# An assessment regime for geographical information systems to promote deeper learning in students of diverse disciplines

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Geographical information systems (GIS) are computer-based systems for the storage, retrieval and analysis of spatial data. They emerged as a tool in the 1950s; however, GIS is now recognised as a science in its own right. GIS enables the integration of data from different disciplinary areas with existing GIS data. Acquiring GIS skills and knowledge is known to improve students' spatial thinking, a highly desirable and valued graduate attribute cited in recent educational reviews both in Australia and internationally. GIS tools – both software and hardware – are becoming simpler and more affordable to use, thereby increasing the popularity of GIS across a diverse range of disciplines. However, these developments – in particular the availability of easy-to-use software applications – have encouraged superficial approaches to both learning and assessment in this emerging discipline. This study analyses the performance in a variety of assessment tasks of students enrolled over a period of four years from 2007 to 2010 in an introductory undergraduate GIS course. The assessment tasks cover the three aspects of GIS as suggested in model GIS curricula, namely: GIS technique; the science behind GIS; and the application of GIS to diverse disciplinary areas. The study attempts to investigate whether disciplinary background together with a student's year level at university might influence performance. This analysis will be used to modify the assessment regime of the course as well as of similar introductory GIS courses, which are becoming popular across several different universities throughout the world, in a way that takes into consideration the disciplinary diversity of the students.

**Keywords:** formative assessment; formative feedback; geographical information systems; GIS; summative assessment.

## Introduction

Over the past few decades, geographical information systems (GIS) have emerged as an innovative tool that is now becoming ubiquitous. Examples of its application include virtual earth systems such as Google Earth, and satellite-based navigation systems such as global positioning systems (GPSs). In large research and information-management environments, GIS offers tremendous potential as an analytical system. Many dreams of the past, such as creating a digital representation of the earth (Gore, 1999), have now been realised with GIS technologies (Craglia, et al., 2008; Goodchild, 2007). With recent developments in its technological capacity, GIS is fast becoming a multidisciplinary technology with relevance beyond its traditional geographical disciplinary base (Zerger, Bishop, Escobar, & Hunter, 2002). GIS has been applied to a wide variety of disciplines including forestry, health sciences and genomics (Dolan, Holden, Beard, &

Bult, 2006; Hess & Cheshire, 2002; Koch & Denike, 2004; Moss & Schell, 2004; Wing & Sessions, 2007). As a consequence, GIS is becoming part of university curricula across a wide range of disciplines from anthropology to zoology (Carver, Evans, & Kingston, 2004).

In recent years, GIS technologies have not only become much simpler, but also cheaper and more accessible (Kerski, 2008). Several 'virtual earth' systems (Butler, 2006) are free and extremely popular, and are being recommended as effective educational tools (Kerski, 2008; Patterson, 2007). In these contexts, GIS is becoming recognised as a necessary tool, even being referred to as "the fourth R" of education (Goodchild, 2006) and as a "new landscape of science" (Colwell, 2004). Implementation of this technology across different organisations is growing, and this is enabling greater use of GIS in different discipline areas. Industry requirements for competence in the use of the technology are prompting the requirement for GIS to be embedded in various undergraduate and graduate programs, and graduating students with GIS competence are reported as having greater employment opportunities (Gewin, 2004).

While expansion in the use of GIS tools across relevant disciplines would seem to be an imperative, a number of challenges have been encountered. In particular, many of the students enrolling in introductory-level GIS courses come from different discipline areas and have inadequate elementary knowledge of geography, which is considered to be the base discipline of GIS (Sui, 1995). For example, a poor understanding of the concept of space is a well recognised issue for students with limited knowledge of geography (Marble, 1998). Teaching the basics of GIS to such a diverse student population is a challenging task, as students perceive space differently depending on their educational background and cognitive development. This situation could be seen to be encouraging surface learning among GIS students, as well as among other GIS users. For example, students with only superficial knowledge of geography may be able to create a colourful map, but it may depart from basic cartographical principles. Surface learning approaches are generally considered as being undesirable (Biggs, 1989), because they encourage students to focus attention on the easiest way to 'learn for the test'. Teaching strategies and course structures for teaching GIS to multidisciplinary audiences need to be developed to facilitate deeper and more holistic learning among students. Furthermore, these approaches need to cover different aspects of the discipline, including the fields of science, technology and the applications of GIS (DiBiase, et al., 2006).

