure a good foundation for establishing a comprehensive set of competencies for curriculum development and programme accreditation in South Africa, and perhaps internationally.

Consequently, the following questions arise:

What knowledge and skills should an individual have to be regarded as a GISc professional?

How can the required knowledge and skills be formulated into a standard set of competency requirements to assess individuals and accredit academic programmes?

How can a set of competency requirements be used by universities to develop level-specific (i.e. years 1 to 5) syllabi that would better prepare individuals for professional registration?

To answer these three questions, the research will pursue the aims and objectives set out in the next section.

1.3 AIMS AND OBJECTIVES

The primary aim of this research is to develop an academic framework and competency set with the twofold purpose of 1) assessing the competencies of individuals applying for professional registration and 2) evaluating the content of academic programmes for accreditation. The secondary aim is to use the framework in the development of a web tool and to demonstrate how it can be employed for assessing and designing GISc programmes.

The research will seek to achieve the following objectives:

1. Review the literature and other secondary information sources to gain an understanding of GISc workforce needs and existing competency requirements.
2. Design a curriculum framework for GISc training at South African universities by identifying high-level intersections between existing GISc competency sets.
3. Carry out a detailed, quantitative and qualitative comparison of the USBQ, PLATO model and UCGIS GI S&T BoK to determine the gaps and overlaps between them and evaluate the specific competencies regarded as important by the international and South African GISc industries.
4. Generate a comprehensive set of competencies and minimum requirements that can be used for quantitatively assessing the competencies of individuals as well as the content of academic programmes.
5. Develop a web-based, self-assessment tool and demonstrate how it can be applied to assess existing programmes and guide curriculum development.
6. Critically evaluate the proposed GISc framework and self-assessment tool and make recommendations for further research.

The approach taken for achieving these aims and objectives is described in the next section.

1.4 RESEARCH METHODOLOGY AND DESIGN

A mixed-methods approach (Bergman 2009) was followed in this research with emphasis on the use of secondary data, particularly the SAQA-registered USBQs, the GISc PLATO model and the 2006 version of the UCGIS BoK for GI S&T. The data and the other literature related to the expected competencies of GISc practitioners were studied using a combination of qualitative and quantitative methods (e.g. content analysis, curriculum review and statistical analysis) to develop a GISc competency set and self-assessment tool. The self-assessment tool was applied to three hypothetical GISc programmes to demonstrate the tool's use to support accreditation, programme design and an individual's application for professional registration. The results of the assessments were interpreted to determine if the programmes will sufficiently prepare students for professional registration. The research design is shown in Figure 1.1 and involves eight steps, each representing a chapter. The structure of the dissertation and content of each chapter are summarised in Table 1.1.

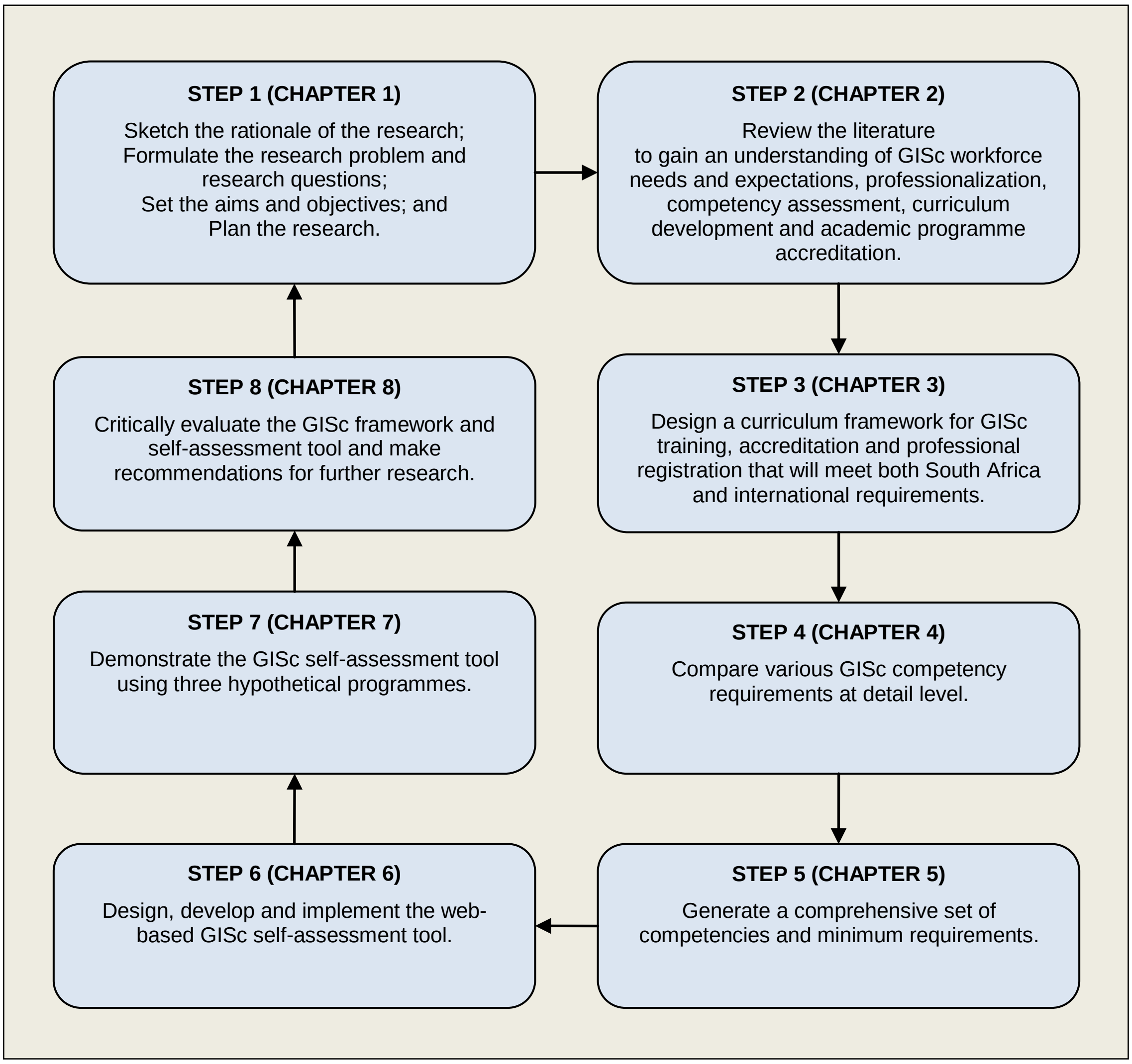


Figure 1.1 Research design, consisting of eight steps

This chapter sketched the historical development of the GISc profession in South Africa and provided a rationale for the research. The research problem and how it was addressed was formulated. An overview of the GISc workforce needs and expectations and a review of the existing competency sets are provided in the next chapter. In Chapter 3 a curriculum framework for GISc training at South African universities is developed by combining themes from three competency sets. Chapter 4 describes a comparison of GISc competency requirements through an investigation of the similarities and dissimilarities between three competency sets.

Table 1.1 Dissertation structure and chapter content

Chapter no.	Chapter title	Main points
1	A methodology for developing a self-assessment tool for geographical information science programmes in South Africa	Rationale Research problem Aims and objectives Research methodology and design
2	Review of GISc workforce needs and existing competency models	Workforce needs and expectations Competencies in GISc Overview of the Geographical Information Science and Technology (GI S&T) Body of Knowledge (BoK)
3	A curriculum framework for geographical information science training at South African universities (Published journal article)	High-level comparative content analysis of the BoK, USBQ and PLATO model Intersections among the competency sets Introduction of a GISc framework that will meet the South African as well as international requirements Evaluation and discussion on the limitations and strengths of the proposed GISc framework
4	A comparison of geographical information science competency requirements (Published journal article)	Detailed comparative content analysis of the USBQ, PLATO model and BoK Identification of gaps and overlaps between the competency sets Identification of competencies regarded as important by the international and South African GISc industries Evaluation and discussion of the findings
5	Development of a new GISc framework and competency set for curricula development at South African universities (Published journal article)	Procedure for the unification of the three competency sets Restructuring of competency sets into 16 knowledge areas (KAs) Competency set workshop Finalization of the GISc framework Evaluation and discussion of the GISc framework
6	Implementation of the GISc self-assessment tool	Requirement analysis Conceptual design Implementation
7	Demonstration of the GISc self-assessment tool	Explanation of user and administrator views Application of the tool to three hypothetical academic programmes Shortcomings in the evaluated programmes Explanation of how universities can use the tool to design accreditation-ready programmes Explanation of how individuals can use the tool to ready themselves for professional registration
8	Evaluation and conclusion	Research aims and objectives revisited Potential and limitations of the assessment methods Status of GISc training at South African universities Value of the research for students, universities and employers Avenues of future research

Chapter 5 deals with the creation of a GISc competency set for curricula development at South African universities by the unification of the three competency sets compared in Chapter 4 and by incorporating fundamental competencies (mathematics and physics), social competencies (training and geographical science) and technical competencies (photogrammetry and remote sensing). Chapter 6 gives an account of the development and implementation of a GISc self-assessment tool (GISc SAT) as a web application. The tool is accessible via the Internet and caters for a diverse GISc user group, including, but not limited to, programme coordinators, curricula developers, students, candidate professionals, interns, employers, employees and human resource (HR) practitioners. Chapter 7 recounts a demonstration of the GISc SAT based on a comparison of three university programmes. The demonstration illustrates the usefulness of the GISc SAT as a self-assessment instrument and how it could benefit the GISc industry and, more specifically, academia, students, professional bodies and employers. Chapter 8 revisits the research aims and objectives, gives an account of the value and limitations of the research and makes recommendations.

CHAPTER 2 REVIEW OF GISc WORKFORCE NEEDS AND EXISTING COMPETENCY MODELS

Stakeholders in the geospatial industry are competing to find and employ practitioners in the GISc field who are both qualified and competent in the practice of geospatial technologies and sciences (Gaudet, Annulus & Carr 2003). The Geospatial Workforce Development Center at the University of Southern Mississippi, with assistance from industry stakeholders, defines geospatial technology as "... an information technology field of practice that acquires, manages, interprets, integrates, displays, analyzes, or otherwise uses data focusing on the geographic, temporal, and spatial context. It also includes development and life-cycle management of information technology tools to support the above" (Gaudet, Annulus & Carr 2001: 10). In South Africa, a geomatics practitioner is defined by the Geomatics Act (Act 19 of 2013) as a "person who exercises skills and competencies in the science of measurement, the collection and assessment of geographic information and the application of that information in the efficient administration of land, the sea and structures thereon or therein ... and who is registered in one or more of the branches of geomatics ..." (South Africa 2013: 6).

This chapter focusses on the international and South African GISc workforce needs and the various efforts that have been initiated to address the shortage of adequately trained professionals in this emerging field. Several initiatives established to provide guidelines for curriculum development and standardization are discussed. The USBQs and PLATO models are explained to cover the South African perspective, while a detailed account of the BoK is included because it is the most comprehensive international framework and it has been used extensively in the USA and Europe for curriculum development (DiBiase 2006; Toppen & Reinhardt 2009).

2.1 THE GISc PROFESSION AND WORKFORCE NEEDS

The success of a GISc business or organization relies on its ability to attract talented employees. Consequently, organizations must understand what employees need to know and be able to do or, alternatively, what the role, competency and output requirements for geospatial work entail (Gaudet & Annulis 2008). In South Africa, poor service delivery at government levels is largely a result of shortages in skilled and talented employees. Many positions in municipalities, provincial and central government are filled by employees who are inadequately qualified for the job and therefore not able to meet the expectations of the communities they are appointed to serve. This can lead to civil unrest and protests.

This section overviews the international and South African GISc workforce needs. The first subsection scopes the GISc profession in the context of the geomatics field, while the second subsection focusses on the needs and challenges the GISc industry faces. The section concludes with an account of public perceptions of the geospatial industry and how new entries can be recruited into the workforce.

2.1.1 GISc: A new and emerging profession within the geomatics field

Countries have for centuries relied on maps for information about the land and the location of people and resources to be used for sound decision making, planning and developmental purposes. Maps were then, and until recently, almost the only means for managing and communicating geospatial information. Many learners and students are responding to the growing value of GIS skills in the job market and the impact that technologies like Google Earth and GPS are having on society (DiBiase et al. 2006; Morrison 2006). Today, computer technology is widely used, while data have become plentiful, software has become more user-friendly and GIS-analytical tools capable of addressing complex questions have emerged in the developed and developing worlds. GIS and related technologies like GPS and remote sensing are used daily in government institutions, private businesses, community forums and research institutions (DiBiase et al. 2006). South Africa and many other countries need informed citizens, acting as productive members of society, to be aware of and able to apply the basic principles of GIS to contribute to decision making in areas such as planning, adequate water and sewage systems, land use, environmental and other similar issues (Morrison 2006).

GISc is primarily based in the discipline of geography, but it draws on insights and methods from philosophy, psychology, mathematics, statistics, computer science, surveying and other fields. GISc and GIS technologies support a wide variety of uses ranging from data acquisition (e.g. aerial imaging, remote sensing, land surveying and global navigation satellite systems) through data storage and manipulation (e.g. GIS, image processing and database management software), to data analysis (e.g. GIS software for statistical analysis and modelling) and display and output (e.g. GIS visualization software and imaging devices) (DiBiase et al. 2006).

GISc faces a variety of challenges common to sectors endeavouring to become established as professions in the new technologically-advanced world of the 21st century. Papers presented during the 8th European GIS education seminar in 2012 confirm that despite the many international attempts to define the scope of the GISc disciplines or the training and credentials required to work in the geospatial industry, much work remains to be done (Hubeau et al. 2012).

Job opportunities in GISc are directly linked to the demands of the GISc industry, so placing pressure on the job market during high-growth periods when there is great demand for competent and skilled workers. A result of such rapid growth is that many of those employed do not have the appropriate fundamental and core knowledge required to do their jobs. For instance, persons with degrees in environmental science, geology, planning or information technologies who have completed one or two modules in GIS are often employed as GIS managers or specialists.

Technologies such as location-based services, cellphones and the Internet have greatly contributed toward an increase in public awareness of geospatial technologies and their impact on daily professional and personal activities. With greater understanding comes a greater call for new entrants to the profession, as well as an increase in demand for geospatial skills and applications across a wide range of other sectors (Morrison 2006; Oxera Consulting 2013).

The ultimate driver of growth in GISc applications is likely to be everyday users, a market that is fed by an expanding population using embedded geospatial technologies such as car navigation systems, web-based mapping and imagery display appliances (Morrison 2006). A further notable trend fuelling the GISc industry's growth is the increasing adoption of a diversity of GIS technology and spatial information by organizations and persons previously unacquainted with GIS tools in developmental, business and political decision making (Morrison 2006). Anecdotal evidence from meetings, workshops, panel discussions and conferences over the past few years testifies that government departments in South Africa are, for example, using geospatial information to manage forests, to develop defensive and law-enforcement strategies and to determine voting districts using census data (e.g. the municipal elections in May 2011). Utility companies such as Eskom use geospatial information to determine transmission and distribution networks. Road agencies rely on spatial information to plan, build and service road networks. Municipalities use spatial information for applications as diverse as routing sanitation and emergency vehicles, maintenance of water mains and street lights, and administering rates and taxes. Private companies apply it in their daily operations to make more informed decisions in areas ranging from site selection to marketing demographics with the intention to gain a competitive advantage over rival companies (e.g. the location of automatic teller machines (ATMs)).

The Geospatial Information and Technology Association (GITA) in the USA has claimed that 70% to 80% of the information managed by businesses is somehow connected to a specific location – an address, street, intersection or an XY coordinate. The importance of location is drawing geospatial technology into nearly every corner of the business world, an occurrence that is contributing to widespread and diverse applications that touch the lives of almost everyone (GITA 2006). This phenomenon explains much of the exceptional growth in the geospatial sector and the concomitant demand for qualified, skilled and competent employees. Of course, being an emerging global growth industry the GISc profession is now experiencing serious shortfalls in the type of geospatial practitioners named in Table 2.1.

Table 2.1 Types of geospatial practitioners

Practitioner	Description
Land surveyor	Establish official land, airspace, and water boundaries; write descriptions of land for deeds, leases, and other legal documents; define airspace for airports; and measure construction and mineral sites.
Cartographer	Compile geographic, political, and cultural information and prepare maps of large areas.
Photogrammetrist	Measure and analyze aerial photographs that are subsequently used to prepare detailed maps and drawings.
Surveying technician	Assist land surveyors by operating surveying instruments and collecting information in the field, and by performing computations and computer-aided drafting in offices.
Mapping technician	Calculate mapmaking information from field notes, draw topographical maps, and verify their accuracy.
Geographic information specialist	Combine the functions of mapping science and surveying into a broader field concerned with the collection and analysis of geographic data.

Source: DOLETA (2005: 8)

The range of geospatial professions listed in Table 2.1 corresponds well with the registration branches provided for in the Geomatics Professions Act (Act 19 of 2013), namely land surveying, engineering surveying, hydrographical surveying, photogrammetry, cartography and GISc. A geomatics practitioner may be registered in one or more categories (candidate geomatics practitioner; geomatics technician; geomatics technologist; and geomatics professional) and in one or more of the branches (South Africa 2013). To be able to provide a well-trained workforce, training institutions must understand the challenges, requirements and expectations of the workforce operating in the geomatics industry.

The National Center for O*NET Development in the USA has identified two levels of occupational groups in the GISc industry, each with its own standard occupation code and title. They are geospatial information systems (GIS) scientists and technologists at the higher level and GIS technicians at the lower level (National Center for O*NET Development 2006). Their report also lists alternative titles for the occupational groups including, but not limited to, GIS mapping assistant, GIS technician, GIS analyst, GIS application specialist, GIS data specialist and GIS specialist. The report unambiguously states that these occupations are not the same as cartographers, photogrammetrists, surveyors, mapping technicians and geographers, all of which have their own standard occupation code and title (National Center for O*NET Development 2006). The Center has further identified distinct task lists (Table 2.2 and Table 2.3) for the above two occupational groups in which the differences in the expected competencies, skills and knowledge capacity of the occupational levels are clear, although the order in which the tasks are listed does not imply any relative importance of each occupation. It is noteworthy that in Table 2.2 there is no differentiation between scientists (professionals) and technologist, whereas the South African Geomatics Act (Act 19 of 2013) distinctly separates the two categories. The Act further provides for future work reservation and although work reservation for the occupational group might be easy to identify, reservation of tasks within the occupational group will be controversial and difficult to apply due to the overlap between the tasks performed by technologists and professional practitioners (scientists).

Table 2.2 O*NET task list for geospatial information systems scientists and technologists

#	Task
1.	Identify and develop geospatial tools, applications and instruments to satisfy customer specifications.
2.	Design geospatial and related data acquisition processes to provide needed data.
3.	Process geospatial data and extract information to create products, drive conclusions and inform decision-makers.
4.	Catalog, retrieve, distribute and secure geospatial and related data to assure quality products in a timely manner.
5.	Oversee geospatial and related project activities to produce desired outcomes on time and within budget.
6.	Assess requirements including inputs, outputs, processes and timing and performance and recommend necessary additions and adaptations to develop effective systems.
7.	Analyze, design, and develop instructional and non-instructional interventions to provide transfer of knowledge and evaluation for performance improvement.
8.	Render geospatial and related data into visual presentations to produce products such as maps, charts, graphs, videos and Web applications.
9.	Apply knowledge of geospatial information systems to design databases or data analyses for spatial and non-spatial information.
10.	Designs analyses and presentation of this data, applying knowledge of geographic information systems.
11.	Consult with organization decision-makers to determine geospatial information system's needs.
12.	Integrate resources and develop additional resources to support spatial and temporal user requirements.
13.	Meet with users to develop system or project requirements.
14.	Recommend procedures to increase data accessibility and ease of use.
15.	Write reports or make presentations to inform decision-makers.
16.	Conduct meetings to facilitate inter-organizational communication.

Source: National Center for O*NET Development (2006: 42)

The tasks performed mainly by geospatial information technicians are listed in Table 2.3. The main tasks (roles) performed by GISc practitioners in South Africa are shown in

Table 2.4. Tasks performed by GISc practitioners in South Africa correspond well with the tasks performed in the USA. It is, however, noteworthy that GISc practitioners in South Africa spend less time on system analyses, software development, marketing and policy formulation. Reasons for the low proportion of time spend on these tasks could be inadequate training (very few GISc programmes in South Africa include computer science as major) or the employment of inadequately qualified persons in South Africa.

Table 2.3 O*NET task list for geospatial information systems technicians

#	Task
1.	Build, maintain and modify geospatial information system databases to store spatial and non-spatial data.
2.	Meet with users to develop system or project requirements.
3.	Discuss specific problems to be solved, such as development of transportation planning and modeling, marketing and demographic mapping, or assessment of geologic and environmental factors.
4.	Use computers, software and related tools, such as plotters, to represent geospatial information.
5.	Apply knowledge of spatial feature representations to create output, such as graphs or maps.
6.	Enter data into geospatial information systems database, using techniques such as application of coordinate geometry, keyboard entry of tabular data, manual digitizing of maps, scanning and automatic conversion to vectors, or conversion of other sources of digital data.
7.	Determine information to be queried, such as location, trend, pattern, routing, and modeling series of events.
8.	Determine and apply analysis procedures to analyze spatial relationships, including adjacency, containment and proximity.
9.	Select cartographic elements, including two-dimensional or perspective view, map projection, scale, colour, shading, symbols, and additional elements, such as images, graphs, tables, and overlays to develop effective presentation of information.
10.	Check cartographic symbols to verify designation.
11.	Review existing and incoming data for currency, accuracy, usefulness, quality, and completeness of documentation.
12.	Recommend procedures to increase data accessibility and ease of use.

Source: National Center for O*NET Development (2006: 44)

Table 2.4 Proportion of time spent on tasks by GISc practitioners in South Africa

Task performed by GISc practitioners	Time spent (%)
Data analyses	19
Management	15
Project management	14
Data management	10
Research	8
Visualization and mapping	7
Data acquisition	7
Training	4
System management and integration	4
Database administration	3
Coordination	3
Policy formulation	2
Marketing	2
Software development	1
System analysis	1

Source: Coetzee et al. (2014)

A survey of geospatial products and service providers in the USA revealed that 87% of the respondents had difficulty filling positions (National Center for O*NET Development 2006). South Africa is experiencing similar demands for GISc practitioners. This need has prompted the Department of Science and Technology (DST) to include GISc (geomatics) as one of the five technology focus areas for the information communication and technology (ICT) roadmap

(Nadasen & Salojee 1998; DST 2006). Subsequently, the Department of Public Service Administration (DPSA) declared persons with competencies in the practice of GISc a scarce resource. An agreement (Resolution 3 of 2009) between the General Public Service Sector Bargaining Council (GPSSBC) and the DPSA recognizes GISc as one of the occupational groups in the engineering sector to be included in the occupation-specific dispensation (OSD) policies designed to retain and attract persons with the required competencies (DPSA 2009).

The many vacancies in every sphere of the South African GISc industry emphasize the need for a strategy to meet the formidable task of providing a well-trained workforce (DPSA 2009; DHET 2013). The GISc industry and organizations such as the Chief Directorate: National Geo-spatial Information, South Africa's national mapping organization, cannot wait until a crisis in the workforce stimulates efforts to produce the required human capital. During the education advisory committee meetings (PLATO EAC 2011) academics often referred to the challenges to attract students to study geomatics due to the high entrance requirements for mathematics and physics. South Africa's matriculation examination results over the last few years confirm that graduates with computer science, mathematics and physics are (and will remain so in the foreseeable future) the most difficult to recruit due to the small proportion of learners who manage to do well in these subjects. These challenges and other needs relating to the GISc workforce in South Africa and abroad are discussed in the next section.

2.1.2 Workforce needs and challenges

According to Gaudet & Annulis (2008: s.p.), "Human capital is the collective knowledge and brainpower of an organization." Human capital can be developed by the informal and formal education employees contribute to an organization, along with the skills acquired in training and practice. It includes the lessons learned from past successes and mistakes. It also includes the social and professional networks developed over the years through interaction at institutes and professional bodies as well as relationships between co-workers, colleagues and customers (Gaudet & Annulis 2008).

What we should learn about GIS and how we should teach GIS and GISc have been topics of academic discussion for well over 30 years. During this time a still ill-defined profession has emerged among those who practice the application of this technology. Given the traditional lack of communication between academics and professionals, the problem persists of bridging the gap between the academic view of what should be learned and the professional view of what skills and knowledge are needed (Marble 1998; 2003; Kemp & Wiggins 2003; DiBiase et al. 2006; Johnson 2006).

This educational challenge is found in South Africa too. In 2010 and 2011 the Educational Advisory Committee (EAC) of PLATO had several discussions on the most appropriate content of academic models for the accreditation of universities offering programmes in GISc. The South African challenges that manifested during the discussions matched those faced overseas. Some participants expressed concern that the content of the PLATO model appeared to be biased in certain instances toward surveying and in others toward geography. The EAC had to address these concerns to strike a balance between what should be learned and what knowledge and skills are needed to meet the demands of the employment market (PLATO EAC 2011).

Whereas much of the early design of GIS education was inspired and done by university academics, the emergence of the GIS profession has given impetus to building educational opportunities that truly reflect the demands of the employment market. Kemp & Wiggins (2003) explored this from various perspectives. They looked at three issues, namely the need to identify the full set of competencies, knowledge and skills required by professionals in the workplace (through efforts to define necessary competencies and appropriate university curricula); the appropriate design of educational programmes and exploration of emerging delivery mechanisms (designing curriculum content and providing opportunities for distance learning); and the question of quality control of professionals and educational opportunities (through certification and accreditation (registration)). All these requirements are prerequisites which contribute to the image and perception the public has of the GISc profession. Subsequently, similar efforts to define frameworks, competency sets and computerized curricula for the GISc field of study have been recorded and presented at seminars and conferences (DiBiase et al. 2006; Johnson 2006; 2012; Hossain & Reinhardt 2012; Rip & Verbree 2012).

2.1.3 Building the right image for the profession

The National Department of Rural Development and Land Reform (NDRDLR), Directorate: National Spatial Information Framework (NSIF) held a series of provincial workshops on GIS skills development in Durban (9 May 2006), Cape Town (27 July 2006), Polokwane (15 August 2006) and Gauteng (4 October 2006) where participants reported that, due to the emerging nature of the geospatial technologies, there was a lack of understanding by the public of what is meant by ‘geospatial’. Even the users of geospatial data had some misunderstandings. Members of

GISSA pointed out that the industry not only faces an image problem among the youth but also among many decision makers in government and in politics (Skills Development Report 2006).

In reaction, GISSA and the South African Geomatics Institute (SAGI) embarked on an extensive marketing programme to improve the image of geospatial technologies by integrating their institutional resources to make a greater impact on the youth and on decision makers in government and politics. Through workshops, seminars and conferences the two bodies have spread a message demonstrating geospatial technologies as an enabler of other location-based applications. They have developed a communication strategy aimed at academia and industry through publications such as Position IT and the South African Geomatics Journal, newspaper articles, bursary schemes and by engaging with SAQA, the Council on Higher Education (CHE), national and provincial education departments, schools and universities (Geomatics Education Meeting 2007). The next subsection investigates whether these and other efforts will be successful in recruiting new entrants to the GISc profession in South Africa.

2.1.4 Recruitment of new entrants to the profession

During the inauguration of the Standards Generating Body (SGB), representatives of government departments (e.g. Department of Land Affairs, Statistics South Africa, South African Defence Force and Department of Water Affairs), municipalities (e.g. Cape Town, Johannesburg and Port Elizabeth) the business sector (e.g. Intergraph, ESRI and Computer Foundation), and employers of GISc practitioners reported that there was a scarcity of qualified individuals to fill the then and projected job vacancies in the geospatial industry (SAQA 2003). The Department of Rural Development and Land Reform (RDLR), Chief Directorate of National Geospatial Information (CDNGI), also raised concern about the large number of vacancies for GISc practitioners, averaging around 35% for the period 2008 to 2012 (CDNGI 2008; 2012). The pressure to recruit suitably qualified GISc practitioners prompted the Department of Public Service Administration (DPSA) to enter into an agreement (Resolution 3 of 2009) with the General Public Service Sector Bargaining Council (GPSSBC) to declare GISc a scarce skill together with engineering, surveying and other occupations experiencing the same problem (DPSA 2009). The DPSA responded with new OSD models for persons with scarce skills to attract and retain persons who are competent in geospatial technologies.

Further examples of interventions are the increased number of bursaries available from government departments (RDLR and Water Affairs) for persons wanting to enrol for degrees in geoinformatics (GISc) as well as the availability of internships offering post-qualification training. A meeting in January 2013 of the Buffalo City Metropolitan Council and the Department of the National Treasury initiated a pilot programme to release funds to municipalities for employing interns with the purpose of developing and retaining GISc capacity at municipalities in the Eastern Cape. The Nelson Mandela Metropolitan Council and the Buffalo City Metropolitan Council were selected as the first two municipalities in the project which gives preference to interns drawn from the Eastern Cape region. An immediate challenge to the project was the alignment of the academic qualifications of the interns with the registration requirements of the PLATO model before work-integrated learning (WIL) or training could commence.

Two problems became apparent. The first is that none of the universities in the Eastern Cape, where most of the interns studied, offered a PLATO-accredited undergraduate programme in GISc. All the interns had excellent qualifications but their major subjects were geology, environmental science or geography, and often excluded fundamental knowledge areas such as mathematics or physics. Most of the interns had, however, completed one or two introductory modules in GIS as part of their qualifications. Unfortunately, these qualifications do not meet the requirements of professional registration. The second problem that emerged is that the municipalities were already employing so-called GIS specialists with qualifications that do not meet the registration requirements of PLATO. These ‘specialists’ were consequently not suitable mentors for the interns (PLATO requires mentors to be registered professionals).

These unfavourable circumstances are not limited to the Eastern Cape. Similar situations occur throughout the South African and international GIS industries. This has led to increasing pressure on universities to be held accountable for producing graduates who are competent in the tangible and intangible skills in GISc (Prager & Plewe 2009). Without accredited university programmes in GISc, human resource practitioners will remain uncertain about who will meet the employers’ expectations.

The genuine concern in the industry about recruiting new entrants to the profession has been substantiated by academics from various universities in South Africa (SAQA 2003-2009). The academics emphasized that matriculated youth with mathematics and science as subjects viewed careers in geospatial technology as less attractive and exciting than competing careers such as engineering. Consequently, universities find it difficult to attract students who meet the prerequisites for GISc programmes and they suggested that the GISc industry offers more incentives to foster the youths’ interest in this field.

Delegates to the NSIF-organized provincial workshops on skills development (see Section 2.1.3), included representatives of academic institutions, professional bodies, and the public and private sectors who resolved that the industry make several commitments, namely to recruit qualified workers; and to develop support to enhance their retention through legislation, professional registration, work reservation, a stratification providing increased compensation, mobility across industries and specific discipline and industry applications. Delegates also concluded that there is a serious need for specific survey tools to track salaries, benefits, workforce needs, best practices and competency requirements (Skills Development Report 2006).

2.2 TRAINING AND CURRICULUM DEVELOPMENT GUIDELINES

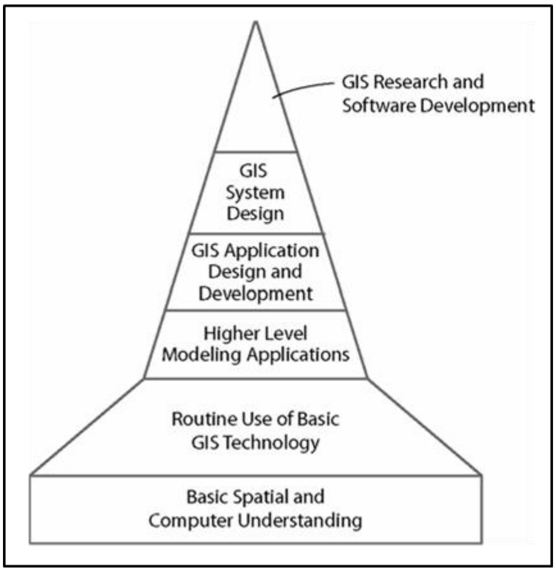
The previous section noted the great demand for competent GISc practitioners who meet the requirements of industry and society. This section examines how this demand can be addressed through training programmes specifically designed to meet workforce needs. First an account is given of how GISc curricula have developed over the last four decades. This is followed by a description of the levels of competencies that GISc practitioners should possess. The section concludes with an overview of the competency models that have been proposed to guide the development of international and South African curricula.

2.2.1 Historical development of GISc curricula

Historically, much of the early design of GIS education was done by university academics in North America. Consequently, most of the research, articles and reports originate in the USA and Canada and deal with topics such as the need to identify the full set of competencies, knowledge and skills required by professionals in the workplace; the obligation to design appropriate educational programmes; and the question of certification and accreditation as a form of quality control among both professionals and educational institutions (Kemp & Wiggins 2003; Gaudet & Annulis 2008). The focus of GIS education on the development of software applications and spatial databases during the period 1960 to 1980 shifted to a post-1980 environment that is application orientated. This has made GIS technology more available and more user-friendly so leading to the erroneous notion that these developments imply that the technology can be mastered by almost anyone with minimal effort. According to Marble (1998) a generation of students has emerged (at the beginning of the 21st century) who were able to apply perhaps only ten per cent of the power of GIS technology and then often incorrectly. This is still very much the case in South Africa where assessors reported in 2012 to the EAC about students applying for registration with the professional body but possessing inadequate qualifications, often only a single module comprising an introduction to GIS.

2.2.2 GISc competency levels

Marble (1998) has compiled a pyramid of six competency levels that undergraduate degree programmes should prepare students to achieve (Figure 2.1). Public awareness of geospatial technologies forms the base of the pyramid. One level above the base is the relatively large number of workers who need to be prepared for careers involving routine use of commercial off-the-shelf (COTS) and related geospatial technologies. A somewhat smaller number of graduates work with higher-level modelling applications within COTS and they must possess knowledge and skills in spatial analysis, computer programming and database management systems. More demanding, and involving fewer students, are application design and development roles that require workers to create software applications rather than simply using them. Specialists responsible for system design require advanced analytical as well as technical skills, including systems analysis, database design and development, user interface design and programming. Finally, the apex of the pyramid represents the relatively small number of individuals whose sophisticated understanding of geography, spatial analysis, and computer and information sciences prepares them to lead research and software development teams in software companies, government agencies and universities. Marble (1998) warned that while the base of the pyramid is expanding rapidly, the upper levels have shrunk with insufficient resources entering the job market at these levels.



Source: Marble (1998). Reproduced from DiBiase et al. (2006: 10).

Figure 2.1 Pyramid of roles played by geographical information science and technology (GI S&T) professionals

Marble (1998) urged the GISc industry to significantly raise the then levels of GIS education to keep pace with the rapid advances in technology. For example, in the upper levels of the pyramid he proposed re-establishing the strong role of computer science education in GIS while simultaneously restructuring GIS education to integrate competence in computing into the structure of GIS education. His argument implied that all GIS education programmes and providers raise the level of their presentation of both fundamental concepts and of the full capabilities of the technology. The notion of a curriculum must advance beyond some of the contemporary attempts to specify the content of one or two introductory courses to a fullyfledged examination of the entire spectrum of courses required to support an adequate GIS education at each level of the pyramid (Marble 1998).

In South Africa, users of GISc applications are expanding in proportion to the number of users having access to computers, smartphones and related technologies, so that the base of the pyramid is expanding rapidly too. However, the registration figures in Table 2.5 for GISc practitioners in South Africa give a somewhat different picture with the upper levels (technologist and professional) matching those of technicians at the lower level (Coetzee et al. 2014).

Table 2.5 PLATO registration categories

Registration category	Persons (%)
Professional	32
Technologist	32
Technician	36

Source: Coetzee et al. (2014)

This disproportion in registration is partly attributable to persons who entered the profession via the ‘grandfather clause’ dispensation in 2004, 2009 and 2014 which allows practitioners with more than 15 years of experience to be registered without the required qualifications. This is supported by Table 2.6 which shows that the majority of those working in the South African GISc field have postgraduate degrees and are consequently expected to be performing roles in the upper levels of the pyramid. As the profession matures it is expected that registrations of technicians will eventually considerably exceed the number of persons registered at the technologist and professional level.

Table 2.6 Highest qualification obtained by persons working in the GISc field in South Africa

Qualification	Persons (%)
PhD	4
Masters	18
Honours, 4-year degree	37
3-year degree	22
2-year diploma	9
Grade 12	9
Other	1

Source: Coetzee et al. (2014)

Despite the inconsistencies between the South African GISc field and Marble's pyramid highlighted above, there are also some common aspects. In particular, the complexity of work performed by GISc practitioners in South Africa (recall

Table 2.4) is similar to that specified in Marble's pyramid. There is a relatively small proportion (4%) of GISc practitioners who perform complex tasks such as system design, software development and policy formulation.

Most competency models attempt to incorporate some aspects of Marble's pyramid. This is often done by specifying whether a particular competency is fundamental, core or elective. Some models associate subsets of competencies with different types of practitioners (e.g. technician vs technologist). These approaches are discussed in the next section.

2.2.3 GISc competency models

Competency models are built around integrated models based on key success factors (competencies) required for excellent performance in a particular work role. Role definitions, competencies, outputs and quality requirements are important components of the prerequisites for successful work performance (Gaudet, Annulis & Carr 2002). According to Dalton (1997), cited by Gaudet, Annulis & Carr (2002), competencies can be described as the knowledge, skills, abilities, motives and values required to accomplish a particular task or job within a particular work role. Competencies are also the behaviours that distinguish effective work performance from ineffective performance. GISc competency models are useful for career guidance, curriculum development and assessment, recruitment and hiring, continuing professional development, as criteria for voluntary certification and for marketing efforts intended to communicate characteristics of the geospatial field to the public (Gaudet, Annulis & Carr 2002). The next five subsections outline a selection of international and national GISc competency sets.

2.2.3.1 The Workplace Learning and Performance Institute – roles and competencies

In 2001 NASA mobilized a team of workforce-development specialists at the University of Southern Mississippi to identify key competencies for geospatial professionals (Table 2.7). The Geospatial Workforce Development Center - later reorganized as the Workplace Learning and Performance Institute (WLPI) - convened workshops to identify the key competencies and roles employees expected geospatial professionals to play (Table 2.8). The team concluded that "For geospatial technology professionals to be successful in today's marketplace, it is critical to understand that the knowledge, skills, and abilities required for their jobs include a blend of technical, business, analytical, and interpersonal competencies" (Gaudet, Annulis & Carr 2003: 25). Each role outlined in Table 2.7 requires a subset of the technical, analytical, business and interpersonal competencies as marshalled in Table 2.8.

Table 2.7 Key competencies and roles played by geospatial technology professionals

Competencies	Roles
Applications Development	Identify and develop tools and instruments to satisfy customer needs.
Data Acquisition	Collect geospatial and related data.
Coordination	Inter-organisational facilitation and communication
Data Analysis and Interpretation	Process data and extract information to create products, drive conclusions, and inform decision-making reports.
Data Management	Catalogue, archive, retrieve, and distribute geospatial data.
Management	Efficiently and effectively apply the company's mission using financial, technical, and intellectual skills and resources to optimize the end products.
Marketing	Identify customer requirements and needs, and effectively communicate those needs and requirements to the organization, as well as promote geospatial solutions.
Project Management	Effectively oversee activity requirements to produce the described outcomes on time and within budget.
Systems Analysis	Assess requirements to produce the desired outcomes on time and within budget.
Systems Management	Integrate resources and develop additional resources to support spatial and temporal user requirements.
Training	Analyze, design, and develop instructional and non-instructional interventions to provide transfer of knowledge and evaluation for performance enhancement.
Visualization	Render data and information into visual geospatial representations.

