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Incorporating Geographic Information Science in the BSc Environ-mental Science Program in Botswana

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Abstract: Critical human capacity in Geographic Information Science (GISc) is developed at the Botswana International University of Science and Technology, a specialized, research university. Strategies employed include GISc courses offered each semester to students from various programs, the conduct of field-based projects, enrolment in online courses, geo-spatial initiatives with external partners, and final year research projects utilizing geospatial technologies. A review is made of available GISc courses embedded in the Bachelor of Science Environmental Science program. GISc courses are incorporated in three Bachelor degree programs as distinct courses. Geospatial technologies are employed in several other courses. Student researches apply GIS and Remote Sensing methods to environmental and geological themes. The overarching goals are to equip students in various disciplines to utilize geospatial technologies, and enhance their spatial thinking and reasoning skills.

Keywords: Geographic Information Science, Geospatial technologies, Higher education, Research university, Spatial thinking, Spatial reasoning, Botswana

1. Introduction

Geospatial information and technologies are increasingly adopted in various fields. The possession of spatial thinking and reasoning skills is critical as such skills are integral to everyday life. Understanding these technologies and spatial thinking is increasingly vital to contemporary life, including common activities and hobbies; learning in science, mathematics, and social science; and employment within fields as diverse as engineering, health, business and planning (Nielsen et al. 2011). According to the National Research Council (2006, 5):

> People, natural objects, human-made objects, and human-made structures exist somewhere in space, and the interactions of people and things must be understood in terms of locations, distances, directions, shapes, and patterns.

Kozak et al. (2008) described the integration of GIS-based environmental data in evolutionary biology. Durr and Gatrell (2004) edited a volume on the application of GIS and spatial analysis in veterinary science. This widespread adoption of geospatial technologies increases the demand for geospatially skilled personnel (Ramli et al. 2010). Though the context of application might differ, the consensus is that there is a lack of skilled geospatial manpower in several countries (Akinyemi 2014). Training and education in the spatial sciences is an imperative for attaining the sustainable development goals (United Nations 2015, Choi et al. 2016).

Over the years, educational and training programs at different levels have emerged worldwide to meet this huge demand for geospatial specialists. Kerski (2015) examined opportunities in utilizing geospatial technologies in education. Other studies focused on the roles of GIS in higher education (Sinton 2009, Songer 2010, McMaster and Robert McMaster 2012, Lukinbeal and Monk 2015, Bearman et al. 2016). Eksteen et al. (2015) conducted a comparative study of GISc modules and degree programs in African and Latin American Universities. They found that there are more universities per country in Latin America than in Africa. Moreover, there is one university with Geographic Information Science (GISc) education for every 6 million people in Africa, whereas there is one for every 3.6 million people in Latin America. From the perspective of secondary education, the use of geospatial information and technologies was introduced in schools in different parts of the world since the 1980s (Lam et al. 2009, Kerski et al. 2013, Akinyemi 2014). Akinyemi (2015, 2016) assessed GIS use for teaching in Rwandan secondary schools. At the primary school level, studies have shown the necessity to enhance students' spatial reasoning skills (Davis and the Spatial reasoning Study Group 2015, Azevedo et al. 2016). With the aim of developing human capacity in GISc, different trajectories are taken in program design and development in higher education. For example, an examination of available educational and training programs in higher education reveals that GISc courses are either focused on teaching about or teaching with geographic information and technologies. Most of these courses are offered as part of undergraduate or postgraduate programs in various fields (Akinyemi 2012, Eksteen et al. 2015).

This paper describes the development of human capital in GISc and technologies within the educational programs of the Botswana International University of Science and Technology (BIUST), specifically in Environmental Science (ENVS). The paper outline is as follows: a brief background is given about available Bachelor GISc courses in BIUST. It describes various strategies

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employed in developing critical human capacity in GISc. Some student research applying GIS and Remote Sensing methods are also presented. The study contributes to ongoing efforts assessing the availability of GISc courses in developing countries.