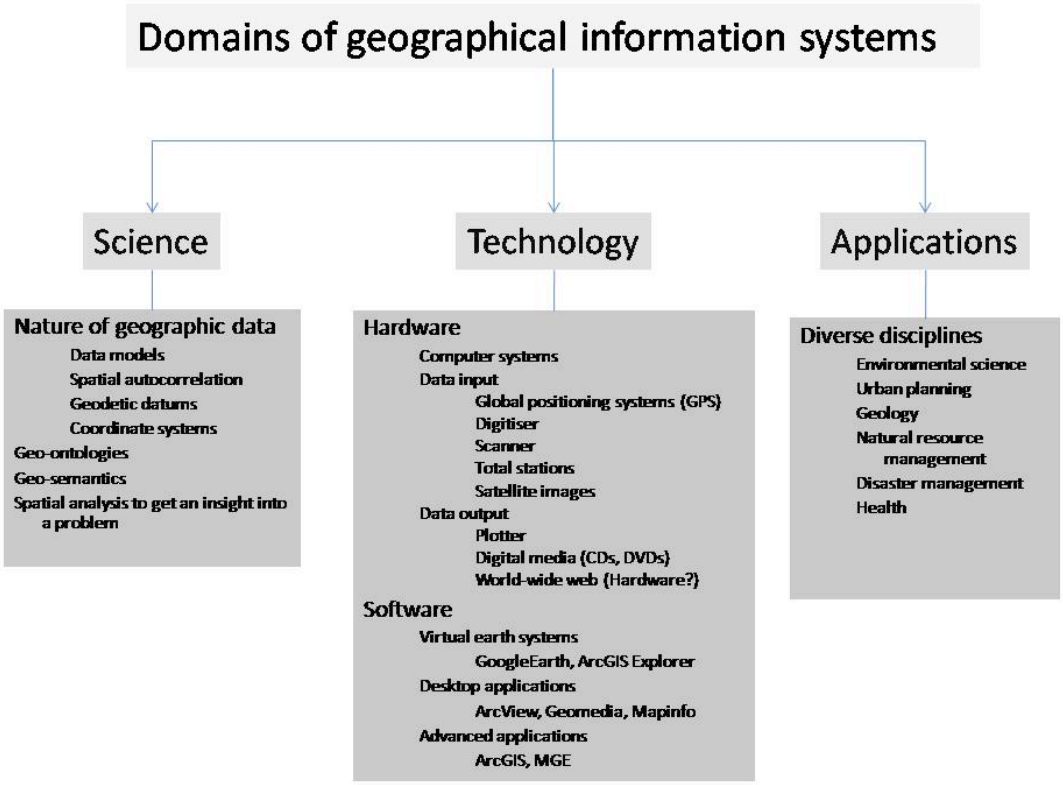
There are two main challenges encountered in assessing students' performance in GIS: dealing with the different aspects of GIS and assessing students from diverse disciplinary backgrounds. This study presents the assessment regimes used in an introductory GIS course for multidisciplinary students over a period of four years from 2007 to 2010. These were designed based on recommendations of the model GIS curricula. The study analyses the relationships between different assessment tasks and students' disciplinary backgrounds, based on their performance in the course.