Source: Gaudet, Annulis & Carr (2003: 25)

Table 2.8 Thirty-nine competencies required for success in the geospatial technology profession

Category	Core competencies	Other competencies
Technical	▪ Ability to assess relationships among geospatial technologies ▪ GIS theory and applications ▪ Technical writing ▪ Technological literacy	▪ Cartography ▪ Computer programming skills ▪ Environmental applications ▪ Geology applications ▪ Geospatial data processing tools ▪ Photogrammetry ▪ Remote sensing theory and applications ▪ Spatial information processing ▪ Topology
Business	▪ Ability to see the 'big picture' ▪ Change management ▪ Cost-benefit analysis ▪ Visioning	▪ Business understanding ▪ Buy-in/Advocacy ▪ Ethics modelling ▪ Industry understanding ▪ Legal understanding ▪ Organizational understanding ▪ Performance analysis and evaluation
Analytical	▪ Problem-solving skills ▪ Creative thinking	▪ Knowledge management ▪ Model building skills ▪ Research skill ▪ Systems thinking
Interpersonal	▪ Self-knowledge/Self-management ▪ Relationship building skills ▪ Leadership skills ▪ Feedback skills ▪ Communication	▪ Coaching ▪ Conflict management ▪ Group process understanding ▪ Questioning

Source: Gaudet, Annulis & Carr (2003: 28)

2.2.3.2 The UCGIS GI S&T body of knowledge (BoK)

In the late 1990s Duane Marble was concerned about the lack of structure in geographical information science and technology (GI S&T) curricula compared to the solid designs in the established sciences such as computer science (Marble 1998). He volunteered to lead a task force to create a model curriculum for GI S&T. The result was the Strawman Report published in June 2003 (Marble 2003; UCGIS 2003). Shortly after, in early 2005, the UCGIS Education Committee, chaired by David DiBiase, narrowed its attention to the body of knowledge (BoK) part of the model curriculum due to the limited funding available and time constraints. The first edition of the GI S&T BoK was published in 2006 with the intention to help identify the breadth and depth of the knowledge that represents the domain of GI S&T (DiBiase et al. 2006).

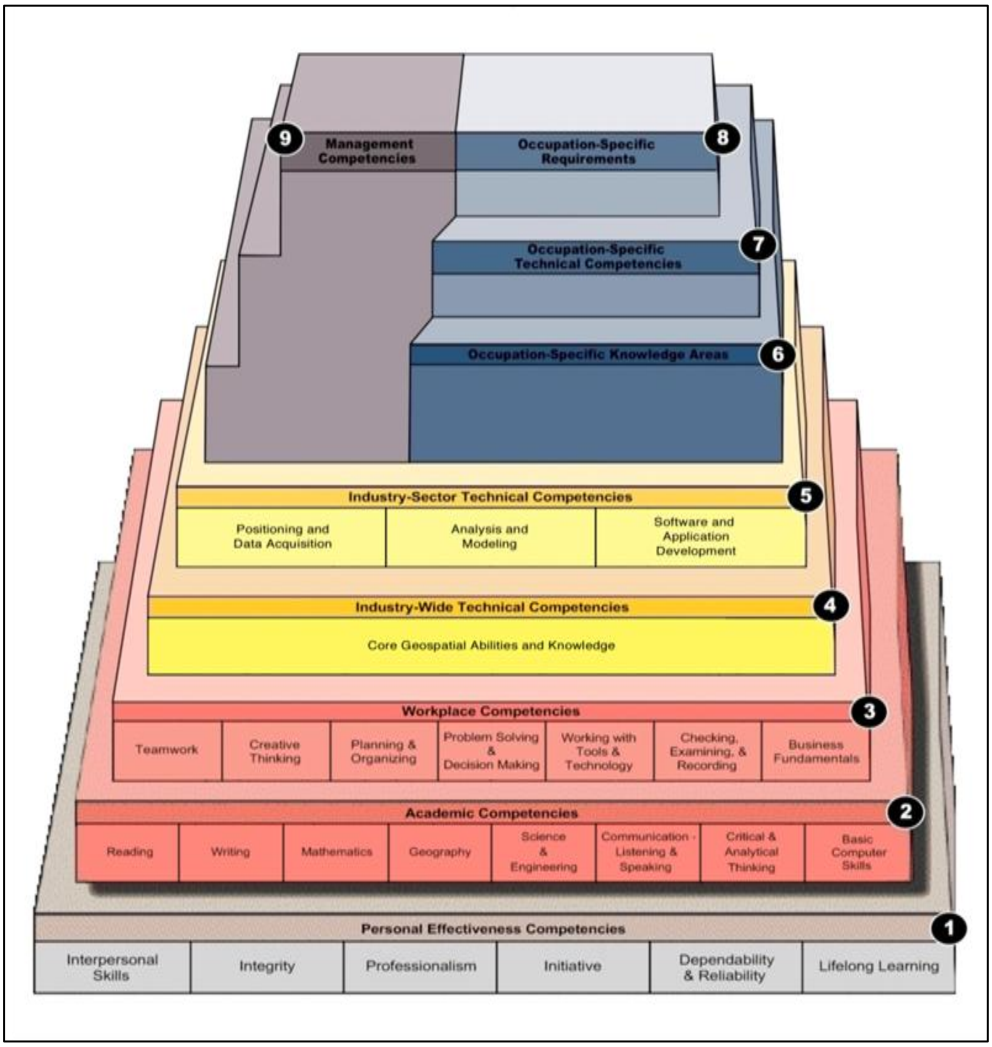
Between 1988 and 2006 the works of the National Center for Geographic Information and Analysis (NCGIA 1988), Goodchild & Kemp (1990), Unwin (1997), Longley et al. (2002), Huxhold & Craig (2003), Kemp (2003), Marble (2003) and DiBiase et al. (2006) established the USA as the global leader in GI S&T and geospatial education.

To ensure interoperability with corresponding documents in computer science, information science, project management and other fields, the GI S&T BoK is a hierarchical outline composed of three tiers called knowledge areas (KAs), units and topics (Johnson 2006). The first tier consists of ten KAs that span the breadth of the GI S&T domain. Each KA consists of several constituent units meant to be coherent sets of topics that embody representative concepts, methodologies, techniques and applications. Units begin with brief descriptions, followed by a list of topics. Units are designated as either core or elective. Core units are those in which all graduates of a degree or certificate programme should be able to demonstrate some level of competence. Elective units represent the breadth of the GI S&T domain, including advanced topics related to the upper levels of the competency pyramid, such as application design, system design, and research and development (DiBiase 2006; Johnson 2006). Section 2.3 deals with the BoK in considerably more detail.

2.2.3.3 The DOLETA geospatial technology competency model

In collaboration with the GeoTech Center, the United States Department of Labor Employment and Training Administration (DOLETA) worked with leaders in industry and education to develop a comprehensive competency model for geospatial technology (DOLETA 2010). The geospatial technology competency model (GTCM) is depicted as a pyramid with nine tiers (Figure 2.2). This depiction shows how occupational and industry competencies can be built on a foundation of personal effectiveness, academic and workplace competencies. Each tier consists of one or more blocks representing the skills, knowledge and abilities essential for successful performance in the industry or occupation represented by the model. At the base of the model, competencies apply to a large number of occupations and industries. As one moves up in the model, the competencies become industry- and occupation-specific.

Tiers 1 through 3 in Figure 2.2 represent the fundamental competencies needed to enter the workplace. The personal effectiveness competencies of Tier 1 correspond to personal attributes or ‘soft skills’ generally learned in the home or community and reinforced at school and in the workplace. Academic competencies in Tier 2 are mastered primarily in a school setting and include cognitive functions and thinking styles, and are likely to apply to most industries and occupations. The workplace competencies in Tier 3 represent motives and traits, as well as interpersonal and self-management styles honed in the workplace.



Source: DOLETA (2010: 1)

Figure 2.2 The geospatial technology competency model (GTCM)

Tiers 4 and 5 are called industry competencies and show proficiencies specific to the geospatial industry or to other industrial sectors. They support the development of an agile workforce, rather than a single-occupational career ladder. The industry-wide technical competencies in Tier 4 denote the knowledge and skills common across sectors in a broader industry. Industry-sector technical competencies in Tier 5 represent a subset of technical competencies specific to an industrial sector. Tiers 6 through 9 signify specializations that occur in specific occupations within an industry. [1]

[1] Information on occupational competencies is available online through O*NET (http://online.onetcenter.org/) and in an ongoing series of DACUM (develop a curriculum) occupational analyses performed by the National Geospatial Technology Center (http://www.geotechcenter.org). The body of the GTCM is a table available online at http://www.doleta.gov containing definitions and associated key behaviours for each competency block depicted in the pyramid (DOLETA 2010).

Expected uses of the GTCM include career guidance, curriculum development and assessment, recruitment and hiring, continuing professional development, criteria for voluntary certification, and outreach efforts intended to communicate characteristics of the geospatial field to the public.

The following two subsections deal with South African-developed competency sets, namely the PLATO model and the USBQ respectively.

2.2.3.4 The South African Council for Professional and Technical Surveyors' registration model (PLATO model)

The PLATO model[2] is a selection of competencies in GISc that provides for the registration of three categories of practitioners, namely technician, technologist and professional. Each category contains common and category-specific subject areas supplemented with non-common core and elective subject areas to meet occupation-specific (e.g. land surveying, engineering surveying, hydrographical surveying, photogrammetry, cartography and GISc) requirements. Common subject areas such as mathematics, physics and analytical skills are associated with critical competencies that include cognitive functions and thinking styles, and they apply to most sub disciplines and occupations in the geomatics industry. The category-specific knowledge areas, such as GIS, information technology (IT), three dimensional (3D) modelling, cartography, visualization, data acquisition, photogrammetry and remote sensing are associated with occupation-specific competencies such as GISc. The model provides for elective core subject areas that cater for specialization as well as specialized occupation categories not normally associated with the geomatics occupational group such as occupations in the fields of health and environmental sciences. PLATO is the statutory (professional) body responsible for regulating the geomatics profession in terms of Act 40 of 1984 (South Africa 1984) and it is the custodian of the PLATO registration model developed through inputs received by the Education Advisory Committee (EAC), a subcommittee of the professional body, and through public participation processes such as conferences and meetings organized by GISSA and SAGI.

[2] The PLATO model is available online and can be viewed at http://www.plato.org.za/index.php.

2.2.3.5 The South African GISc unit standards-based qualification (USBQ)

The GISc USBQ[3] comprises three tiers namely KAs, unit standards and outcomes. A USBQ consists of fundamental, core and elective unit standards. The fundamental unit standards cover mathematics, statistics, physics, business management (professionalism and ethics) and analytical skills associated with critical competencies including cognitive functions and thinking styles that are expected of persons working in the geomatics field (SAQA 2009). The core unit standards such as GIS, data acquisition, IT, data management, photogrammetry and remote sensing are associated with occupation-specific competencies that are core to the business of the GISc practitioner. The elective unit standards allow for specialization of GISc practitioners working at operator, technician, technologist and professional levels in occupations where the core business objectives focus on various outcomes such as occupations in the health, engineering, IT, planning and environmental sciences (South Africa 1995; SAQA 2009). The next section provides a detailed account of the GI S&T BoK.

2.3 THE GEOGRAPHICAL INFORMATION SCIENCE AND TECHNOLOGY BODY OF KNOWLEDGE (GI S&T BoK)

In 1997 the University Consortium for Geographic Information Science (UCGIS) identified the setting up of a framework for the assessment of GI S&T curricula as a worthy educational endeavour (Kemp & Write 1997; Marble 1998). As discussed in Section 2.2.3.2, this historical decision marked the beginning of the UCGIS GI S&T BoK. The following subsections provide an overview of the important contributions made to the evolution of the GI S&T set of competencies; as well as the BoK stucture; applications; and unanticipated outcomes.

2.3.1 Important contributions to the development of the BoK

Unwin (1997: 159) asserted that "GIS instructors in higher education have shown an almost exemplary concern for teaching" and insisted that employees' criticisms of the preparedness of graduates should not imply that GI S&T educators have neglected their responsibilities. For many years (1988 to 2006) educators in the USA were recognized as the international leaders in GI S&T and during this unprecedented period of initiating geospatial education curricula they devoted much time to curriculum planning; writing textbooks; development of educational software products; convening of workshops; organizing of international and local conferences;

---

[3] The GISc USBQ is available online at http://www.saqa.org.za/show.asp?include=qualstds.html.

leading investigations dealing with job titles, salaries and job roles; and the publication of GIS course syllabi and curricula. The following three examples testify to important curriculum design efforts in the USA that contributed to creating a comprehensive set of GI S&T competencies and which culminated in the BoK (DiBiase et al. 2006).

2.3.1.1 NCGIA GISc core curriculum

The National Center for Geographic Information and Analysis (NCGIA) consortium of the University of California at Santa Barbara, the State University of New York at Buffalo and the University of Maine produced the NCGIA GISc core curriculum in 1988. The curriculum details a three-course sequence of 75 one-hour units which can be taught over an academic year at postgraduate level (Goodchild & Kemp 1990). The courses are entitled: 'Introduction to GIS'; 'Technical issues in GIS' and 'Application issues in GIS'.

More than 100 institutions worldwide agreed to implement the three-course sequence as soon as it became available and to share their assessment data with the NCGIA[4] to aid further development and refinement of the courses. In 1995, the NCGIA announced plans for a New Core Curriculum in GIScience (GISc), but it was never completed (DiBiase et al. 2006).[5]

2.3.1.2 The remote sensing core curriculum

A further initiative of the NCGIA, started 1992, is the core curriculum in remote sensing which involved an integration of remote sensing and geographic information systems. The four original courses, namely Introduction to aerial photo interpretation and photogrammetry; Overview of remote sensing of the environment; Introductory digital image processing; and Applications in remote sensing, along with four subsequent courses, are available as an unofficial complement to the UCGIS core curriculum for technical programmes and GIScience (DiBiase et al. 2006).

2.3.1.3 The UCGIS model curricula project

Under the auspices of the UCGIS, and with backing from leading GIS software vendors, Duane Marble and others organized a task force in 1998 to create a new undergraduate curriculum in GI S&T. An initial Strawman Report was released in June 2003 (Marble 2003). In 2005, the model

---

[4] See http://www.ncgia.ucsb.edu/pubs/core.html.

[5] A partial version (last updated 2000) can be accessed at http://www.ncgia.ucsb.edu/giscc/.

curricula project resumed as an activity of the UCGIS Education Committee and was published in 2006 (DiBiase et al. 2006).

These three examples – NCGIA core curriculum, the remote sensing core curriculum and the UCGIS model curricula – all contributed individually and collectively to the completion of the 2006 version of the UCGIS GI S&T BoK. The next section overviews the BoK structure.

2.3.2 Structure

The BoK consists of six sections that offer the most comprehensive set of competencies available and it is the most used standard for the development of GI S&T curricula. The first section, 'What is geographic information science and technology?', scopes the domain of GI S&T and describes the relationships with allied fields such as computer science and information science. Section II, 'Why is a GI S&T body of knowledge needed?', recounts the workforce needs, examines the education infrastructure responsible for addressing workforce need, and looks at various applications of the BoK. Section III puts the BoK in the historical context of efforts to develop GI S&T curricula. Section IV, 'How was the body of knowledge developed?', describes the vision of curricula and explains how the GI S&T BoK has evolved since the advent of the 2003 Strawman Report. Section V presents the ten KAs that comprise the BoK. Finally, Section VI speculates on the direction the UCGIS model curricula project is heading (DiBiase et al. 2006).

The basic structure of the BoK shown in Table 2.9 comprises three tiers, namely KAs, units and topics. The first tier consists of ten KAs that span the breadth of the GI S&T domain. The 2006 edition of the BoK is an inventory of the KAs and not a set of academic course outlines (DiBiase et al. 2006). The KAs are study areas concerning all the sectors of the GI S&T education infrastructure.

Table 2.9 Basic structure of the UCGIS GI S&T BoK

Tier	Count	Description
Knowledge Areas	10	Two-letter code (KA) and description
Units	79	Number and title with brief description (references as applicable)
Topics	350	Unit number and individual number and descriptive title

Source: Johnson (2006)

Each KA consists of several units designed as either core or elective units, followed by a list of topics. Core units are those in which all graduates should be able to demonstrate some level of mastery. Elective units expand the breadth of the GI S&T domain and include advanced topics, such as application design, system design and research and development which all relate to the upper levels of Marble's competency pyramid (DiBiase et al. 2006).

Each unit consists of a number of topics where each topic represents a single concept, method or technique. Topics are defined according to one or more formal educational objectives (DiBiase et al. 2006). Although the BoK includes some 350 topics (Johnson 2006) with 1660 objectives, these are intended to be representative rather than exhaustive (DiBiase et al. 2006). The success of the BoK was soon evident where it was successfully applied in education institutions in the USA and thereafter in European and other countries.

An outline of the knowledge areas and core units that comprise the BoK is given in Table 2.10 and a comprehensive list of KAs, units, topics and educational objectives is appended in Appendix B.

2.3.3 Applications

The BoK can be applied for curriculum planning, programme accreditation, curriculum revision, programme articulation, professional certification and employee screening. Brief elucidations of each of these applications are provided in the next subsections.

2.3.3.1 Curriculum planning

As the demand for academic qualifications in GI S&T increases, programme planners look for resources to guide curriculum choices and content. Educators responsible for planning new GISc certificate or degree programmes can use the BoK to specify the minimum course content to ensure that students develop core competencies.

Most topics in the BoK are defined as ranges of objectives (usually from fundamental to advanced) to allow curriculum designers to build activities into courses that can produce the necessary knowledge and skills at targeted levels of competence. On the other hand, curriculum designers can readily convert objectives into assessment instruments to evaluate competence in a particular study area (DiBiase et al. 2006).

Table 2.10 Knowledge areas and core units comprising the BoK

Knowledge area	Core units
Analytical Methods (AM)	Geometric measures (AM3)
	Basic analytical operations (AM4)
	Basic analytical methods (AM5)
Conceptual Foundations (CF)	Domains of geographic information (CF3)
	Elements of geographic information (CF4)
Cartography and Visualization (CV)	Data considerations (CV2)
	Principles of map design (CV3)
	Map use and evaluation (CV6)
Design Aspects (DA)	Database design (DA4)
Data Modeling (DM)	Database management systems (DM2)
	Tessellation data models (DM3)
	Vector and object data models (DM4)
Data Manipulation (DN)	Representation transformation (DN1)
	Generalization and aggregation (DN2)
Geocomputation (GC)	
Geospatial Data (GD)	Earth geometry (GD1)
	Georeferencing systems (GD3)
	Datums (GD4)
	Map projections (GD5)
	Data quality (GD6)
	Land surveying and GPS (GD7)
	Aerial imaging and photogrammetry (GD10)
	Satellite and shipboard remote sensing (GD11)
	Metadata, standards, and infrastructures (GD12)
GI S&T and Society (GS)	Ethical aspects of geospatial information and technology (GS6)
Organizational and Institutional Aspects (OI)	Institutional and inter-institutional aspects (OI5)
	Coordinating organizations (national and international) (OI6)

Source: UCGIS GI S&T Bok (DiBiase et al. 2006: 29)

2.3.3.2 Programme accreditation

Accreditation is the process by which institutions such as professional bodies responsible for quality assurance attest to the qualifications and effectiveness of educational institutions and their programmes. The traditional model of accreditation involves a periodic self-assessment by a university followed by a site visit to the university by a panel of reviewers and, finally, an evaluation report (CHE 2004a; 2004b; DiBiase et al. 2006). According to DiBiase et al. (2006), in the US most GI S&T programmes are not subject to disciplinary accreditation regulated by legislation but they are expected to be submitted to periodic self-assessments by internal and or external reviewers. In 2005 the Geospatial Intelligence Foundation started a process to establish curriculum guidelines and accreditation standards for geospatial intelligence academic courses and certificate programmes. If exposed to this initiative, the BoK should be found to be a valuable resource for defining academic guidelines and accreditation standards to meet educational objectives. Such assessments should also help prospective students to choose educational programmes that align with their interests and career goals.

2.3.3.3 Curriculum revision

Regular reviews and subsequent revisions of existing university curricula are essential so that programme designers can build in responses to changing technologies and ensure that curricula reflect new areas of specialization. Academic institutions that make such revisions might find it necessary to recruit new faculty members with specialist knowledge in GI S&T. The BoK is a useful tool for faculties to plan for growth, devise recruitment strategies and identify the topics and objectives that meet the demands of the job market. A substantial benefit of meeting the requirements of curriculum revision is that such universities are equipped to offer curricula more representative of the evolving GI S&T field (DiBiase et al. 2006).

2.3.3.4 Programme articulation

The GI S&T education infrastructure spans a lifetime of learning in support of continuous professional development and lifelong learning over the careers of the professional practitioners. Universities in the USA accommodate the mobility of GI S&T professionals through mutual agreements that ensure that credits earned in one university count toward relevant qualifications at another university. Universities using the BoK as a standard for their GI S&T courses thus find it easier to enter into mutual agreements (DiBiase et al. 2006). Because GISc programmes in South Africa differ considerably, no mutual agreements have yet been concluded between universities so that students moving between universities are seriously disadvantaged where programmes or large parts of a programme often have to be repeated.

2.3.3.5 Professional certification

In the USA certification is the process by which professional bodies accredit individuals who are able to demonstrate certain qualifications and/or competencies. Barnhart (as cited in DiBiase et al. 2006) distinguishes three types of professional certification, namely portfolio-based, competence-based and curriculum-based. Some professional bodies expect candidates to demonstrate, by examination, their mastery of a common body of knowledge within their profession, whereas others promote portfolio-based certification where persons only need to document relevant qualifications. In most instances, before being certified as a GISc professional, applicants must agree to comply with a code of ethics contained in the constitution or rules of conduct of the professional body (Huxhold & Craig 2003; DiBiase et al. 2006).

In South Africa registration with the professional body largely follows the same route, namely appropriate qualification, work-integrated learning under supervision, assessment of work experience or learning, law examination and affirmation to abide by a code of ethics and the rules of the professional body. There are no exceptions in the registration process which applies to all geomatics practitioners working in South Africa, thereby offering recourse to every South African making use of the services of a professional GISc practitioner. South Africa could well be the first country in the world where registration of GISc practitioners is rigidly controlled through national legislation (South Africa 2013). However, this cannot be done without considering the competencies that are required in other countries. The BoK can play a central role in assuring that South African professionals also adhere to international standards.

2.3.3.6 Employee screening

HR practitioners responsible for recruiting and screening applicants to GI S&T positions seldom possess the relevant knowledge to identify suitable candidates for posts. To assist HR departments, several resources have been developed to help identify qualified candidates (Gaudet, Annulis & Carr 2003; DOLETA 2006; 2010). The WLPI’s geospatial technology competency model identifies the roles and competencies required of GI S&T professionals. The BoK complements these resources by defining, in unprecedented breadth and detail, the knowledge and skills that well-educated professionals should possess. HR practitioners can use these aids to derive job descriptions and to set up interview protocols (DiBiase et al. 2006). Commenting from a European perspective, Toppen & Reinhardt (2009) have alerted programme designers to the importance of defining the basics in mathematics, physics, computer science, economics and geography when designing curricula for a GISc programme. These basics have, inexplicably, not been included as KAs or units in the BoK. This limitation of the BoK highlights the need for also considering other competencies when designing a GISc curriculum. According to Toppen & Reinhardt (2009) greater participation by European and other countries must be encouraged to contribute to the further development of the BoK.

2.3.4 Unanticipated outcomes of the UCGIS GI S&T BoK

An unanticipated outcome of the BoK has been its contribution to a perception of the GI S&T domain as representing a profession rather than being a mere tool used in a profession (Johnson 2008). A survey conducted among GI S&T practitioners on the question of an examination as part of the certification process found that 84% of the respondents agreed that if an examination is required, it should be based on the core competencies identified in the BoK (Butler 2007).

Another upshot was that soon after the BoK was completed, one of the editors of the BoK (Plewe, cited by Johnson 2006; 2008) used it to help students assess their knowledge of GI S&T. This self-assessment based on the BoK helped students identify what they knew and what they did not know about GI S&T. Johnson (2006; 2008) noted that to make this process really effective for students, universities needed to list their course contents indexed to the BoK so enabling students to select appropriate courses that meet industry and personal preferences.

A further repercussion to the BoK emerged from a survey conducted during the ESRI Education User Conference in San Diego in 2008 on the structure of the BoK and its possible uses. It transpired that curriculum planning was cited most, followed by the topic of creating self-assessment instruments, specifying accreditation standards and laying down curriculum pathways (Johnson 2008).

2.4 CONCLUSION

It is vital that programme managers and students realize that one or two introductory modules in GISc will neither address the concerns of industry nor those of employers who need competent GISc practitioners equipped with the relevant technical, interpersonal, business and analytical competencies (Marble 1998; UCGIS 2003; DiBiase 2006). A GISc competency model should consequently conform to a number of specifications. It must cater for different tiers of competencies to meet occupation-specific expectations (Section 2.2.3.3). The model must accommodate GISc practitioners who practice in occupational fields not always recognized as subsets of the broader geomatics profession (e.g. environmental science). The model must allow the fundamental KAs, for example mathematics and physics, to be common to all subset occupation categories. This implies that the model must include natural and social science components. The core KAs (e.g. computer science, cartography, remote sensing) must define the occupational area. Electives must cater for specialization in one or more core KAs or they may cater for different occupational areas.

South African GISc practitioners must be able to integrate into and compete with relative ease in the international job market. However, a practitioner will experience difficulties articulating or pursuing a GISc academic qualification in a foreign country with a South African undergraduate qualification based either on the PLATO model or the USBQ. This perceived difficulty to exchange with international institutions is because there is no extant research on the extent to which the PLATO model or the USBQ differ from international requirements. The PLATO model and the USBQ may contain KAs unique to and preferred by the South African GISc industry but, conversely, may have ignored KAs considered to be important by the international GISc industry. This chapter confirmed that the BoK has been used extensively to guide the development of GISc in the USA, Europe and other countries. The BoK has many uses, namely as a means to identify the breadth and depth of the knowledge representing the GI S&T domain and as a tool for curriculum planning, programme accreditation, programme evaluation and assessment, curriculum revision, facilitating student exchanges between programmes, professional certification and employment screening. The BoK has also contributed to an improved perception of GISc as a profession and assisted in career planning by the selection of appropriate courses.

The next chapter reports on a macro level comparison of the BoK, USBQ and PLATO model with the aim to establish a comprehensive framework that meets local and international requirements that can be used by South African universities as a general guide for curriculum planning.

CHAPTER 3 A CURRICULUM FRAMEWORK FOR GEOGRAPHICAL INFORMATION SCIENCE TRAINING AT SOUTH AFRICAN UNIVERSITIES[6]

3.1 ABSTRACT

Geographical information science (GISc) is one of the fastest growing industries worldwide. Being a relatively new discipline, universities often provide training as part of geography, surveying, town planning, environmental and computer science programmes. This complicates professional accreditation assessments as the content, outcomes, extent and quality of training can vary significantly. In this article one international and two South African GISc curriculum development models are qualitatively compared. Results show that, although there is significant intersection between the three models, some characteristics are unique to specific models. A new framework consisting of 15 components and compatible with international curricula is proposed. It addresses the needs of the South African industry while meeting the requirements of the South African GISc professional registration body. It is furthermore useful for comparing curricula and can support general curriculum design.

3.2 INTRODUCTION

A growing demand exists worldwide for geographical information science (GISc) practitioners. GISc includes both the science and technology underpinning the complete field of study, often referred to as Geographical Information Science and Technology (GI S&T). Government agencies as well as the private sector are competing to find and employ GISc practitioners that are both qualified and competent in the application of the relevant technologies. The U.S. Bureau of Labor Statistics projected a growth of up to 26 per cent in the GISc labour market for the period 2006 – 2016 (U.S. Department of Labor 2006), while China's geospatial industry grew by more than 300 per cent in five years (2006 – 2010) (Niraj 2011).

Similarly, South Africa is experiencing a growing demand for GISc practitioners. The Chief Directorate of National Geospatial Information (CDNGI) had as many as 30 per cent vacancies for persons competent in GISc during 2008 and 2011. Other government departments report

---

[6] Chapters 3, 4 and 5 are peer-reviewed articles published in the *South African Journal for Higher Education* and the *South African Journal of Geomatics*. Consequently, certain parts of the content are repeated in various chapters to provide continuity and/or to explain certain concepts of the research. The content of the articles was edited slightly after publication and reformatted for standardization. The original published version of this chapter (Du Plessis & Van Niekerk 2012) is included as Appendix A1.

similar shortages. The industry thus presents an increasing demand for more GISc graduates, which has prompted the Department of Science and Technology (DST) to include GISc (Geomatics) as one of the five technology focus areas for the Information Communication and Technology (ICT) roadmap (Nadasen & Salojee 1998; DST 2006). Employers are also seeking assurance that the employees hired by them are competent in the tangible and intangible skills necessary to excel in GISc (Prager & Plewe 2009).

In order to address the above concerns, the South African GISc community revived the dormant Geographical Information Society of South Africa (GISSA) in 2001, with the aim of promoting professionalism in the practice of GI S&T (PLATO 2002). One of the immediate objectives of GISSA was to develop educational standards in GISc that will meet the South African Council for Professional and Technical Surveyors (PLATO) registration requirements, set in terms of the PLATO academic model for the accreditation of GISc practitioners (South Africa 1984). PLATO, established as a professional body in terms of Act 40 of 1984, is the statutory body responsible for regulating the geomatics profession, which includes GISc practitioners. A geomatics practitioner is defined by the Draft Geomatics Bill as a “person who exercises skills and competencies in the science of measurement, the collection and assessment of geographic information and the application of that information in the efficient administration of land, the sea and structures thereon or therein ... and who is registered in one or more of the branches of geomatics ...” (South Africa 2011).

Historically, much of the early design of geographic information system (GIS) education was motivated by university academics. This has led to the emergence of GISc as a new and emerging profession begging for education opportunities that truly reflect the demands of the employment market. This includes the need to identify the full set of competencies, knowledge and skills required by professionals in the workplace; the need to design appropriate education programmes; and the question of quality control among both professionals and educational institutions through certification and accreditation (Kemp & Wiggins 2003).

GISc training courses in South Africa are primarily offered as part of geography, surveying, town planning, environmental and computer science programmes. Consequently, the content, outcomes and quality of training vary significantly. Internationally, the same problem has been noted and graduates of many existing academic programmes find themselves ill-equipped when seeking employment in one of the many public and private sector organizations that make substantial use of GISc (Kemp 2003). According to Gaudet, Annulis & Carr (2003: 22) ”... [in] the absence of recognized standards or industry certification, it is no surprise that organisations equipped with increased geospatial technology capabilities for decision support are questioning the kind of people to hire." PLATO assessors experience similar difficulties when considering individuals for GISc professional status (PLATO 2008). This situation is unlikely to improve unless consensus can be reached on establishing a curriculum framework for GI S&T programmes that can be offered at traditional universities as well as at universities of technology (UT). Assessors and employers will welcome academic programmes specifically designed and accredited for training GISc professionals where the focus is on the technology and not only on the science. The concept fits in well with the approach of UT where the focus is on increasing technological capabilities and the primary concern is with professional and career-focussed education.

An overview of the role of universities in GISc training in South Africa revealed that some universities base their GISc programme content on existing programmes such as surveying and geography while others use the National Center for Geographic Information and Analysis (NCGIA) Core Curriculum and the University Consortium for Geographic Information Science (UCGIS) Body of Knowledge (BoK) for programme development (Goodchild & Kemp 1990; DiBiase et al. 2006). The evaluation of individuals' knowledge and understanding of GISc concepts and practical skills will be simplified significantly if university programmes are accredited for training professional GISc practitioners.

GISc was offered in South Africa as an academic programme leading to a full qualification at universities of technology since 2011. The Cape Peninsula University of Technology (CPUT) became the first to offer qualifications at technician and technologist levels. It was also the first GISc programme to incorporate work integrated learning (WIL) as part of the qualification.

In contrast with established academic universities, South African UT are still on a developmental trajectory, especially where GISc is concerned. UT are relatively new institutions of higher education in South Africa and should be given sufficient time, with the necessary facilitation and funding, to develop into fully fledged UT, able to hold their own with traditional universities and international UT offering programmes in GISc.

Following the registration of unit standards-based qualifications (USBQs) with the South African Qualifications Authority (SAQA) (South Africa 1995; SAQA 2009 decision number 0012/08) on 18 February, its inputs, outputs and outcomes are frequently translated into measures for assessing candidate competencies and qualifications. The assessment process essentially involves the comparison of a candidate's qualifications and schedule of work experience with the

USBQs, to determine knowledge (inputs/outputs) and competence (outcomes). Consequently, an applicant's competence as a GISc practitioner is related to his/her knowledge and understanding of GISc concepts and experience in applying geospatial technologies, in particular GIS.

Other than the USBQs, there are no curriculum frameworks serving as a standard to be used for programme accreditation. Using the USBQs for programme evaluation is problematic as their focus is mainly on technical skills. For instance, many science programmes in which GISc is taught include generic scientific modules (e.g. chemistry, physics and biology). These generic subjects are, understandably, not represented in the USBQs, which complicates its comparison with existing academic programmes.

Before the GISc, USBQs, or any other academic model, can be regarded as a standard for GISc study in South Africa, it is essential to carry out a content analysis to determine similarities in knowledge areas with existing international guidelines, such as the UCGIS BoK, and consequently to assess whether they meet international standards (Unwin 1997; DiBase 2003; DeMers 2009). According to DiBiase et al. (2006) and Johnson (2006), assessment and curriculum evaluation are of the primary intended uses of the BoK, which include Duane Marble's six-tier competency pyramid. Gaudet, Annulis & Carr (2003) identified 39 competency requirements (i.e. the knowledge, skills and abilities individuals need to perform satisfactorily) for the geospatial technology workforce. It is not clear to what extent these requirements overlap with or differ from those specified in the USBQs. Such an analysis would provide a good foundation for the establishment of a comprehensive set of skill and knowledge requirements to be used toward establishing a curriculum framework for GISc (Forer & Unwin 1999; CHE 2004a; 2004b; DeMers 2009).

Three main problems exist in South Africa relating to the professional registration of GISc practitioners: 1) the inconsistencies found in the knowledge and skills development of GISc professionals; 2) the lack of a standard set of competency requirements to assess individuals and accredit academic programmes; and 3) the challenges faced by universities to prepare students for registration with the PLATO Council. These problems are aggravated by the significant variation in content, outcomes and quality of training offered by different universities. This situation is unlikely to improve unless a curriculum framework for GISc is established, whereby university programmes can be evaluated for accreditation. Human resource practitioners responsible for recruiting and employing suitably qualified GISc practitioners will welcome academic programmes specifically designed and accredited for training GISc professionals.

This article aims to establish a framework of generic components (knowledge areas or themes) to guide GISc curriculum development and assessment. The framework should be compatible with international curricula, address the needs of the South African industry and meet the requirements of the South African GISc professional registration body.

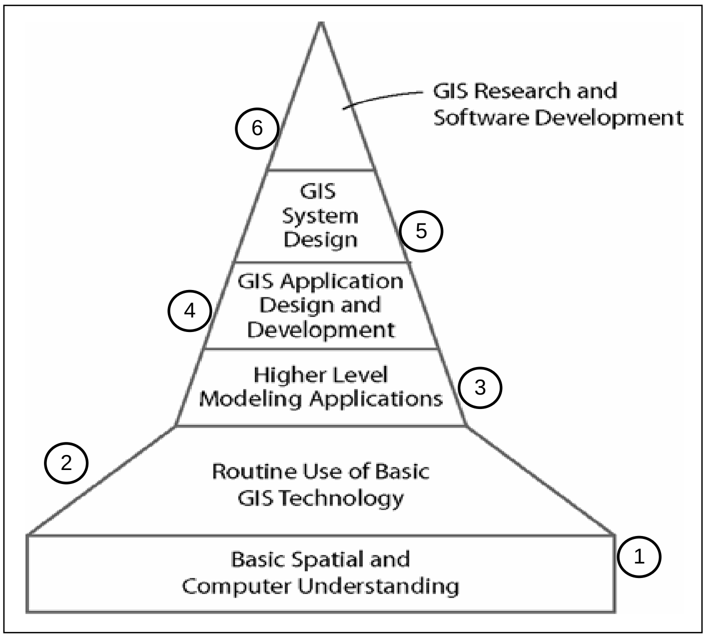
3.3 METHODS

The research methods used in the article are qualitative and based on the use of secondary data, in particular the UCGIS BoK (2006) for GI S&T, the SAQA-registered USBQs and the PLATO GISc model. These models were integrated using the internationally-accepted structure of the UCGIS GI S&T BoK as a common framework (DiBiase et al. 2006). The three models were quantitatively compared to identify commonalities and inconsistencies. An overview of each of these curriculum models is provided in the next sections.

3.3.1 International GISc curriculum development efforts

A number of international GISc curriculum development efforts have been carried out to date. In 1988, the NCGIA consortium of the University of California at Santa Barbara, State University of New York at Buffalo, and the University of Maine developed and distributed for comment the NCGIA Core Curriculum. The materials were grouped into three 'courses', each of which contains 25 units of lecture notes grouped into several modules (Goodchild & Kemp 1990; DiBiase et al. 2006). In 1995, the NCGIA announced plans for a 'New Core Curriculum in GIScience (GISc)'. The partial New Core Curriculum in GIScience (last updated 2000) can be accessed at http://www.ncgia.ucsb.edu/giscc/ (DiBiase et al. 2006). One of the NCGIA's research initiatives concerned the integration of remote sensing and geographic information systems. The four original courses, *Introduction to air photo interpretation and photogrammetry*, *Overview of remote sensing of the environment*, *Introductory digital image processing*, and *Applications in remote sensing*, along with four subsequent courses are accessible at http://www.r-s-c-c.org/.

Students should be prepared by GISc degree programmes to achieve a 'pyramid' of six competency levels, as identified by Marble (1998) (Figure 3.1). He argued that the base of the pyramid is expanding 'at an explosive rate while the upper levels have been permitted to crumble' and that the notion of a curriculum must advance beyond some of the current attempts to specify the content of one or two introductory courses to a fullyfledged examination of the entire spectrum of courses required to support an adequate GISc education at each level of the pyramid. ”We must cease confusing mastery of software commands with attaining a grasp of critical intellectual concepts. We also must ensure that those who teach our introductory GIS courses are competent professionals who fully understand the substantive structure of the technology" (Marble 1998: 28).



Source: DiBiase et al. (2006: 10)

Figure 3.1 Pyramid of competency levels and roles in which fewer, but more highly skilled resources are needed at the upper levels of the pyramid.

In 2001, NASA mobilized a team of workforce development specialists at the University of Southern Mississippi to conduct a study to identify key competencies of geospatial professionals. The Geospatial Workforce Development Center (later reorganized as the Workplace Learning and Performance Institute (WLPI)) convened workshops to identify the key competencies and 'roles' expected of geospatial professionals by employees. The twelve roles identified in the study are shown in Table 3.1.

Authors of the study concluded that "for geospatial technology professionals to be successful in today's marketplace, it is critical to understand that the knowledge, skills, and abilities required for their jobs include a blend of technical, business, analytical, and interpersonal competencies" (Gaudet, Annulis & Carr 2003: 25). Each of the roles outlined in Table 3.1 requires a subset of the technical, analytical, business, and interpersonal competencies set out in Table 3.2.