2. Background

BIUST is a specialized, research university in Botswana. Having started its operations in 2012, it was established to provide an array of services in higher education in Science, Engineering and Technology – and applied research in an environment that fosters problem-based learning, discovery, creativity, and community engagement. The university seeks to stimulate local, national and regional economic development through the fulfilment of its mandate. This com-prise teaching and learning through training and education, research (basic and applied), and community service through engagement. It provides excellent research based academic programs, quality teaching and learning experience to students (BIUST 2016). At BIUST, research is intended to be an integral part of student learning that feeds into training and education as well as service to the community. Figure 1 shows that critical human capacity in GISc and technologies is built according to the three pillars of BIUST's mandate.

Fig.1. Building capacity in GISc and technologies in BIUST

GISc courses are embedded and taught as part of undergraduate and/or postgraduate programs. This study focuses only on undergraduate programs as these are well underway with the first cohort having graduated in 2016. Under-graduate programs with GISc courses as core or electives are Bachelor of Science (BSc) Environmental Science, BSc Earth and Environmental Science (EES), BSc Geology, and Bachelor of Engineering (BEng) Geological Engineering (GeoEng). All four undergraduate programs currently run for 8 semesters over a 4-year period except the BEng which currently runs for 10 semesters over a 5-year period. As a relatively young university, these four Bachelor programs commenced at different times; BSc Geology, BSc EES and BEng GeoEng commenced in 2012, whereas BSc Environ-mental Science commenced in 2014.

2.1 Structure of the BSc Environmental Science program

Only the BSc Environmental Science (ENVS) program is described as all GISc courses are housed within this pro-gram. The first year aims to strengthen the science foundation of students by offering courses in mathematics, statistics, biology, chemistry, computer science and physics. By design, all first year programs in BIUST start with these science foundation courses. Students are introduced to environmental science in year two, as well as further grounding in physics, chemistry, mathematics, and statistics. Year three and four are almost entirely focused on environmental science courses with possibilities of electives from other undergraduate programs and a mandatory final research-based project. Students in the ENVS program also take a range of courses in entrepreneurial studies and technical writing.

3. Developing Human Capacity in GISc

Various methods employed in developing human capacity in GISc at BIUST include semester based courses, con-ducting field based projects incorporating students, enrolment in online GIS courses, geospatial information and technology initiatives with external partners, and research-based final year projects.

3.1 Embedded GISc courses in the ENVS program

GISc courses are taught to undergraduate students from different disciplines. A key component of teaching and learning in the ENVS program is the incorporation of GIS and Remote Sensing courses. The use of geospatial technologies are also taught in several other courses. Graduates of our programs possess geospatial skills, skills required by industry and/or governmental institutions in the 21st century (Walden University 2010, Qian and Clark 2016, Shin et al. 2016). These GISc courses are taught for 12 weeks during a semester (Table 1).

Course code & title	Programs Offering	Credit	Level/ Semester	Type	Pre-requisite
ENVS 305: Geographic Information Systems and Databases	BSc Geology, BSc Environmental Science, BSc Earth & Environmental Sciences	3	300 level/1	Core	none
ENVS 302: Remote Sensing in Earth and Environmental Sciences	BSc Geology, BSc Environmental Science, BSc Earth & Environmental Sciences	3	300 level/2	Core	ENVS 305
ENVS 404: Applied Geographic Information System & Remote Sensing	BSc Environmental Science	3	400 level/2	Core/ Elective	ENVS 302, ENVS 305

Source: author's compilation.

Table 1. GISc undergraduate courses at BIUST

Time allotted each week include 1 hour which is used for lecture, i.e. for teaching theoretical aspects; a 3-hour laboratory session for developing hands-on and a 1-hour tutorial session where students discuss in groups, ask and answer questions. The ENVS 305 course outline for is shown in Table 2. Continuous assessments (CA) are over 40-50 % for individual and/or group assignments, lab exercises and pre-exam with laboratory and theory aspects examined. End of semester examination is conducted to examine both practical and theory with some essay questions requiring critical thinking abilities of students. These GISc courses are offered to students in the various programs but only ENVS 302 and ENVS 305 are running as the ENVS program has students currently only up to year three.