## Context

As an evolving discipline, emphasis has been placed on the development of a standard curriculum in the field of GIS, and several have been developed over recent years. The current model curricula include those developed by the US-based National Center for Geographic Information and Analysis (NCGIA), the Core Curriculum in GIScience (Kemp & Goodchild, 1992) and the

Geographical Information Science and Technology Body of Knowledge (GIS&T BoK) (DiBiase, et al., 2006). The development of the GIS&T BoK involved more than 70 educators, researchers and practitioners (DiBiase, et al.). It includes 10 knowledge areas, 73 units and 330 topics covering diverse aspects of the discipline (DiBiase, et al.). One of its major recommendations takes into account the three domains of GIS education: geographical information science; geographical information technology; and the application of GIS to different disciplinary areas (Figure 1). Assessment tasks should thus be designed accordingly, covering these three domains of the discipline.

This study is based on the contention that the nature of learning, including the assessment methods adopted, is influenced by the curriculum. Assessment is considered to be the core of learning (Boud, 2000, 2010; Boud & Falchikov, 2005; Gibbs & Simpson, 2004; Ramsden, 2003). It encompasses engaging students through appropriate tasks and providing plentiful feedback, and is underpinned by a commitment to improve learning for all (McDowell, Wakelin, Montgomery, & King, in press). The type of assessment used, coupled with the feedback provided, influences




students' learning, with different forms of assessment expected to lead to different approaches to learning (Joughin, 2010).

**Figure 1: The three domains of geographical information systems**

It has been suggested there are three types of assessment:

- formative assessment, in which students receive substantial feedback to support improved performance but with either no grading or a low weighting assigned to the task, and which is designed primarily to improve learning
- summative assessment, in which students are assigned a grade, and which is designed primarily to judge learning
- synoptic assessment, which is used over the course of a whole program (Boud, 2000; Crisp, in press; Gibbs, 2003).

Although all forms of assessment are inextricably linked, the significance of summative assessment cannot be ignored (Joughin, 2010). Research has shown that formative assessment involves a significant emphasis on appropriate feedback to students to enhance learning as well as achievement (Boud, 2000, 2010; Gibbs & Simpson, 2004). Feedback may be defined as any of the numerous procedures used to inform a learner (Kulhavy 1977, cited in Sadler, 2010). The term "formative feedback" has been used by many researchers to describe information communicated to the learner that is intended to support his or her thinking or behaviour to improve learning and future performance on assessment tasks (Shute, 2008, p. 154). Assessment tasks should therefore be designed in such a way that they provide opportunities for feedback, which is well recognised as significantly accelerating the effective learning process (Sadler, 2010). In addition, it has been noted that a variety of assessment tasks distributed across weeks and topics – as opposed to one or two similar summative assessment tasks – help to keep students engaged throughout a course (Boud & Falchikov, 2005; Gibbs & Simpson, 2004).

For the new and emerging discipline of GIS, which is now studied by students from a diverse range of disciplines, assessment tasks need to be designed judiciously. They should not only be based on current model GIS curricula but also take into consideration current education research. Tasks should provide opportunities for both formative feedback to inform future assessment in the course and summative assessment of the different aspects of the discipline. Students also need opportunities to combine their existing discipline-specific knowledge with their developing GIS knowledge in assessment tasks designed to promote a deep approach to learning (Ramsden, 2003) in GIS by students, irrespective of their disciplinary background.

## Methodology

### Course structure

An Introduction to Geographical Information Systems is taught as a second-year undergraduate course at the University of the Sunshine Coast, and is becoming extremely popular across several different disciplines. The number of students, as well as their disciplinary diversity, is increasing every year. The course is structured as two hours of lectures, which deal with the theoretical aspects of GIS, plus two hours of tutorials, which focus mostly on the technological component and in which students acquire skills in applying GIS software to real-world contexts. The tutorials

are conducted in groups with a maximum of 20 students: this facilitates a good student-to-tutor ratio and provides excellent opportunities for one-on-one discussion.