Table 3.1 Twelve roles played by geospatial technology professionals

Role	Description
Applications development	Identify and develop tools and instruments to satisfy customer needs
Data acquisition	Collect geospatial and related data
Coordination	Inter-organizational facilitation and communication
Data analysis and interpretation	Process data and extract information to create products, drive conclusions, and inform decision-making reports
Data management	Catalogue, archive, retrieve, and distribute geospatial data
Management	Efficiently and effectively apply the company's mission using financial, technical, and intellectual skills and resources to optimize the end products
Marketing	Identify customer requirements and needs, and effectively communicate those needs and requirements to the organization, as well as promote geospatial solutions
Project management	Effectively oversee activity requirements to produce the desired outcomes on time and within budget
Systems analysis	Assess requirements to produce the desired outcomes on time and within budget
Systems management	Integrate resources and develop additional resources to support spatial and temporal user requirements
Training	Analyze, design, and develop instructional and non-instructional interventions to provide transfer of knowledge and evaluation for performance enhancement
Visualization	Render data and information into visual geospatial representations

Source: Gaudet, Annulis & Carr (2003: 25)

Table 3.2 Thirty-nine competencies required for success in the geospatial technology profession

Category	Core competencies	Other competencies
Technical	▪ Ability to assess relationships among geospatial technologies ▪ GIS theory and applications ▪ Technical writing ▪ Technological literacy	▪ Cartography ▪ Computer programming skills ▪ Environmental applications ▪ Geology applications ▪ Geospatial data processing tools ▪ Photogrammetry ▪ Remote sensing theory and applications ▪ Spatial information processing ▪ Topology
Business	▪ Ability to see the 'big picture' ▪ Change management ▪ Cost-benefit analysis ▪ Visioning	▪ Business understanding ▪ Buy-in/Advocacy ▪ Ethics modelling ▪ Industry understanding ▪ Legal understanding ▪ Organizational understanding ▪ Performance analysis and evaluation
Analytical	▪ Problem-Solving skills ▪ Creative thinking	▪ Knowledge management ▪ Model building skills ▪ Research skill ▪ Systems thinking
Interpersonal	▪ Self-knowledge/Self-management ▪ Relationship building skills ▪ Leadership skills ▪ Feedback skills ▪ Communication	▪ Coaching ▪ Conflict management ▪ Group process understanding ▪ Questioning

Source: Gaudet, Annulis & Carr (2003: 28)

The GISc curriculum development efforts described above contributed to the establishment of the UCGIS Model Curricula project and the development of the BoK for GI S&T. The BoK was initiated in 1997 with one of the UCGIS' education challenges to provide a framework for the assessment of GI S&T curricula from a wide range of constituencies (Kemp & Write 1997). Under the auspices of the UCGIS, and with backing from leading GIS software vendors, a task force was organized in 1998 to create a new undergraduate curriculum for GI S&T. The UCGIS task force set out to identify a comprehensive set of 'knowledge areas' and their constituent 'units' and 'topics', comprising a 'body of knowledge' for the GI S&T domain. The task force also aimed to explore several 'pedagogy areas', including supporting topics and courses, integrative experiences, supporting infrastructure, and implementation and dissemination. An initial 'Strawman' report was released in July 2003 (UCGIS 2003). In 2005, the Model Curricula project resumed as an activity of the UCGIS Education Committee and the core component of the Model Curricula, the GI S&T BoK, was published in 2006 (DiBiase et al. 2006). The BoK structure (Table 3.3) is composed of three tiers, namely knowledge areas, units, and topics (DiBiase et al. 2006). [7]

Table 3.3 BoK structure

Tier	Count	Description
Knowledge Areas	10	Two-letter code (KA) and description
Units	79	Number and title with brief description (references as applicable)
Topics	350	Unit number and individual number and descriptive title

Source: Johnson (2006)

An unanticipated outcome of the BoK has been its effect on the perception of the GI S&T domain as representing a profession (Johnson 2006), rather than a mere tool used in a profession. Soon after the BoK was completed, one of the editors (Plewe, cited by Johnson 2006) used it to help students assess their knowledge of GI S&T. Johnson (2006) noted that to make this process truly effective for students, courses would need to list the course content indexed to the BoK to enable the appropriate courses to be selected. In addition, the skill sets contained in the BoK could be used to determine the competency requirements for specific job classifications.

3.3.2 South African GISc curriculum development efforts

Although GISc has been offered at South African universities since the early 1990s, the need for curriculum development and standardization only emerged recently when GISc was

[7] An outline of the knowledge areas and units that comprise the BoK as it appears in the UCGIS 2006 document is accessible at http://www.ucgis.org/priorities/education/modelcurriculaproject.asp.

professionalized. This process led to the generation and registration of the GISc USBQ and the PLATO models.

The GISc USBQ (accessible at http://www.saqa.org.za) is composed of four tiers, called 'study areas', 'unit standards', 'outcomes', and 'assessment criteria'. A total of 19 study areas and 128 unit standards, spanning the breadth of the GISc domain, were identified by the GISc standards generating body (SGB). A unit standard is composed of learning outcomes and assessment criteria, which determines the knowledge, skills and abilities a learner is required to attain in order to be assessed as competent (Bruniquel and Associates 2009). Each qualification contains exit-level outcomes as well as certain cross-field outcomes. Each exit-level outcome contains associated assessment criteria that will provide students with an opportunity to display an ability to integrate practical performance, actions, concepts and theory across unit standards to achieve competence in relation to the purpose of this qualification.

The unit standards are classified as fundamental, core and elective. The fundamental unit standards are related to mathematics, statistics, business management (professionalism and ethics) and analytical skills, which are associated with critical competencies such as cognitive functions and thinking styles expected of persons working in the geomatics field. The core unit standards such as those relating to *Geographical information systems*, *Data acquisition*, *Information technology*, *Data management*, *Photogrammetry* and *Remote sensing* are associated with occupation-specific competencies essential for GISc practitioners. The elective unit standards allow for specialization of GISc practitioners working at operator, technician, technologist and professional levels in occupations where the core business objectives are focussed on a diversity of outcomes such as occupations in the health, engineering, information technology, planning and environmental sciences (South Africa 1995; SAQA 2009).

The SAQA GISc SGB has mapped and prioritized the learning pathway for GISc qualifications as follows: National Certificate: GISc NQF Level 5 ► National Diploma: GISc NQF Level 5 ► BA: GISc NQF Level 6 ► Bachelor of GISc NQF Level 7 ► Master of GISc: NQF Level 8 ► Doctor of Philosophy: GISc NQF Level 8+. This pathway compares well with Marble's pyramid (Figure 3.1) of competency levels as illustrated in Table 3.4.

Table 3.4 Comparison of qualification levels

Marble's pyramid level	USBQ NQF level	South African education level	Plato Registration Model
1	2-4	Secondary	-
2	4-5	Certificate	-
3	5	Diploma	Technician
4	6	3-year degree	Technologist
5	7	Postgraduate Honours degree (or 4-year professional degree)	Professional
6	8+	Postgraduate Masters or Doctoral degree	Professional

The South African geomatics registration model, also known as the PLATO Model (accessible at http://www.plato.org.za), provides for the registration of three levels of practitioner competencies, namely technician, technologist and professional (Table 3.4). Each competency level contains common and category-specific subject areas supplemented with non-common core and elective subject areas to meet occupation-specific requirements. The elective core subject areas cater for specialization as well as specialized occupation categories not normally associated with the geomatics occupational group, such as occupations in the health and environmental sciences fields (South Africa 1984).

3.3.3 RESULTS

A matrix comparing the UCGIS BoK knowledge areas (KA), the SAQA GISc USBQ themes, and the PLATO model themes is provided in Table 3.5.Table 3.4 Each BoK KA is described (in parenthesis) by its core units. Similarly, the fundamental and core unit standards for each USBQ theme are provided. In the PLATO model, themes are defined by a set of keywords or phrases. Due to limited space, only a selection of keywords is shown in Table 3.5.

Table 3.5 Comparison of common themes and knowledge areas

BoK knowledge areas (and core units)	**USBQ themes (and core unit standards)***	**PLATO core themes (and selected key words)**
Analytical methods (geometric measures; basic analytical operations; basic analytical methods)	Spatial analysis (2.5D vector surface queries; spatial and hybrid queries; cartographic modelling; spatial error analysis; spatial modelling)	Geospatial information science (nature of geospatial information; components of a GIS; data acquisition and manipulation; data models and structures; geospatial databases; spatial analysis & modelling; design and implementation of GIS; standards & metadata; data quality; uncertainty; 2.5D and 3D geospatial information)
Conceptual foundations (domains of geographic information; elements of geographic information)	Geography literacy (context of GISc) Spatial awareness (work with map projections; principles of spatial data; topology)	
Data modelling (database management systems; tessellation data models; vector and object data models)		
Data manipulation (representation transformation; generalization and aggregation)	Data manipulation (map projections; data conversion; generalization and aggregation; life-cycle management of spatio-temporal data)	

Continued overleaf

Table 3.5 continued

BoK knowledge areas (and core units)	USBQ themes (and core unit standards)*	PLATO core themes (and selected key words)
Cartography and visualization (data considerations; principles of map design; map use and evaluation)	Map production (web mapping)	Cartography & visualisation (cartographic communication; multimedia mapping; 2-D & 3D visualization; web mapping; types of maps; intellectual property and copyright; CAD; printing)
Design aspects (system design; database design; application design; analysis design)	Databases (database theory; design and develop a database; SQL) Geographical information systems & software (GIS software skills; GIS customization)	Information technology (hardware, operating systems; communications; programming; systems development; databases; data mining)
Geocomputation (information technology, emergence of geo-computation, computational aspects and neuro-computing)		
Geospatial data (earth geometry; georeferencing systems; datums; map projections; data quality; land surveying; GPS)	Data capture (data quality; GPS; data errors; procedures for data capture) Spatial awareness (work with map projections) Photogrammetry for orthophoto and map production Remote sensing (basic principles of remote sensing imagery; acquire remote sensing imagery; design GPS/GNSS assisted photography)	Data acquisition (from primary and secondary sources including surveying, GPS, etc.) Coordinate systems & map projections (coordinate systems; shape of the earth; ellipsoids; coordinates; types & properties of map projections; coordinate and projection transformations; datums; SA coordinate system; UTM) Photogrammetry and remote sensing (image acquisition; analogue and digital photography; accuracy assessment; image interpretation; image processing; applications; fundamentals of remote sensing; image characteristics; multispectral, thermal and hyperspectral sensing; passive & active sensors; electromagnetic spectrum)
GI S&T and society (legal aspects; ethical aspects of GI S&T; dissemination of geospatial information) Organizational and institutional aspects (origin of GI S&T, GI S&T workforce themes, Institutional and inter-institutional aspects, coordinating organizations)	Data exchange (spatial data transfer protocols; collect and capture metadata); Professional practice (professional execution of daily functions; planning and control; PLATO Act; GIS legislation; Spatial Data Infrastructure Act) Work ethics (sustainable ethical practices; ethics and professionalism in business)	Professional practice and ethics (professionalism; ethics; professional practices; partnerships; PLATO rules; social responsibility) Business and project management (management functions; human resource management; financial management; marketing; labour legislation; tax; project planning; costing; report writing; contract law)
BoK knowledge areas (and core units)	USBQ themes (and core unit standards)*	PLATO core themes (and selected key words)
-	Research methodology (undertake a research project)	Research project (system design or spatial analysis; reporting and presentation of results)
-	Training (mentor and advise learners; develop, support and promote recognition of prior learning practices)	-
-	-	Physics (mechanics; kinematics; electricity; wave theory; electromagnetic spectrum)
-	Mathematics & statistics (micro- and macroeconomic indicators; statistical techniques);	Mathematics, applied mathematics & statistics (calculus; algebra; trigonometry; descriptive statistics; sampling; statistical computer packages; multivariate statistics)
-	-	Geographical science (human & physical geography; environmental science; earth science)

* Themes and unit standards applicable to the four-year bachelor Honours degree in GISc only

From Table 3.5 it is clear that there is significant correspondence between the three models, particularly regarding the themes directly related to GISc. While the PLATO model combines all GISc components into one theme (*Geospatial information science)*, the BoK and USBQ provide a more detailed classification. Similar terminology is used throughout the models, although some exceptions occur (e.g. *Analytical methods* and *Spatial analysis*). In such cases the descriptions of the units can be used to match the corresponding themes. Some themes were combined in Table 3.5 to provide a better match between models.

All of the BoK KAs are, to some degree, represented by the USBQ and PLATO themes. The opposite is, however, not the case as *Mathematics and statistics* (*Mathematics, applied mathematics and statistics* in the case of the PLATO model) are not specified as a separate theme in the BoK. It is likely that the BoK assumes a background in mathematical sciences as it includes advanced mathematical and statistical concepts such as spatial statistics, geostatistics, spatial regression and cluster analyses as part of the *Analytical methods* KA. However, the fact that most of these concepts are listed in the BoK as non-essential (not core) units raises the question whether a high level of mathematical science background is necessary for GISc curricula.

Research methodology (*Research project* in the case of the PLATO model) is another common theme in the USBQ and the PLATO model, but not included in the BoK as a separate theme. It may be that the ability to carry out research is inherent in the BoK or it could indicate that it is not essential for GISc practitioners. However, its inclusion in both the USBQ and the PLATO models seems to indicate that the South African industry and existing GISc professionals require this ability.

The requirement of *Physics* is unique to the PLATO model. This is likely because existing GISc programmes at South African universities have a strong physical sciences component (because physics is compulsory in many BSc programmes). The exclusion of physics in both the BoK and the USBQ, however, seems to indicate that it is not a critical (core) component. More research is needed to verify this.

Another theme unique to the PLATO model is *Geographical science*, presumably because much of the existing GISc training in South Africa is offered by geography departments. Although it is not listed as a separate KA in the BoK, some geographical concepts are represented in the Conceptual foundations KA which includes topics such as: *Perception and cognition of geographic phenomena*; *Geography as a foundation for GIS*; *Place and landscape*; *Common-sense geographies*; *Cultural influences*; and *Political influences*. The exclusion of geographical science from the USBQ indicates, however, that the South African industry regards it as being non-essential.

Only one theme, namely *Training*, is unique to the USBQ, which is indicative of the South African GISc industry's need for structured work integrated learning (WIL). This is also a prerequisite for registration with PLATO, which requires a minimum of 220 working days under the supervision of a registered GISc professional, GISc technologist or other professional person suitably qualified who has been practising as such for at least five years after registration. In most cases, this experience must be obtained after a qualification is completed, which is likely why it is not included as a separate theme in the PLATO model. However, some instruction and experience on how best to mentor a GISc practitioner in training is a sensible inclusion in any GISc curriculum.

A new framework accommodating the themes of all three models is presented in Table 3.6. Where the three models overlapped, the BoK KAs were given preference as this would facilitate compatibility with international curricula. Gaps in the BoK were filled by using the theme names of the USBQ or PLATO models. The new framework makes provision for the fundamental sciences (geography, physics, mathematics and statistics), research and training, and consequently represents both the international and South African requirements for GISc curricula.

3.4 CONCLUSION

This article compared the GISc BoK, USBQ and PLATO models at KA and theme level to identify commonalities and inconsistencies (gaps) and to develop a framework incorporating both South African and international GISc curricula guidelines. It is concluded that, at KA and theme level, the SAQA GISc USBQ and the PLATO academic models correspond well with the BoK and consequently are solid foundations for GISc curriculum development. Although some inadequacies were identified in the BoK, its content is generally much more detailed, having a three-tier structure consisting of 10 knowledge areas, 79 units and 350 topics. It is recommended that a new GISc model be developed, combining the BoK, USBQ and PLATO models. This will ensure that future GISc curricula meet South African and international requirements, thereby allowing graduates to register with the South African professional body (PLATO) as well as articulation with international universities and registration bodies.

Table 3.6 Proposed framework

Component	Description
Geographical science	Human & physical geography; environmental science; earth science
Physics	Mechanics; kinematics; electricity; wave theory; electromagnetic spectrum
Mathematics & statistics	Calculus; algebra; trigonometry; descriptive statistics; sampling; statistical computer packages; multivariate statistics
Analytical methods	Geometric measures; basic analytical operations; basic analytical methods
Conceptual foundations	Domains of geographic information; elements of geographic information
Data manipulation	Representation transformation; generalization and aggregation
Data modelling	Database management systems; tessellation data models; vector and object data models
Cartography and visualization	Data considerations; principles of map design; map use and evaluation
Design aspects	System design; database design; application design; analysis design
Geocomputation	Information technology, emergence of geocomputation, computational aspects and neuro-computing; GIS software skills; GIS customization; hardware, operating systems; communications; programming; systems development; databases; data mining
Geospatial data	Earth geometry; georeferencing systems; datums; map projections; data quality; land surveying; GPS; Image acquisition; analogue and digital photography; accuracy assessment; image interpretation; image processing; applications; fundamentals of remote sensing; image characteristics; multispectral, thermal and hyperspectral sensing; passive & active sensors; electromagnetic spectrum
GI S&T and society	Legal aspects; ethical aspects of GI S&T; dissemination of geospatial information; professional execution of daily functions; planning and control; PLATO Act; GIS legislation; Spatial Data Infrastructure Act; sustainable ethical practices; ethics and professionalism in business; professionalism; ethics; professional practices; partnerships; PLATO rules; social responsibility
Organizational and institutional aspects	Origin of GI S&T, GI S&T workforce themes, institutional and inter-institutional aspects, coordinating organizations; management functions; human resource management; financial management; marketing; labour legislation; tax; project planning; costing; report writing; contract law
Research methodology	System design or spatial analysis; reporting and presentation of results
Training	Mentor and advise learners during WIL; develop, support and promote continuous professional development (CPD) in the profession

To this end, a new model framework is proposed Table 3.6, consisting of 15 components representing all the BoK KA, as well as the USBQ and PLATO themes. Although the framework provides a good foundation for the development of a new comprehensive GISc model, more work is needed to identify and define the minimum requirements within each component.

The GISc curriculum framework developed in this study represents the critical knowledge areas for the training of GISc practitioners. Educators charged with planning GISc certificate, diploma or degree programmes can employ the framework to outline the minimum course content for the development of core competencies. The traditional model of accreditation involves a periodic institutional self-study, followed by a site visit to the university by a panel of reviewers, and finally an evaluation report (CHE 2004a; 2004b; DiBiase et al. 2006). Adopting the proposed framework will provide a nationally and internationally accepted standard. Assessment instruments used by reviewers of academic programmes derived from the above framework will assist in determining their status relative to educational objectives and aid prospective students in choosing educational programmes aligned with their interests and career goals. The framework will be useful to faculties in planning future growth, recruitment strategies, and in identifying the topics and objectives that will meet the demand of the job market, while offering curricula that are more representative of the evolving GISc field. Institutions which agree to specify course topics and objectives consistent with the standard framework derived from this study may find it easier to execute articulation agreements. Statutory or professional bodies such as PLATO will be supported if the above GISc framework is consistently applied to accredit students as well as university programmes and to enter into reciprocal agreements with other countries. The framework will also assist human resource professionals to develop job descriptions and to set interview protocols.

No study is without limitations and the authors recognize that the GISc industry and its requirements are not static. The GISc framework provides a baseline from which to build as the industry continues to evolve. The value of the GISc curriculum framework will ultimately be measured by its implementation as a tool for training and education at universities. It is recommended that the framework be extended into a more detailed list of knowledge and skills that will become the minimum requirement to inform the development of GISc programmes at universities, to better serve as a standard for the accreditation of university programmes and the registration of professional practitioners with the relevant statutory body.

3.5 REFERENCES

Bruniquel and Associates 2009. Unit standards, a plea for common sense [online]. Available from: http://www.e-biznews.co.za/uploads/files/biznews1st2009.pdf [Accessed 2 February 2009].

Council on Higher Education (CHE) 2004a. Framework for programme accreditation [online]. Available from: http://www.che.ac.za/documents/d000080/ [Accessed 22 October 2009].

Council on Higher Education (CHE) 2004b. Criteria for programme accreditation [online]. Available from: http://www.che.ac.za/documents/d000084/ [Accessed 22 October 2009].

DeMers, MN 2009. Using intended learning objectives to assess curriculum materials: The UCGIS body of knowledge. *Journal of Geography in Higher Education* 33(1): 70–77 [online]. Available from: http://dx.doi.org/10.1080/03098260903033980 [Accessed 16 October 2009].

DST (Department of Science and Technology) 2006. Programme 5: *Government sector programmes and coordination*. Annual Report 2005/2006: 65. Pretoria. Department of Science and Technology.

DiBiase, D, M DeMers, A Johnson, K Kemp, AT Luck, B Plewe & E Wentz (Eds.) 2006. *GI S&T body of knowledge: University consortium for geographic information science* [online]. Penn State University. Association of American Geographers. Available from: http://www.ucgis.org/priorities/education/modelcurriculaproject.asp [Accessed 26 February 2009].

DiBiase, D 2003. On accreditation and the peer review of education in geographical information systems and science [online]. *URISA Journal* 15(1): 7–13. Available from: http://www/urisa.org/files/DiBiasevol15no1.pdf [Accessed 13 October 2009].

Forer, P & D Unwin 1999. Enabling progress in GIS and education. . In Longley PA, Goodchild MF, Maguire DJ and Rhind DW (eds) In *Geographical information systems. Management issues and applications,* 747–756. 2nd ed. New York: John Wiley & Sons.

Gaudet, CH, HM Annulis & JC Carr 2003. Building the geospatial workforce. *URISA Journal* 15(1): 21–30 [online]. Available from: http://www/urisa.org/files/Gaudetvol15no1.pdf [Accessed 13 October 2009].

Goodchild, MF & KK Kemp 1990. *Introduction to GIS: NCGIA core curriculum*. National Centre for Geographic Information and Analysis. Santa Barbara: University of California.

Johnson, AB 2006. *Developing a GIS curriculum*. ArcUser [online]. Available from: http://www.esri.com/news/arcuser/0706/curricula.html [Accessed 20 October 2009].

Kemp, KK 2003. Update on the UCGIS model curricula project [online]. *URISA Journal* 15(1): 47–49. Available from: http://www.urisa.org/files/Kempvol15no1-5.pdf. [Accessed 12 April 2009].

Kemp, KK & L Wiggins 2003. Introduction to the special issue on GIS Education [online]. *URISA Journal* 15(1): 4–6. Available from: http://www.uris.org/journal/protect/vol15no1/wigginskemp.pdf [Accessed 11 April 2009].

Kemp, KK & R Wright 1997. UCGIS Identifies GIScience education priorities [online]. Available from: http://www.ucgis.org/priorities/education/priorities/geoinfosystems.html [Accessed 23 June 2011].

Marble, DF 1998. Rebuilding the top of the pyramid, management issues and applications. *ArcNews* 20(1): 28–29.

Nadasen, L & I Salojee 1998. *ICT: Technology roadmaps* [online]. Pretoria: Department Science and Technology, South Africa. Available from: http://www.dst.gov.za/publications-policies/magazine/vol5_html [Accessed 27 February 2009].

Niraj. 2011. China geospatial industry. The flight of the dragon. *Geospatial World* 1(9): 31–37.

PLATO 2002. Minutes of the 19th Annual Meeting of PLATO Council held in Stutterheim, 24-26 September. Johannesburg. South African council for professional and technical surveyors.

PLATO 2008. Minutes of the 25th Annual Meeting of PLATO Council held in Wynberg, Cape Town, n.d. October. Johannesburg. South African council for professional and technical surveyors.

Prager, SD & B Plewe 2009. Assessment and evaluation of GIScience curriculum using the Geographic Information Science and Technology body of knowledge [online]. *Journal of Geography in Higher Education* 33(1): 46–69. Available from: http://dx.doi.org/10.1080/03098260903034012 [Accessed 16 October 2009].

SAQA 2009. South African qualifications authority. *SAQA decision number 0012/08 2009*. Field 12 – Physical Planning and Construction: Physical Planning, Design and Management: GISc SGB [online]. Available from: http://regqs.saqa.org.za/ [Accessed 17 August 2014].

South Africa 1984. Professional and Technical Surveyors Act as amended, Act 40 of 1984. *Government Gazette* Vol. 226 (9157), 11 April 1984. Pretoria. Government Printer.

South Africa 1995. The South African Qualifications Act, Act 58 of 1995.*Government Gazette Notice* 1521, 4 October. Pretoria: Government Printer.

South Africa 2011. Geomatics Profession Bill. *Government Gazette* 35801, 22 October. Pretoria: Government Printer.

UCGIS 2003. *Task force on the development of model undergraduate curricula: The Strawman Report* [online]. Available from: http://www.ucgis.org/priorities/education/priorities/FINALSTRAWMANTEXT.Pdf [Accessed 12 April 2009].

Unwin, DJ 1997. *Curriculum design for GIS: NCGIA core curriculum in GIScience* [online]. Available from: http://www.ncgia.ucsb.edu/gisc/units/u159/u159_f.html [Accessed 26 February 2009].

U.S. Department of Labor 2006. *Career voyages* [online]. U.S. Department of Labor. Available from: http://www.careervoyages.gov/allindustries-indemand.cfm [Accessed 11 March 2009].

CHAPTER 4 A COMPARISON OF GEOGRAPHICAL INFORMATION SCIENCE COMPETENCY REQUIREMENTS[8]

4.1 ABSTRACT

Because universities often provide training in geographical information science (GISc) as part of geography, surveying as well as environmental and computer science programmes, the content, outcomes, extent and quality of training can vary significantly. Very little research has been done on how the existing sets of competency requirements for GISc overlap or differ. No literature exists that identifies commonalities and inconsistencies (gaps) at detail level that could assist with developing a framework that incorporates both South African and international GISc curricula guidelines.

Three sets of competency guidelines, namely the USA-developed Geographic Information Science and Technology (GI S&T) Body of Knowledge (BoK) developed by the University Consortium for Geographic Information Science (UCGIS), the South African unit standard-based qualifications (USBQ) and the South African Council for Professional and Technical Surveyors (PLATO) model, are compared qualitatively and quantitatively to identify commonalities and inconsistencies. The exercise identified duplication among the three models and highlighted themes that the South African GISc community deems to be important. The study further identifies topics in the GI S&T BoK that the GISc community in the USA considers to be essential knowledge for anyone wishing to practice in the GISc field. The BoK offers the most comprehensive and detailed set of GI competencies, but lacks generic competencies such as physics. Some competencies are unique to a specific set, for example physics and geographical science in the PLATO model, while training is unique to the USBQ. The authors conclude that a new competency set based on the findings of the research is needed to best serve the GISc industry and academia. Recommendations for further research are made.

[8] Chapters 3, 4 and 5 are peer-reviewed articles published in the *South African Journal for Higher Education* and the *South African Journal of Geomatics*. Consequently, certain parts of the content are repeated in various chapters to provide continuity and/or to explain certain concepts of the research. The chapter has been edited slightly and reformatted for standardization purposes. Original published version (Du Plessis & Van Niekerk 2013) included as Appendix A2 on the attached compact disk (CD).

4.2 INTRODUCTION

The South African Council for Professional and Technical Surveyors (PLATO), established as a professional body in terms of Act 40 of 1984 (South Africa 1984), is the statutory body responsible for regulating the geomatics profession. A geomatics practitioner is defined by the Draft Geomatics Bill as ”...a person who exercises skills and competencies in the science of measurement, the collection and assessment of geographic information and the application of that information in the efficient administration of land, the sea and structures thereon or therein ... and who is registered in one or more of the branches of geomatics ...” (South Africa 2011: 9). This definition includes geographical information science (GISc) practitioners.

Historically, much of the early design of geographical information systems (GIS) education was initiated by university academics. This has led to the emergence of GISc as a new profession but little research has been done on what GISc professionals should know or be able to do. A set of competencies, knowledge and skills needed by professionals in the workplace is required to design appropriate education programmes and to guide those responsible for controlling quality within the profession (through certification) as well as in educational institutions (through accreditation) (Kemp & Wiggins 2003).

GISc courses at universities are offered as part of geography, earth science, surveying, town planning as well as environmental and computer science programmes. Consequently, the content, outcomes and quality of training and education vary significantly. Many programmes require that students take one or two introductory geographic information system (GIS) courses to be able to produce simple maps and carry out basic spatial operations. In-depth knowledge of geospatial concepts and theories is not required. However, many of these students eventually seek employment as professional GIS practitioners, an occupation for which they are often ill-prepared. The same problem has been noted internationally with graduates often finding themselves ill-equipped when seeking employment in one of the many public and private sector organizations that make substantial use of GISc (Kemp 2003). According to Gaudet, Annulis & Carr (2003: 22) ”... [in] the absence of recognized standards or industry certification, it is no surprise that organizations equipped with increased geospatial technology capabilities for decision support are questioning the kind of people to hire.” PLATO assessors experience similar difficulties when considering individuals for registration as professional GISc practitioners (PLATO 2008).

Three main problems exist in South Africa concerning the professional registration of GISc practitioners: 1) the inconsistencies found in the knowledge and skills development of GISc professionals; 2) the lack of a standard set of competency requirements to assess individuals and accredit academic programmes; and 3) the challenges faced by universities to prepare students for professional registration with the PLATO council. This situation is unlikely to improve in the absence of a GISc curriculum framework. Such a framework should not only guide the design of new university programmes but should also be used to evaluate existing programmes for accreditation.

Currently there are curriculum frameworks that serve as guidelines for accreditation and programme development: the South African Qualifications Authority (SAQA) unit standards-based qualifications (USBQ) (South Africa, 1995) and the PLATO model (PLATO 2011a; 2011b). It is problematic to use the set of competencies in the USBQ for programme evaluation because it focusses mainly on technical skills, while many GISc practitioners have indicated a concern that the competencies in the PLATO model appear to be biased towards surveying. Another concern is that at theme level both frameworks differ from the geographic information science and technology (GI S&T) body of knowledge (BoK) which is used by many international universities for GISc curriculum development and assessment (Du Plessis & Van Niekerk 2012). A revised edition of the BoK is currently under consideration and future editions may contain some generic competencies such as physics and mathematics as a result of contributions from European geoinformatics practitioners.

Conformity to international academic requirements will facilitate opportunities for articulation with international universities and registration bodies. It is therefore essential that the competency sets derived for professional GISc practitioners, such as the USBQ and PLATO models, are compared with the GI S&T BoK to identify significant gaps (Unwin 1997; DiBiase 2003; DeMers 2009). According to DiBiase et al. (2006) and Johnson (2006), assessment and curriculum evaluation are the primary intended uses of the BoK. During the European GIS in Education Seminar (EUGISES 2006) the Association of GI Labs in Europe (AGILE) commenced with an initiative to deal with certain aspects of the BoK, such as the completeness of the BoK (Reinhardt 2012). Another aspect was the incorporation of an European view that includes but is not limited to the following important aspects:

- The BoK represents primarily a geographic point of view and excludes important aspects such as geodesy and computer science.

- The definition of topics related to basics in natural sciences, mathematics, and computer science etc. is as important as the definition of GISc topics.
- An indicator for the depth of teaching should be added to the topics, e.g. Bloom's taxonomy.

Toppen & Reinhardt (2009) regard the BoK as valuable work that is very important and helpful for a number of tasks such as curriculum design. It is, however, not clear which BoK requirements are absent from the USBQ and PLATO models. Also, some requirements identified by the South African GISc industry may not be included in the BoK. An identifying of the discrepancies among the different frameworks will provide a good foundation for establishing a comprehensive set of competencies to be used for a curriculum framework for GISc (Forer & Unwin 1999; Council on Higher Education 2004a; 2004b; DeMers 2009; Toppen & Reinhardt 2009).

This paper reports on a comparative content analysis using the competency sets derived from the GI S&T BoK, the USBQ and the PLATO model to develop a comprehensive set of competency requirements for professional GISc practitioners in South Africa. The paper concludes with recommendations on how the set of competency requirements can be organized into a meaningful concept framework that can be used by educators charged with the planning of professional degree programmes to outline the minimum course content for the development of a GISc curriculum that will meet the PLATO requirements for accreditation, and for entering into reciprocal and articulation agreements with national and international institutions.

4.3 EXISTING COMPETENCY FRAMEWORKS

Brief overviews follow of some USA and South African efforts to develop GISc curricula.

4.3.1 Efforts to develop GISc curricula

A number of attempts have been made in the USA to develop GISc curricula. In 1988 the National Center for Geographic Information and Analysis (NCGIA) consortium of the University of California, the State University of New York, and the University of Maine developed and distributed for comment the NCGIA core curriculum modules (Goodchild & Kemp 1990; DiBiase et al. 2006). In 1995 the NCGIA announced plans for a new core curriculum in GIScience. In 2001 NASA mobilized a team of specialists at the University of Southern Mississippi to identify key competencies for geospatial professionals. The Geospatial Workforce Development Center (later reorganized as the Workplace Learning and Performance

Institute (WLPI)) convened workshops to identify the key competencies and roles expected of geospatial professionals by employees (DiBiase et al. 2006).

The curriculum development efforts described above contributed to the establishment of the UCGIS Model Curricula project and the development of the BoK for GI S&T. The BoK was initiated in 1997 as one of the UCGIS' education challenges to provide a framework for the assessment of GI S&T curricula (Kemp & Wright 1997). A task force was organized under the auspices of the UCGIS in 1998 to identify a comprehensive set of 'knowledge areas' (KAs) and their constituent 'units' and 'topics', comprising a 'body of knowledge' for the GI S&T domain. An initial 'Strawman' report was released in July 2003 (UCGIS 2003). In 2005 the Model Curricula project resumed as an activity of the UCGIS Education Committee and the core component of the Model Curricula, the GI S&T BoK, was published in 2006 (DiBiase et al. 2006). The BoK structure (Table 4.1) comprises three tiers, namely 10 knowledge areas, 79 units, and 350 topics (DiBiase et al. 2006; Johnson 2006).

Table 4.1 BoK structure

Tier	Count	Description
Knowledge Areas	10	Two-letter code (KA) and description
Units	79	Number and title with brief description (references as applicable)
Topics	350	Unit number and individual number and descriptive title

Source: (Johnson 2006)

In sum, the BoK KAs encompass the domain of GI S&T. Each KA is made up of units that include a title and brief description. Units are made up of topics that include a short descriptive title and bulleted educational objectives (Johnson 2006).

4.3.2 South African efforts to develop GISc curricula

Although GISc has been offered at South African universities since the early 1990s, the need for curriculum development and standardization only emerged in 2004 when GISc was professionalized. This process led to the generation and registration of the GISc USBQs (South Africa 1995) and the PLATO model (PLATO 2011b).

The GISc USBQ comprises four tiers called 'study areas', 'unit standards', 'outcomes', and 'assessment criteria'. A total of 19 study areas and 128 unit standards, spanning the breadth of the GISc domain, were identified by the GISc Standards Generating Body (SGB). Each unit standard includes learning outcomes and assessment criteria which determine the knowledge, skills and abilities a student is required to attain to be assessed as competent (Bruniquel and

Associates 2009). The unit standards are classified as fundamental, core and elective. The fundamental unit standards relate to mathematics, statistics, business management (professionalism and ethics) and analytical skills. The core unit standards, such as those relating to GIS, data acquisition, information technology (IT), data management, photogrammetry and remote sensing, are associated with occupation-specific competencies essential for GISc practitioners. The elective unit standards allow for specialization of GISc practitioners in occupations where the core business objectives focus on a diversity of outcomes such as occupations in the health and environmental sectors (South Africa 1995).

The South African geomatics registration model, also known as the PLATO model (PLATO 2011b), provides for the registration of three levels of practitioner competencies, namely technician, technologist and professional. Each competency level contains common and category-specific subject areas with descriptions of their content. The model is further divided into non-common core and elective subject areas to meet occupation-specific requirements.

4.4 METHODS

Qualitative and quantitative methods were used to do a comparative content analysis of the BoK, the USBQ and PLATO model (2012 edition). The comparison was done at the most detailed level and involved a systematic comparison of the USBQ unit standard outcomes, the descriptions of the PLATO model for professional registration and the BoK topics. The PLATO descriptions were transformed to keywords and phrases, representing competencies, to enable direct comparison with the other two frameworks. The outcomes, keywords, phrases and topics were regarded as specific GISc competencies.

The USBQ and PLATO sets of competencies were cross-tabulated with the BoK, which was used as a common framework, mainly because it has the most comprehensive structure and also because it is an internationally-accepted framework (DiBiase et al. 2006). The result was two matrices of which the rows represent the 350 BoK topics and the columns respectively represent the 296 USBQ outcomes and 211 PLATO keywords and phrases. Altogether 177 450 comparisons were made to determine the level of correspondence between the BoK, the USBQ and PLATO model.

An example on how the topics of the BoK *Analysis of surfaces* unit was quantitatively compared to the outcomes of unit standard (US) no. 258803 (*Perform 2.5D vector surface queries*) is shown in Table 4.2. Each outcome of the US is systematically compared to all the topics in the BoK and where the respective rows and columns intersect a value ranging from 0 to 1 is allocated. A value of 0 implies no correspondence between the outcome and the respective topic and a value of 0.5 implies a 50% correspondence or partial match between the outcome and the topic, while a value of 1.0 denotes 100% correspondence. In Table 4.2 the BoK unit includes the topic *Calculating surface derivatives* which has seven objectives, namely:

- List the likely sources of error in slope and aspect maps derived from digital elevation models (DEMs) and state the circumstances under which these can be very severe.
- Outline a number of different methods for calculating slope from a DEM.
- Outline how higher-order derivatives of height can be interpreted.
- Explain how slope and aspect can be represented as the vector field given by the first derivative of height.
- Explain why the properties of spatial continuity are characteristic of spatial surfaces.
- Explain why zero slopes are indicative of surface specific points such as peaks, pits and passes; and list the conditions necessary for each.
- Design an algorithm that calculates slope and aspect from a triangulated irregular network (TIN) (DiBiase et al. 2006).

When these objectives are compared to specific outcome 1 of the US 258803, namely to *Understand and explain the principles of a triangular irregular network (TIN) in the context of a surface,* there is clearly some overlap but the specific BoK topic also includes many other concepts relating to DEMs and terrain analysis not covered by outcome 1 of US 258803. In this particular case the overlap was interpreted to be approximately 10% (or 0.1 using a scale of 0 to 1). The other outcomes of US 258803 were compared to the *Calculating surface derivatives* topic in the same manner and a 10% overlap resulted with all four of the US outcomes. On the perimeter of the matrix the sum of each row is calculated to provide a value indicating the total overlap (0.4) between the US and the *Calculating surface derivatives* topic. When done for all the topics in a unit, the totals of the columns can be used to indicate how much overlap there is between each US outcome and all the topics in a unit. The total of the last column (0.2) indicates the degree of correspondence between US 258803 and the BoK *Analysis of surfaces*. For this particular example, there is a 20% overlap. It should be noted that the level of correspondence is a subjective value assigned by the researchers. A more robust approach would have been to use several assessors to evaluate each of the 177 450 corresponding pairs of competencies and to use the mean correspondence values. However, such an approach would have been prohibitively time-consuming and costly. For the purposes of this paper the subjective values were deemed sufficient as indicators of where there is no correspondence, partial correspondence or full correspondence between the relevant data sets.

Table 4.2 Comparison of topics in the BoK analysis of surfaces unit with the outcomes of Unit Standard (US) no. 258803 Perform 2.5D vector surface queries

Topics in the BoK analysis of surfaces unit	Overlap with outcome 1	Overlap with outcome 2	Overlap with outcome 3	Overlap with outcome 4	Total overlap with US
Calculating surface derivatives	0.1	0.1	0,1	0.1	0.4
Interpolation of surfaces	0.1	0.0	0.0	0.0	0.1
Surface features	0.1	0.0	0.0	0.0	0.1
Intervisibility	0.0	0.1	0.0	0.0	0.1
Friction surfaces	0.0	0.0	0.0	0.0	0.0
Total overlap of the respective outcome with all the topics.	**0.3**	**0.2**	**0.1**	**0.1**	**0.7/4=0.2**

This cross-tabulation method was applied to all of the BoK topics to facilitate a systematic identification of overlaps and gaps between the different curriculum frameworks. Once completed, a second set of tables was created that summarized the overlap at knowledge area (KA) level. For example, Table 4.3 summarizes the USBQ comparison with the BoK *Analytical methods* KA units. The three columns on the right for each unit of the KA respectively record the number of topics that match fully, match partly, or do not match at all with the set of USBQ outcomes. This procedure was carried out for all KAs and for the USBQ and the PLATO model.

Table 4.3 The level of correspondence, at detail level, between the topics of the *Analytical methods* BoK KA units and the USBQ outcomes

The BoK KA Analytical methods and unit descriptions	Total number of BoK topics in each respective unit	Number of BoK topics in each unit that are fully matched by one or more USBQ outcome	Number of BoK topics in each unit that are partly matched by one or more USBQ outcome	Number of BoK topics in each unit that are not matched by any USBQ outcome
Academic and analytical origins	2	0	0	2
Query operations and query languages	3	0	3	0
Geometric measures	6	0	4	2
Basic analytical operations	4	0	0	4
Basic analytical methods	8	0	0	8
Analysis of surfaces	5	0	4	1
Spatial statistics	7	0	2	5
Geostatistics	5	0	3	2
Spatial regression and econometrics	4	0	1	3
Data mining	4	0	4	0
Network analysis	7	0	7	0
Optimization and location-allocation modelling	4	0	0	4
Total	**59**	**0**	**28**	**31**

Of the 59 topics, not one topic could be matched 100% by one or more USBQ outcomes, while 28 topics could be partially matched and 31 topics could not be matched by any USBQ outcome.