Week	Lecture Topics	Labs	Exercises
1	General overview of GIS	Lab #1 Overview of GIS functions/tools	Exercise 1: Creating an administrative map of Botswana
2 & 3	Spatial data representation 1 (spatial data models and data structures)	Lab #2 Spatial data types • Identifying geographic phenomena	Exercise 2: Identifying geographic phenomena and data types
4 & 5	Projections & coordinate systems	Lab #3 Getting started with GIS	
6 & 7	Spatial database management	Lab #4 Database design and implementation • Creating attribute data • Creating/importing spreadsheet data into GIS • Joining and relating tables	Exercise 3: Spatial Database Design for applications
8	Data capture 1: GIS data sources	Lab #5 Capturing spatial data • GPS data capture	Exercise 4: Onscreen digitizing of spatial entities using high resolution image e.g. Orthophotograph of Palapye.
9	Data capture 2: GIS data sources from Remote Sensing images	Lab #6 Onscreen digitizing • Creating and editing shapefiles • On-screen digitizing	
10	Pre-exam (Theory & lab)	Lab #7 Spatial data retrieval • Selecting features by attributes and location	
11	Spatial data query and analysis (vector operations)	Lab #8 Capturing features on Campus with handheld GPS	Project: Getting started with GIS online course.
12	Spatial data analysis (Raster operations)	Lab #9 Introduction to DGPS	

Table 2. GIS and Databases course outline

3.2 Undergraduate final year research projects

The conduct of research-based projects by undergraduates in their final year is another way to build human capacity in GISc (Table 3). An example of a remote sensing image data utilized by projects include the use of the Normalized Difference Vegetation Index, a proxy for vegetation cover and production, for evaluating deviation of the current sea-son from the normal vegetation condition in a time series. Another project utilized image data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) TIR bands for geological mapping. Most projects with field work components utilize GPS in capturing location attributes, for example, where soil samples were collected.

	Geospatial applications	**Aim**	**Data set/Date**	**Source**	**GIS Functions /Software**
1	Remote sensing based drought assessment in a semi-arid context: The case of the Central District in Botswana.	Assess vegetation variability over an 18-year period; map current season vegetation anomaly (September 2015 to April 2016); identify spatial and temporal variations of drought severity using the Vegetation Condition Index (VCI), a Remote Sensing based drought index; and comparing with a traditional drought index, the Standardized Precipitatio	SPOT VGT / 1998 - 2013, *Proba-V* Normalized Difference Vegetation Index (NDVI)/*2013-2016*, and gauge station rainfall data from 1960 - 2015 for validating imag	SPOT Image, European Space Agency (ESA) through MESA-SADC The main project, Botswana Department of Meteorological Services (BDMS).	MESA's Drought Monitoring Services 2.4 software / NDVI difference index, Anomaly, VCI, ArcGIS 10.2.2/map reclassification, SPI 6/SPI software, MS Excel/graph.

		n Index (SPI).	e analysis products.		
2	Landfill site selection using GIS - Multi Criteria Analysis based approach for Palapye sub-district.	Determine suitable sites for locating a landfill in Palapye sub-district to minimize impacts on the environment, human health, and tourism.	Land use-cover, roads, railways, settlements, tourist sites, river network.	Botswana Department of Survey and Mapping.	ArcGIS 10.2.2/ Buffer, Euclidian distance, weighted overlay analysis, symbolization. It utilizes GIS based multi-criteria analysis as a spatial decision support tool.
3	Francistown region geological mapping using ASTER and aeromagnetic data.	Comparison of image data from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor and airborne geomagnetic data for geological mapping of the Francistown region.	ASTER Level-1B (L1B) daytime TIR data of January 2015 and directional cosine filtered Total Magnetic Intensity (TMI) map of 1996.	Geological Survey of Japan, Advanced Industrial Science and Technology MADAS https://gbank.gsj.jp/madas/index.php#top, Botswana Geoscience Institute.	ArcGIS 10.4/Image analysis tool, Raster calculator, NASA rock spectral reflectance library, MS Excel/graph, Geosoft /directional cosine filter, GPS for coordinates of rock samples collected during fieldwork.