### Assessment tasks

The recommendations of the model curricula (see Context, above) were followed when designing the assessment tasks for the course. Four different assessment tasks (see Table 1), covering the diverse aspects of the discipline, were well distributed across weeks and topics, and provided ample opportunities for the students to both receive and act on formative feedback.

**Table 1: The variety of assessment tasks used in the course**

| Assessment code | Task type | Description | Aspect of GIS covered | Weighting (%) |
|---|---|---|---|---|
| A1 | Weekly quizzes | Students encouraged to discuss quiz questions with their tutor and with each other | Geographical information technology and science | 30 |
| A2 | Assignment 1 | Students asked to submit a project proposal on a GIS application to their respective discipline | GIS application | 10–20 |
| A3 | Assignment 2 | Students worked on their proposed GIS project in a real-world context | GIS application | 20–30 |
| Ex | Examination | Invigilated examination | Geographical information science | 30–40 |

The students' assessment began in the first week with a weekly quiz that focused on assessing the technology component of the discipline. Students were encouraged to discuss the quiz questions with their tutor and with each other. The weekly quizzes were marked over the subsequent week and, if required, specific feedback was provided to students. To manage the large class size a 'comment bank' of correct answers was prepared and made available to students as required through the online learning system Grade Centre. This weekly feedback not only helped students to become aware of their performance early on but also enabled the identification of students at risk so that more targeted intervention could be offered to them.

In the second assessment task (Assignment 1), students were asked to submit a project proposal demonstrating how they could use their GIS skills to solve a real-world issue within their disciplinary domain. This helped them to combine their GIS skills with their existing discipline-specific knowledge. This proposal led students on to the next task (Assignment 2), in which they were required to actually perform their proposed GIS analysis to solve a real-world problem within their discipline. The second part of this two-part assessment task leveraged the detailed feedback given on the first part. Assignment 1 was marked in the early phase of the course, with significant suggestions offered on how to proceed with the third assessment task (Assignment 2). Between the two stages, a one-on-one discussion with the tutor was organised for each student during the tutorial (see Figure 2). During this discussion the students were asked about their data needs, and feedback was provided on how they could apply their knowledge and skills to solve their chosen real-world issue. Students who were struggling were asked to make another appointment with the tutor for a longer discussion.

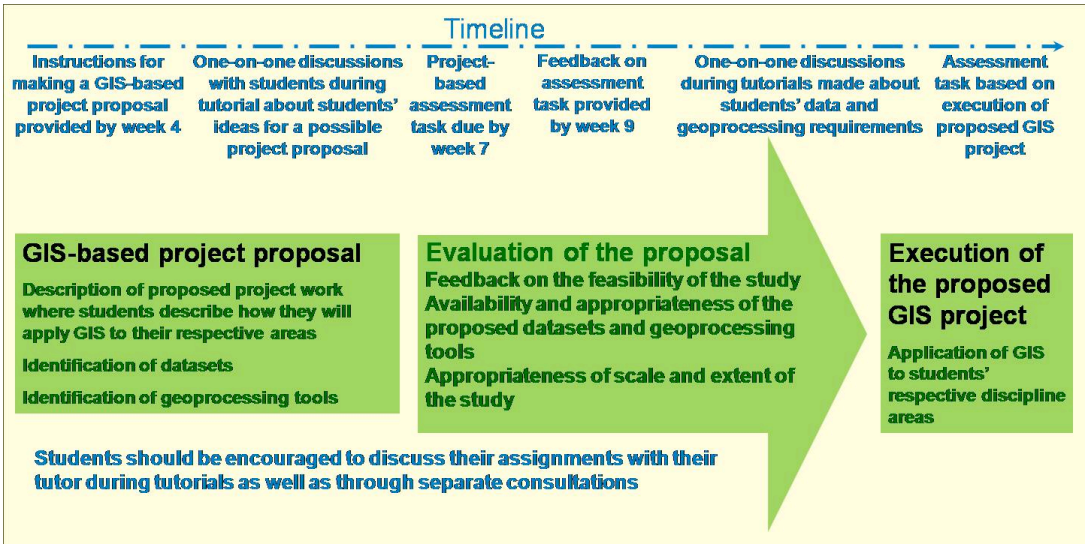



**Figure 2: Timeline of the two-part assessment task (Assignments 1 and 2), which encouraged formative feedback**

Finally, the students underwent an invigilated examination aimed at assessing their theoretical knowledge of the discipline. The weighting of these assessment tasks varied over the four years, with the weighting of the exam being reduced in later years.