4.5 RESULTS AND DISCUSSION

The results of the content analysis are summarized in Table 4.4. Only 35 (10%) and 9 (3%) of the BoK topics are fully covered by the USBQ and the PLATO model respectively. However, most (57% and 65% respectively) of the BoK topics are partly covered by the USBQ and the PLATO model. This suggests that despite much overlap between the South African frameworks and the Bok, there is a lack of depth in the existing national curriculum guidelines. It may also indicate that the South African frameworks are not as detailed as the U.S. guidelines. Most concerning is that about one third (33% and 32% respectively) of the BoK topics is not covered by the USBQ or the PLATO model at all. Either some of the topics in the BoK have been overlooked when the South African frameworks were designed and compiled (i.e. they can be considered gaps) or these topics were excluded on purpose because they are unimportant in a South African context.

Table 4.4 Results of the analysis of the matrices containing the BoK topics and USBQ outcomes, and BoK topics and PLATO model keywords (study areas), expressed in numbers and percentages.

Comparison	USBQ outcomes	PLATO model keywords (study areas)
BoK topics that are matched by one or more	35 (10%)	9 (3%)
BoK topics partly matched by one or more	186 (57%)	213 (65%)
BoK topics not matched by any	108 (33%)	107(32%)

The levels of correspondence between the BoK topics and the USBQ outcomes as well as the PLATO model keywords (study areas) range between 67% and 68%. As much as 85% of the USBQ outcomes and 55% of the PLATO model keywords (study areas) are contained in the BoK. It is concluded that the BoK includes most of the content of the USBQ but there is a significant (45%) component of the PLATO model not represented by the BoK units. Much of the excluded content relates to mathematics, physics and research methodology which are not explicitly listed in the BoK. Discussions by European academics and professional practitioners at forums such as AGILE mentioned similar inconsistencies between the BoK and curricula at European universities (Reinhardt 2012).

Table 4.5 considers the particular BoK units that are fully, partially or not covered at all by the USBQ or the PLATO model. A distinction is made between the core and non-core BoK units, where the core units (indicated by an asterisk *) are regarded as essential competencies to be included in any professional qualification.

Table 4.5 Identification of the BoK units fully, partially or not covered at all in the USBQ and the PLATO model.

Model	Level of cover	BoK Units
USBQ	Fully covered	CV2*, CV3*, DA4*, GD6*, GD8, GD10*, GD11*, GS6*, OI4
	Partially covered	AM2, AM3*, AM6, AM7, AM8, AM9, AM10, AM11, CF3*, CF4*, CF6, CV1, CV4, CV5, CV6*, DA1, DA2, DA3, DA5, DA6, DA7, DM1, DM2*, DM3*, DM4*, DM5, DN1*, DN2*, DN3, GC1, GC8, GD1*, GD3*, GD4*, GD5*, GD7*, GD9, GD12, GS1, GS2, GS3, GS4, GS5, GS7, OI2, OI3, OI5*, OI6*
	Not covered	AM1, AM4*, AM5*, AM12, CF1, CF2, CF5, GC2, GC3, GC4, GC5, GC6, GC7, GC9, GD2, OI1
PLATO	Fully covered	GD4*
	Partially covered	AM1, AM2, AM3*, AM4*, AM5*, AM6, AM7, AM10, CF2, CF3*, CF4*, CF5, CF6, CV1, CV2*, CV3*, CV4, CV6*, DA1, DA2, DA3, DA4*, DA5, DA6, DA7, DM1, DM2*, DM3*, DM4*, DM5, DN3, GC8, GD1*, GD2, GD3*, GD5*, GD6*, GD7*, GD8, GD9, GD10*, GD11*, GD12*, GS1, GS2, GS3, GS4, GS5, GS6*, GS7, OI2, OI5*, OI6*
	Not covered	AM8, AM9, AM11, AM12, CF1, DN1*, DN2*, GC1, GC2, GC3, GC4, GC5, GC6, GC7, GC9, OI1, OI3, OI4

* BoK core units are indicated by an asterisk.

From Table 4.5 one can determine which units in the BoK do not correspond with the USBQ or the PLATO model and which units are regarded as core. Of the 16 units in Table 4.5 not covered by the USBQ two are regarded as core units by the BoK, namely AM4 (Basic analytical operations: buffers, overlays, neighbourhoods, map algebra) and AM5 (Basic analytical methods: point pattern analysis, kernels and density estimation, spatial clusters analysis, spatial interaction, analysing multidimensional attributes, cartographic modelling, multi-criteria evaluation, spatial process models). A number of the non-core units that are excluded from the USBQ are important for South African GISc practitioners. For example, AM12 (optimization and location-allocation modelling) and CF5 (relationships) include important topics such as p-median problems and topology respectively. At least some of these fundamental concepts should be included in GISc curricula. A total of 18 BoK units, including two core units (DN1 and DN2) are not covered and consequently do not correspond with any keywords or study areas (phrases) in the PLATO model.

It was determined that 45 USBQ outcomes and 7 unit standards within three themes are not included in the BoK. These themes are: *Information technology* (unit standard numbers 115387, 115381 and 115382), *GI S&T and society* (unit standard 258798) and *Research methodology* (unit standards 258816, 242915, 117434). Similarly, there are 94 sets of keywords (study areas) and two themes (subject areas), namely *Physics* and *Research methodology* that are not specified in the BoK. *Research methodology* is the only common theme in the USBQ and the PLATO model not included in the BoK. *Physics* only appears in the PLATO model as a theme, while the two themes *Information Technology* and *GI S&T and society* appear in all three models, although certain unit standards and their outcomes are unique to the USBQ.

4.6 CONCLUSION

This paper compared the GI S&T BoK, the USBQ and the PLATO model at detail level, i.e. topic, outcome and keyword (study area) levels, to identify commonalities and inconsistencies. The USBQ and the PLATO model for professional GISc practitioners correspond well with the BoK, particularly regarding the themes directly related to GISc. Significant duplication was identified of the different components of the three models. Clearly, the competencies that occur in all three sets are essential in any GISc curriculum. The competencies that the South African GISc community regards as important for inclusion in GISc curricula, but which are not considered necessary in the BoK, were also highlighted. These competencies mostly relate to the fundamental sciences and research methods. Similar inconsistencies were identified in Europe (Reinhardt 2012). A number of competencies that the USA GISc community regards as essential are not represented in the USBQ and/or the PLATO model. It is critical that these competencies are included in South African GISc curricula and that a detailed list of fundamental and core competencies is developed that can be used as the minimum academic requirements that a student must fulfil to be regarded as being competent in GISc. This list should be a union of the core BoK topics, the USBQ outcomes and the PLATO model keywords (study areas) at detail level. Educators charged with planning GISc certificate, diploma and degree programmes should use the list to outline the minimum course content. The list should also be used by reviewers of academic programmes to determine their quality and it will be valuable for prospective students to choose educational programmes that are aligned with their interests and career goals. Institutions which agree to specify course topics and objectives consistent with the list of competencies may find it easier to execute articulation agreements. Statutory or professional bodies, such as PLATO, will be supported if the GISc competencies are consistently applied to accredit learners and university programmes and to enter into reciprocal agreements with other countries. The list will also assist human-resource professionals to develop job descriptions and to set interview protocols.

The authors recognize that the GISc industry and its requirements are not static. This research thus provides a baseline for the development of a list of GISc competencies. The value of the list will ultimately be measured by its implementation as a tool for training and education at universities, as a standard for the accreditation of university programmes and the registration of professional practitioners with the relevant statutory body. It is recommended that future research focus on the development of a concept GISc framework for curriculum development which must also be subjected to a public participation process. The minimum requirements regarding contact hours (lecture hours), directed study hours and credits for each component must be determined. An easy-to-use and accessible assessment tool, ideally in the form of a Web application, that would support curriculum development, the accreditation of university programmes and the registration of professional GISc practitioners, will also have great value for the South African and the international geospatial communities.

4.7 REFERENCES

Bruniquel & Associates 2009. Unit standards, a plea for common sense [online]. Available from: http://www.e-biznews.co.za/uploads/files/biznews1st2009.pdf [Accessed 2 February 2009].

CHE (Council on Higher Education) 2004a. Framework for programme accreditation [online]. Available from: http://www.che.ac.za/documents/d000080/ [Accessed 22 October 2009].

CHE (Council on Higher Education) 2004b. Criteria for programme accreditation [online]. Available from: http://www.che.ac.za/documents/d000084/ [Accessed on 22 October 2009].

DeMers MN 2009. Using intended learning objectives to assess curriculum materials: The UCGIS body of knowledge. *Journal of Geography in Higher Education* 33 (1): 70-77 [online]. Available from: http://dx.doi.org/10.1080/03098260903033980 [Accessed 16 October 2009].

DiBiase D 2003. On accreditation and the peer review of education in geographical information systems and science [online]. *URISA Journal* 15 (1): 7-13. Available from: http://www/urisa.org/files/DiBiasevol15no1.pdf [Accessed 13 October 2009].

DiBiase D, DeMers M, Johnson A, Kemp K, Luck AT, Plewe B & Wentz E. (eds.) 2006. *GI S&T body of knowledge: University consortium for geographic information science* [online]. Penn State University. Association of American Geographers. Available from: http://www.ucgis.org/priorities/education/modelcurriculaproject.asp [Accessed 26 February 2009].

Du Plessis HJ & Van Niekerk A 2012. A curriculum framework for geographical information science (GISc) training at South African universities. *South African Journal for Higher Education,* 26 (2): 329-345. Available from: http://reference.sabinet.co.za/document/EJC123985 [Accessed 30 September 2014]

Forer P & Unwin D 1999. Enabling progress in GIS and education. In Longley PA, Goodchild MF, Maguire DJ and Rhind DW (eds) *Geographical information systems. Management issues and applications*, 747-756. 2nd ed. New York: John Wiley & Sons.

Gaudet CH, Annulis HM & Carr JC 2003. Building the geospatial workforce. *URISA Journal* 15 (1): 21-30 [online]. Available from: http://www/urisa.org/files/Gaudet vol15no1.pdf [Accessed 13 October 2009].

Goodchild MF & Kemp KK 1990. *Introduction to GIS: NCGIA core curriculum*. National Center for Geographic Information and Analysis. Santa Barbara: University of California.

Johnson AB 2006. *Developing a GIS curriculum*. ArcUser [online]. Available from: http://www.esri.com/news/arcuser/0706/curricula.html [Accessed 20 October 2009].

Kemp Karen K & Wright Richard 1997. UCGIS Identifies GIScience education priorities [online]. Available from: http://www.ucgis.org/priorities/education/priorities/geoinfosystems.html [Accessed 23 June 2011].

Kemp KK 2003. Update on the UCGIS model curricula project [online]. *URISA Journal* Vol. 15 (1) 47-49. Available from: http://www.urisa.org/files/Kempvol15no1-5.pdf [Accessed 12 April 2009].

Kemp KK & L Wiggins. 2003. Introduction to the special issue on GIS education [online]. *URISA Journal* 15 (1): 4-6. Available from: http://www.urisa.org/journal/protect/vol15no1/wigginskemp.pdf [Accessed 11 April 2009].

PLATO 2008. Minutes of the 25th Annual Meeting of PLATO Council held in Wynberg, Cape Town, n.d. October. Johannesburg. South African council for professional and technical surveyors.

PLATO 2011a. Notes for guidance for the registration of GISc practitioners [online]. Approved September 2011. Available from: http://www.plato.org.za. [Accessed 29 April 2012].

Reinhardt W 2012. Statement of usage of BoK in our institute [online]. Available from: http://www.geo-informatie.nl/rip001/edumapping/AGILE_2012-Reinhardt.pdf. [Accessed 3 April 2013].

South Africa 1984. Professional and Technical Surveyors Act as amended, Act 40 of 1984. *Government Gazette* 226 (9157), 11 April. Pretoria: Government Printer.

South Africa 1995. The South African Qualifications Act, Act 58 of 1995.*Government Gazette Notice* 1521, 4 October. Pretoria: Government Printer.

South Africa 2011. Geomatics Profession Bill. *Government Gazette* 35801, 22 October. Pretoria: Government Printer.

Toppen F & Reinhardt W 2009. A European approach towards the UCGIS geographic information science and technology body of knowledge a discussion paper [online]. Available from: http://itcnt05.itc.nl/agile_old/Conference/2009-hannover/WS2/Ws2_Agile09_abstracts/2009_paper_Toppen_Reinhardt_AGILEws-2009.pdf. [Accessed 3 April 2013].

UCGIS 2003. *Task force on the development of model undergraduate curricula: The Strawman report* [online]. Available from: http://www.ucgis.org/priorities/education/priorities/FINALSTRAWMANTEXT.Pdf [Accessed 12 April 2009].

Unwin DJ 1997. *Curriculum design for GIS: NCGIA core curriculum in GIScience* [online]. Available from: http://www.ncgia.ucsb.edu/gisc/units/u159/u159_f.html (Accessed 26 February 2009).

CHAPTER 5 DEVELOPMENT OF A NEW GISc FRAMEWORK AND COMPETENCY SET FOR CURRICULA DEVELOPMENT AT SOUTH AFRICAN UNIVERSITIES[9]

5.1 ABSTRACT

In this study the commonalities and inconsistencies between three geographical information science (GISc) competency sets are used to develop a new framework of essential competencies that can be used for curricula development at South African universities. A prototype GISc framework of 16 knowledge areas (KAs), consisting of 20 fundamental and 89 core competencies, was introduced to a group of GISc experts to gauge its usefulness and to determine the relative importance of specific KAs. From the response it is clear that some KAs, in particular *Physics* and *Organisational and institutional aspects* are considered less important than *Data modelling* and *Geospatial data*. However, all of the KAs were considered essential by the workshop participants for inclusion in the GISc framework. A simple algorithm was developed and implemented to determine whether a particular competency should be included in the GISc framework. The new framework is an extension of the GI S&T BoK and consists of 14 KAs and can be used to develop curricula that meet the requirements of South African and international GISc industries.

5.2 INTRODUCTION

The Geospatial Workforce Development Center (GWDC) at the University of Southern Mississippi defines geographical information science (GISc) as an information technology (IT) field of practice that acquires, manages, interprets, integrates, displays, analyses, or otherwise uses data focussing on the geographic, temporal, and spatial contexts (Gaudet, Annulis & Carr 2003). In South Africa a geomatics practitioner is defined as "...a person who exercises skills and competencies in the science of measurement, the collection and assessment of geographic information and the application of that information in the efficient administration of land, the sea and structures thereon or therein ... and who is registered in one or more of the branches of geomatics ..." (South Africa 2011: 9). This very broad definition of the geomatics profession illustrates the wide range of knowledge, skills and abilities (competencies) needed by GISc

[9] Chapters 3, 4 and 5 are peer-reviewed articles published in the *South African Journal for Higher Education* and the *South African Journal of Geomatics*. Consequently, certain parts of the content are repeated in various chapters to provide continuity and/or to explain certain concepts of the research. The chapter has been edited slightly and reformatted for standardization purposes. Original published version (Du Plessis & Van Niekerk 2014) included as Appendix A3 on the attached compact disk (CD).

practitioners and the diversity of applications for which the technology can be applied. Although the versatility of GISc is one of its main strengths, it complicates staff recruitment and the definition of job requirements. To better define GISc workforce needs, organizations need to know what competencies employees need to be a GISc practitioner and to have an understanding of the roles, competencies and output requirements for geospatial work (Gaudet & Annulis 2008). In turn, these requirements must be incorporated into the development of training programmes and academic qualifications to ensure that universities produce graduates who are adequately prepared for the job market.

The Geographical Information Science and Technology (GI S&T) Body of Knowledge (BoK) was initiated in 1997 as one of the education challenges of the University Consortium for Geographic Information Science (UCGIS) to provide a framework for the assessment of GI S&T curricula (Kemp & Wright 1997). An initial Strawman report was released in July 2003 (UCGIS 2003). In 2005, the Model Curricula project resumed as an activity of the UCGIS Education Committee and the core component of the Model Curricula, the BoK, was published in 2006 (DiBiase et al. 2006). The BoK structure comprises three tiers, namely 10 knowledge areas, 79 units and 350 topics (DiBiase et al. 2006; Johnson 2006). The BoK structure is currently being revised and a future structure may include recommendations following this and other research that have highlighted certain requirements for the GISc profession that are currently not included in the existing BoK. The current version of the BoK (2006) is, however, the most comprehensive guideline for GISc curricula development and is used in many countries throughout the world (DiBiase et al. 2006; Reinhardt 2012).

Although GISc has been offered at South African universities since the early 1990s, the need for curriculum development and standardization only emerged in 2004 when GISc was professionalized. This process led to the generation and registration of the GISc unit standards-based qualifications (USBQs) (South Africa 1995) and the South African Council for Professional and Technical Surveyors (PLATO) model (PLATO 2011a; 2011b). The GISc USBQ comprises four tiers called ‘study areas’, ‘unit standards’, ‘outcomes’, and ‘assessment criteria’. A total of 19 study areas and 128 unit standards, spanning the breadth of the GISc domain, were identified by the GISc Standards Generating Body (SGB). Each unit standard includes learning outcomes and assessment criteria which determine the knowledge, skills and abilities a student is required to attain to be assessed as competent (Bruniquel and Associates 2009). The unit standards are classified as fundamental, core and elective. The fundamental unit standards relate to mathematics, statistics, business management (professionalism and ethics) and analytical skills. The core unit standards, such as those relating to GIS, data acquisition, IT, data management, photogrammetry and remote sensing, are associated with occupation-specific competencies essential for GISc practitioners. The elective unit standards allow for specialization of GISc practitioners in occupations where the core business objectives focus on specific applications of GISc such as cartography and web applications but may include other job specific non-core competencies (South Africa 1995).

The PLATO model (PLATO 2011b) provides for the registration of three levels of practitioner competencies, namely technician, technologist and professional. Each competency level contains common and category-specific subject areas with descriptions of their content. The model provides for the different streams in geomatics and each stream contains core and elective subject areas to meet occupation-specific requirements while some subject areas may be common between the different streams.

The BoK, USBQ and PLATO models for GISc were qualitatively compared by Du Plessis & Van Niekerk (2012) at knowledge area and theme levels. Their results showed that, although there is significant intersection between the three models, some themes are unique to specific models. A more detailed and quantitative analysis at topic, outcome and keyword level (Du Plessis & Van Niekerk 2013) highlighted various commonalities and inconsistencies between the three models, suggesting that none of these models is comprehensive enough to represent the full competency requirements of the South African and international GISc industries. This supports the view of Toppen & Reinhardt (2009) who commented that it is difficult to determine the completeness of the BoK because it depends on personal views and perspectives. While the European GIS in Education Seminar (EUGISES 2008) concluded that:

- The BoK represents primarily a geographic view and topics such as computer science are weakly represented.
- The relevant work of International Organization for Standardization (ISO) TC 211 and Open Geospatial Consortium (OGC) as well as the basics for modelling services need more consideration.
- Geodesy and space-based satellite navigation system such as global positioning system (GPS) issues are underrepresented.
- Web-related issues are not well covered.

Prager & Plewe (2009) made similar observations when comparing the BoK to two established GISc courses. They found that both courses included important topics that were not explicitly identified in the BoK. Such omissions require specific consideration during an assessment and evaluation of courses and curricula. They further pointed out that it is important to consider that the BoK may be predisposed toward a North American view of GI S&T and in this context they cite Reinhardt & Toppen (2008) who observed that in Europe the study of GI S&T occurs in a wide range of disciplines, ranging from geography and cartography to computer science, engineering, surveying and photogrammetry.

It is clear from the literature that the BoK is a great resource for curriculum development but that it does not (on its own) represent a comprehensive list of GISc competencies. Du Plessis & Van Niekerk (2013) concluded that if the BoK is to be used as a standard for GISc curricula development in South Africa it should be extended to include all of the essential competencies listed in the GISc USBQs and the PLATO model. It is also critical that all the core BoK competencies are included in South African GISc curricula to ensure international recognition of those trained in South Africa. Du Plessis & Van Niekerk (2013) emphasized the need for the development of a comprehensive and detailed list of fundamental, core and non-core competencies that can be used as a standard for the accreditation of academic qualifications and the assessment of professional registration applications.

The aim of this research is to develop a new academic framework consisting of a detailed list of fundamental and core competencies that can be used in support of GISc curriculum development at South African universities. The paper describes the first version (i.e. prototype) of the framework which was introduced to a group of GISc experts (see appendix B2) to gauge its comprehensiveness and usefulness, and to identify possible weaknesses. Suggestions for improvement were incorporated into the latest version of the framework as outlined in this paper. The paper also advocates the inclusion of specific competencies such as IT and mathematical skills. Suggestions on how the new framework can be used to support curriculum development are made.

5.3 METHODS

Du Plessis & Van Niekerk (2012; 2013) highlighted the inconsistencies between the BOK, USBQ and PLATO model and suggested that the three models be unified so that the needs of the international GISc community and the specific needs of the South African GISc community are met. This section describes the methodology used to combine the three models to produce a new GISc framework consisting of a list of fundamental, core and elective competencies within specific knowledge areas that represent the broad workforce requirements for professional GISc practitioners. The framework was modelled on the BoK as it is the most comprehensive set of competencies available. This approach is similar to that of Reinhardt (2012) who uses the BoK as basis for developing various GI programmes, namely computer science, business informatics and civil engineering based on the BoK. A competency is defined as the minimum knowledge, skills and abilities required by a practitioner to perform a task with confidence. In the context of the framework development, a competency is equated to the core unit together with its relevant topics and objectives. The following set of rules was used to select competencies from the BoK, USBQ and PLATO model for inclusion in the new framework:

- Include a competency if it occurs in all three the models.
- Include a competency if it is considered core or fundamental in any one of the three models.
- Include a competency if it is regarded as essential by the South African GISc community.

The first two rules involved a re-evaluation of the cross-tabulation results of Du Plessis & Van Niekerk (2013) and resulted in a prototype framework. This framework was presented to representatives of the GISc community for feedback, after which a final version of the framework was developed.

5.3.1 Competencies included in the prototype framework

According to Di Biase et al. (2006) the BoK core units are regarded as essential knowledge that any person should have mastered before they can be regarded as competent in GISc (GI S&T). Of special interest are the core units (shown in bold in the BoK) that are not covered by the USBQ or PLATO model. Specifically, units AM4 *Basic analytical operations* and AM5 *Basic analytical methods* are not covered in the USBQ and only partially covered in the PLATO model, while DN1 *Representation transformation* is only partially covered in the USBQ but not covered at all in the PLATO model. The fact that these units are at least partially covered by one of the two South African models suggests that the content of these units is regarded as important by the South African GISc community and they were consequently included in the framework as new units (by applying rules 1 and 2).

The core unit standards not covered in the current version of the BoK relate to three USBQ themes namely, Professional practice, Research methodology and Information technology. All three themes can be matched to specific BoK KAs namely GI S&T and Society (GS), Design Aspects (DA) and Geocomputations (GC). Unit standard 258798 deals with the South African spatial data infrastructure (SDI) and relates to unit Institutional and inter-institutional aspects in KA Organisational and institutional aspects in the BoK. In consideration of the importance of

SDI, specifically in a developing country, and the role of GISc professionals in the collection maintenance, exchange and analysis of geographical information, it was clear that this content should be included in the framework. In addition, although Research methodology relates to BoK KA Design aspects, the BoK only includes some basic principles of project management. Because the USBQ SGB regarded proficiency in carrying out a research project as an important skill for any South African GISc practitioner to have, it was added to the Design aspects KA of the framework. The presence of the unit Query operations and query languages, in the Analytical methods KA alludes to a level of competency in computer programming, but no explicit requirement is set in the BoK. Skills in IT are, however, considered a core competency by the South African GISc industry (through the USBQ SGB) and given that computer programming is often required in the application of GIS, particularly when existing software is unable to perform the required operations, it was included (by applying rule 2) in the framework under KA Geocomputation.

Much of the content in the PLATO model that is not explicitly listed in the BoK relates to mathematics, physics and research methodology. Discussions by European academics and professional practitioners at forums such as the EUGISES 2006 conference highlighted similar inconsistencies between the BoK and curricula at European universities (Reinhardt 2012). *Physics* does not feature at all in either the BoK or USBQ, while the South African Geomatics professional body (PLATO) explicitly specified it as a fundamental competency requirement. This is likely due to the importance of physics in survey applications such as electronic measurements where distances are derived from radio waves or infrared light and in photogrammetry and remote sensing where data is remotely captured using sensors such as radar, lidar and light reflection characteristics to capture images on the earth’s surface from space and airborne platforms. Although it is debatable whether physics is critical for all GISc applications, some understanding of the fundamental principles of physics is essential when working with technologies such as space-based satellite navigation systems and remotely sensed imagery. Based on rule 2, *Physics* was consequently included in the framework as a separate KA.

Training is included as a theme in the USBQ and as a topic in the BoK under the KA *Organizational and institutional aspects* but is absent from the PLATO model. With important developments such as work-integrated learning (WIL) as well as recognition of prior learning (RPL) where interns rely on the guidance of a mentor (Unit Standard 14299 *Mentor and advice learners in higher education and training* and Unit Standard 116587 *Develop, support and* *promote RPL practices*) they seem to be important topics that should be included in the new framework (by applying rule 2).

Table 5.1 and Table 5.2 show the prototype framework that resulted from applying rules 1 and 2. This framework was presented to representatives of the GISc community attending a dedicated workshop held at the Ukubuzana Conference in October 2012. The 17 participants included GISc academics, professional practitioners and industry representatives. In particular, the aim was to determine which of the candidate KAs and associated competencies are essential for inclusion in academic curricula. The participants were asked to complete a questionnaire in which they had to:

- Comment on the relevance of each of the KAs; and
- Identify missing KAs (if any).

The participants were also requested to rate the importance of each KA using a scale of 1 to 5, with 1 representing a low importance and 5 representing a high importance. Units occurring in KAs with an average importance rating of more than 3 were regarded as fundamental or core competencies.

Table 5.1 Prototype framework used at the workshop for input from the GISc community: fundamental competencies.

#	Themes	Academic fundamental competencies in GISc
1	Geographical science*	Human & physical geography; environmental science; earth science: Geography: Its nature and prospective (e.g. location. space, place, scale, pattern, regionization, globalization), Population (e.g. distribution, change), Cultural pattern and process (e.g. cultural landscapes); Political organization of space (e.g. territorial of politics); Agricultural and rural land use; Industrialization; Cities and urban land use (e.g. models of urban systems, eternal city structures); Physical geography (e.g. earth systems, resources, earth science concepts (atmosphere, hydrosphere, pedisphere, biosphere).
2	Physics*	Mechanics; kinematics; electricity; wave theory; electromagnetic spectrum: Kinematics, Newton's laws of motion, work, energy, power, rotational dynamics, torque, angular momentum, gravitation, periodic motion, simple harmonic motion, interference, wave motion, diffraction, refraction and reflection of waves, Doppler effect, electric charge and field, electric potential, capacitance, resistance, electric current, electromagnetic induction, magnetic field, electromagnetic spectrum.
3	Mathematics & statistics*	Calculus; algebra; trigonometry; descriptive statistics; sampling; statistical computer packages; multivariate statistics: Differential and integral calculus of functions of one variable; differential equations, partial derivatives, mean value theorem, solving systems of linear and non-linear equations, functions (e.g. trigonometric, hyperbolic), conic sections, complex numbers, matrix algebra, intersection of lines/planes, distance from points to lines/planes, differential geometry, series and polynomials; Descriptive statistics including sampling and the collection of data, frequency distributions and graphical representations; Descriptive measures of location and dispersion; Probability and inference including introductory probability theory and theoretical distributions, sampling distributions; Estimation theory and hypothesis testing of sampling averages and proportions (one and two sample cases); Identification, use and interpretation of statistical computer packages and statistical techniques; Multivariate statistics, curve fitting (e.g. regression and correlation).

***** Content derived from the PLATO model.

Table 5.2 Prototype framework used at the workshop for input from the GISc community: core competencies.

#	Component	Academic core competencies in GISc
1	Analytical methods**	Unit 1: Query operations and query languages Unit 2: Geometric measures Unit 3: Asic analytical operations Unit 4: Basic analytical methods Unit 5: Analysis of surfaces Unit 6: Spatial statistics Unit 7: Geostatistics Unit 8: Geocomputation Unit 9: Data mining Unit 10: Network analysis
2	Conceptual foundations **	Unit 1: Philosophical and social perspective Unit 2: Domains of geographical information Unit 3: Elements of geographical information Unit 4: Geospatial relationships Unit 5: Imperfections in geographic information
3	Data manipulation**	Unit 1: Representation transformation Unit 2: Generalization and aggregation Unit 3: Change management of geospatial data
4	Data modelling**	Unit 1: Basic storage and retrieval structure Unit 2: Database management systems Unit 3: Tessellation data models (e.g. Raster data model) Unit 4: Vector and object data models Unit 5: Three-dimensional, temporal, and uncertain phenomena data models
5	Cartography and visualization **	Unit 1: Data considerations Unit 2: Principles of map design Unit 3: Graphic representation techniques Unit 4: Map production Unit 5: Map use and analysis Unit 6: Map evaluation
6	Design aspects**	Unit 1: The scope of GIS system design Unit 2: Project definition Unit 3: Resource planning Unit 4: Database design Unit 5: Analysis design Unit 6: Application design Unit 7: System implementation
7	IT (Geo-computation)***	Information technology, emergence of geocomputation, computational aspects and neuro-computing; GIS software skills; GIS customization; hardware, operating systems; communications; programming; systems development; databases; data mining
8	Geo-spatial data**	Unit 1: Earth geometry Unit 2: Georeferencing systems Unit 3: Datums, SA coordinate system, utm Unit 4: Map projections Unit 5: Land partitioning systems Unit 6: Data quality Unit 7: Spatial data compilation Unit 8: Field data collection Unit 9: Metadata, standards, and infrastructure

Continued overleaf

Table 5.2 continued

	Component	Academic core competencies in GISc
9	Photogrammetry and remote sensing (Imaging knowledge) **	Unit 1: Cameras and photography Unit 2: Radiometry, detection, and sensing Unit 3: Frame geometry Unit 4: Image measurements Unit 5: Stereoscopy and parallax Unit 6: Mathematical modelling and analytical photogrammetry Unit 7: Computer vision Unit 8: Estimation, adjustment, statistics, and error propagation Unit 9: Stereo restitution Unit 10: Rectification and resampling Unit 11: Mapping and cartography Unit 12: Topography and digital elevation modelling Unit 13: Digital photogrammetry Unit 14: Project planning Unit 15: Close-range photogrammetry Unit 16: Satelite photogrammetry Unit 17: Remote sensing Unit 18: Active sensing with lidar Unit 19: Applications
10	GI S&T and society** (KA: Legal and Ethical Aspects of GIS)	Unit 1: Legal aspects, PLATO Act and rules; GIS legislation; Spatial Data Infrastructure Act. Unit 2: Geospatial information as property Unit 3: Dissemination of geospatial information Unit 4: Ethical aspects of geospatial information and technology, professional execution of daily functions; planning and control Unit 5: Critical thinking about GIS
11	Organizational and institutional aspects** (KA: Management and Organisation Aspects)	Unit 1: Management aspects Unit 2: Economic aspects Unit 3: Organizational structures and procedures Unit 4: GIS workforce Unit 5: Institutional and inter-institutional aspects Unit 6: Coordinating organizations (national and international)
12	Research methodology*	System design or spatial analysis; reporting and presentation of results; the research project must have a system design and or spatial analysis component and include reporting and presentation of final results. The time spent on research topic selection, development of a research proposal, analysis and interpretation, progress reporting, and liaison with research supervisor must be a minimum of 300 hours
13	Training****	Mentor and advise learners during WIL; develop, support and promote continuous professional development (CPD) in the profession

* Content derived from the PLATO model.
** Content derived from the UCGIS BoK, topics not shown due to space constraints.
*** Content derived from the UCGIS BoK, USBQ, and PLATO model.
**** Content derived from the USBQ.

5.4 RESULTS AND DISCUSSION

5.4.1 Feedback from the GISc community

The results of the workshop are summarized in Table 5.3. The *Data modelling* and *Geospatial data* KAs were rated the most important, while Physics was rated the least important KA for inclusion in GISc curricula. *Geographical science* received an average score of 4.5 as the most important fundamental competency. A number of respondents suggested that human and physical geography (including earth science and geomorphology) be included in this KA. One participant requested the inclusion of geophysics, while another requested that mathematics should be constrained to geospatial applications.

Table 5.3 Workshop results showing the perceived importance of each KA.

KA description	Level	Average importance rating (1-5)
Data modelling	Core	4.7
Geospatial data	Core	4.7
Geographical science	Fundamental	4.5
Analytical methods	Core	4.5
Cartography and visualization	Core	4.5
Mathematics and statistics	Fundamental	4.2
Conceptual foundations	Core	4.2
Data manipulation	Core	4.2
Design aspects	Core	4.2
Information technology	Core	4.2
Research methodology	Core	4.0
Training	Core	3.9
GI S&T and society (legal and ethical aspects of GISc)	Core	3.7
Photogrammetry and remote sensing	Core	3.5
Organizational and institutional aspects (management and organization aspects)	Core	3.1
Physics	Fundamental	3.0

In terms of the core competencies *Data modelling* and *Geospatial data* received the highest importance ratings (4.7). *Analytical methods* together with *Cartography and visualization* received a score of 4.5, followed by *Conceptional foundations*, *Data manipulation*, *Design aspect* and *Information technology* which were all rated 4.2. The importance of computer networks and web GIS was highlighted by some participants. *Research methodology*, *Training* and *GI S&T and society* (legal and ethical aspects of GISc) received ratings of 4.0. 3.9 and 3.7 respectively, with some participants suggesting that research should be restricted to the 3rd-year level of study. One participant emphasized the importance of the Land Survey Act and Information Communication Technology Act as part of the *GI S&T and society* KA, while another participant requested the inclusion of basic survey methods under *Photogrammetry and remote sensing*. The relatively low score (3.5) allocated to *Photogrammetry and remote sensing* suggests that GISc practitioners do not need a high level of understanding of these techniques and that a dedicated KA is not warranted. *Photogrammetry and remote sensing* was consequently included in the *Geospatial data* KA of the new framework (see Table 5.3). Although *Organizational and institutional aspects* also received a relatively low score (3.1), it is listed as a KA or theme in all three models considered in the comparative analysis (i.e. it adheres to rule 1) and was therefore kept as a separate KA in the framework.

5.4.2 The structure of the new framework

The new framework is based on the design of the BoK, but includes four additional KAs. Due to limited space, only an outline of the framework is provided in Table 5.4. A complete list of KAs and associated competencies is available at http://academic.sun.ac.za/cga/downloads/GISc_competency_list_V1.6.xlsx.

The KAs are structured into two categories, namely fundamental and core, and the structure allows for specialization through the inclusion of non-core competencies. The BoK's *Analytical methods, Conceptual foundation, Data manipulation* and *Data modelling* were preferred to the PLATO subject area *Geospatial information science* as these KAs provide the curriculum designer as well as the student with a better understanding of the diversity of the GISc profession. *Design aspects* and *Geocomputation* were retained as separate KAs in preference to *Information technology* as used in the PLATO model. *Data acquisition* and *Coordinate systems and projections* were grouped with *Photogrammetry and remote sensing* in a single KA titled *Geospatial data* due to the increased accessibility of digital space and airborne imagery and advances in technology to analyse such imagery. Competencies related to research, physics, mathematics and geographical science were grouped under the KAs *Research methodology, Physics, Mathematics and statistics* and *Geographical science.* The credits, lecture hours and directed study hours allocated to each KA are informed by the PLATO model and USBQs. The resulting new structure of the GISc framework is presented in Table 5.4 and consists of 14 KAs with their respective criteria and units.

5.5 CONCLUSION

The aim of this paper was to develop a framework and comprehensive list of competencies (KAs and units) that can be used for GISc curricula development. The key finding is that the existing BoK is the most comprehensive set of competencies available, but needs to be extended to include four additional KAs and 15 units (competencies). The new KAs and units relate to fundamental and core competencies in the USBQs and PLATO model that are absent from the BoK, as well as those competencies regarded by representatives of the GISc community as being essential.

The adoption of the proposed framework by South African universities will significantly simplify the programme accreditation process as it will provide a common reference. By extension, the framework and list of competencies will be invaluable in the assessment and registration of practitioners with professional bodies. The framework will assist learners and universities with articulation agreements and guide employers in formulating work descriptions and recruitment criteria. At the international level, the findings of this study will support existing efforts to update and modify the BoK so that it meets international requirements.

Table 5.4 New GISc framework, with fundamental and core competencies defined by their respective KAs, criteria and units.

Level	Knowledge area	Criteria	Units
Fundamental	GS: Geographical science	36 Credits, 90 lecture hours (8% of programme) and 270 directed study hours*	GS1 Human geography GS2 Physical geography GS3 Environmental geography
	MS: Mathematics and statistics	48 Credits, 120 lecture hours (10% of programme) and 360 directed study hours	MS1 Mathematics MS2 Basic statistics
	PS: Physical science	16 Credits, 40 lecture hours (2% of programme) and 120 directed study hours	PS1 Kinematics and Newton's laws of motion
Core	AM: Analytical methods	48 Credits, 120 lecture hours (10% of programme) and 360 directed study hours	AM3 Geometric measures AM4 Basic analytical operations AM5 Basic analytical methods AM8 Geostatistics
	CF: Conceptual foundations	36 Credits, 90 lecture hours (8% of programme) and 270 directed study hours	CF3 Domains of geographic information CF4 Elements of geographic information
	CV: Cartography and visualization	40 Credits, 100 lecture hours (8% of programme) and 300 directed study hours	CV2 Data considerations CV3 Principles of map design CV4 Graphic representation techniques CV6 Map use and evaluation
	DA: Design aspects	36 Credits, 90 lecture hours (8% of programme) and 270 directed study hours	DA4 Database design
	DM: Data modelling	36 Credits, 90 lecture hours (8% of programme) and 270 directed study hours	DM2 Database management systems DM3 Tessellation data models DM4 Vector and object data models
	DN: Data manipulation	36 Credits, 90 lecture hours (8% of programme) and 270 directed study hours	DN1 Representation transformation DN2 Generalization and aggregation
	GC: Geocomputation	36 Credits, 90 lecture hours (8% of programme) and 270 directed study hours	GC10 Computer programming
	GD: Geospatial data	48 Credits, 120 lecture hours (10% of programme) and 360 directed study hours	GD1 Earth geometry GD3 Georeferencing systems GD4 Datums GD5 Map projections GD6 Data quality GD7 Land surveying and GPS GD10 Aerial imaging and photogrammetry GD11 Satellite and shipboard remote sensing GD12 Metadata, standards, and infrastructures
	GI S&T and society	12 Credits, 30 lecture hours (3% of programme) and 60 directed study hours	GS6 Ethical aspects of geospatial information and technology
	OI: Organizational and institutional aspects	12 Credits, 30 lecture hours (2% of programme) and 60 directed study hours	OI5 Recognition of Prior Learning and Work Integrated Learning OI6 Institutional and interinstitutional aspects OI7 Coordinating organizations (national and international)
	RM: Research Methodology	40 Credits, 100 lecture hours (8% of programme) and 300 directed study hours	RM1 Research methodologies RM2 Research problem and methods RM3 Analysing the results and discussion RM4 Writing an academic paper, article or thesis

Note 1: One lecture hour is considered to be 45 to 60 minutes in duration. 1 Credit equates to 10 nominal hours or 2.5 lecture hours, the remainder is regarded as directed study hours used for fieldwork and self-study.

Note 2: Non-core competencies (units) are excluded from the table.

In its present format the new framework, which consists of 14 KAs, 6 fundamental, 33 core units, 48 non-core units and 355 topics, is unwieldy and cumbersome to use. The development of an easy-to-use and accessible assessment tool, ideally in the form of a web application, is recommended. Such a tool should be designed to support curriculum development, guide the accreditation of university programmes and facilitate the registration of professional GISc practitioners.