Source: author's compilation.

Table 3. Some examples of undergraduate student research projects conducted

3.3 Field-based semester project

Students undertake a field-based project during the ENVS 305 course that entails applying GIS and/or Remote Sensing techniques in any field. The goal is to aid student learning outside the classroom by applying geospatial technologies to solve problems in real world situations. One such project, titled "BIUST real estate (properties) information system" was conducted in 2015 over a 4-6 week period. With class sizes ranging from 38 to 112 students, the project is conducted as group assignment. Group work involved conducting an inventory of buildings and roads, digitizing buildings from images and GPS points (e.g., to create building outline), and spatial database design (conceptual, logical and physical) and implementation. Geotagged photographs of buildings and roads were also made. Identification codes for buildings and roads in BIUST were also developed (Table 4). The questionnaire used for building inventory is shown as Appendix 1. This project contributes to the spatial planning of the campus. Students learn to source and create spatial data, as well as databases for mapping purposes.

ID	**Name**	**Remarks**	**Indicate assigned group**
B001	Administrative block		
B002	Old College of Sciences classrooms		
B003	Hostel A		
B004	Hostel B		
B005	Hostel prefab		
B006	Hostel SN		
B007	Hostel Q		
B008	Hostel SN1		
B009	Hostel Q1		
B010	Multi-purpose hall		
R001	North gate to campus junction	Tarred road	
R002	Administration block to	Tarred	

	waste water treatment plant	road	
R003	Campus junction to south gate	Gravel road	
R004	Alternative road from north gate to campus junction	Gravel road	
R005	Hostel junction to quarters	Tarred road	
R006	Quarters road	Tarred road	
R007	Senior quarters road	Tarred road	

Table 4. Identifier for buildings and roads in BIUST as of 2015

3.4 Enrolment in the Environmental Systems Research Institute (ESRI) virtual campus online courses

Students in the ENVS 305 course also enroll in the "Getting started with GIS" online course of the ESRI virtual cam-pus. The scope of the online course aligns with the preliminary topics covered in the earlier part of the semester. This is an opportunity for students to gain out-of-class experience in learning at their own pace using web-based technologies. For majority of the students, this was their experience with an online course. The possibility to earn an internationally recognized GIS certificate is an incentive which makes the ENVS 305 course attractive to students in BIUST. Upon successful completion of the online course, a certificate is obtained (see a sample in Figure 2). Upon submission of the certificate, grade for completing the online course is awarded to each student as a project component of the continous assessment.

Fig. 2. A sample certificate obtained upon completion of the online course

3.5 Monitoring for environment and security in Africa Thema project (MESA)

The MESA project is implemented for the Southern African Development Community (SADC) with funds from the European Union and African Union. It commenced in 2013 with the goals of improving access to Earth Observation data, developing geospatial-based services on drought, agriculture, flood and wildfire. It develops expertise in geospatial technologies through regional and national trainings (Table 5). The project also provided BIUST as one of the beneficiary universities in the region with a receiving station (e-Station) to access a variety of Earth Observation images through the EUMESAT (both archives and present) for use in teaching and research.