## Data collection and analysis

Over the four-year period, 318 students enrolled in the introductory GIS course and the performance of 256 students was analysed. Students who failed, dropped out of the course or did not attempt one or more of the assessment tasks were omitted from the study. Students enrolled in the course had diverse disciplinary backgrounds which could be grouped into eight broad groups. In addition to grouping the students by their disciplinary backgrounds, students in their first year of study within each discipline were also identified (see Table 2).

**Table 2: Numbers of GIS students according to broad disciplinary background (showing major undergraduate programs included) and level of study**

| Disciplinary group | Undergraduate programs included | Year of study | | Total |
|---|---|---|---|---|
| | | First | Later | |
| Arts | Arts, cultural studies, design, historical studies, politics and international relations | 0 | 12 | **12** |
| Business | Business, tourism | 1 | 6 | **7** |
| Education | Arts, English, geography, mathematics, science, sustainability | 2 | 27 | **29** |
| Engineering | Civil engineering, construction management, environment and water | 16 | 17 | **33** |
| Environmental studies | Climate change adaptation, coastal studies, environmental sciences, environment and planning, marine science | 12 | 94 | **106** |
| Information and communication technology (ICT) | Information and communication technology, information systems, software engineering | 0 | 7 | **7** |
| Science | Biological science, biomedical science, biotechnology, microbiology, science, sustainability | 3 | 13 | **16** |
| Urban planning | Regional and urban planning | 8 | 38 | **46** |
| **Total** | | **42** | **214** | **256** |

Students undertaking environmental science degrees constituted the largest group, followed by students undertaking urban planning degrees. The next two largest disciplinary groups were engineering and education.

The data sets on students' performance were analysed using R-statistics software (Ripley, 2001). Students' marks for different assessment tasks were cross-tabulated according to their level of study and their broad disciplinary background. Analysis of variance (ANOVA) was then performed on the data sets to determine the effects of students' disciplinary background and level

of study on their performance in the different assessment tasks (Chambers, Freeny, & Heiberger, 1992). The analysis of variance is the standard statistical technique for modelling a quantitative response variable with categorical explanatory variables. In this study, students' marks were the quantitative variables, which were analysed with two categorical variables: their discipline and their level of study.

A t-test was then performed to determine the significant influence of these factors on students' performance (see Table 3). A paired t-test was performed on students' marks to study the relationships among different assessment tasks used in the course. The paired t-test analysed the mean value of percentage marks scored in different assessment tasks, and provided probability values to indicate whether the mean value of the marks was equal. Furthermore, the correlation coefficient was calculated among students' marks obtained in different assessment tasks. The Spearman test p-values were then calculated to test the significant correlation among the marks.

**Table 3: Probability of paired t-test and correlation coefficient between the marks obtained in different assessment tasks**

| | p-value for paired t-test | Correlation coefficient |
|---|---|---|
| Quizzes and Assignment 1 | 0.000[a] | 0.30[b] |
| Quizzes and Assignment 2 | 0.554 | 0.43[b] |
| Quizzes and examination | 0.422 | 0.45[b] |
| Assignment 1 and Assignment 2 | 0.000[a] | 0.43[b] |
| Assignment 1 and examination | 0.000[a] | 0.36[b] |
| Assignment 2 and examination | 0.043[c] | 0.50[a] |