5.6 REFERENCES

Bruniquel & Associates 2009. Unit standards, a plea for common sense [online]. Available from: http://www.e-biznews.co.za/uploads/files/biznews1st2009.pdf [Accessed 2 February 2009].

CHE (Council on Higher Education) 2004a. Framework for programme accreditation [online]. Available from: http://www.che.ac.za/documents/d000080/ [Accessed 22 October 2009].

CHE (Council on Higher Education) 2004b. Criteria for programme accreditation [online]. Available from: http://www.che.ac.za/document/d000084/ [Accessed 22 October 2009].

DeMers MN 2009. Using intended learning objectives to assess curriculum materials: The UCGIS body of knowledge. *Journal of Geography in Higher Education* 33 (1): 70-77 [online]. Available from: http://dx.doi.org/10.1080/03098260903033980 [Accessed 16 October 2009].

DiBiase D, DeMers M, Johnson A, Kemp K, Luck AT, Plewe B & Wentz E. (eds.) 2006. *GI S&T body of knowledge: University consortium for geographic information science* [online]. Penn State University. Association of American Geographers. Available from: http://www.ucgis.org/priorities/education/modelcurriculaproject.asp [Accessed 26 February 2009].

Du Plessis HJ & Van Niekerk A 2012. A curriculum framework for geographical information science (GISc) training at South African universities [online]. *South African Journal for Higher Education*, 26(2): 329-345. Available from: http://reference.sabinet.co.za/document/EJC123985 [Accessed 30 September 2014]

Du Plessis HJ & Van Niekerk A 2013. A comparison of geographical information science competency requirements [online]. *South African Journal of Geomatics*, 2 (3): 206-217. Available from: http://www.sajg.org.za/index.php/sajg [Accessed 30 September 2014]

Forer P & Unwin D 1999. Enabling progress in GIS and education. In Longley PA, Goodchild MF, Maguire DJ and Rhind DW (eds) *Geographical information systems. Management issues and applications,* 747-756. 2nd ed. New York: John Wiley & Sons.

Gaudet CH, Annulis HM & Carr JC 2003. Building the geospatial workforce. *URISA Journal* 15 (1): 21-30 [online]. Available from: http://www/urisa.org/files/Gaudet vol15no1.pdf [Accessed 13 October 2009].

Gaudet CH & Annulis HM 2008. Developing the geospatial workforce. *The Global Geospatial Magazine* March, [online] Available from: http://www.gisdevelopment.net/magazine/global/2008/march/48.htm. [Accessed 11 April 2011]

Johnson AB 2006. *Developing a GIS curriculum*. ArcUser [online]. Available from: http://www.esri.com/news/arcuser/0706/curricula.html [Accessed 20 October 2009].

Kemp Karen K & Wright Richard 1997. UCGIS Identifies GIScience education priorities [online]. Available from: http://www.ucgis.org/priorities/education/priorities/geoinfosystems.html [Accessed 23 June 2011].

PLATO 2011a. Notes for guidance for the registration of GISc practitioners [online]. Approved September. Available at: http://www.plato.org.za. [Accessed 29 April 2012].

Prager SD & Plewe B 2009. Assessment and evaluation of GIScience curriculum using the Geographic information science and technology body of knowledge [online]. *Journal of Geography in Higher Education* 33 (1): 46-69. Available from: http://dx.doi.org/10.1080/03098260903034012. [Accessed 16 October 2009].

Reinhardt W 2012. Statement of usage of BoK in our institute [online]. Available from: <http://www.geo-informatie.nl/rip001/edumapping/AGILE_2012-Reinhardt.pdf>. [Accessed 3 April 2013].

South Africa 1984. Professional and Technical Surveyors Act as amended, Act 40 of 1984. *Government Gazette* 226 (9157), 11 April. Pretoria: Government Printer.

South Africa 1995. The South African Qualifications Act, Act 58 of 1995.*Government Gazette Notice* 1521, 4 October. Pretoria: Government Printer.

South Africa 2011. Geomatics Profession Bill. *Government Gazette* 35801, 22 October. Pretoria: Government Printer.

Toppen F & Reinhardt W 2009. A European approach towards the UCGIS geographic information science and technology body of knowledge a discussion paper [online]. Available from: http://itcnt05.itc.nl/agile_old/Conference/2009-hannover/WS2/Ws2_Agile09_abstracts/2009_paper_Toppen_Reinhardt_AGILEws-2009.pdf. [Accessed 3 April 2013].

UCGIS 2003. *Task force on the development of model undergraduate curricula: The Strawman report* [online]. Available from: http://www.ucgis.org/priorities/education/priorities/FINALSTRAWMANTEXT.Pdf [Accessed 12 April 2009].

CHAPTER 6 IMPLEMENTATION OF THE GISc SELF-ASSESSMENT TOOL

A new GISc framework developed as a standard for curricula development to meet South African and international requirements was described in Chapter 5. These requirements, if adopted by the South African professional body, must be satisfied by newly developed training programmes and academic qualifications so as to ensure that universities produce graduates who are adequately prepared for the job market.

The South African Council for Professional and Technical Surveyors (PLATO) (South Africa 1984) has been registering GISc professionals since 2004 using the South African Qualifications Authority (SAQA 2009) unit standards-based qualifications (USBQ) and PLATO model as bases. It took universities about eight years to adopt the criteria prescribed by the professional body for the development of GISc university programmes. The delay was mainly a result of the inconsistencies and perceived biases in the available criteria. In 2012, PLATO started the first round of GISc programme accreditations. Before 2012 many individuals with diverse qualifications and academic backgrounds applied for registration, so necessitating time-consuming, labour-intensive and expensive compliance assessments using the then existing criteria. The PLATO Council (2013) estimated the cost of accrediting a single university programme to be R40 000 for the 2013/2014 financial year. This excluded evaluator costs as voluntary assistance was assumed. Universities applying for accreditation are expected to refund PLATO for any direct costs incurred during the accreditation process. The universities are also responsible for any internal costs incurred during the preparatory stages of programme accreditation.

A self-assessment tool (SAT) that reduces the time required by universities to prepare for accreditation and simplifies the assessment process is clearly needed. This need is not limited to South Africa. A survey conducted during the ESRI Education User Conference in San Diego in 2008 on the structure of the body of knowledge (BoK) and its possible uses found that curriculum planning was cited most, followed by the topic of creating self-assessment instruments, specifying accreditation standards and laying down curriculum pathways (Johnson 2006).

In response to the need for a SAT, an assessment instrument was developed in 2012 as part of this research. The instrument was first implemented as a set of forms in Microsoft Word, which were later translated to Microsoft Excel. However, these software platforms were not ideal as deployment and maintenance were difficult. The forms were often used incorrectly which led to inconsistencies in the self-evaluation results. It was also difficult to effectively update the instrument as many versions were in circulation.

This chapter focusses on the development of a web-based GISc SAT that is robust, user-friendly and easy to maintain. The tool's purpose is to facilitate the assessment of university programmes by identifying gaps in an existing curriculum when compared with the standard set of competencies developed in Chapter 5. Such a tool will be useful to universities for reviewing a programme or it can be used by HR practitioners to verify if an applicant for a GISc position meets the minimum competency requirements.

According to Grazioli & Morris (2014), the development of an information system typically follows five steps, namely 1) planning and requirement analysis, 2) conceptual design, 3) logical design, 4) physical design and 5) implementation. A similar order was followed in the development of the GISc SAT as described in the following subsections. The activities associated with conceptual and logical design were combined owing to their similarity.

6.1 PLANNING AND REQUIREMENT ANALYSIS

According to Nielsen (2000) and Friesen (2013), system planning usually involves the determination and definition of business, processing, functional, user-interface and usability requirements. Essentially, this involves what the system is supposed to do and how it should perform. These requirements are expounded in the following subsections.

6.1.1 Business and processing requirements

Friesen (2013) distinguishes business requirements as project summary and objectives; target audience; perception and tone; branding elements; communication strategy; competitive positioning; types of content; marketing and promotion; design process; testing, prototyping and approval; maintenance; and schedule. Business requirements do not necessarily document functions that a system must support but describe what part of these functions can be made available through the system. These requirements contribute to the look and feel of the system, identify the audience and determine what is generally needed for the application. Consequently, project summary and objective; target audience; content design and processing; testing, prototyping and approval; and maintenance are deemed relevant to the planning of the system and are discussed below to guide the development and ensure that the application meets its goals.

According to DiBiase et al. (2006), self-assessment instruments not only help determine whether programmes meet educational objectives, they also assist prospective students to choose educational programmes that align with their interests and career goals. Content and credits are therefore the preferred requirements for meeting the objectives of the GISc SAT. The result should contribute to the primary aim of this research, namely to develop a method for assessing the competencies of individuals applying for professional registration and for evaluating the content of academic programmes for accreditation purposes. The content of the assessment report should inform the assessor if a programme (qualification) adequately covers the content and credit requirements specified in the competency set.

Possible users of the tool include programme developers (i.e. education institutions), programme assessors (i.e. accreditation panels), applicants (i.e. individuals applying for registration with the professional body) and HR departments (i.e. HR practitioners, employers and employment agencies).

To meet the objective of assessing the competencies of individuals applying for professional registration and for evaluating the content of academic programmes for accreditation purposes, the system needs to evaluate programmes and applications according to some quantitative value that determines an acceptable degree of conformity. The primary content of the SAT is the GISc framework consisting of knowledge areas (KAs) and units as well as the university academic programme comprising modules that relate to certain subject areas. Whereas the BoK does not provide for any quantitative guidelines at KA, unit or topic levels, the PLATO model stipulates the required lecture hours and percentage of lecture hours per subject area. The SAQA (South Africa 1995) and the Council on Higher Education (CHE 2004a; 2004b) provide additional guidelines in the form of notional hours and they define that every ten notional hours is equivalent to one credit offered in an academic programme. In GISc modules, one credit roughly equates to 2.5 lecture hours (i.e. a 16-credit module would include about 40 lecture hours). Given that the number of notational hours and lecture hours can be inferred from the number of credits and also that credits are the CHE standard, a credit-based quantification of GISc requirements was adopted for the GISc framework and applied in the SAT.

Each KA is assigned a number of credits based on the lecture hours derived from the PLATO academic model. For example, KA DN (Data Manipulation) in the GISc framework was assigned 90 lecture hours in the PLATO model or 36 SAQA credits according to the National Qualifications Framework (NQF). The KA DN consists of two units and a number of topics in each unit. In this research the credits assigned to the KA are divided between the number of units, i.e. 18 credits for each unit, and topics were not included as an additional level in the new GISc framework. However, should universities and the professional body accept the new GISc framework, it is recommended that both the academic model prescribed by the professional body and the related programmes offered at universities should include detail and credits at the topic level.

In essence, the SAT must follow a procedure to compare the competency sets, i.e. the university academic programme with the GISc framework. The procedure must:

Match the credits of the units in the GISc framework with the content of modules in the university programme being evaluated on a pro rata basis (e.g. 5% of a module can be associated with a particular unit).

Keep track of the total number of credits assigned to each module and ensure that the total number of associated credits does not exceed the total number of credits of a particular module (i.e. stop the user from associating core units to a particular module once 100% of its credits have been allocated). Identify the KAs that are not adequately covered by comparing the total number of matched credits with the total number of credits per KA.

Sum the total matched credits and compare these with the total core-unit credits in the competency set to determine the overall level of compliance.

The aim of these rules is to provide an objective and consistent compliance rating for each programme that is assessed. The resulting compliance rating must be stored in a database so that users can refer to previous assessments. The functional requirements for such a system are dealt with in more detail in the next section.

6.1.2 Functional requirements

Functional requirements describe what a system must do to support the business objectives. These functional requirements cover aspects such as user editing or authoring, online chat (e.g. Twitter), e-commerce (e.g. shopping carts), slide shows (e.g. demos), specific files needed to be downloaded (e.g. pdf documents, movies and sound files), login and security features (e.g. registration and sign in with a protected password). The functional requirements depend on the objective of the site.

The SAT must be able to handle multiple concurrent users and must provide a secure working environment through which users can input information (e.g. name of applicant, university programme and modules). The system must provide for the editing of related content entered by a user, for example changes to personal information. As the system must be able to handle multiple concurrent users, the data must be protected. Users must therefore log in to the system using a username and password. The system must also keep track of the different users. User-specific information needs to be stored centrally so that users can continue with or modify previous sessions (e.g. matching of modules) after logging in to the system. The system should include some data-validation procedures to check for inconsistencies in the entered information.

6.1.3 User-interface requirements

User-interface requirements specify the presentation and layout of a system's interface (or website in the case of a web application) and describe how the user will interact with it. The graphical user interface together with its input devices provides the 'look-and-feel' of the system. Elements such as windows, pull-down menus, buttons, scroll bars, iconic images and the mouse pointer contribute toward an intuitive and user-friendly application (Rouse 2006). Nielsen (2000) maintains that an important user-interface requirement is the positioning of the name of the application at a prominent location to orientate users. The layout of the pages should be consistent and the application should start on a landing page, or home page. Users must be able to easily navigate back to the home page at all times while finding it equally easy to move between pages regardless of which page is active. Each page must contain a label at the top to direct users through the process. Consistency in page layout assists users to know at all times where they are on the site (Nielsen 2000; Tedesco et al. 2008; Friesen 2013).

6.1.4 Usability requirements

Usability requirements of a system consider accessibility, costs, response times, screen resolution and compatibility. These characteristics are described in the following subsections.

6.1.4.1 Accessibility and costs

For the GISc SAT to be successful, it must be accessible to all its intended users. This has a number of logistical and design implications as a large component of software development costs relates to distribution and maintenance, for example updates (Nielsen 2000). According to Royal Pingdom (2012), the World Wide Web is accessible to about 4.6 billion users internationally and 8.5 million users in South Africa. Availability of Internet access is standard at all the universities in South Africa as confirmed by the Education Advisory Committee's visits to 11 universities during 2012 and 2014. Thus, most users are likely to have access to the Internet.

The web provides a cost-effective development, distribution and maintenance platform that offers many advantages over desktop applications. A prime advantage is that the burden of deploying software on each client machine is avoided as the web application's software resides on a centralized server which makes distribution, support and maintenance easier. There is thus no need to enforce version checks on client machines and updates are easier. Web applications do not require special software as they are platform independent and they can be accessed from many places like home, work, public areas such as airports offering free Internet access, smartphones and Internet shops (Nielsen 2000; Strohm et al. 2011; IBM 2014). It is very likely that a web-based application will be more accessible than a stand-alone desktop software package that needs to be distributed and installed on different workstations.

Another significant benefit of web applications is that users require little additional skills or training to use them because the interface consists of standard web pages and components such as text, images, form fields and buttons, all of which are familiar to most users. This means that users are more likely to adopt and use web applications, such as the GISc SAT, than other forms of implementation (Sintes 2002; Strohm et al. 2011; IBM 2014).

6.1.4.2 Response times

According to Nielsen (2000), Barber (2014) and Hossain & Reinhardt (2012), web applications must consider response times as they may differ for different applications. For the GISc SAT to be successful it must provide response times of less than one second when moving from one page to another. One second is about the limit for a user's flow of thought without being interrupted, while ten seconds is about the limit for keeping a user's attention (Nielsen 2000). Users' experience of response times can be affected by external factors other than the design of the web application. For example, in South Africa the majority of Internet users do not have access to broadband Internet connections and connection speeds are generally low. Attaining website speed can also be affected by combinations of software and hardware, such as screen resolution, browser compatibility, server throughput when traffic on a site increases or instances where a user's browser and computer are not regularly maintained and upgraded. Given these determinants, the GISc SAT must be designed for minimum bandwidth to accommodate a variety of screen resolutions and be compatible with most of the popular Internet browsers. Graphics such as large images and flash components should be avoided and complex table structures kept to a minimum (Nielsen 2000).

6.2 CONCEPTUAL AND LOGICAL DESIGN

The conceptual design of the GISc SAT is shown in Figure 6.1. The inference engine is a key element as it performs the essential function of determining the extent to which a university programme meets the accreditation requirements. It also communicates with the two databases, which store the GISc framework and user information respectively. The website component serves as an interface between the users and the inference engine. Users interact with the website component via a web browser and reference a specific web Internet protocol address. The inference engine responds with a request for the data from the database management system (DBMS), which is then processed in some way and sent to the client through the website.

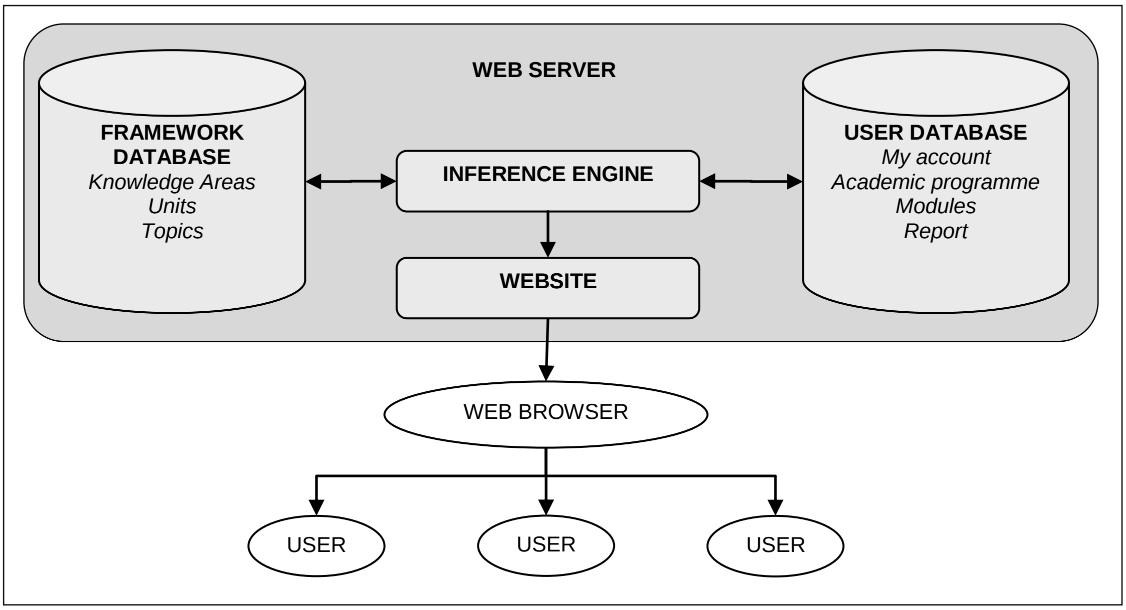


Figure 6.1 Conceptual design of the web-based GISc SAT

6.2.1 Database design

The data in the *framework database* consists of records representing individual and sets of competencies as defined in the GISc framework. These competencies are structured as KAs, units and topics. The data relating to the university programmes are stored in the *user database* and are structured as subject areas and modules. The data must be managed carefully and the use of a DBMS is essential. Data management involves four actions, namely (a) data creation, (b) data retrieval, (c) data modification and updating, and (d) data deletion (Umanath & Scamell 2007). A well-designed database is efficient and flexible for data searches, data retrievals, data editing, and creation of tabular reports. Tables in the database remain separate until a query or an analysis require the attribute data from the two tables to be linked or combined by using a relational DBMS (RDBMS) for instance (Chang 2006). The user sends requests to the web server using hypertext transfer protocol (HTTP) and the inference engine uses server-side scripting to communicate with the RDBMS. Once the requested data have been located in the database the RDBMS returns the result to the inference engine where it can be processed. The result is published as a web page which is returned to the user via the website using hypertext markup language (HTML).

To ensure the integrity of the data in the two databases, a logical data modelling approach was used.

6.2.1.1 Logical data modelling

Umanath & Scamell (2007) point out that the relational data model was proposed as early as 1970 as a logical basis for describing the structure of data as well as data manipulation operations. In the structure of the relational database the data are stored in tables (entities) and fields consisting of rows (tuples) and columns (attributes) (DeMers 2005; Chang 2006). The relational data model has gained popularity as it represents the database as a collection of relations that resemble a two-dimensional table with values represented in rows and columns. Umanath & Scamell (2007) characterize a logical data model (LDM) as a technology-independent logical schema, whereas Grazioli & Morris (2014) describe it as an information repository that specifies the business needs and how the information will be organized. The LDM effectively communicates the business requirements to users, designers and developers, while providing a foundation for designing a correct, consistent, sharable and flexible relational database using database technology and software that allow for the storage and retrieval of large quantities of related data. The LDM focusses on what data should be stored in the database, whereas the process model deals with how the data are processed. A LDM was used in this study to design the relational tables, or entities, of the two GISc SAT databases and a process model was used to design the queries that access and perform operations on these entities.

6.2.1.2 Entities and attributes

Entities are that which is important in the business situation being modelled and about which information is collected. A total of five entities relating to the user database were defined (Table 6.1). They are UNIVERSITY, APPLICANT, PROGRAMME, SUBJECT and MODULE. For the framework database three entities were defined, namely KA, UNIT and TOPIC (Table 6.2). Each entity has one or more attributes. The UNIVERSITY entity has three attributes namely UNIVERSITY.ID, UNIVERSITY.NAME and UNIVERSITY.PROVINCE. Examples of entries into these attributes would be “1”, “Stellenbosch University” and “Western Cape” respectively.

The province where the university is located was included in this entity to facilitate statistical analyses about the differences between curricula in the South African provinces. UNIVERSITY.ID acts as a primary key in UNIVERSITY. A primary key is a unique identifier that can be a number or a name. The primary key is underlined in the entity-attribute table and entity-relationship diagram (ERD) to distinguish it from the other attributes. Each primary key is named using the entity name and the suffix ID for uniformity (Grazioli & Morris 2014).

The APPLICANT entity has seven attributes, namely APPLICANT.ID, APPLICANT.ROLE, APPLICANT.FIRST_NAME, APPLICANT.LAST_NAME, APPLICANT.E-MAIL, APPLICANT.TEL and UNIVERSITY.ID. The duplication of the attribute UNIVERSITY.ID in UNIVERSITY and APPLICANT allows for a definition of a relationship between these two entities (i.e. it acts as a foreign key). A foreign key is an attribute that relates to a primary key in another entity (Grazioli & Morris 2014). Entities PROGRAMME, SUBJECT and MODULE each have attributes: primary key, NAME and foreign key.

Table 6.1 GISc SAT entities and attributes

Entity name	Attribute name	Attribute description
UNIVERSITY	UNIVERSITY.ID UNIVERSITY.NAME UNIVERSITY.PROVINCE	Unique identification number for university (primary key) Name of university (i.e. where a qualification was acquired) Province in which the university is located
APPLICANT	APPLICANT.ID APPLICANT.ROLE APPLICANT.FIRST_NAME APPLICANT.LAST_NAME APPLICANT.E-MAIL APPLICANT.TEL UNIVERSITY.ID	Unique identification number for applicant (primary key) Applicant role (i.e. programme coordinator or private person) Applicant's first name Applicant's last name Applicant's e-mail address Applicant's telephone number Unique identification number for applicant's university (foreign key)
PROGRAMME	PROGRAMME.ID PROGRAMME.NAME PROGRAMME.CREDITS APPLICANT.ID	Unique identification number for programme (primary key) Name of programme Credits allocated to programme Unique identification number for applicant (foreign key)
SUBJECT	SUBJECT.ID SUBJECT.NAME PROGRAMME.ID	Unique identification number for subject (primary key) Name of subject areas contained in the programme and criteria Unique identification number for programme (foreign key)
MODULE	MODULE.ID MODULE.NAME MODULE.CREDITS SUBJECT.ID	Unique identification number for module (primary key) Name of modules making up the subject area and criteria Credits allocated to module Unique identification number for subject (foreign key)

The FRAMEWORK entity in the GISc framework (Table 6.2) only has one attribute, namely the identification number (FAMEWORK.ID). This number corresponds to the version of the framework should it be updated or replaced. The rest of the entities in the framework database only have an identification number and a name as attributes.

Table 6.2 GISc framework entities and attributes

Entity name	Attribute name	Attribute description
FRAMEWORK	FRAMEWORK.ID	Unique identification number (version) for academic framework (primary key)
KA	KA.ID KA.IDENTITY KA.NAME KA.DESCRIPTION KA.CREDITS FRAMEWORK.ID	Unique identification number for knowledge area (primary key) Knowledge area code Knowledge area name Knowledge area content description Credits allocated to knowledge area Unique identification number (version) for academic framework (foreign key)
UNIT	UNIT.ID UNIT.IDENTITY UNIT.NAME UNIT.DESCRIPTION UNIT.CREDITS KA.ID	Unique identification number for unit (primary key) Unit code Unit name Unit content description Credits allocated to unit Unique identification number for knowledge area (foreign key)
TOPIC	TOPIC.ID TOPIC.IDENTITY TOPIC.NAME TOPIC.DESCRIPTION TOPIC.CREDITS UNIT.ID	Unique identification number for topic (primary key) Topic code Topic name Topic content description Credits allocated to topic Unique identification number for unit (foreign key)

Key business rules ensure the integrity of the entities, for instance primary keys are not allowed to be null (i.e. zero or empty) as they must always be a number and that number may never be duplicated, thus two tuples may not have the same value. Non-key attributes provide additional information on the primary key attribute (DeMers 2005; Garmany, Walker & Clark 2005; Umanath & Scamell 2007; Grazioli & Morris 2014).

6.2.1.3 Relationships

Relationships between entities have direction and can be defined as one-to-one (1:1), one-to-many (1:M) or many-to-many (M:M). A one-to-many relationship between entities A and B signifies that one instance of A will relate to many instances of B. For example, one university can relate to many applicants (programme coordinators). A many-to-one (M:1) notation can be used to indicate an inverse relationship. Table 6.3 outlines the relationships between the different entities in the user database. The APPLICANT entity (second row) has a M:1 relationship with UNIVERSITY (first column) because a university can have many GISc SAT users (e.g. programme coordinators). The APPLICANT entity has a 1:M relationship with PROGRAMME (third column) as an applicant can submit more than one programme for accreditation. The PROGRAMME entity has a M:1 relationship with APPLICANT (second column) because an APPLICANT can offer many PROGRAMME. The PROGRAMME entity has a 1:M relationship with SUBJECT (fourth column) as a programme consists of many subject areas. The entity SUBJECT has a M:1 relationship with PROGRAMME and a 1:M relationship with SUBJECT. The entity MODULE has a M:1 relationship with SUBJECT as many modules will make up a SUBJECT.

Table 6.3 Relationship matrix of entities in the user database

Entities	UNIVERSITY	APPLICANT	PROGRAMME	SUBJECT	MODULE
UNIVERSITY	-	1:M	*	*	*
APPLICANT	M:1	-	1:M	*	*
PROGRAMME	*	M:1	-	1:M	*
SUBJECT	*	*	M:1	-	1:M
MODULE	*	*	*	M:1	-

*No direct relationship

In Table 6.4 the FRAMEWORK entity relates to a number of KAs, whereas each KA relates one or more UNIT and each UNIT can relate to a number of TOPICs. Only the direct relationships are considered in the matrix.

Table 6.4 Relationship matrix of entities in the framework database

Entities	FRAMEWORK	KA	UNIT	TOPIC
FRAMEWORK	-	1:M	*	*
KA	M:1	-	1:M	*
UNIT	*	M:1	-	1:M
TOPIC	*	*	M:1	-

*No direct relationship

Because the GISc SAT aims to compare content of the user database with content of the framework database, the system relies on the RDBMS to process sequential query language (SQL) requests to fetch and relate the correct data from the respective databases. An ERD is used to illustrate how the different entities can be related to produce the required output. An ERD has three main components, namely entities, attributes and relationships. Modelling the major entities and relationships in the ERDs reveals if there are any entities that are not connected to any other entity or any many-to-many relationships that can be transformed to two one-to-many relationships using an intersection table to remove redundant relationships and transform attributes with more than one value into separate entities (Grazioli & Morris 2014). For instance, the ERD in Figure 6.2 shows that there is, through the entity APPLICANT, an indirect relationship between UNIVERSITY and PROGRAMME.

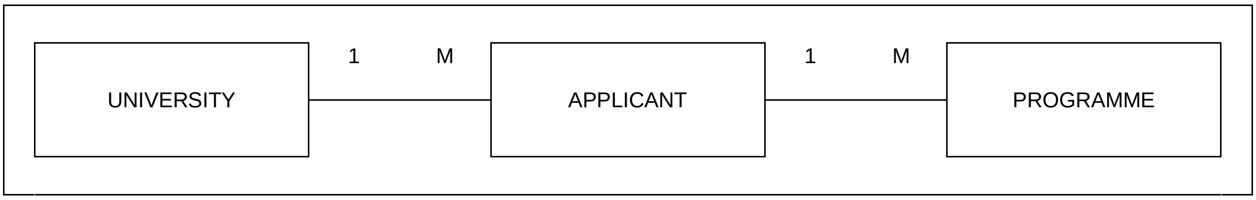


Figure 6.2 ERD illustrating the relationships between the UNIVERSITY, APPLICANT and PROGRAMME entities

The aim of the GISc SAT is to compare the university PROGRAMME (i.e. a set of modules and their content) with the FRAMEWORK (i.e. the competency set comprising KAs, units and topics). The MATCH MODULE entity is used to store the results of a comparison between these entities and, in effect, it enables a many-to-many relationship between the PROGRAMME and FRAMEWORK entities, as shown in Figure 6.3.

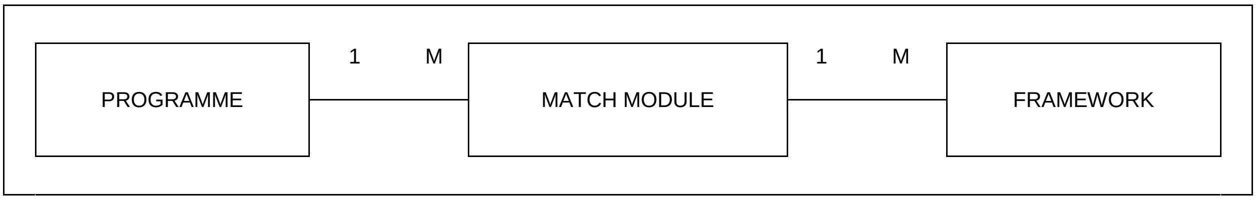


Figure 6.3 ERD illustrating the use of the MATCH MODULE entity to link the PROGRAMME and FRAMEWORK entities

6.2.1.4 Logical data model diagrams

The logical data model diagram (LDMD) is a graphical representation of the logical data model that clarifies the relationships between the entities. The LDMD helps a database manager to design and implement a database. Figure 6.4 and Figure 6.5 illustrate the LDMDs for the *user database* and the *framework database*, respectively.

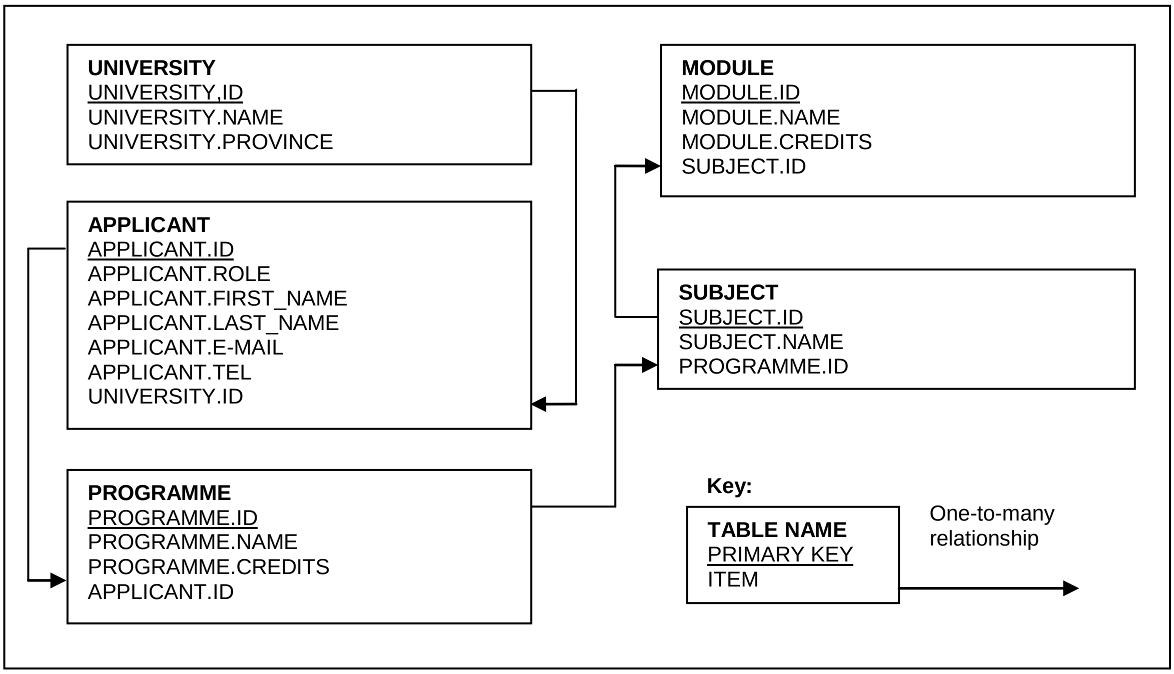


Figure 6.4 Logical data model diagram of the user database

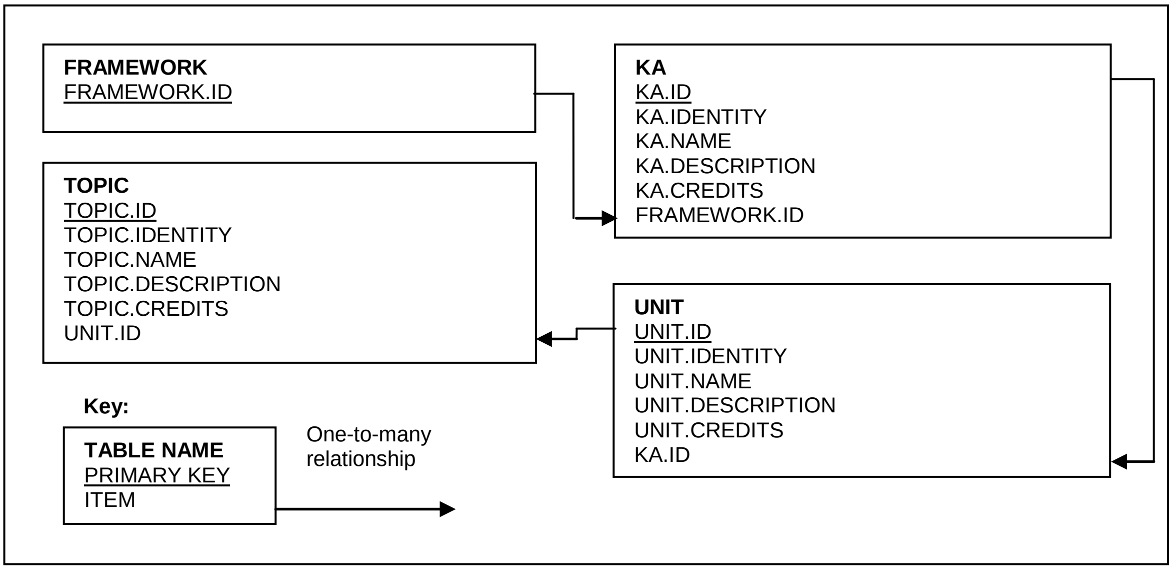


Figure 6.5 Logical data model diagram of the GISc framework database

The logical model design phase is not specific to a database. The logical model identifies entities and describes the relationships among these entities. It contains representations of entities and attributes, relationships, subtypes and super types as well as constraints between relationships (IBM 2009).

6.2.1.5 Normalization

Normalization is a systematic way of ensuring that a database structure is suitable for general-purpose querying and free of undesirable features such as insertion, update and deletion anomalies that could cause loss of data integrity. A detailed overview of the normalization process is not provided here (see Garmany, Walker & Clark 2005; Chang 2006; Grazioli & Morris 2014 for more detail). Quite simply, normalization is the process of removing redundant data from a relational database (Grazioli & Morris 2014). Chang (2006) defines normalization as the process of taking a table with all the attribute data and breaking it into smaller tables while maintaining the necessary linkages (integrity) between them. An entity is in its first normal form (1NF) if all values of the attributes contain no multiple or repeating values. An entity is in second normal form (2NF) if it is in 1NF and every non-key attribute is fully dependent on the primary key and in third normal form (3NF) if all attributes in the entity are dependent on the primary key. Grazioli & Morris (2014) contend that most practitioners believe that normalization to the third normal form (3NF) is sufficient as it is unlikely that entities in this form will not also satisfy the fourth and fifth normal forms. Consequently, the entities in the two GISc SAT databases were normalized to 3NF only (Garmany, Walker & Clark 2005; Grazioli & Morris 2014). All the entities in Table 6.3 and Table 6.4 met the requirements of 3NF and so were ready for the physical design and implementation stages.

6.2.2 Website design

One of the main activities of web application development is the design of the website which acts as the interface between users and the system. Interface requirements (Section 6.1.3), such as the positioning of the name of the application and the positioning of navigation buttons, are incorporated during the construction of the wireframe. The wireframe serves as interface specification for the website and is considered to be the blueprint for the design of the web pages to follow (Angeles 2013). The wireframe provides a visual reference on which to structure every page in the website. It allows for variations while maintaining design consistency (Angeles 2013). Wireframes focus on the kinds of information to be displayed, the range and relative priorities of information and functions available on the page, the rules for displaying certain information and different scenarios on the display (Brown 2011).

The GISc SAT wireframe, shown in Figure 6.6, was developed based on the business, functional, user-interface and usability requirements set out in Section 6.1. The wireframe consists of information buttons, action buttons and a work area. The primary function of the *information buttons* is to provide users with essential reference information during the assessment process, such as information on how to use the SAT, the content of the GISc framework, how to contact the helpdesk and redirecting the user to the home page. These buttons are positioned in a prominent location at the top of the page just below the banner.

The *action buttons* are positioned on the right-hand side of the wireframe and form part of the user menu. The first six buttons represent the sequence of steps that must be followed when using the GISc SAT, namely 1) add and 2) view the university academic programme to be assessed, 3) add and 4) view the modules of the academic programme, 5) match the modules to the academic framework and 6) present the results as a report. The last two buttons allow users to update their details and to log in or out.

Most of each web page is reserved as a *working area* where graphics, tables and content such as the university academic programme, the modules of each programme, the content of the report, information about the SAT and the GISc framework are displayed (Nielsen 2000).