	Training	Scope	Date	Participants	Location
1	Training of trainers for the Agriculture and Drought Services	Regional	25 July-05 August 2016	National focal persons (NFPs) and university thematic experts (TEs).	Botswana University of Agriculture and Natural Resources (BUAN)
2	Training of Trainers for the Flood service	Regional	29 August-9 Sept. 2016	NFPs and TEs	University of Zimbabwe (UoZ), Harare
3	Workshop for beneficiary universities receiving stations and monitoring services	Regional	14-18 March 2016	TEs and system administrator	Namibia University of Science and Technology, Windhoek
4	Training of users (ToU) on products and services	National Training (NTW)	5 Sept. -2 Dec. 2016	1-week training was hosted in each of the 15 countries in SADC.	
5	ToU	Tanzania NTW	7-11 Sept. 2015	Ministry of Agriculture, Food and Cooperative, Tanzania Meteorological Agency, BDMS (Meteorological services)/SADC-CSC, Tanzania Forestry Research Institute	Dar es Salaam, Tanzania
6	ToU	Botswana NTW	10-15 August 2015	BUAN, Department of Forestry and Range Resources, BDMS/SADC-CSC	BIUST, Palapye, Botswana
7	ToU	4. South Afr	5-7 August 2015	CSIR-Meraka Institute, Agric Research	South Africa

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		ica NTW		Council, BDMS/SADC-CSC	
9	ToU	**5.** Zambia NTW	27-31 July 2015	Environmental Council of Zambia, Land Husbandry, Zambia Meteo Department	Zambia
11	ToU	**6.** Zimbabwe NTW	20-24 July 2015	National Meteorological Services, Scientific and Industrial Research and Development Centre, UoZ,BDMS/SADC-CSC	Zimbabwe

Source: author's compilation, from MESA-SADC website (http://www.mesasadc.org/).

Table 5. Selected MESA-SADC Thema training and workshop

7. Conclusions

GISc use in higher education is described from the perspective of a developing country context. Various strategies used in developing critical human capacity in Geographic Information Science (GISc) including utilizing geospatial technologies is discussed. GISc courses embedded in the Bachelor of Science Environmental Science program were re-viewed. With a strong research underpinning, students enrolled in these courses undertake research-based projects as individuals and in groups. Undergraduate students from various disciplines acquire the ability to utilize geospatial technologies, as well as develop their spatial thinking and reasoning skills. The role of web-based GIS online courses in enhancing student performance and outcome will be considered for future research.

8. Appendix (optional)

Building inventory questionnaire

No. of student survey group: …………………………
Date: ……………………………..

No	**Attribute**	**Fill in**	**Remarks**	• **Meaning**
• **BUILDING IDENTIFICATION PROFILE**				
1	B_Name			Name of building
2	BID			• Building identification
3	x			• Coordinates
4	y			• Coordinates
5	Address			Street location of building
6	Bno			Building Number, if available
7	B_type			Building type e.g. Storey building, Detached house, Bungalow, Duplex
8	Use			Use to which building is put e.g. residential, administrative, educational, religious, refectory
9	Yr_Com			Year building was completed
10	Yr_Inaug			Year building was inaugurated
11	Person_ Inaug			Name of person that inaugurated the building
12	Funder			Name of donor, if applicable
13	Value			The cost of building
CAPACITY				
14	Size			Size of building in Sq. metres
15	No_Floor			No. of floors
16	No_labs			No. of laboratories
17	No_class			Number of classrooms
18	No_office			No. of office rooms
19	No_meeting_room			No. of conference rooms
AMENITIES				
20	No_toilet			No of toilets
21	No_bath			No of bathrooms
22	Energy			Source of energy (e.g., Solar, generator, both etc.)
23	Elevator	Yes No		Is the elevator functional?
B_MATERIALS				
24	Ceiling			Material for ceiling
25	Floor			Material for floor (e.g., cemented, tiled,

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				etc.)
26	Wall			Material for walls (e.g., Bricks, plastered, etc.)
27	Paint	Ye s No		Whether paints are applied to walls.
28	Roofi ng			Material for roofing (e.g., Corrugated iron sheets, cement, etc.)

Any additional supporting data may be appended, provided the paper does not exceed the limits given above.

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