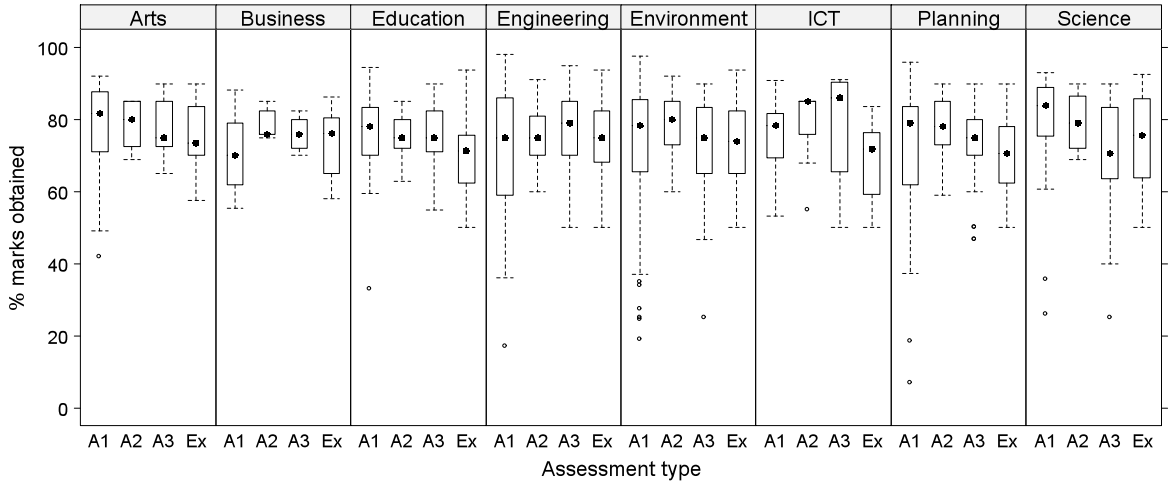
a Significant at <0.0001; b Significant at <0.01; c Significant at <0.05

## Results and discussion

The use of a variety of assessment tasks enabled evaluation of students' performance on the diverse aspects of GIS. The paired t-test performed on students' marks clearly indicated variation in their performance. The only exception was in the mean of marks obtained in the quizzes, which was significantly similar to the marks obtained in Assignment 2 and the examination. All other assessment tasks were unrelated to one another (see Table 3) and the students' marks were significantly different. However, students' performance in the diverse assessment tasks was significantly correlated (Table 3). This indicates a similar trend in students' performance, but with a variation in the marks scored. The variation noted in students' marks across the different assessment tasks can be attributed to their diversity and to the wide-ranging approaches to learning the subject.

The disciplinary diversity of the students undertaking the introductory GIS course meant that we could anticipate that they may achieve differently. While assisting students with their assessment

tasks, differences in their ways of learning were clearly apparent. Similar differences were noticed in their performance on the various assessment tasks (see Figure 3). However, the overall effect of disciplinary background on students' performance was found statistically insignificant. This could be attributed to the variety of assessment tasks used in the course and to the assessment tasks on GIS application which were flexible enough to accommodate the individual student's disciplinary background. For example, students undertaking an education degree had an interest in using GIS as a teaching tool and were therefore supported to prepare teaching materials for school students using GIS. Similarly, environmental science students were more interested in analysing the habitats of flora or fauna, according to their specialisations.