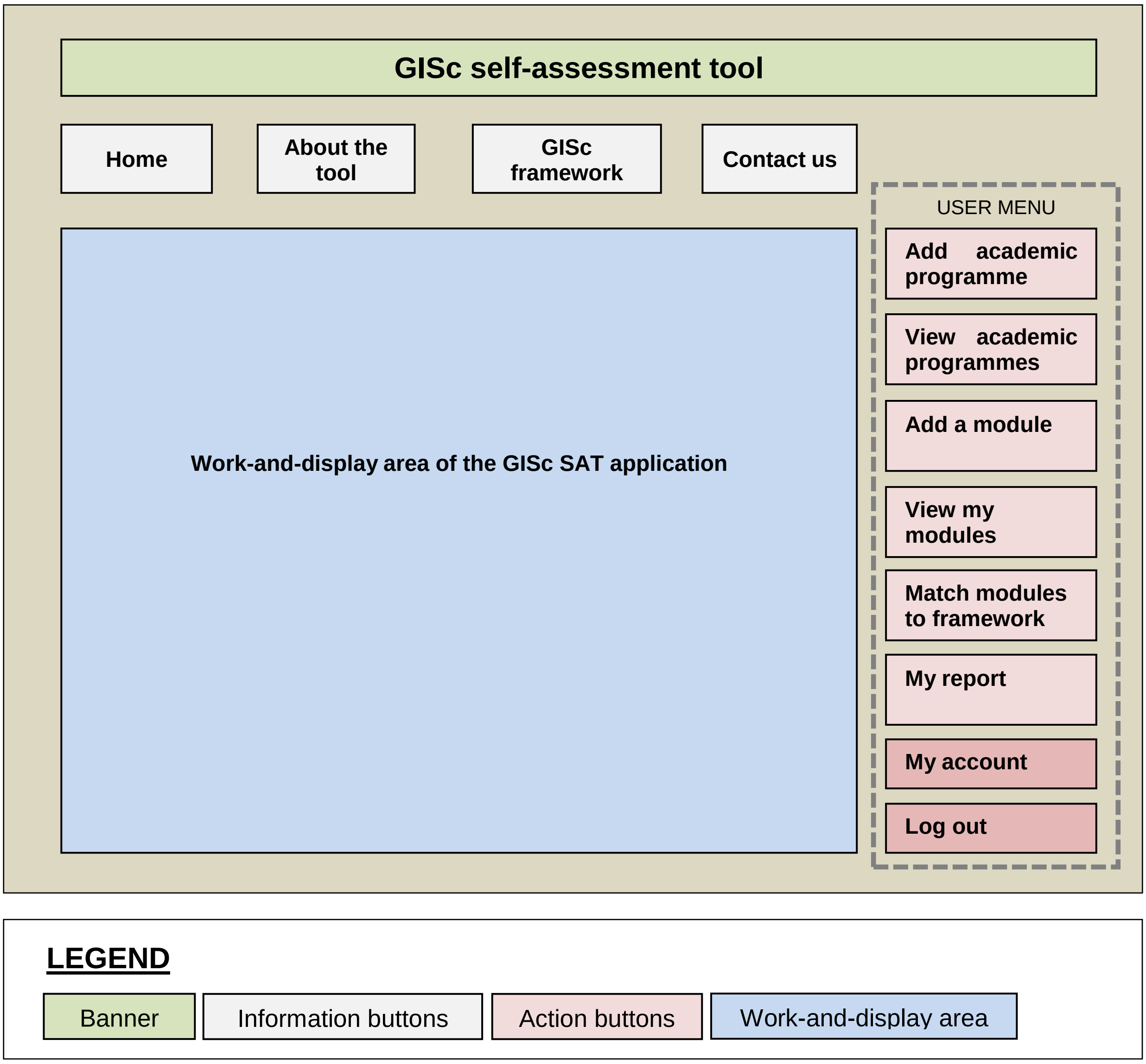


Figure 6.6 GISc SAT wireframe that defines the layout of the application's pages

The next step in user-interface planning involved the construction of a sitemap (Figure 6.7). A sitemap can be in the form of a flow diagram, a mind map or may even be a sketch put together during a brainstorming session (Nielsen 2000; Tedesco et al. 2008; Friesen 2013). The sitemap shows the names of the sections and subsections of the site and defines the navigation controls (buttons) on the web pages (Najjar 2002). The sitemap shows that the SAT was designed using three levels of web pages. The highest level represents the *Home page* which links to nine sub-pages (2nd level). Four of these pages link to a deeper level (3rd level). The sitemap also provides succinct comments explaining the purpose of each page. Each page and functionality is explained in more detail later (see Section 7.1).

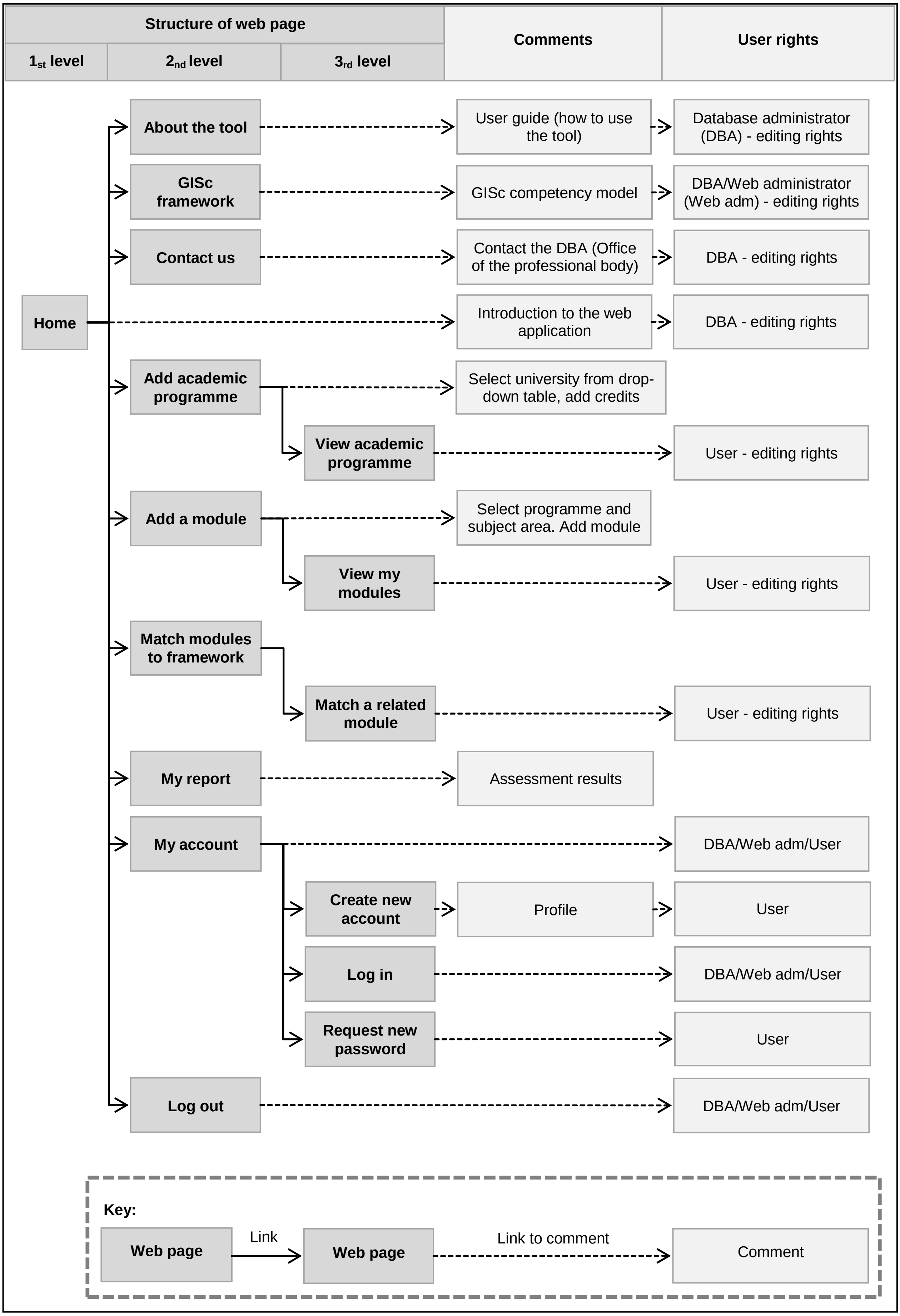


Figure 6.7 Sitemap for the SAT web application

6.3 PHYSICAL DESIGN

The physical design of the system depends on the operational requirements of the web application (IBM 2014). Users who access a web application do not need powerful computers as most of the processing takes place on the server hosting the application software. Depending on the architecture of the system, a user could access the application on a thin client terminal, a workstation, tablet or mobile phone using browser software (Sintes 2002; Strohm et al. 2011; IBM 2014). The physical design of a system is used by the application developer and/or database manager to implement the website, application and database on a server (or servers). A computer system consists of hardware and software components. The hardware physically stores the data in the database on hard drives (storage medium) in a structured format and software, such as RDBMS, manages the data. Computer software is a general term that describes computer programs and includes software programs, applications, scripts and instruction sets (Sintes 2002; Strohm et al. 2011; IBM 2014).

In many instances clients and servers hosting the web application and databases will use different operating systems. A client could be using a workstation-based platform such as Windows, Linux or UNIX while the server hosting the web application and database could be on another workstation-based platform or on an enterprise server such as IBM DB2 for z/OS. The benefits IBM (2014) recommends for consideration when deciding on the server to host the databases and the web application are:

- *Scalability*. To cater for the volume of transactions this can vary from time to time and increase substantially in the future.
- *Availability*. Data and applications should be available at all times.
- *Workload*. Hosting the web application, databases and database application will result in a mixed workload that could impact on the performance of the server.
- *Data integrity*. Involves strengths in the areas of security and reliability.

The components of the GISc SAT (Figure 6.1) can be separated into three tiers, namely a client, application and database tier with each tier residing on a different server. Each of these types of servers is described in the next subsections.

6.3.1 Web server (client tier)

Specialized web browser software is used to access, download and view web pages and information stored as web pages on the Internet. The client (web browser) receives an HTTP request from a user for an operation to be performed on the web server or database server. The user must enter a uniform resource locator (URL) into the web browser. A URL is simply an easily recognizable representation of the web server's Internet protocol (IP) address which is stored in a distributed Internet database. The client connects to the respective server through the application server using standard protocols. It processes the response and displays HTML web pages from the web server along with any files referenced by it to a user. The web pages are physically stored on computers or web servers permanently connected to the Internet (Sintes 2002; Strohm et al. 2011; IBM 2014).

Web servers that host websites for multiple users are shared hosts used for personal sites, small business sites and websites run by small organizations. Web servers that host websites for a single person or a company are dedicated hosts and they are appropriate for high-traffic websites and sites that require custom server modifications. Dedicated hosts are generally more reliable than shared hosts since there are fewer sites that can cause bottlenecks or other issues with the server.

6.3.2 Inference engine server (application tier)

On receiving an HTTP request from a client, the web server responds with an HTML page. To process a request other than displaying a static web page, the web server may delegate the response to a server-side application which will connect to the database server using a SQL query to retrieve the data through the RDBMS and then generate a response. The server-side application is usually developed as a set of server-side scripts. The main function of server-side scripting is to instantly generate HTML code related to the client's request. A new web page, based on the information supplied by the user, is created and once the page has been downloaded, it is removed from the server.

Fundamentally, any programming language can be used for server-side scripting, although several languages have been specifically developed for this purpose. Of these, PHP (PHP hypertext pre-processor) (79%) and ASP.NET (active server pages) (20%) are the most popular (Clavijo 2013). Although PHP can be run on any web server, it is most often used for Linux implementations, while ASP.NET, developed by Microsoft, runs only on Windows-based web servers.

Sophisticated web applications can be developed using server-side scripting. This means that the behaviour of the web server can be scripted in separate files, while the actual server software remains unchanged (Sintes 2002; Strohm et al. 2011; IBM 2014).

6.3.3 Database server (database tier)

The database server accommodates the database tier that consists of the DBMS and the database. The DBMS manages the storage, retrieval, access, security, data integrity and any other database support applications. The application server initiates communication by requesting a specific resource using HTTP on behalf of the client and the database server responds with the content of that resource or an error message if unable to do so. The content could be available in a file on the server's secondary storage depending on how the database server is implemented. While the primary function is to serve content, a full implementation of HTTP includes ways of receiving content like web forms or the uploading of files from users via the web and application servers (Strohm et al. 2011; IBM 2014). The next section explains how the databases and other GISc SAT components were implemented.

6.4 SYSTEM IMPLEMENTATION

System implementation involves setting up the databases, developing the server-side scripts and setting up both these components on a server (or servers). Database implementation involves setting up the schema entities and enforcing the constraints on the data relationships. IBM (2014) describes a schema as a logical classification of objects (entities) with a schema name that serves as a qualifier for SQL objects such as tables, views, indexes and triggers. Implementation is the responsibility of the database administrator (DBADM) or database developer and is usually done using SQL statements to create the database structure.

The design specifications for the GISc SAT were provided to a software and database developer for implementation. The developer used the web-based Drupal content management platform as the base framework for the SAT with further customizations and add-ons to accommodate the tool's functions as required by the specifications. Drupal is an open-source content management platform used and supported internationally by an active and diverse community of users and developers. Drupal has been used for the development of millions of websites and applications (Van der Merwe 2014, Pers com).

As explained in the previous section, the client, application and database tiers are often implemented on multiple servers. This is mainly to lighten the computational load on any of the three tiers. However, because it is expected that the computational load of the GISc SAT will not be high (relatively few users will be accessing the server at any given time) all of the GISc SAT components were implemented on a single Linux-based server hosted by Stellenbosch University. The application was developed using hypertext pre-processor (PHP) scripts, while

MySQL was used as the RDBMS (Oracle 2014). The web application can be accessed online using the URL http://giscsat.sun.ac.za/.

6.5 SUMMARY

Some assessment methodologies, tools and systems for quality assurance or assessment of GISc programmes have been implemented internationally with varying degrees of success (Forer & Unwin 1999; Johnson 2006; DeMers 2009; Hossain & Reinhardt 2012). A tool that can facilitate qualitative and quantitative assessments of university programmes against a standard set of competencies (such as the new academic framework developed in Chapter 5) will greatly support the design of curricula that meet the requirements of the GISc industry (Hossain & Reinhardt 2012). The development of a GISc SAT started with a set of forms implemented in MS Word later translated to a flat file system implemented in MS Excel. However, notable challenges such as the maintenance of the forms and versioning problems favoured the development of a web-based system.

The development and implementation of the GISc SAT web application involved a requirement analysis which defined the business, processing, functional, user interface and usability needs of the system. Based on these requirements, a wireframe and sitemap were developed for the website component of the system. Conceptually, the system was designed to include web browsers, a website, an inference engine and two databases. The GISc SAT was implemented using the web-based Drupal open-source content management platform and customized to meet the specified functional requirements. The application is hosted on a Linux-based server with PHP server-side scripting and MySQL as the database to store and access the data.

The next chapter demonstrates how the GISc SAT can be used for assessing university programmes or by individuals wanting to register with PLATO.

CHAPTER 7 DEMONSTRATION OF THE GISc SELF-ASSESSMENT TOOL

The geographical information science (GISc) self-assessment tool (SAT) developed in Chapter 6 provides an easy-to-use and accessible facility for assessing university GISc programmes and assisting users in determining if a programme or an individual meet the academic requirements established in Chapter 5. This chapter provides an overview of the SAT user interface and system functionality, specifically how views are used to separate the functionality of users and administrators. The chapter also explains the purpose of each web page and how each one contributes to the assessment procedure and objectives of the research. This is followed by a demonstration of the SAT using three GISc programmes. The chapter concludes with a discussion of the limitations and value of the SAT and makes recommendations for improving the tool.

7.1 USER VIEWS AND SYSTEM FUNCTIONALITY

This section deals with two user interfaces of the SAT, namely the user and administrator views. Figure 6.1earlier illustrated that the SAT makes use of two databases. The first (called the *user database*) stores the university academic programmes to be assessed and the second (the *framework database*) is dedicated to managing the set of competencies developed in Chapter 5. The information in the *user database* is entered by an applicant (user), while the *framework database* is maintained by the system administrator(s). Each of these roles requires a unique interface and set of functions as detailed in the following subsections.

7.1.1 User view

The *user view* defines the functions that users require. The SAT assessment procedure comprises five steps as portrayed in Figure 7.1. Each of the steps in Figure 7.1 and their associated web pages is explained in the following subsections.

7.1.1.1 Step 1: User registration

Upon entering the site URL (see Section 6.4) into a web browser, users are taken to the *Home* Page (Figure 7.2). On this page a user is presented with a short introduction to the GISc SAT and a *User login* form on the right-hand side of the page. In case a password has been forgotten, a new password can be requested using the *Request new password* link.

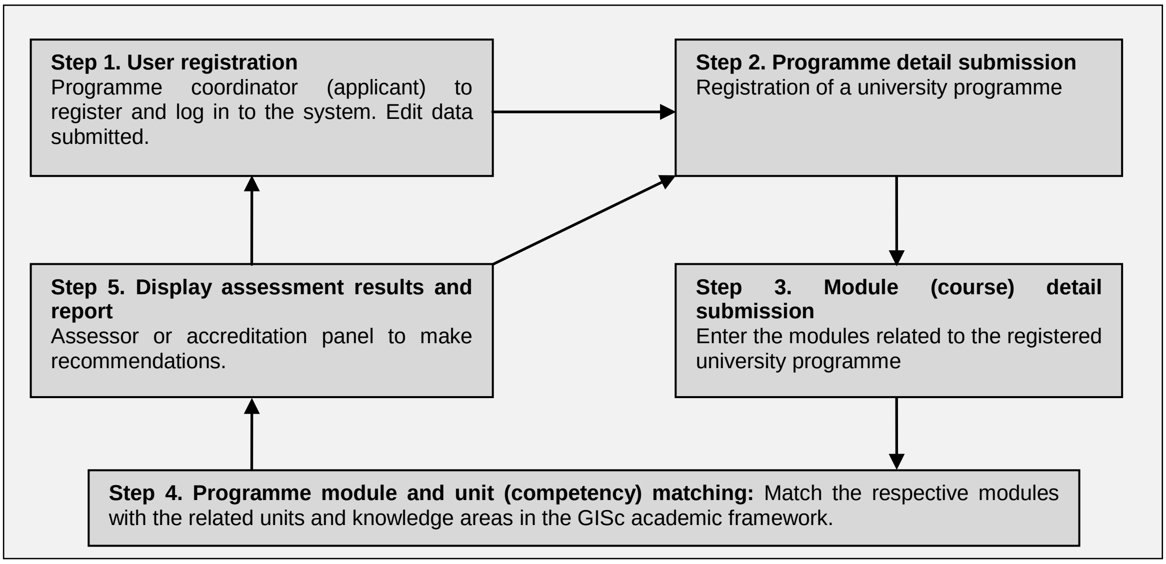


Figure 7.1 The five steps users must follow to complete an assessment using the GISc SAT

Figure 7.2 *Home* page of the GISc self-assessment tool

In Step 1 of the assessment procedure a new user is required to establish a personal profile using the *Create new account* link (below the *User login* form). This will open the *User account* page (Figure 7.3) which contains a form into which the user must enter the requested information.

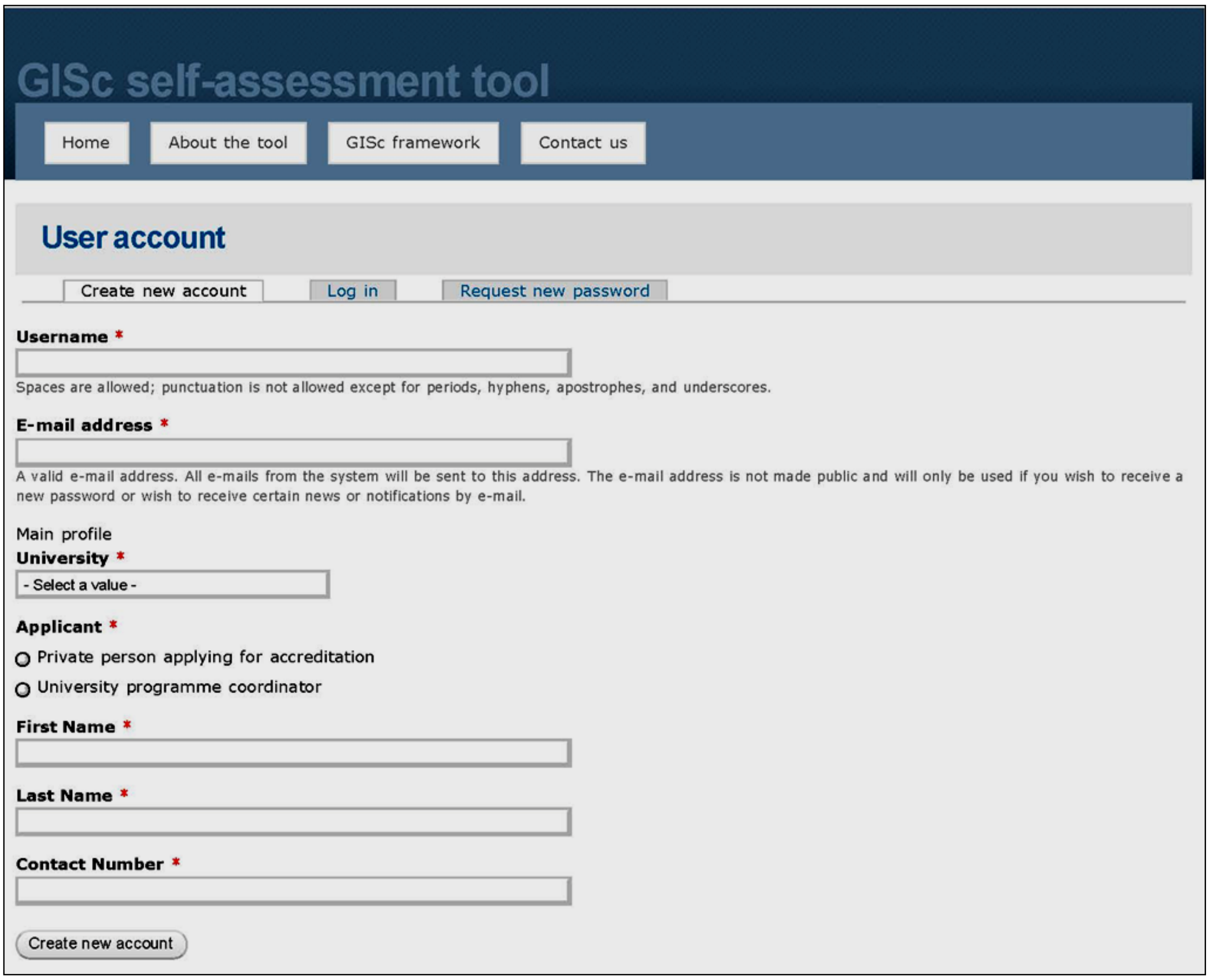


Figure 7.3 The *User account* page of the GISc SAT

The fields on the *User account* page relate to the attributes of the USER entity (Section 6.2.1.2). To complete the *University* field on the *User account* page, a drop-down list containing the names of all the South African universities is presented from which users can make an appropriate selection. Users can also add a new university name if one is missing from the list. The tool requires users to indicate if they are registering in their private capacity or on behalf of an institution so as to distinguish between a student wanting to register with the professional body and a university coordinator requesting accreditation of a university programme. On completion of all the required fields users must press the *Create new account* button to save the information. The system generates a temporary password which is sent to the e-mail address given by the user. Users must log in to the system with a temporary password within 24 hours after registration. Upon first login, a user is requested to select a new password which replaces the temporary one. Once the process has been completed, a user can proceed to Step 2 of the assessment procedure.

7.1.1.2 Step 2: Programme detail submission

During Step 2 of the assessment procedure a user adds a new programme to the SAT. This is done by selecting the *Add academic programme* menu item which will open the *Add academic programme* page (Figure 7.4). All the information requested on the *Add academic programme* page is compulsory. The form has two fields, namely *Programme* and *Total Credits*. These fields relate to the PROGRAMME.NAME and PROGRAMME.CREDITS attributes of the PROGRAMME entity in the user database (Section 6.2.1.2). In the *Programme* field users must add the programme name to be assessed and in the *Total Credits* field users must insert the total number of credits associated with the programme. Once these fields have been completed users must select the *Save* button to store the entered information in the user database. A message appears at the top of the page to notify users that the programme has been successfully created. This information can be reviewed and updated using the *View academic programmes* menu item (the *View academic programmes* page is not discussed here as it is very similar to the *Add academic programme* page).

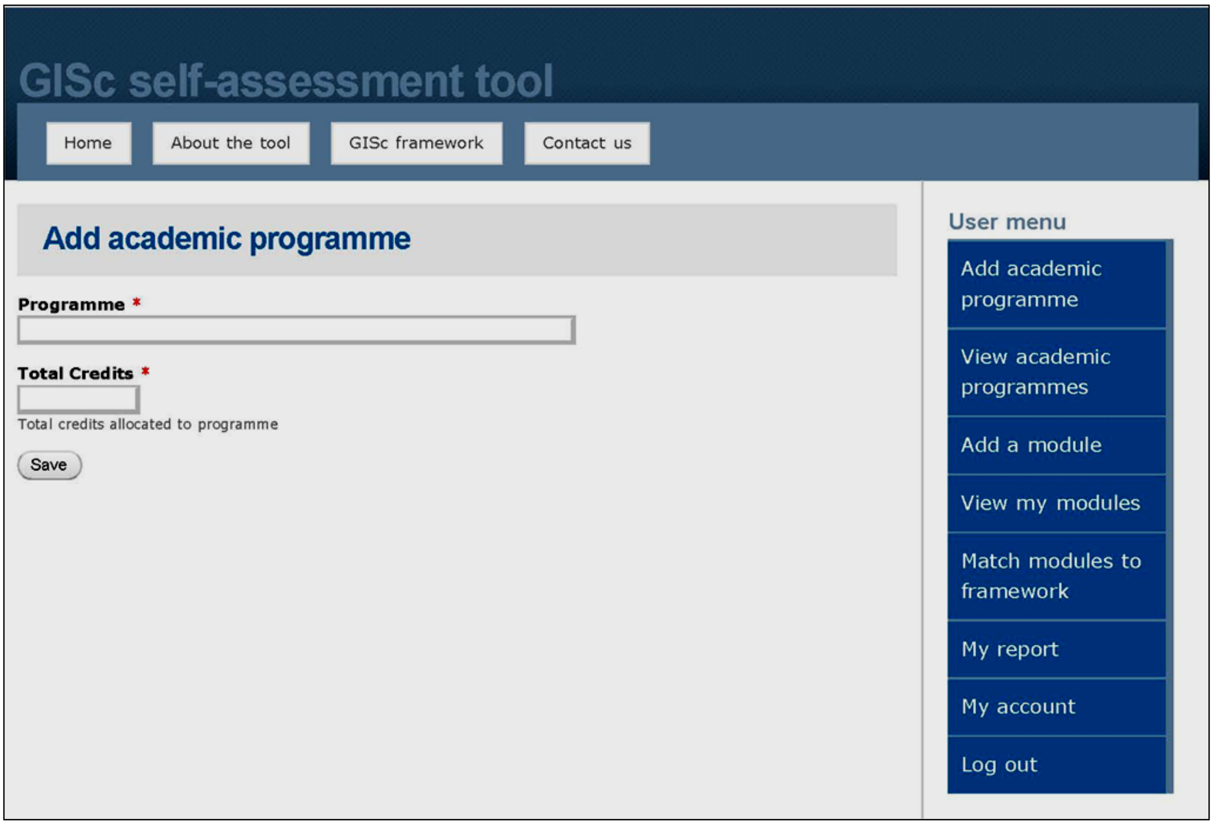


Figure 7.4 The *Add academic programme* page in the GISc SAT

7.1.1.3 Step 3: Module detail submission

In Step 3 of the assessment procedure users must load the modules of the programme to be assessed by selecting the *Add a module* menu item. Users are then presented with the *Add a* *module* page (Figure 7.5) which contains a form into which information about the module must be entered. The fields of this form relate to the attributes of the MODULE entity of the user database (Section 6.2.1.2). The information requested on the *Add a module* page is compulsory and must be provided by an applicant. The *University Programme* field is a drop-down list containing the university programme (or programmes) added in Step 2 of the assessment process. The page also requires users to add the subject and module name as well as the total number of credits for the module. The credits are used by the SAT when the modules are matched to the framework and to inform users when the number of credits matched exceeds the total credits associated with the module. Once the information has been entered, users must select the *Save* button. Multiple modules can be entered by repeatedly completing and saving the form.

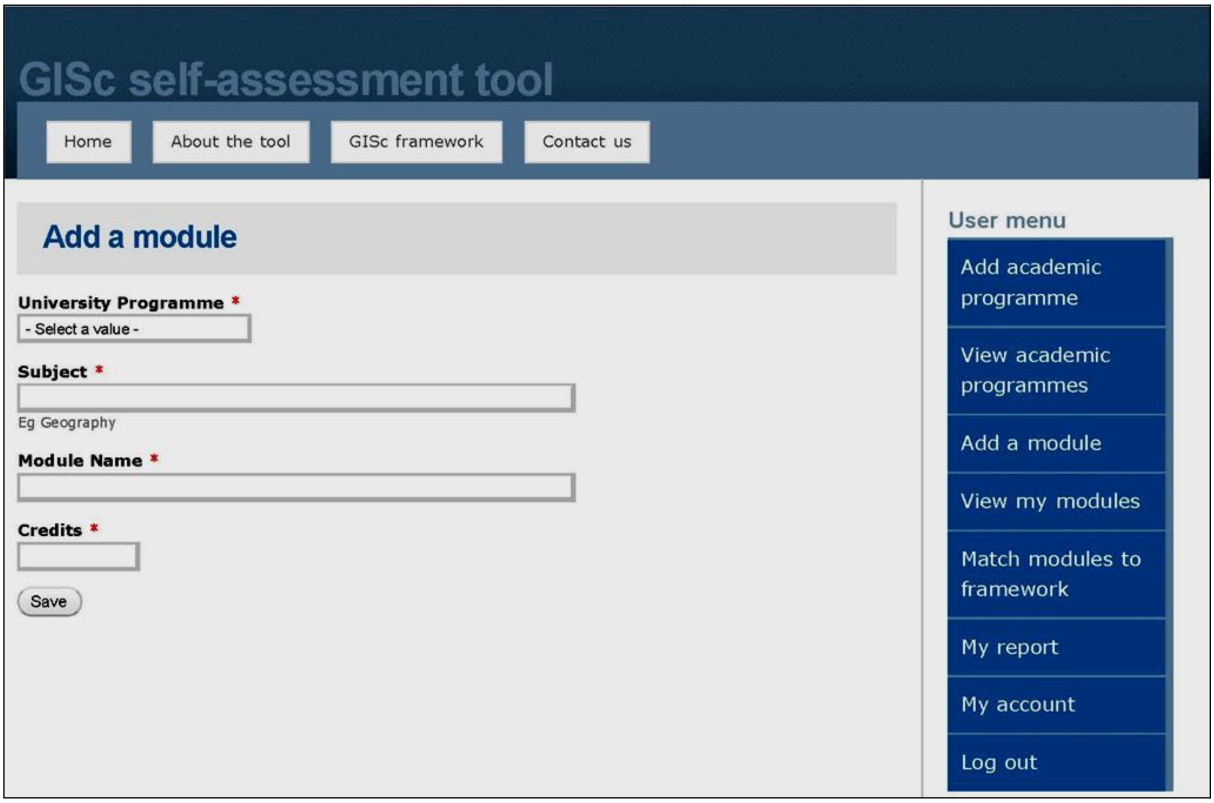


Figure 7.5 The *Add a module* page in the GISc SAT

The *View my modules* menu item can be used to view all the modules entered by a particular user (Figure 7.6). Existing modules can be edited or deleted by using the associated buttons. If no modules have been captured yet, the *View my modules* page will inform users that no modules are available and return them to the *Add a module* page (Figure 7.5).

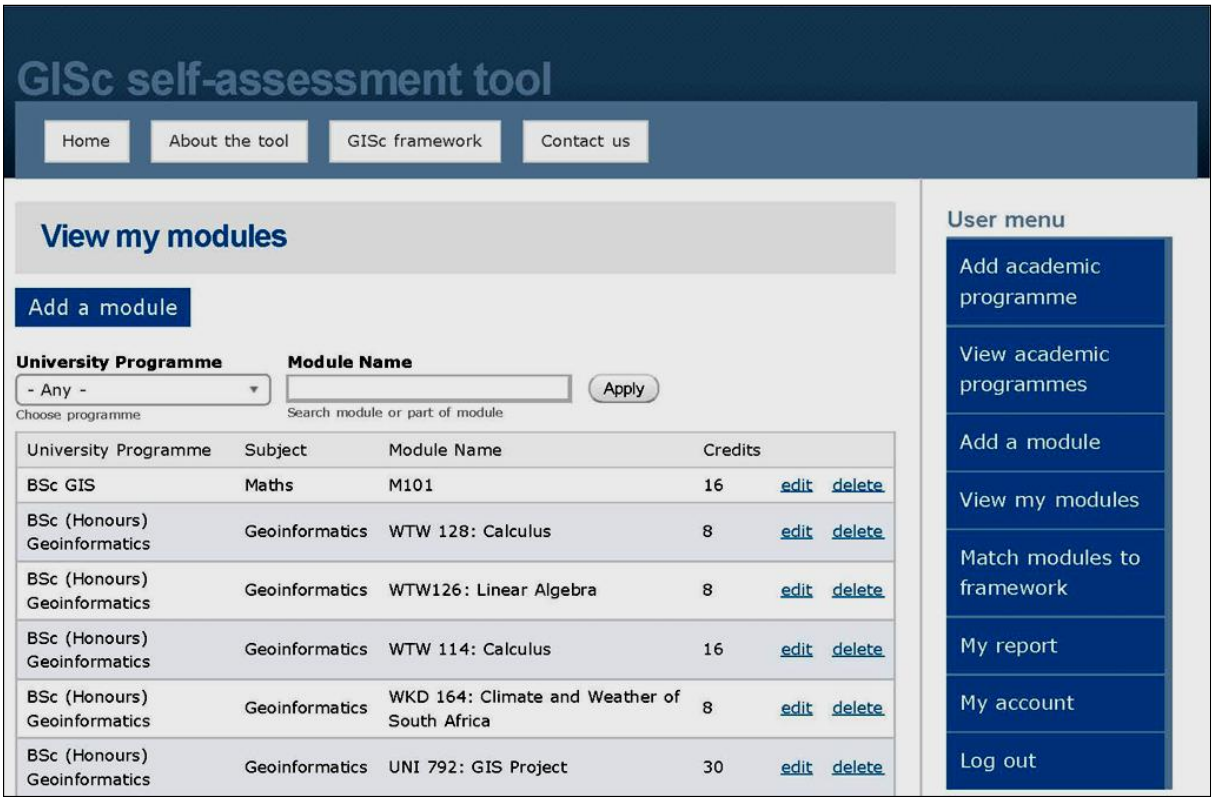


Figure 7.6 The *View my modules* page in GISc SAT

When all the modules have been ingested into the user database, users can proceed to the next step of the assessment procedure, namely to match each module with the GISc academic framework.

7.1.1.4 Step 4: Programme module and unit matching

Step 4 of the assessment procedure involves a systematic matching of competencies (units) in the GISc framework to the modules in the user database. This is done by comparing the content of a module (the content is assumed to be known to a user) to the units in the GISc framework. The *GISc framework* page (Figure 7.7) offers users the following two views: 1) *Filter by Name* allows user searches on KA, unit or topic, and 2) the credits for the KA, units and topics are displayed in brackets next to the KA name, e.g. *Knowledge Area: GSc Geographical science (36)*.

If the content of the module is similar to a unit's content, users can match that unit to the module. Potentially, a module can be matched with several units and a unit can relate to several different modules.

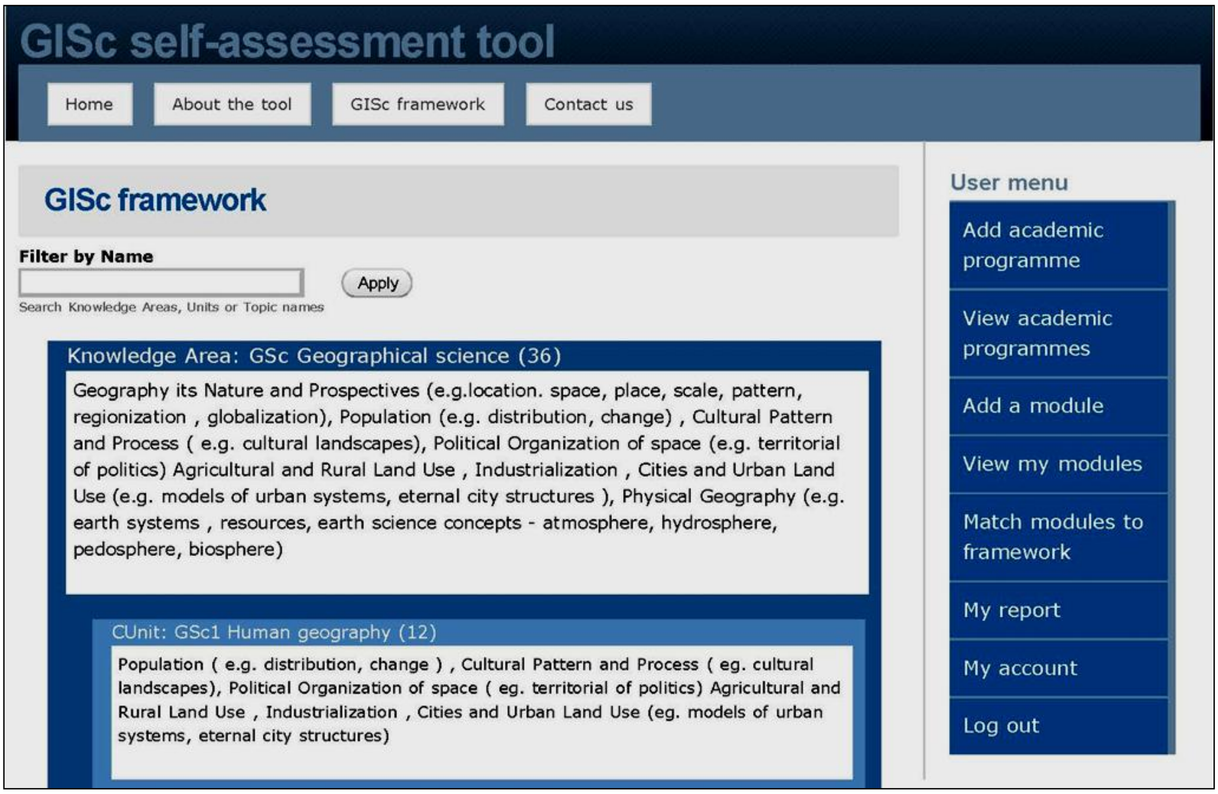


Figure 7.7 The *GISc framework* page in the GISc SAT

The process is facilitated by the *Match a related model* menu (on the *Match modules to framework* page shown in Figure 7.9) item which opens the *Match a related module* page (Figure 7.8) where users can add a module or modify the credits to be matched. The *Match a related module* page presents a form consisting of three fields:

- *Module* – A drop-down list permits the selection of the module to be matched.
- *Knowledge Area* (KA) – Specifies the KA of the unit that matches the content of the module. Once the KA is selected from the drop-down list a *Unit* field is added to the form. The *Unit* field allows users to select the appropriate unit from a drop-down list of all the units associated with the selected KA.
- *Match Credits* – Quantifies how many credits (and, indirectly, learning hours) of a particular module are dedicated to the content of the selected unit.

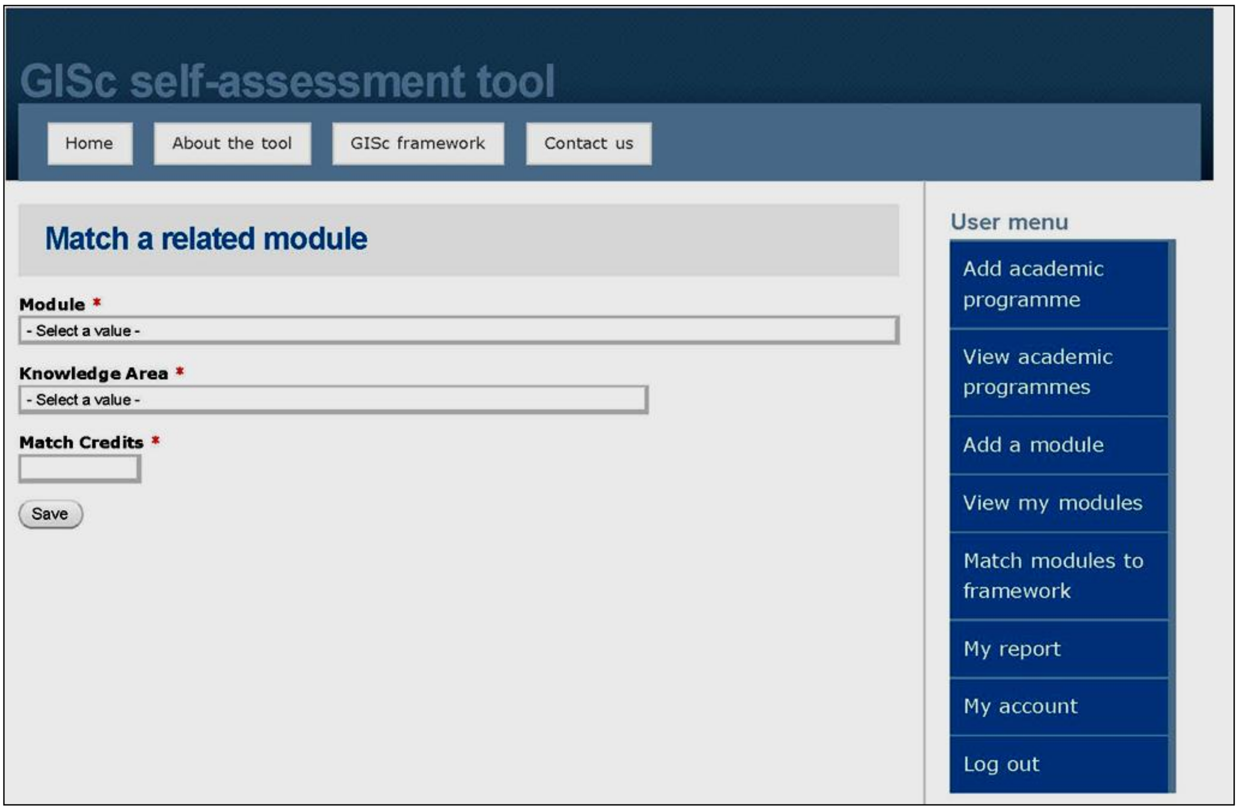


Figure 7.8 The *Match a related module* form in the GISc SAT

All combinations of matched modules and units are dynamically added to the *Match modules to framework* page (Figure 7.9), which provides important information about each matched item. The *Module* column shows the name of the matched module and the *Module Credits* column gives a quantitative indication of the number of credits allocated (matched) vis-à-vis the total number of credits associated with the particular module (as defined in Step 3 of the assessment procedure). The *Knowledge Area and unit* column specifies which KAs and units were matched to each of the listed modules. The total number of credits per KA as prescribed by the GISc framework is supplied in the *Total Credits* column. This information is critical in assisting the module capture process because users can easily monitor the progress and identify which modules have not been fully allocated. Users can modify the matched items using the *edit* or *delete* functions. The system ensures that the number of credits matched to a particular module does not exceed the total number of credits associated with the module (as defined in Step 3 of the assessment procedure). For instance, the first item in Figure 7.9 relating to the *WTW 128: Calculus* module includes a '8/8' notation in the *Module Credits* column which indicates that all eight credits of the particular module were matched to the *MS1: Mathematics* unit. The '4/8' module credit notation in the second item indicates that only four of the eight credits of the *WTW 126: Linear Algebra* module have been allocated to the *MS1: Mathematics* unit. The KA and unit information is extracted from the KA and UNIT entities of the framework database (Section 6.2.1.2).

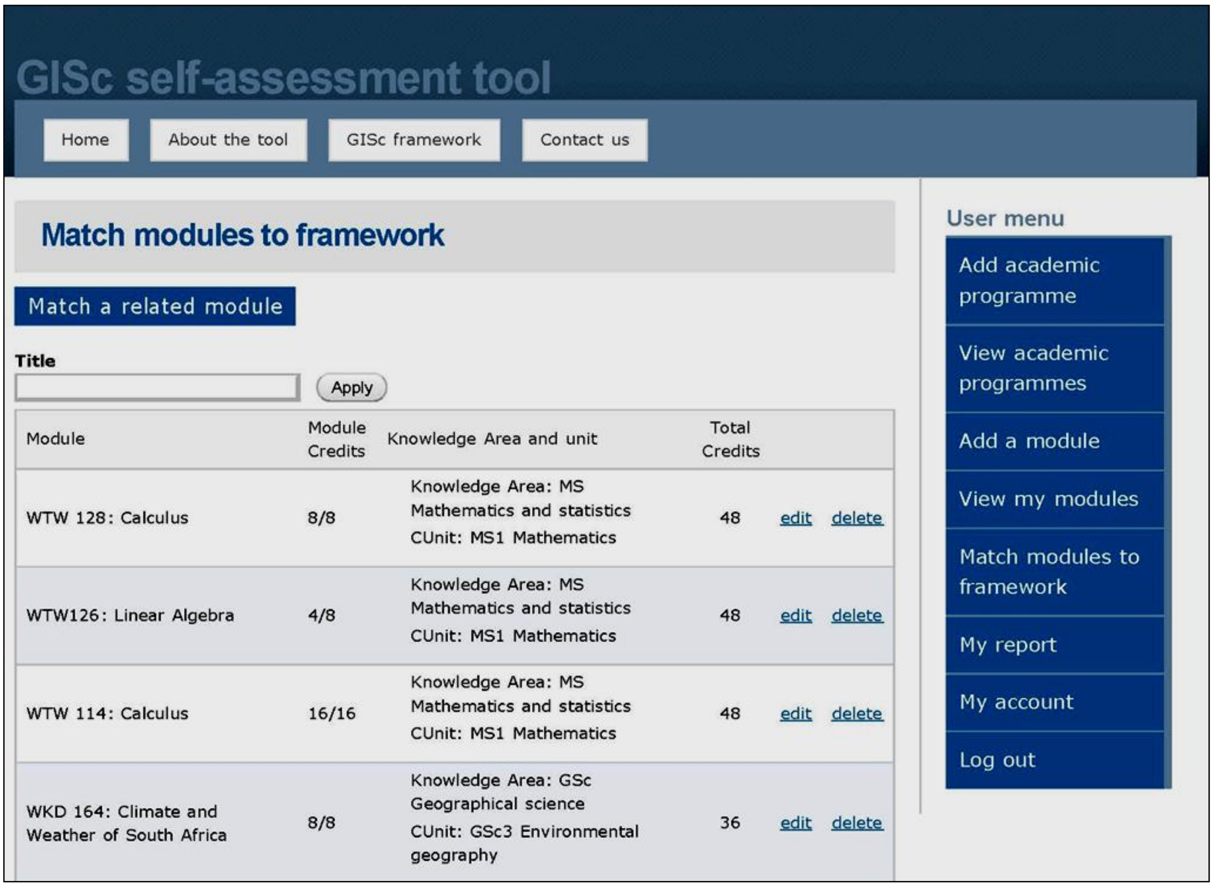


Figure 7.9 The *Match modules to framework* page in the GISc SAT

7.1.1.5 Step 5: Display assessment results and report

In Step 5 of the assessment procedure a summary report of the matched modules and units is produced. The reporting function is activated by selecting the *My report* menu item. Figure 7.10 shows part of a report for a university programme (Programme A). The report is much longer than can fit onto one page and only one of the KAs and its related core units is visible in Figure 7.10. To see the rest of the report, users can scroll down. A summary of the complete report that incorporates all the KAs, units and modules matched for Programme A is given in Table 7.1.

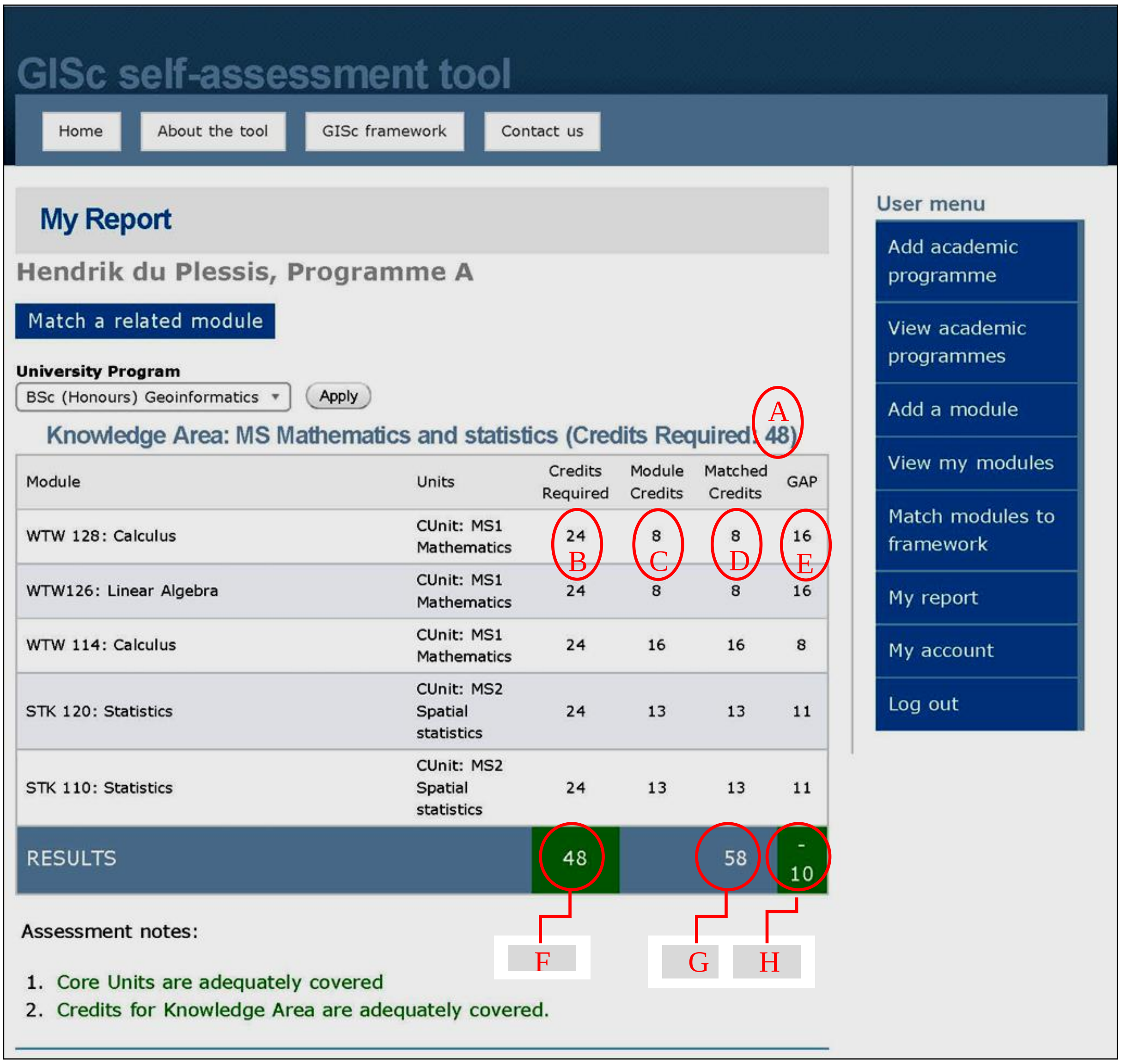


Figure 7.10 Part of a report on Programme A showing the results for *KA MS Mathematics and statistics*

Some values in the report (Figure 7.10) are highlighted and annotated (A to H) to facilitate the explanation. The report is structured according to KAs and shows the name of the KA as well as the total number of credits required (A). The value is taken from the KA.CREDITS attribute of the KA entity as stored in the framework database (Section 6.2.1.2). Each module credit (C) that was matched to the unit's associated credits (B) is listed along with the matched credits (D) and the gap (E) between the matched (D) and required (B) credits.

The report helps to determine if a KA is covered in sufficient width (i.e. does it include all the core units) and depth (i.e. is enough time spent on the particular theme). F is the sum of all the core units' credits that are matched to a module. If F is equal to A it indicates that all the prescribed core units for the KA are covered by the programme (sufficient width). When F is less than A then the core units are inadequately covered (insufficient width). If G is equal or larger than A it indicates that the KA is adequately covered in terms of depth (i.e. enough time is spent on the theme), while G values less than A can be used to identify KAs that are not adequately covered in terms of depth. These measures can be used to determine if a programme's attention to a particular theme is too generalized (sufficient width but not depth), too specialized (sufficient depth but not width), or satisfactory (sufficient width and depth).

The SAT keeps track of the total number of credits allocated to core units (CUnits). According to the GISc framework the *KA MS Mathematics and statistics* require 48 credits, (see A) i.e. 24 credits each are required for *CUnit: MS1 Mathematics* and *CUnit: MS2 Spatial statistics*. In the example in Figure 7.10, 24 module credits each were associated with *CUnit: MS1 Mathematics* and *CUnit: MS2 Spatial statistics*. This means that, at unit level, Programme A meets the requirement of 48 core credits (F). The value of F determines the first qualitative assessment statement for a particular KA, which is shown below the table. The first qualitative assessment statement declares whether a programme meets the requirements of a particular KA at unit level (i.e. sufficient width). In Figure 7.10 the outcome is "Core units are adequately covered" because F is equal to A and all the credits of core units have been matched to module credits.

Furthermore, 58 module credits (G) were matched to *KA MS Mathematics and statistics*. Given that only 48 credits (A) are required, Programme A exceeds the requirements at KA level by 10 credits. Negative values of H imply that more credits than the minimum required have been allocated to the KA, while positive values indicate a shortage in matched credits. The value of H determines the second assessment statement for a particular KA, which only considers credits at KA level (i.e. for this qualification no attempt is made to determine the distribution of credits between the core units). The outcome of this assessment is "Knowledge area adequately covered" because the value of H is negative which means more credits have been allocated to KA MS *Mathematics and Statistics* than what the framework prescribes (i.e. sufficient depth).

In Figure 7.11 to Figure 7.13, the symbols follow the same sequence as in Figure 7.10 and are therefore not repeated. Figure 7.11 shows the assessment of *KA DN Data Manipulation* for which F is less than A, and H is negative. In this case all of the module credits were allocated to one core unit (*CUnit: DN1 Representation transformation*) of *KA DN*. However, *KA DN* has a second core unit (*DN2 Generalization and aggregation*) that was not matched to a module. The assessment shows that although enough credits were allocated to the particular knowledge area (i.e. H is negative), too many credits were associated with a particular core unit DN1 *Representation transformation* and that some core units are not covered at all (as reflected by the first qualitative assessment statement). This result indicates that the data manipulation training that Programme A provides is sufficient in extent, but the focus is too narrow (i.e. it does not include enough content to cover the second core unit namely, *DN2 Generalization and aggregation*).

Knowledge Area: DN Data Manipulation (Credits Required: 36)

Module	Units	Credits Required	Module Credits	Matched Credits	GAP
UNI 766: Spatial statistics and geodesy	CUnit: DN1 Representation transformation	18	20	20	-2
GMA 705: Advanced remote sensing	CUnit: DN1 Representation transformation	18	20	20	-2
RESULTS		18		40	-4

Assessment notes:

1. Core units are inadequately covered.
2. Knowledge area adequately covered.

Figure 7.11 Results of matching modules in *KA DN Data Manipulation* in Programme A

Figure 7.12 shows the section of Programme A's assessment report that relates to *KA GSc Geographical Science*. In this example *CUnit: GSc1* is not adequately covered by the associated modules (gap of 6 credits). However, the first qualitative statement is "Core units are adequately covered". The current version of the GISc framework assumes that all core units within a KA are of equal importance (i.e. have equal number of credits). Because this assumption has not been sufficiently tested, the system was designed to allow some flexibility in the allocation of credits at unit level. In this case all the units were at least partially covered by a module and consequently the qualitative statement is positive. The number of credits allocated to the KA is, however, insufficient (G is less than A). This means that Programme A covers all the core units to some extent (i.e. enough width) but does not offer enough depth in geographical science.

In the geocomputation section of Programme A's assessment report (Figure 7.13) two modules, namely *INF 164: Informatics* and *INF 154: Informatics*, are matched to core unit *GC10 Computer Programming*. The KA consists of three core units of 12 credits each (i.e. a total of 36 credits). In this example only 10 credits were matched to core units indicating that Programme A does not adequately cover the content and depth of this theme. More modules relating to informatics (computer programming) are needed to meet the minimum requirement.

Knowledge Area: GSc Geographical science (Credits Required: 36)

Module	Units	Credits Required	Module Credits	Matched Credits	GAP
GGY 156: Introduction to Human Geography	CUnit: GSc1 Human geography	12	6	6	6
GGY 166: Southern African Geomorphology	CUnit: GSc2 Physical Geography	12	8	8	4
ENV 101: Introduction to Environmental Science	CUnit: GSc3 Environmental geography	12	8	8	4
WKD 164: Climate and Weather of South Africa	CUnit: GSc2 Physical Geography	12	8	4	8
WKD 164: Climate and Weather of South Africa	CUnit: GSc3 Environmental geography	12	8	4	8
RESULTS		36		30	6

Assessment notes:

1. Core units are adequately covered.
2. Knowledge area inadequately covered.

Figure 7.12 Results of matching modules for *KA GSc Geographical Science*

Knowledge Area: GC Geocomputation (Credits Required: 36)

Module	Units	Credits Required	Module Credits	Matched Credits	GAP
INF 164: Informatics	CUnit: GC10 Computer Programming	12	5	5	7
INF 154: Informatics	CUnit: GC10 Computer Programming	12	5	5	7
RESULTS		12		10	26

Assessment notes:

1. Core Units are inadequately covered.
2. Credits for Knowledge Area are inadequately covered.

Figure 7.13 Results from *KA GC Geocomputation*

In addition to providing unit and KA level assessments, the report also indicates overall compliance of the programme being assessed with the GISc framework. Each assessment report gives a tally of matched credits for the programme being assessed (562 in the case of Programme A). Because the GISc framework prescribes a minimum of 480 credits, it is clear that more than adequate credits have been allocated for Programme A. When this result is considered in the context of the unit and KA level assessments, it is obvious that Programme A includes too much non-core content. Recommendations on how this can be remedied are discussed later (Section 7.2.1).

The SAT only allows the matching of modules against the KAs and units in the GISc framework. Modules that do not relate to the content of any of the KAs in the framework are ignored. Similarly, modules matched to non-core units are not considered in the assessments. However, the recording of such matches is useful because it allows for some degree of flexibility. For instance, assessors can use their discretion to also consider the non-core areas covered by the academic programme being assessed.

The above examples have demonstrated how the SAT can be used to assess whether a programme meets the unit, KA and overall requirements of the GISc framework. The demonstration followed the five assessment procedure steps. The *About the tool* page (Figure 7.14) explains these steps and guides the user through the process. It also provides a comprehensive description of the SAT.

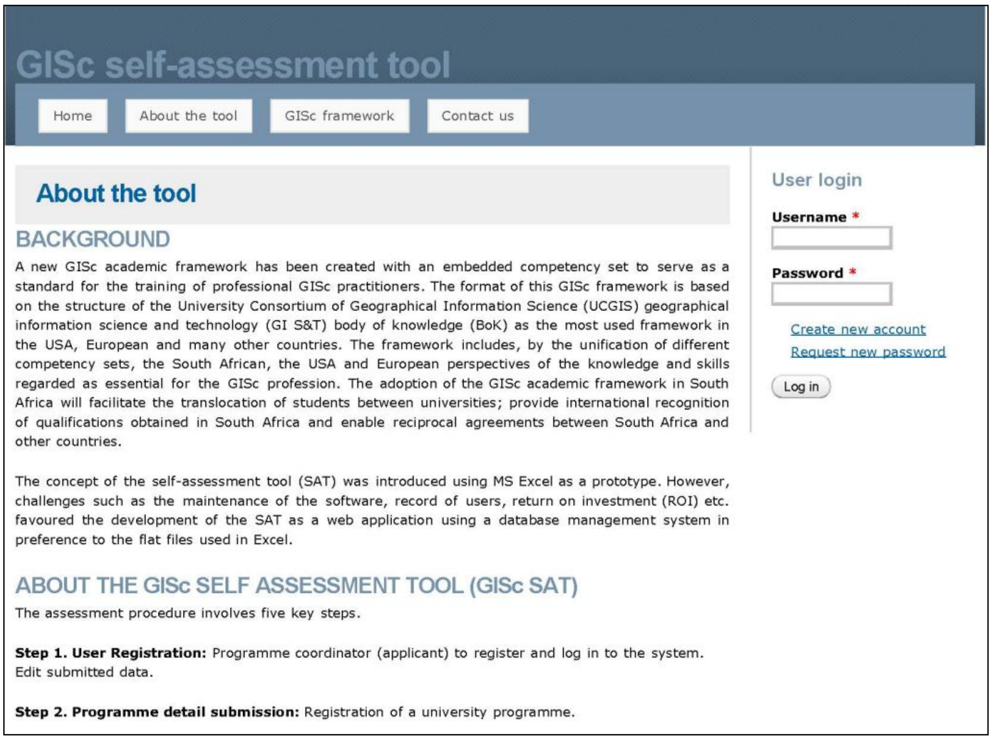


Figure 7.14 The GISc SAT introduced on the *About the tool* page

This section covered the first part of the user interface which deals specifically with the user’s view. The second part of the user interface, namely the administrator view, is described in the next section.

7.1.2 Administrator view

It would not be sensible to give users access to all aspects of the system. For instance, only system administrators should be able to modify the content of the *Home*, *About the tool* and *GISc framework* pages. A separate user interface that provides writing privileges to these pages was consequently created. This so-called *Administrator view* is only available to users with administrator privileges.

The *Home*, *About the tool* and *GISc framework* pages have functions that are only visible to administrators. For instance, on the *Home* page (recall Figure 7.2) *Add content*, *Manage KAs* and *Manage universities* links appear outside the frame area (see Figure 7.15). By activating the *Add content* link, the administrator can edit content relating to the university programme, the modules and matching of modules. The link *Manage KAs* enables the administrator to edit KAs, units and topics. The link *Manage universities* allows editing of university information. Two buttons, namely *View* and *Edit* have also been added inside the frames of the *Home*, *About the tool* and *My account* pages. By activating these buttons the administrator can view and edit the content of the respective pages.

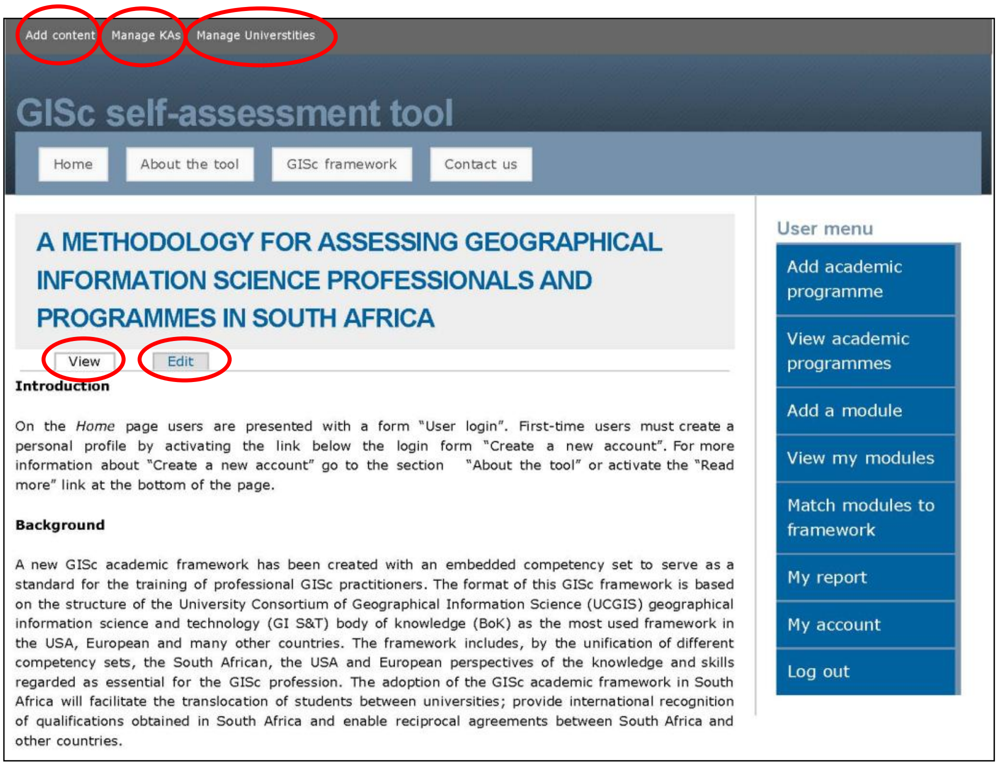


Figure 7.15 Administrator view of the *Home* page of the GISc SAT

The SAT focusses on the assessment of the four-year academic programmes (professional degrees). This section described the GISc SAT user interface by demonstrating how the tool can be used to assess a particular programme. The programme used in the demonstration is an actual

GISc programme (named Programme A for convenience and anonymity) offered at a South African university. To further demonstrate the value of the SAT, it is employed to assess two additional programmes (B and C) in the next section. The assessment results are also compared to those of Programme A.

7.2 COMPARISON OF THREE EXISTING PROGRAMMES USING THE SAT

Three existing GISc programmes offered at South African universities were selected for demonstrating how the SAT can be used to assess how they meet the requirements of the new GISc framework and competency set (Chapter 5). The results of each example are summarized and interpreted in this section to determine the degrees of compliance, as well as the strengths and weaknesses of each programme. The results are used to make suggestions about the types of recommendations an assessor should make when advising a university or applicant of shortcomings of a programme and how they can be dealt with.

The programme information used in the three examples was taken from sources in the public domain (e.g. websites, prospectuses and calendars). This information was captured into the user database and the respective modules associated with each programme were matched to the units and KAs in the framework database. This matching was done by the researcher and not by the respective programme coordinators. In some cases the information about the content of modules is not very detailed so that some of the matches may be inappropriate or even incorrect. The findings reported in this section should therefore be regarded as illustrative and should not be seen as a true reflection of the actual programmes. The three programmes are referred to as Programme A, B and C respectively to protect the identity of the institutions.

7.2.1 Programme A

The full reports generated by the SAT are too comprehensive to reproduce here but the assessment results of Programme A are summarized in Table 7.1. The original reports are available in Appendix B5. The letter symbols introduced earlier in Figure 7.10 are shown in parentheses in the column headings of Table 7.1. The *Credits required* column refers to the total credits prescribed for the KA (recall A in Figure 7.10). The sum of the credits matched to core units is shown in the *Credits matched (F)* column and the *Credits matched (G)* column displays the sum of credits matched to the KA. By subtracting F from A gives the value shown in the *Deficit/Surplus* (at unit level) column, while the result of G subtracted from A is given in the *Deficit/Surplus* (at knowledge area level) column. The entries in the *Interpretation* column describe the assessment as interpreted from the results in columns *G* and *A* - *G*. The same explanation applies to Table 7.2 and Table 7.3.

Table 7.1 Summary of SAT results of Programme A

Knowledge area	Credits required (A)	Unit level		Knowledge area level		Interpretation
		Credits matched (F)	Deficit / Surplus (A - F)	Credits matched (G)	Deficit / Surplus (A - G)	
GSc: Geographical Science	36	24	12	32	4	Units inadequately covered Knowledge area inadequately covered
MS: Mathematics and Statistics	48	48	0	48	0	Units adequately covered Knowledge area adequately covered
PS: Physical Science	16	16	0	32	-16	Units adequately covered Knowledge area adequately covered
AM: Analytical Methods	48	24	24	32	16	Units inadequately covered Knowledge area inadequately covered
CF: Conceptual Foundations	36	0	0	0	0	Not covered at all in the programme
CV: Cartography and Visualization	40	26	14	38	2	Units inadequately covered Knowledge area inadequately covered
DA: Design Aspects	36	36	0	26	10	Units adequately covered Knowledge area inadequately covered
DM: Data Modelling	36	24	12	106	-70	Units inadequately covered Knowledge area adequately covered
DN: Data Manipulation	36	0	0	0	0	Not covered at all in the programme
GC: Geocomputation	36	12	24	102	-66	Units inadequately covered Knowledge area adequately covered
GD: Geospatial Data	48	20	28	110	-62	Units inadequately covered Knowledge area adequately covered
GS: GI S&T and Society	12	12	0	8	4	Units adequately covered Knowledge area inadequately covered
OI: Organizational and Institutional Aspects	12	4	8	18	-6	Units inadequately covered Knowledge area adequately covered
RM: Research Methods	40	20	20	35	5	Units inadequately covered Knowledge area inadequately covered
Total credits required: 480	**480**			**587**		**Total credits matched: 587**

As discussed in Section 7.1.1.5, Programme A does not sufficiently cover all the core units in some of the KAs (i.e. AM, CV, DM, DN, GC, GD and OI). Clearly, there are gaps in the content of Programme A and not all essential content is covered. These gaps can be identified by studying the detailed report in Appendix B5.

Table 7.1 also shows a number of instances (KAs GSc, AM, CV and GC) where the sums of the credits for the modules matched with the related core units in the KA do not meet the minimum credits prescribed for the KA. These KAs are not covered in sufficient depth. More lectures, laboratory time, assignments and self-study should be allocated to these KAs. The KA PS: Physical Science is not catered for in the university programme (as indicated by the zero values in the report). Physical Science is a fundamental and core unit in the GISc academic framework and thus essential knowledge that must be included in any university GISc programme.

The 562 credits allocated to Programme A far exceed the minimum of 480 credits required for the four-year professional qualification. However, the gaps identified in the report indicate that too much time is spent on non-core content. One must conclude that Programme A does not properly align with the GISc framework and the design must be refashioned to cover all the core units and KAs.

7.2.2 Programme B

The assessment of Programme B is summarized in Table 7.2. The original report is available in Appendix B5. There is evidence of a number of inadequacies in Programme B as shown in Table 7.2. The programme does not sufficiently cover all the core units in eight of the KAs (GSc, AM, CV, DM, GC, GD, OI and RM). This represents significant gaps in the programme content and indicates that the essential content defined in the GISc academic framework is not covered. The total number of the matched credits at knowledge area level does not meet the minimum credits prescribed for the respective KAs (GSc, AM, CV, DA, GS and RM). As in Programme A, this indicates that despite the respective core units and KAs being covered, coverage is insufficiently deep so that more time must be allocated to lectures, laboratory time, assignments and self-study to cover the width and depth of the respective KAs. The KAs CF and DN are missing in the programme despite both being essential knowledge. Although the 587 credits associated with Programme B far exceed the 480 credits required for the four-year professional qualification, one must conclude that Programme B is not properly aligned with the academic framework and a redesign is required.

Table 7.2 Summary of SAT results for Programme B

Knowledge area	Credits required (A)	Unit level		Knowledge area level		Interpretation
		Credits matched (F)	Deficit / Surplus (A - F)	Credits matched (F)	Deficit / Surplus (A - F)	
GSc: Geographical Science	36	24	12	32	4	Units inadequately covered Knowledge area inadequately covered
MS: Mathematics and Statistics	48	48	0	48	0	Units adequately covered Knowledge area adequately covered
PS: Physical Science	16	16	0	32	-16	Units adequately covered Knowledge area adequately covered
AM: Analytical Methods	48	24	24	32	16	Units inadequately covered Knowledge area inadequately covered
CF: Conceptual Foundations	36	0	0	0	0	Not covered at all in the programme
CV: Cartography and Visualization	40	26	14	38	2	Units inadequately covered Knowledge area inadequately covered
DA: Design Aspects	36	36	0	26	10	Units adequately covered Knowledge area inadequately covered
DM: Data Modelling	36	24	12	106	-70	Units inadequately covered Knowledge area adequately covered
DN: Data Manipulation	36	0	0	0	0	Not covered at all in the programme
GC: Geocomputation	36	12	24	102	-66	Units inadequately covered Knowledge area adequately covered
GD: Geospatial Data	48	20	28	110	-62	Units inadequately covered Knowledge area adequately covered
GS: GI S&T and Society	12	12	0	8	4	Units adequately covered Knowledge area inadequately covered
OI: Organizational and Institutional Aspects	12	4	8	18	-6	Units inadequately covered Knowledge area adequately covered
RM: Research Methods	40	20	20	35	5	Units inadequately covered Knowledge area inadequately covered
Total credits required: 480	**480**			**587**		**Total credits matched: 587**

7.2.3 Programme C

Table 7.3 summarizes the assessment report for Programme C (see Appendix B5 for the full report).

Although the total number of credits for Programme C (505) exceeds the minimum number required, shortcomings were highlighted in the KAs MS, AM, CF, DM, GC and RM. KAs DA and DN are not covered at all. The KAs where the core units are insufficiently covered are CF, CV, DM, GC, GD OI and RM. Although MS and AM appear to be adequately covered, the total credits matched to these KAs show some shortfalls, indicating that the respective core units are not adequately covered.

Table 7.3 Summary of SAT results for Programme C

Knowledge Area	Credits required (A)	Unit level		Knowledge area level		Interpretation
		Credits matched (F)	Deficit / Surplus (A - F)	Credits matched (F)	Deficit / Surplus (A - F)	
GSc: Geographical Science	36	36	0	128	-92	Units adequately covered Knowledge area adequately covered
MS: Mathematics and Statistics	48	48	0	40	8	Units adequately covered Knowledge area inadequately covered
PS: Physical Science	16	16	0	16	0	Units adequately covered Knowledge area adequately covered
AM: Analytical Methods	48	48	0	40	8	Units adequately covered Knowledge area inadequately covered
CF: Conceptual Foundations	36	18	18	20	16	Units Inadequately covered Knowledge area Inadequately covered
CV: Cartography and Visualization	40	39	1	56	-16	Units inadequately covered Knowledge area adequately covered
DA: Design Aspects	36	0	0	0	0	Not covered at all in the programme
DM: Data Modelling	36	24	12	32	4	Units Inadequately covered Knowledge area Inadequately covered
DN: Data Manipulation	36	0	0	0	0	Not covered at all in the programme
GC: Geocomputation	36	12	24	16	20	Units Inadequately covered Knowledge area Inadequately covered
GD: Geospatial Data	48	35	13	89	-41	Units inadequately covered Knowledge area adequately covered
GS: GI S&T and Society	12	12	0	24	-12	Units adequately covered Knowledge area adequately covered
OI: Organizational and Institutional Aspects	12	4	8	12	0	Units inadequately covered Knowledge area adequately covered
RM: Research Methods	40	10	30	32	8	Units Inadequately covered Knowledge area Inadequately covered
Total credits required: 480	**480**			**505**		**Total credits matched: 505**

The following section briefly compares the three programmes.

7.2.4 Comparison

Table 7.4 is a summary comparison of Programmes A, B and C.

Table 7.4 Comparison of the GISc framework with the three programme reports

Comparison	Programme A	Programme B	Programme C
KAs where some core units are not covered	AM, CV, DM, DN, GC, GD and OI	AM, CV, DM, GC, GD, OI and RM	CF, CV, DM, GC, GD, OI and RM
KAs where some core units are partially covered	GSc, AM, CV and GC	GSc, AM, CV, DA, GS and RM	MS, AM, CF, DM, GC and RM
KAs not covered at all	PS	CF and DN	DA and DN
Total programme credits	562	587	505

Note: See Table 7.3 for knowledge area abbreviations.

A number of core units in KAs AM, CV, DM, DN, GC, GD, OI and RM are not covered in one or more of the three programmes, whereas some of the core units in GSc, MS, AM, CF, CV,DA, DM, GC, GS and RM are only partially covered. Knowledge areas PS, CF, DA and DN are absent from some of the programmes. All three programmes contain more credits than the minimum prescribed in the GISc framework and two (A and B) have considerably more credits than required. One can safely conclude that all three programmes have sufficient allocation of credits to cover the content of the GISc framework but that a redesign of all three the programmes is needed to meet the content requirements. In the case of Programme C, this might only involve changing the focus of a number of modules to include some of the missing content. Programme A's assessment report can be used to identify the modules that may need modification. In the case of Programmes A and B, some non-essential modules might have to be replaced by new modules. The content of these modules can be determined by studying the assessment reports. The search tool in the *GISc framework* page (Figure 7.7) can be used to identify the specific knowledge and competencies (topics) that are insufficiently covered.

7.3 CONCLUSION

This chapter has demonstrated the capacity of the GISc SAT for assessing the competencies of individuals applying for professional registration and its ability to evaluate the content of academic programmes for accreditation purposes. The demonstration makes it clear that once the applicant has entered the programme details and completed the matching of modules, the SAT can considerably reduce the time spent on assessments. This time-saving feature will make the GISc SAT very attractive to PLATO assessors who would normally spend much time comparing programme structures with the GISc framework. The tool will also be beneficial to the South African GISc-user community, in particular universities, as it facilitates programme design. Furthermore, the process yields unbiased and consistent results so that assessors and other users can confidently make recommendations.

In sum, the SAT is a instrument that, if adopted by the relevant professional bodies and universities, will be useful to:

- universities for preparing applications for accreditation;
- professional bodies for drafting reciprocal agreements between countries;
- individuals applying for registration with the GISc professional body; and
- employers who want to determine if applicants meet their workforce competency requirements.

These and other benefits of the GISc SAT are discussed in the next chapter.

CHAPTER 8 EVALUATION AND CONCLUSION

There is a growing demand worldwide for geographical information science (GISc) practitioners. Government agencies and the private sector are competing to find and employ practitioners in the GISc field who are suitably qualified and competent in the practice of the relevant technologies and sciences. The demand for GISc practitioners in South Africa has initiated a number of actions, through the Presidential Infrastructure Co-ordinating Committee (PICC), chaired by the President and including heads of departments such as the National Treasury, Co-operative Government and Traditional Affairs (COGTA) and Department of Higher Education and Training (DHET), to reduce the scarcity in GISc skills, especially those skills needed to address infrastructural development and capacity building in the country's rural municipalities.

Little research exists in South Africa on what GISc professionals should know or be able to do. A set of competencies (knowledge and skills) is required by professionals in the workplace to design appropriate programmes and to guide those responsible for controlling quality in the profession (through registration) as well as in educational institutions (through accreditation). Consequently, the research first aimed to develop an academic framework and competency set and, second, to construct a tool to guide universities and applicants.

This chapter first revisits the research problem, the literacy review, and the aims and objectives of the research. The remainder of the chapter focusses on the evaluation and assessment of the GISc self-assessment tool and the limitations and advantages revealed during the implementation of the tool.

8.1 RESEARCH PROBLEM

There is a demand from the GISc industry that universities be held accountable for academic output in the GISc field. This led to PLATO accreditation visits during 2012 and 2013 to six universities offering GISc programmes. In the absence of recognized standards employers are seeking assurance that the employees they hire are competent in the tangible and intangible skills necessary to excel in GISc. The evaluation of individuals' knowledge and understanding of GISc concepts and practical skills will be simplified significantly if university programmes are accredited for training professional GISc practitioners.

The research identified three problems relating to the professional registration of GISc practitioners: 1) the inconsistencies found in the knowledge and skills development of GISc professionals; 2) the lack of a standard set of competency requirements to assess individuals and accredit academic programmes; and 3) the lack of an assessment tool to guide universities applying for accreditation of GISc programmes and aspirant applicants who want to register with the professional body. In South Africa, two competency sets have been used as standards for accreditation and programme development, namely the South African unit standards-based qualifications (USBQ) and the PLATO model. The use of the USBQ competency set for programme evaluation was problematic because the USBQ focusses on technical skills only. The PLATO model includes more theoretical knowledge but it is regarded by many GISc practitioners as being biased towards the surveying profession. This bias complicates comparisons with international standards such as the UCGIS Geographical Information Science and Technology (GI S&T) Body of Knowledge (BoK). A further complication is that, at a theme level, both South African competency sets differ from the BoK which is used by many international universities for GISc curriculum development and assessment. Although it is clear that USBQ and the PLATO models differ from the BoK, it is uncertain which international requirements are absent from the South African models and, moreover, whether any of the South African requirements are absent from the BoK. A clear and complete identification of the discrepancies between the various frameworks was needed to provide a good foundation for establishing a comprehensive set of competencies for curriculum development and programme accreditation in South Africa, and perhaps internationally.

8.2 LITERATURE STUDY AND RESULTS

The value of the GI S&T BoK has been confirmed by its many uses, namely as a means to identify the breadth and depth of the knowledge representing the GI S&T domain and as a tool for curriculum planning, programme accreditation, programme evaluation and assessment, curriculum revision, student transfers between programmes, professional certification and employment screening. It is by far the most used, researched, applied and comprehensive GISc competency set available. The GI S&T BoK is used extensively in the USA, Europe and other countries (Gaudet, Annulis & Carr 2003; DiBiase et al. 2006; Toppen & Reinhardt 2009; EUGIS 2012; Reinhardt 2012).

The BoK has also contributed to an improved perception of GISc as a profession and assisted in career planning by the selection of appropriate courses. Surveys based on the BoK have established that the creation of self-assessment instruments, setting down accreditation standards and stipulating curriculum pathways are high priorities within the GI S&T community (Butler 2007; Johnson 2008). These issues and challenges underlie the aims and objectives of this research.

8.3 AIMS AND OBJECTIVES REVISITED

The primary aim of the research was to develop an academic framework and competency set with the purpose of assessing the competencies of individuals applying for professional registration and evaluating the content of academic programmes for accreditation. The secondary aim was first to develop a web-based self-assessment tool and, second, to demonstrate how it can be used for assessing and redesigning existing GISc curricula so that they meet the training requirements of the national and international GISc industry.