A1 Weekly quizzes; A2 Assignment 1; A3 Assignment 2; Ex Examination

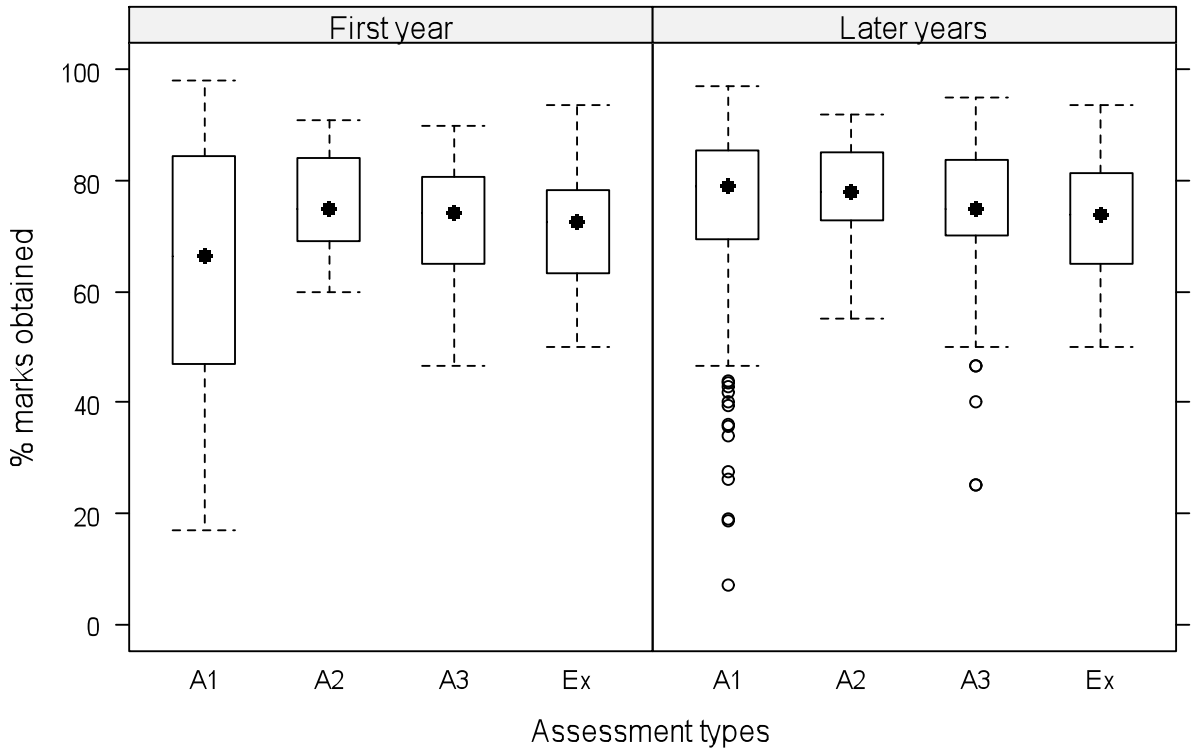
**Figure 3: Students' performance in different assessment tasks, grouped by discipline**

Useful information about students' performance came out of the study. For example, those students undertaking information and communication technology programs performed extremely well in the assessment tasks designed to assess their ability to apply GIS to a real-world problem. These students found GIS application interesting and easy. Moreover, these students made use of their existing computer expertise – such as in programming or web design – in their GIS work. However, their performance in the exam was worse than on the other assessment tasks. A similar trend was noticed among students undertaking engineering degrees. The benefits of the two flexible assignment-based tasks were also noticed among education students, who performed well in the task designed to assess the application of GIS to the real world.

In addition, students' marks were analysed with respect to their year of study. A comparison was made between first-year students and the higher-level students (see Figure 4), which showed the significant influence of the students' level on their performance in the first two assessment tasks as well as on their final marks (see Table 4). This analysis of students' performance in the course indicates that initially the first-year students had trouble adjusting to the course; however, after several opportunities for feedback they performed well in the later parts of the course. Outliers towards poorer performance were noticed in the students' marks for the first assessment task (weekly quizzes) and the third assessment task (Assignment 2) (Figures 3 and 4).