8.3.1 Research outputs

In dealing with these aims the research had two outputs in mind: First, a new competency set or academic framework for the GISc profession; and second, a web-based self-assessment tool. The products are intended to (a) address inconsistencies so that they can be used as standards for guiding curriculum development to meet the prescribed requirements for professional GISc practitioners, and (b) to facilitate the assessment of GISc programmes for accreditation and the registration of aspirant applicants with the GISc professional body responsible for regulating the GISc industry.

8.3.2 Research objectives

To achieve these aims seven specific objectives were identified and systematically addressed in Chapters 2 to 7.

The first objective involved (Chapter 2) a *secondary-source survey and study of GISc literature* to uncover and better understand the complexities of professionalization, competency assessments, curriculum development, academic programme accreditation and the historical and developmental contexts of GISc professionalization. The reviewed material was used to author and co-author six articles which were published in *PositionIT* (copies enclosed in Appendix C), the official journal of the South African GISc profession. The content of these articles was also shared with the broader GISc community in South Africa during conferences and seminars organized by the Geographical Information Society of South Africa (GISSA) and the South African Geomatics Institute (SAGI), for example during the Ukubuzana Conference in October 2012 where a peer-reviewed paper was presented and a workshop on the GISc framework and SAT was facilitated. These articles and presentations have already contributed to healthy debate, knowledge sharing, a more informed profession and better decision making at a critical time of transformation in 2011 to 2014 when registration of GISc practitioners was at a peak and new legislation in the form of the Draft Geomatics Bill was a hot topic in the South African geomatics profession.

Chapter 3 pursued the second objective to *compare existing GISc competency sets* to reveal any significant high-level intersections between two South African sets and the BoK and to develop a macro-curriculum framework for GISc training at South African universities. The results were published as a peer-reviewed paper (Du Plessis & Van Niekerk 2012) which successfully identified the consistencies and inconsistencies between the BoK, the USBQ and the PLATO model. The article and underlying research has played an invaluable role in preparations during 2012 for the accreditation of South African universities offering GISc programmes. The knowledge and experience gained from the research was shared with the accreditation panel and the universities applying for accreditation. The exposed inconsistencies between the three competency sets used by universities in the development of their GISc programmes were important in the final deliberations of the accreditation panel which led to recommendations submitted to PLATO Council. A Microsoft Word-based assessment instrument to assist with the accreditation of universities was developed as part of this research and extensively used in the accreditation process.

The third objective (Chapter 4) engaged in a *detail-level comparison of the USBQ and PLATO model with the BoK* to show the gaps in and overlaps between the models. Some 177 450 detail-level comparisons identified topics in the BoK that are not included in the South African competency sets as well as competencies absent from the BoK that are regarded as important by the South African GISc community. The outcomes of the analyses were introduced and debated at a GISSA workshop held in October 2013 and attended by university academics, senior public officers and practitioners in the private sector. Valuable inputs were received and the results were published as a peer-reviewed article (Du Plessis & Van Niekerk 2013).

The fourth objective (Chapter 5) was to *unify the competency requirements of the USBQ and PLATO model with those of the UCGIS BoK* to produce an internationally and South African acceptable competency set for assessing the competencies of individuals as well as the content of academic programmes. The resulting competency set includes basic natural science competencies (mathematics and physics), social science competencies (research methodology and geographical science), and technical competencies (photogrammetry and remote sensing). The new competency set was included in the GISc Assessment Committee’s report to the PLATO EAC and PLATO Council meeting in October 2013. Based on the report, the need to review the present PLATO model was accepted in principle and the new competency set will be introduced to the EAC for support and eventual recommendation to PLATO Council in 2014. However, the complexity of the new competency set was raised as a concern and the need for an easy-to-use and objective assessment tool was recommended.

Objective five (Chapter 6) turned to *creating a self-assessment tool*. The process involved five steps, namely 1) planning and requirement analysis, 2) conceptual design, 3) logical design, 4) physical design and 5) implementation. A web-based application was found to meet most of the requirements as it offered appreciable benefits by eliminating much of the distribution and maintenance costs of new versions of files (and software) through client-server web technology. In contrast to local (i.e. desktop) tools, the web-based application can be updated on a continuous basis without seriously inconveniencing users and there is always an up-to-date version of the system that simplifies support, maintenance and training activities. The resulting custom-built, web-based SAT provides flexibility and accessibility while being more intuitive and user-friendly than a ‘flat-file’ (e.g. spread sheet) approach. The SAT consists of four components, namely the website, inference engine and two databases. These components were designed as three physical tiers (i.e. client, application and database) which were implemented on a single server.

Objective six (Chapter 7) involved a *demonstration of the GISc SAT* based on a comparison of three university programmes. The system’s ability to match modules with the related KAs at a detail level, enables qualitative and quantitative analyses and assessments. The application of the SAT for assessing the three programmes demonstrated how the tool can be used to identify curriculum shortcomings. Deficiencies such as core units not being sufficiently covered; core units not being covered at all; and excessive time being spent on non-core content were highlighted in the SAT assessment reports. The results of the three examples used in the demonstration illustrated the usefulness of the new GISc academic framework and GISc SAT and how singularly and in combination the new competency set and assessment tool can add value through implementation. By meeting the aims and objectives, the research has successfully resolved the three research questions identified in Chapter 1, namely:

What knowledge and skills should an individual have to be regarded as a GISc professional?

This question was addressed in Chapter 2 which outlined the workforce needs, competency levels and existing competency sets.

How can the required knowledge and skills be formulated into a standard set of competency requirements that can be used to assess individuals and accredit academic programmes?

To answer this question, Chapters 3, 4 and 5 compared the various competency sets at thematic and detail levels culminating in the production of a comprehensive competency set and GIS framework that meet international as well as South African requirements.

How can a set of competency requirements be used by universities to develop syllabi that would better prepare individuals for professional registration?

Chapters 6 and 7 addressed this question by using the new competency set to develop a web-based SAT. A demonstration of how the SAT can be used to highlight shortcomings in university programmes and to guide programme development was also provided.

8.4 LIMITATIONS AND CONTRIBUTIONS

This section outlines the limitations and contributions of the research, the main contention being that the contributions of the research, specifically to the South African GISc professional and academic community, far exceed the limitations.

8.4.1 Limitations of the research

The problems experienced during this study have had little effect on the results and did not reduce the value and contributions of the research, however they are worth noting.

It was difficult to align the PLATO model with the structures of the BoK and USBQ. Both the BoK and the USBQ are outcomes-based, consisting of KAs, units, topics and objectives in the case of the BoK, while the USBQ comprises subject areas, unit standards, outcomes and specific outcomes. The PLATO model simply defines the KAs or subject areas and then provides a broad description of each. To compare the content of the PLATO model with the BoK or USBQ, the content had to be split into keywords and phrases. This process was subjective and prone to misinterpretation. However, uncertainty and error in interpretation would have had little effect on the outcomes of the research because most of the content of the PLATO model was encompassed in the BoK or USBQ (see Section 4.5). Content relating to physics is the only exception, but given that physics was absent from the other models the PLATO descriptions were reformatted into two units, namely *Motion as energy* and *Electricity as energy* which comprise the *Physical Science* KA. These units, as well as those relating to mathematics and statistics, may require refinement.

Another problem encountered during the development of the competency set and SAT was to find appropriate measures whereby the relative importance, expected complexity, width or depth of a particular KA or unit can be determined. In South Africa credits are used as a standard measure of how many learning hours should be spent on a particular topic, where one credit equals ten nominal learning hours. Because the BoK provides no quantitative measure to indicate the level of importance of a particular unit or KA, it was difficult to assign an appropriate number of credits to each of the KAs and its core units. In cases of overlap the values specified by the other two modules were used (the PLATO model stipulates the number of lecture hours per theme and the USBQ allocates credits to each unit standard). Inputs from the GISc community were also used (see Section 5.4.1) but in most cases this only allowed for setting credits at KA level. The unit-level allocation of credits was done by assuming that each core unit within a KA is equally important. This assumption was not tested and more research is needed to refine the allocations. In the SAT the impact of this limitation was minimized by allowing some flexibility in the matching of modules to core units. This flexibility was implemented by not enforcing minimum credits at unit level. The implication of this is that a unit is considered to be adequately covered by a programme if even a single module credit was matched to it. This is of course not an effective way of verifying whether a student has mastered the related competencies. Assessors should scrutinize the assessment reports (particularly the *Gap* column) to ensure that the depth of training in all core units is adequate. However, more consultation with the GISc community about the credits and lecture time required for core units is needed. No credits have been assigned to non-core units, a defect that must also be corrected. It may also be sensible to allow for matching at topic level instead of unit level as this will remove much of the uncertainty when units are covered by multiple modules.

Very little research on GISc curriculum development, competency requirements and SATs has been done in South Africa and much of the international work that has been done in this field has not been well documented or published. The study consequently had to rely on secondary sources, inputs from the South African GISc community (e.g. unstructured interviews, meetings, workshops) and personal experience to determine what competencies are needed and what SAT functionality is required.

The SAT was demonstrated by using three existing programmes as examples. The modules of these programmes were matched to core units based on publicly available information (e.g. module descriptions). The matching process is subjective in nature and in some cases the available information may not have been detailed enough for making correct matches. The implementation of the three programmes was for demonstration purposes only and no conclusions about their conformity to the GISc framework should be drawn from the resulting assessment reports (hence the anonymity of the programmes). The SAT was developed so that the matching of modules and units can be done by the users (e.g. programme coordinators) who will have a much better understanding of the content of the respective programmes.

8.4.2 Value of the research

This research makes a number of indisputable contributions to knowledge. The detailed comparison of the existing competency sets provides a deeper understanding of the GISc competency requirements at national and international level. These comparisons, especially the highlighted inconsistencies between the models, will stimulate new debates about why certain competencies are present in some of the models while being excluded from others. Some exclusions might have been deliberate (e.g. physics) and further discourse about their value to the profession is clearly needed. This research provides a good foundation for setting the agenda of such a debate.

Through interaction with the GISc community (individuals as well as representative groups such as PLATO, SAGI, and GISSA) and involvement in the PLATO EAC accreditation panel and the GISc SGB, significant insights were gained into the needs of the South African GISc industry, the challenges faced by universities to provide adequate training and the concerns of the professional body about ensuring standards. These insights were shared through a number of occupation-specific and research articles, presentations and this dissertation.

GISc programmes that are designed according to the new GISc academic framework will meet the South African and international requirements for accreditation and will facilitate reciprocal agreements between universities and professional bodies across the globe. The GISc framework will be invaluable to the PLATO EAC as a means to evaluate foreign GISc qualifications for conformance with South African registration requirements. Immigrants and employees of international companies can relatively easily be assessed to see if they have the prerequisite skills and competencies to practice as GISc professionals in South Africa. Similarly, South Africans wanting to work in foreign countries where registration or certification is required can fruitfully use the GISc framework.

The SAT is a practical aid for accrediting university GISc programmes and assessing aspirant professionals wanting to register with a professional body to be certified as competent and licensed to practice in GISc. The tool supports curriculum development by identifying shortcomings in existing programmes about coincidence of the content of KAs and units in the GISc framework. The GISc SAT facilitates the registration of professional GISc practitioners as much of the work is done by either the university or the individual through the matching of a programme with the academic framework so emphasizing the inadequacies and adequacies contained in programmes submitted for assessment. An unexpected bonus is the value the SAT adds as a time- and cost-saving device, an advantage that should encourage universities and individuals to apply to be accredited or registered with the professional body. The combination of the GISc academic framework and the SAT should assist students to select relevant core study areas and allow them to test permutations of modules to find combinations appropriate to a qualification that satisfies specialization interests while ensuring compliance with registration requirements. Given that universities are expected to perform regular self-reviews of their programmes and update programme content to keep abreast of the evolution of GISc thinking, the GISc SAT adds considerable value by making sure that updated programmes still meet accreditation requirements. The SAT will also help students to choose appropriate university courses and guide employers, human resource practitioners and employment agencies in setting up employment criteria and requirements, drafting appropriate job descriptions and job profiles and formulating advertisements for vacancies.

The literature study revealed no other GISc web-based SAT, so making the concept of a web-based and database-driven SAT – that can be applied with ease anywhere in the world – unique. The SAT is a prime example of how information technology can be used to support curriculum development, not only for GISc but many other disciplines. It is likely that it will open up new research opportunities in the application of information technology for curriculum design.

In sum, the SAT will contribute significantly to meeting the challenges faced by universities to prepare students for professional registration with the PLATO Council; guiding university programme coordinators to satisfy the accreditation requirements for GISc programmes; and supporting curriculum development and the design of new GISc programmes by providing a method and tool to test the work against the specifications of the GISc framework.

Although the SAT has been developed specifically for the South African GISc industry it can easily be adapted for other disciplines. The methodology of using qualitative and quantitative methods to compare different competency sets with the intention to merge them into a single set is unique and lends itself for application in similar studies regardless of the discipline. Work has already begun on modifying it for the assessment of South African land surveying, engineering surveying and mine surveying curricula. Given that the SAT incorporates international competency requirements, it can also be applied in other countries. The administrator view facilitates effortless modification of the GISc framework and any country-specific competencies can be accommodated easily. The tool is versatile enough to be applied in any country and for any discipline.

In 2014 the SAT was employed for the accreditation of geomatics programmes at seven South African universities. The value of the tool was acknowledged by a number of the universities and the accreditation panel reported the benefits of the SAT to the EAC and PLATO Council. The information gathered through the application of the SAT and the populating of the user database will contribute toward new insights into university GISc programmes, in particular the relative importance that universities attribute to specific competencies (units). This information will be of great value for fine-tuning the credits that are currently allocated to units.

The findings of this research have already been shared with international academics and GISc education specialists. In particular, Prof Josef Strobl from the University of Saltzburg – a major contributor to ongoing efforts to update and modify the BoK – has shown interest in collaborating on further research.

8.5 RECOMMENDATIONS

In this section a number of weaknesses in the GISc academic framework and the GISc SAT are exposed. Recommendations for addressing these weaknesses and for enhancing the usefulness of the GISc academic framework and the SAT are made.

8.5.1 Recommendations: GISc academic framework

A number of recommendations can be made in relation to the GISc framework. The four KAs that were not included in the BoK namely, *GS: Geographical Science*; *MS: Mathematics and Statistics*; *PS: Physical Science* and *RM: Research Methods* must be refined so that they conform to the formatting and detail of the BoK. The descriptions of the KAs, units, topics and objectives (outcomes) may need improvement. It is recommended that the framework should be used in its current format to review the USBQs using its comprehensive list of outcomes as the basis for the assessment of recognition of prior learning (RPL) as defined in the Geomatics Professions Act (Act 19 of 2013). The new competency set should be reorganized under broad study areas with the respective KAs as subcategories to better align the competency set with the South African traditional GISc (geoinformatics) programmes. Another recommendation is that the results of the assessment reports be interpreted in consultation with universities to find the correct balance in content per KA and credits for the core units. The new competency set, and specifically the non-core units with the addition of credits, should be incorporated in short courses to broaden the knowledge base of GISc practitioners while still satisfying some of the requirements of continuous professional development (CPD) as defined in the Geomatics Professions Act. It may also be useful to add an additional level of detail. For instance, the definition of a number of objectives (outcomes) for each topic will assist programme designers to better understand the requirements of the GISc profession regarding those competencies. This may also help to identify duplication between different KAs, improve the balancing of credits allocated per core unit and ensure that important study areas receive sufficient attention. Attention to these actions should add to the usefulness and effectiveness of the GISc academic framework.

8.5.2 Recommendations: GISc SAT

Work is needed to extend the functionality of the GISc SAT. It is recommended that the SAT be extended to enable the matching of modules against topics. Matching of modules at a more detailed level may reduce the uncertainties that are created when topics associated with a particular unit are offered in multiple modules. However, this implies that credits must be allocated to each topic, which may be difficult to do. Another suggestion is that the structure of the assessment report be revisited. From the application of the SAT it has emerged that it may be better to group module-unit matches per unit as this will facilitate the identification of gaps. It is recommended that the SAT be expanded to cater for 2- and 3-year programmes so that it can be used to assess GISc technicians and technologists. The following up of these constructive suggestions should help to better serve the purpose for which the GISc SAT application was designed.

8.6 CONCLUSION

It is safe to conclude that this research has successfully answered the posed questions and adequately achieved its objectives. The GISc research community is given direction for further research to resolve the issues raised and act on the various recommendations put forward in the body of the dissertation and summarized in the previous section. Dedicated research will improve the GISc academic framework and SAT solutions to benefit both the South African and the international GISc communities. It is confidently believed that this work opens new avenues of research. A major upshot of this research is that the concepts and applications it developed, particularly the GISc framework and SAT, are already being widely used in South Africa to assist government departments and municipalities to appoint the right people for the job, to provide training and mentoring of candidates wishing to be registered with the professional body, to accredit university programmes and help to address the aims of the PICC to build and retain capacity in rural areas for infrastructural development.

The research particularly endows the GISc community and industry with solutions that can be successfully applied nationally as well as internationally. Internationally, the new GISc framework has the potential to contribute significantly to reviewals of the BoK. The framework provides the South African GISc community with a structure that meets South African and international requirements for the knowledge and skills an individual should have to be considered a GISc professional practitioner. The framework covers the fundamental and subject-specific core study areas making up the GISc field of study, an attribute on which the South African USBQ, PLATO model and the BoK fell short as independent competency sets. Consequently, universities offering GISc programmes will gain significant status and their courses will be much in demand if their programmes are accredited by the respective professional bodies using the new framework as a standard. The predicaments like those of ill-equipped GISc graduates Kemp (2003) mentions at the beginning of this dissertation should be eliminated through the implementation of the new academic model.

The predicament highlighted by Kemp (2003), namely that graduates do not have adequate knowledge of critical KAs, are still prevalent today. The introduction of new science and technologies such as web map applications, tablets, cell phones and unmanned aerial vehicles emphasises the need for competencies in computer science/information and better understanding and management of the special characteristics of spatial information. The implementation of the proposed GISc framework and SAT developed in this dissertation will go a long way to eliminate these shortcomings and will provide the GISc industry with a well-equipped workforce able to fuse these technologies into a coherent system. Such a workforce will be welcomed by employers making substantial use of GIS and spatial data and will help find solutions to the many challenges facing developing nations such as South Africa.

REFERENCES

Angeles M 2013. Wireframes [online]. Available from: http://Konigi.com/node/1819 [Accessed 22 June 2014].

Barber S 2014. Get performance requirements right – think like a user [online]. Available from: http://www.perftestplus.com/resources/requirements_with_compuware.pdf [Accessed 28 April 2014].

Barnhart, P. A. (1997). *The guide to national professional certification programs*, 2nd ed. Amherst, MA: HRD Press. [In DiBiase et al 2006].

Bergman MM (ed) 2009. Advances in Mixed Methods Research. London: SAGE Publication.

Butler A 2007. GISP survey reveals support for certification exam [online]. Available from: http://www.directionsmag.com/articles/gisp-survey-reveals-support-for-certification-exam/122851 [Accessed 20 October 2013].

Brown DM 2011. *Communication design: Developing website documentation for design and planning,* 2nd ed. Berkeley, California: New Riders.

Bruniquel & Associates 2009. Unit standards, a plea for common sense [online]. Available from: http://www.e-biznews.co.za/uploads/files/biznews1st2009.pdf [Accessed 2 February 2009].

CDNGI (Chief Directorate of National Geospatial Information, Department of Rural Development and Land Reform) 2008. Minutes of management meetings. CDNGI: Mowbray, CapeTown.

CDNGI (Chief Directorate of National Geospatial Information, Department of Rural Development and Land Reform) 2012. Minutes of management meetings. CDNGI: Mowbray, CapeTown.

Chang K 2006. *Introduction to geographic information systems*, 3rd ed. New York: McGraw Hill.

CHE (Council on Higher Education) 2004a. Framework for programme accreditation [online]. Available from: http://www.che.ac.za/documents/d000080/ [Accessed 22 October 2009].

CHE (Council on Higher Education) 2004b. Criteria for programme accreditation [online]. Available from: http://www.che.ac.za/document/d000084/ [Accessed 22 October 2009].

Clavijo D 2013. *Server-side programming language statistics* [online] Available from: http://blog.websitesframeworks.com/2013/03/programming-language-statistics-in-server-side-161/ [Accessed 30 September 2014].

Coetzee S, Eksteen S & Roos A 2014. Results from a survey of the South African GISc community shows who they are and what they do [online]. *South African Journal of Geomatics* 3(2): 224-245. Available from: http://www.sajg.org.za/index.php/sajg [Accessed 30 September 2014].

Dalton M 1997. Are competency models a waste? *Training and Development*, 51: 46-49 [In Gaudet, Annulis & Carr 2002].

DeMers MN 2005. *Fundamentals of geographic information systems*. 3rd ed. New York: John Wiley & Sons.

DeMers MN 2009. Using intended learning objectives to assess curriculum materials: The UCGIS body of knowledge. *Journal of Geography in Higher Education* 33(1): 70-77 [online]. Available from: http://dx.doi.org/10.1080/03098260903033980 [Accessed 16 October 2009].

DHET (Department Higher Education and Training) 2013, South Africa. *Meeting the demand for SIP scarce skills*. May 2013. Pretoria. Department Higher Education and Training.

DPSA (Department Public Service and Administration) DPSA 2009, South Africa. Circular 5 of 2009: *Implementation of the occupation specific dispensation (OSD) for engineers and related professions and occupations.* 1 October 2009. Pretoria. Department Public Service and Administration.

DST (Department of Science and Technology) 2006. Programme 5: *Government sector programmes and coordination*. Annual Report 2005/2006: 65. Pretoria. Department of Science and Technology.

DiBiase D 2003. On accreditation and the peer review of education in geographical information systems and science [online]. *URISA Journal* 15 (1): 7-13. Available from: http://www/urisa.org/files/DiBiasevol15no1.pdf [Accessed 13 October 2009].

DiBiase D, DeMers M, Johnson A, Kemp K, Luck AT, Plewe B & Wentz E (eds) 2006. *GI S&T body of knowledge: University consortium for geographic information science* [online]. Penn State University. Association of American Geographers. Available at:

http://www.ucgis.org/priorities/education/modelcurriculaproject.asp [Accessed 26 February 2009].

DOLETA (US Department of Labor, Employment and Training Administration) 2005. *Identifying and addressing workforce challenges in America's geospatial technology sector*; High-growth job training initiative [online]. Available from: http://www.doleta.gov/brg/pdf/Geospatial%20Final%20Report_08212007.pdf [Accessed 27 July 2011].

DOLETA (US Department of Labor, Employment & Training Administration) 2006. *Defining and communicating geospatial technology industry workforce demand* [online]. Available from: http://www.doleta.gov/BRG/JobTrainInitiative/ [Accessed 31 August 2010].

DOLETA (US Department of Labor, Employment and Training Administration) 2010. (www.doleta.gov) *Geospatial technology competency model* [online]. Available from: http://www.careeronestop.org/competencymodel/pyramid.aspx?GEO=Y [Accessed 12 April 2011].

Du Plessis HJ & Van Niekerk A 2012. A curriculum framework for geographical information science (GISc) training at South African universities [online]. *South African Journal for Higher Education*, 26 (2): 329-345. Available from: http://reference.sabinet.co.za/document/EJC123985 [Accessed 30 September 2014].

Du Plessis HJ & Van Niekerk A 2013. A comparison of geographical information science competency requirements [online]. *South African Journal of Geomatics*, 2 (3): 206-217. Available from: http://www.sajg.org.za/index.php/sajg [Accessed 30 September 2014].

EUGISES 2008. European GIS in education seminar, Royal Agricultural College Cirencester, United Kingdom, September 11-14 [online]. Available from: https://www.eugis.eu/proceedings2008/index.html [Accessed 3 April 2013].

EUGISES 2012. 8th European GIS in education seminar, *Where are the boundaries?* Marianne Hubeau, Marinus de Bakker, Fred Toppen, Wolfgang Reinhardt, Thérèse Steenberghen, Jos Van Orshoven (Editors) [online]. Available from: https://ees.kuleuven.be/eugises12/eugises12-seminar-proceedings.pdf [Accessed 21 July 2014].

Forer P & Unwin D 1999. Enabling progress in GIS and education. In Longley PA, Goodchild MF, Maguire DJ and Rhind DW (eds) *Geographical information systems. Management issues and applications*, 747-756. 2nd ed. New York: John Wiley & Sons.

GauFriesen J 2013. Website requirements. Camosun Web foundation course [online]. Available from: http://camosunweb.com/website-requirements/ [Accessed on 3 May 2014].

Garmany J, Walker J & Clark T 2005. Logical database design principles. Boca Raton: Auerbach Publications.

Gaudet CH & Annulis HM 2008. Developing the geospatial workforce. *The Global Geospatial Magazine* March, [online] Available from: http://www.gisdevelopment.net/magazine/global/2008/march/48.htm. [Accessed 11 April 2011].

Gaudet CH, Annulis HM & Carr JC 2001. Workforce development models for geospatial technology. University of Southern Mississippi [online]. Available from: http://www.careeronestop.org/competencymodel/modelFiles/000_WFD_Models_Final_Report_10_23_2001.pdf [Accessed 19 October 2013].

Gaudet CH, Annulis HM & Carr JC 2002. How to recruit, select, and manage geospatial technology professionals. Esri International User Conference [online]. Available from: http://proceedings.esri.com/library/userconf/proc02/pap0559/p0559.htm [Accessed 20 October 2013].

Gaudet CH, Annulis HM & Carr JC 2003. Building the geospatial workforce. *URISA Journal* 15 (1): 21-30 [online]. Available from: http://www/urisa.org/files/Gaudet vol15no1.pdf [Accessed 13 October 2009].

Geomatics Education Meeting 2007. Minutes of the geomatics education meeting held at the office of the Chief Directorate, Surveys and Mapping, Cape Town, Wednesday, 31 October 2007.

Gewin V 2004. Careers and recruitment: Mapping opportunities [online]. *Nature* 427, 376-377 (22 January 2004). Available from: http://www.nature.com/nature [Accessed 27 February 2009].

GITA (Geospatial and technology association) 2006. *The department of labour's grant to define and communicate geospatial industry workforce demand* [online]. Available from: https://www.gita.org/gita-in-action/dol.asp [Accessed 11 April 2011].

Goodchild MF & Kemp KK 1990. *Introduction to GIS: NCGIA core curriculum*. National Center for Geographic Information and Analysis. Santa Barbara: University of California.

Grazioli S & Morris M 2014. Master of Science in management of information technology. Module 1-enterprise architecture [online]. Available from: http://webs.comm.virginia.edu/Grazioli/MSMITMod1/DataModellingTutorial/DMTutorialHome.html [Accessed on 28 April 2014].

Hossain I & Reinhardt W 2012. Curriculum design based on the UC GI S&T body of knowledge supported by a software tool [online]. Available from: https://ees.kuleuven.be/eugises12/eugises12-seminar-proceedings.pdf [Accessed 30 April 2014].

Hubeau M et al. 2012. 8th European GIS in Education Seminar, *Where are the boundaries?* [online]. Available from: https://ees.kuleuven.be/eugises12/eugises12-seminar-proceedings.pdf [Accessed 21 July 2014].

Huxhold WE & Craig WJ 2003. Certification and ethics in the GIS profession [online]. *URISA Journal* 15(1)51-64. Available from: http://www.urisa.org/journal/protect/vol15no1/Harvey.pdf [Accessed 11 April 2009].

IBM 2009. Logical data models [online]. Available from: http://pic.dhe.ibm.com/infocenter/idm/docv3/index.jsp?topic=%2Fcom.ibm.datatools.diagram.core.doc%2Ftopics%2Ftcreateldmdgm.html [Accessed 26 June 2014].

IBM 2014. Introduction to DB2 for z/OS [online]. Available from: http://pic.dhe.ibm.com/infocenter/dzichelp/v2r2/index.jsp [Accessed 4 May 2014].

Johnson AB 2006. *Developing a GIS curriculum*. ArcUser [online]. Available from: http://www.esri.com/news/arcuser/0706/curricula.html [Accessed 20 October 2009].

Johnson AB 2008. *UCGIS body of knowledge – Proposed and unanticipated benefits and possible future initiatives* [online]. Available from: http://eugises.eu/proceedings2008/johnson.pdf [Accessed 22 July 2014].

Kemp Karen K & Wright Richard 1997. UCGIS Identifies GIScience education priorities [online]. Available from: http://www.ucgis.org/priorities/education/priorities/geoinfosystems.html [Accessed 23 June 2011].

Kemp KK 2003. Update on the UCGIS model curricula project [online]. *URISA Journal* Vol. 15 (1): 47-49 [online]. Available from: http://www.urisa.org/files/Kempvol15no1-5.pdf [Accessed 12 April 2009].

Kemp KK & L Wiggins. 2003. Introduction to the special issue on GIS education [online]. *URISA Journal* 15 (1): 4-6. Available from: http://www.urisa.org/journal/protect/vol15no1/wigginskemp.pdf [Accessed 11 April 2009].

Levy, S 2004. A future with nowhere to hide? *Newsweek* 143 (23): 78. In Beyond Mapping 2006(1): Meeting national needs through enhanced geographic information science [online]. Available from: http://www.nap.edu/catalog/11687.html [Accessed 20 July 2014].

Longley PA, Goodchild MF, Maquire DJ & Rhind DW 2002. *Geographic information systems and science.* Chichester: John Wiley & Sons.

Marble DF 1998. Rebuilding the top of the pyramid. Management issues and applications. *ArcNews* 20(1): 28-29.

Marble DF 2003. *Task force on the development of model undergraduate curricula: The Strawman Report* [online]. Available from: http://www.ucgis.org/priorities/education/priorities/FINALSTRAWMANTEXT.Pdf [Accessed 12 April 2009].

MISA (Municipal Infrastructure Support Agency) ca 2013. *Strategic overview of MISA capacity building programmes.* Pretoria. Department of Cooperative Government and Traditional Affairs (COGTA)

Morrison JL 2006. Preface *Beyond Mapping* (2006:xi): Meeting national needs through enhanced geographic information science [online]. Available from: http://www.nap.edu/catalog/11687.html [Accessed 20 July 2014].

Nadasen L & Salojee I 1998. *ICT: Technology roadmaps* [online]. Pretoria: Department

Science and Technology, South Africa. Available from: http://www.dst.gov.za/publications-policies/magazine/vol5_html [Accessed 27 February 2009].

Najjar LJ 2002. An efficient Web user interface design process for commercial clients. Unpublished manuscript [online]. Available from: http://www.lawrence-najjar.com/papers/An_efficient_Web_user_interface_design_process.html [Accessed 22 June 2014].

National Center for O*NET Development 2006. *New and emerging (N&E) occupations*. Report prepared for US Department of Labor [online]. Available from: http://www.onetcenter.org/dl_files/NewEmerging.pdf [Accessed January 2011].

National Treasury (Department National Treasury) 2014, South Africa. Minutes of the infrastructure skills development grant (ISDG) committee meeting, 27 January 2014. Pretoria. Department National Treasury.

NCGIA 1988. *The core curriculum in geographic information systems.* Department of Geography, University of California at Santa Barbara.

Nielsen J 2000. *Designing Web usability*. New Riders Publishing, Indianapolis, Indiana USA.

Niraj 2011. China geospatial industry. The flight of the dragon. *Geospatial World* 1, 9: 31-37.

Oracle 2014. MySQL [online]. Available from: http://www.mysql.com/ [Accessed 27 June 2014].

Oxera Consulting 2013. What is the economic impact of Geo services? *Summary report prepared for Google* [online]. Available from: http://www.oxera.com/Latest-Thinking/News/January-2013/Oxera-quantifies-the-benefits-of-Geo-services-to-g.aspx [Accessed 21 May 2014].

PLATO 2002. Minutes of the 19th Annual Meeting of PLATO Council held in Stutterheim, 24-26 September. Johannesburg. South African council for professional and technical surveyors.

PLATO 2008. Minutes of the 25th Annual Meeting of PLATO Council held in Wynberg, Cape Town, n.d. October. Johannesburg. South African Council for Professional and Technical Surveyors.

PLATO 2011a. Notes for guidance for the registration of GISc practitioners [online]. Approved September. Available from: http://www.plato.org.za [Accessed 29 April 2012].

PLATO 2011b. Minutes of the 28th Annual Meeting of PLATO Council held in Wynberg, Cape Town, November. Johannesburg. South African council for professional and technical surveyors.

PLATO 2012. Minutes of the 29th Annual Meeting of PLATO Council held in Wynberg, Cape Town, November. Johannesburg. South African council for professional and technical surveyors.

PLATO 2013. Council meeting held in Stanger, KZN. Johannesburg 7 September. South African council for professional and technical Surveyors.

PLATO EAC 2011. Minutes of the Education Advisory Committee (EAC) meeting held in Wynberg, Cape Town, circa October. Johannesburg. South African council for professional and technical surveyors.

Prager SD & Plewe B 2009. Assessment and evaluation of GIScience curriculum using the Geographic information science and technology body of knowledge [online]. *Journal of Geography in Higher Education* 33(1): 46-69. Available from: http://dx.doi.org/10.1080/03098260903034012 [Accessed 16 October 2009].

Reinhardt W & Toppen F (2008). The UCGIS geographic information science and technology body of knowledge – Some thoughts from a European perspective. GIScience – Fifth International Conference on Geographic Information Science. Park City, Utah, USA.

Reinhardt W 2012. Statement of usage of BoK in our institute [online]. Available from: http://www.geo-informatie.nl/rip001/edumapping/AGILE_2012-Reinhardt.pdf [Accessed 3 April 2013].

Rip FI & Verbree E . EduMapping the evolution of an academic GI curriculum – the case of Geomatics at Delft University [online]. Available from: https://ees.kuleuven.be/eugises12/eugises12-seminar-proceedings.pdf [Accessed 30 April 2014].

Rouse M 2006. GUI (graphical user interface) [online]. Available from: http://searchwindevelopment.techtarget.com/definitions/GUI [Accessed 23 June 2014].

Royal Pingdom 2012. Internet [online]. Royal Pingdom.com. Available from: http://royal.pingdom.com/2013/01/16/Internet-2012-in-numbers/ [Accessed 30 April 2014].

SA News 2013. The national development plan (NDP) unpacked [online]. Available from:http://www.sanews.gov.a/south-africa/national-development-plan-unpacked [Accessed 29 September 2014].

SAQA 2003. South African Qualifications Authority. Minutes of the inaugural meeting of the GISc standards generating body (SGB) n.d. Pretoria.

SAQA 2009. South African qualifications authority. *SAQA decision number 0012/08 2009*. Field 12 – Physical Planning and Construction: Physical Planning, Design and Management: GISc SGB [online]. Available from: http://regqs.saqa.org.za/ [Accessed 17 August 2014].

SAQA 2012. South African qualifications authority. Registered qualifications [online]. Available from: http://regqs.saqa.org.za/ [Accessed 17 August 2014].

Sintes T 2002. How do Web and application servers fit into the enterprise? [online]. Available from: http://www.javaworld.com/article/2077354/learn-java/app-server-web-server-what-s-the-difference.html [Accessed 28 April 2014].

Skills Development Report 2006. Workshops on GIS skills development held in Durban on 9 May, Cape Town on 27 July, Polokwane on 15 August and Gauteng on 4 October. Pretoria. Department of Rural Development and Land Reform.

South Africa 1984. Professional and Technical Surveyors Act as amended, Act 40 of 1984. *Government Gazette* 226 (9157), 11 April. Pretoria: Government Printer.

South Africa 1995. The South African Qualifications Act, Act 58 of 1995.*Government Gazette Notice* 1521, 4 October. Pretoria: Government Printer.

South Africa 2007. Higher Education Qualifications Framework (HEQSF). *Government Gazette* 30353, 5 October. Pretoria: Government Printer.

South Africa 2011. Geomatics Profession Bill. *Government Gazette* 35801, 22 October. Pretoria: Government Printer.

South Africa 2013. Geomatics Profession Act, Act 19 of 2013. *Government Gazette* 582 (37142), 10 December. Pretoria: Government Printer.

Strohm et al. 2011. Oracle database concepts, 11g Release 1 (11.1) [online]. Oracle USA Inc. Redwood City, USA. Available from: http://docs.oracle.com/cd/B28359_01/server.111/b28318/toc.htm [Accessed 3 May 2014].

Tedesco D, Schade A, Pernice K & Nielsen J 2008. Site map usability. Help users understand your site and what it offers, 2nd edition [online]. Fremont: Nielsen Norman Group. Available from: http://www.nngroup.com/reports/sitemaps/ [Accessed 28 April 2014].

Toppen F & Reinhardt W 2009. A European approach towards the UCGIS geographic information science and technology body of knowledge a discussion paper [online]. Available from: http://itcnt05.itc.nl/agile_old/Conference/2009-hannover/WS2/Ws2_Agile09_abstracts/2009_paper_Toppen_Reinhardt_AGILEws-2009.pdf. [Accessed 3 April 2013].

UCGIS 2003. *Task force on the development of model undergraduate curricula: The Strawman report* [online]. Available from: http://www.ucgis.org/priorities/education/priorities/FINALSTRAWMANTEXT.Pdf [Accessed 12 April 2009].

Umanath NS & Scamell RW 2007. *Data modelling and database design*. Boston Thomson Course Technology.

Unwin DJ 1997. *Curriculum design for GIS: NCGIA core curriculum in GIScience* [online]. Available from: http://www.ncgia.ucsb.edu/gisc/units/u159/u159_f.html [Accessed 26 February 2009].

US Department of Labor 2004. *Penn State live – Heard on campus: Emily DeRocco*, [online]. US Department of Labor. Available from: http://www.live.psu.edu/story/7739 [Accessed 8 March 2009].

US Department of Labor 2006. *Career voyages* [online]. US Department of Labor. Available from: http://www.careervoyages.gov/allindustries-indemand.cfm [Accessed 11 March 2009].

Verfaillie E et al. 2012. A questionnaire to evaluate the GI job market in Flanders: first findings [online]. Available from: http://ees.kuleuven.be/eugises12/eugises12-seminar-proceedings.pdf [Accessed 30 April 2014].

PERSONAL COMMUNICATIONS

PLATO 2010. GISc registration body. Email on 19 January about status of GISc registrations.

Van Der Merwe S 2014. Owner of Trigger Box. Email on 27 June on GISc self-assessment tool.

APPENDICES

(On CD attached to the dissertation)

APPENDIX A: PEER-REVIEWED ARTICLES (CHAPTERS 3, 4 AND 5)

A1	A curriculum framework for geographical information science (GISc) training at South African universities. H. Du Plessis and A. Van Niekerk South African Journal of Higher Education 26(2) pp 339-345
A2	A comparison of geographical information science competency requirements. H. Du Plessis and A. Van Niekerk South African Journal of Geomatics Vol.2(3): 206-217
A3	Development of a new GISc framework and competency set for curricula development at South African universities. H. Du Plessis and A. Van Niekerk South African Journal of Geomatics Vol. 3, No. 1, January 2014

APPENDIX B: CONTENT-RELATED TO THE BODY OF THE DISSERTATION

B1	Competency sets analysis
B2	The Ukubuzana workshop
B3	The GISc Excel Prototype Self-assessment tool
B4	The GISc Web-Based Self-assessment tool
B5	Results of Programmes A, B and C
B6	UCGIS GI S&T

APPENDIX C: RESEARCH-RELATED PUBLICATIONS IN PositionIT JOURNAL (2010 – 2012)

C1	International assessment criteria for the GISc profession. Second Author: Adriaan van Niekerk Published 17 August 2012.
C2	The need for a GISc Qualification. Second Author: Adriaan van Niekerk. Published 22 June 2012.
C3	Assessing GISc technology curricula. Second Author: Adriaan van Niekerk. Published 24 May 2012.
C4	Competencies in geographical information science. Second Author: Adriaan van Niekerk. Published 4 October 2011.
C5	Workforce challenges, needs and expectations. Second Author: Adriaan van Niekerk. Published 20 June 2011
C6	Registration of GISc practitioners in South Africa. Published 25 January 2010.