One of the suggestions of researchers regarding assessment is to orient students to distribute appropriate amounts of time and effort across all the important aspects of the course (Boud, 2010; Gibbs & Simpson, 2004). The variety of assessment tasks used in this study, together with the variation observed in the students' performance across the various assessment tasks, clearly demonstrates that the students were engaged in a variety of learning activities covering diverse aspects of GIS. The variety of assessments accommodated different ways of learning among students with different backgrounds, which has been recognised as important (Joughin, 2010). Another aspect of assessment that has a great influence on learning is the feedback provided to students (Boud, 2010). In this course, three out of four assessment tasks provided opportunities

for the provision of specific and targeted feedback to students. The weekly quizzes provided timely and early feedback to students. This study has indicated that, as first-year students were weakest on this assessment task, more attention will need to be paid to this group of students in future years.




A1 Weekly quizzes; A2 Assignment 1; A3 Assignment 2; Ex Examination

**Figure 4: Students' performance in the different assessment tasks, grouped by level of study**

**Table 4: Probability of influence of students' level of study and disciplinary background on their performance in different assessment tasks, obtained through analysis of variance (ANOVA)**

| | Quizzes | Assignment 1 | Assignment 2 | Exam | Total marks |
|---|---|---|---|---|---|
| **Program** | 0.942 | 0.631 | 0.516 | 0.183 | 0.901 |
| **Level** | 0.001[a] | 0.083[b] | 0.328 | 0.121 | 0.007[a] |
| **Interaction** | 0.130 | 0.141 | 0.917 | 0.674 | 0.377 |

| | | | | | |
|---|---|---|---|---|---|
| **between program and level** | | | | | |

a Significant at <0.01; b Significant at <0.1

The two-part assessment (Assignments 1 and 2) enabled students to act on the written and verbal formative feedback provided during the course. This feedback was not only specific to each student but was also 'forward-looking', leading them on towards the next assessment task. Such feedback has been described as an essential component of learning-oriented assessment (Boud & Falchikov, 2006). Furthermore, the one-on-one discussions with their tutor encouraged the students to request specific feedback, as well as giving their tutor another opportunity to informally assess any knowledge or skill gaps. Another advantage of the two-part assessment task was that it encouraged students to use both their prior knowledge from their respective discipline area and their newly learnt GIS skills in a real-world context. Research in psychology has suggested that human learners are not passive information-storage systems (Shuell, 1986) but rather self-determining agents who actively select information from their environment and construct knowledge in light of what they already know (Shuell). A problem-based learning approach has also been found useful in teaching GIS to people from different backgrounds and skill levels (Dias, 2004). This informed the design of student choice of assessment tasks (Figure 2), and provided students with an opportunity not only to learn about GIS application but also to acknowledge the limitations of the technology.

## Conclusions

The use of GIS will become even more widespread in coming years, as the technology becomes cheaper, more freely accessible and easier to use. These skills will need to be acquired by learners from many disciplines. We are also moving towards an era of 'volunteered GIS' (VGIS), in which individual citizens are acting as 'sensors' for the collection of geographic information worldwide (Goodchild, 2007). It is therefore vital for people to learn to use these tools and have a good understanding of the concepts behind them. A combination of diverse assessment tasks within the curriculum is a key aspect of teaching GIS to students with diverse backgrounds and levels of understanding.

This study clearly demonstrates that a student's disciplinary background is not a major factor when assessment tasks are judiciously designed. The only factor that was found to significantly affect students' performance was their current level of study experience. It was observed that first-year students substantially underperformed across different assessment tasks. Such a finding highlights the need for early identification of underperforming students and better curriculum design to support them in this introductory GIS course in coming years. A similar approach could be adopted for introductory GIS courses offered in other universities throughout the world, as well as in the teaching and assessment of other multidisciplinary areas.

Assessment is acknowledged as a major influence on student learning in all course design and development, and is recognised as being more effective when it reflects an understanding of learning as a multidimensional, integrated and continual process that is revealed in students' performance over time (Boud & Falchikov, 2005). An effective assessment regime for successful GIS education can be achieved through a combination of diverse assessment tasks covering different aspects of the discipline, and the entire process can be considerably accelerated with the incorporation of opportunities for feedback at different stages.

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