Niem Tu Huynh received Honorable Mention in *RGE's* Early Career Scholar Paper Competition. Her paper is below.

GIS Instruction: Learning from Student Perception of Concept Difficulty

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Abstract

The focus of this study is on students' perceived difficulty of GIS concepts and this research is guided by three related research questions: 1) What are students' perception(s) of the difficulty level of geography and GIS concepts?, 2) What patterns of student perception, if any, exist?, and 3) How do the findings inform instructional strategies in a GIS class? The analytic process drew on two mathematical approaches, multidimensional scaling (MDS) and minimum spanning tree (MST). These analytic methods project and compare the data spatially which allows for a visual assessment of the emerged clusters. The preliminary findings identify groups of simple and complex concepts and suggest instructional strategies. Two trends are evident from the results. The first is that students generally agree on the difficulty level of concepts; those ranked more similarly are grouped within a cluster. For example, students found data manipulation (e.g., categorization of data, identification as spatial/non-spatial), geodesy, datum, coordinate systems, geocoding, and neighborhood functions especially difficult. The second trend is that concept clusters are loosely aligned with overall student performance. For example, students do better on concepts they rank as "easy" compared to those they perceive to be "difficult" although anomalies exist. The practical application of the results is to devise in-class exercises that add meaning to theoretical topics and to engage students with hands-on activities.

Keywords: GIS instruction, GIS learning, student perception, hands-on activities

Introduction

To compete in today's economy, employers have high expectations of employees' skills, knowledge, and education level (AACU, 2009). More specifically, a majority of employers and CEOs agreed that graduates should have *broad* as well as *in-depth* knowledge and skills. With the advent of public geographic tools and proprietary geospatial analysis software, geography is in an excellent position to impart future employees in comprehensive content and skills to compete in the growing industry of geospatial technology. Between 2008-2018, the industry is projected to add 339,900 positions (DiBiase et al., 2010) with a revenue that has already increased 12.6% from 2004 ($2.4 billion) to 2008 ($4.3 billion). Thus, geography instructors have a role to play in supporting student performance and preparation for a professional career in geospatial technology.

Classes with a technique component (e.g., laboratory, calculator, computer software) merge theory, knowledge, and skills. Students are required to learn how to use the equipment, understand the content, and demonstrate *how* and *when* to apply the equipment to the content. Thus, foundational, declarative, and procedural knowledge each play a role in learning to use and apply GIS. This process of learning is common in lab based courses, such as in the sciences (e.g., biology, chemistry, and physics) and mathematics, but less common in the social sciences. Within this traditionally technical and application oriented discipline, geography is an exception as physical geography has commonly relied on a range of tools to extract and analyze data. Since the rise of computation speed and accessibility, Geographic Information

Systems (GIS) is recognized within geography as well as across disciplines as an important analytical tool (Haque, 2003; Mennecke, Crossland, & Killingsworth, 2000; Sambhamurthy & Chin, 1994).

GIS and geography are associated by a common link, spatial thinking, while GIS integrates elements of reasoning aligned with processes developed in geography (Bednarz, 2004; NRC, 2006; Self & Golledge, 1994; Self, Gopal, Golledge, & Fenstermaker, 1992). This close tie sees GIS classes to be primarily taught within a geography department, but they may also be found in cognate disciplines, such as planning or environmental studies. GIS instruction is in a different position from other lab based physical courses for several reasons. First, GIS classes at universities are usually offered at the sophomore or junior level limiting the number of years and courses that can be taken at higher years. At the school level, since geography is not tested nationally each year, like reading and mathematics, its instruction varies by state mandate (see Grosvenor Center for Geographic Education, 2010 for a summary). These reasons and others may influence the slower than expected proliferation of GIS and related geospatial technologies in the school system (Kerski, 2003; Milson & Kerski, 2012; Milson & Roberts, 2008) although improvements have resulted from freely available teaching resources (Baker, Palmer, & Kerski, 2009) as well as Internet based GIS (e.g., ArcGIS Explorer Online). Despite efforts to integrate GIS into the state curriculum and to increase its visibility in the learning environment, teachers are still confronted with barriers, new and old. Surveys, conducted in the 1990s to present, point to such challenges as access to computers, support of administration, time to teach GIS in a crowded curriculum, and teacher preparation (Bednarz & Audet, 1999; Kerski, 2003; McClurg & Buss, 2007). Milson and Kerski (2012) identify a new issue to contend with, students' ability to reason spatially. Of these challenges, students geographic and GIS declarative knowledge is central to this paper.

The authors are interested to learn what geography and GIS concepts, within a GIS learning context, students deem to be difficult and whether any patterns or relationships exist. With this information, the authors are equally interested in determining how instructional approaches make learning with GIS more effective, a research question borrowed from Howarth and Sinton (2011). The paper is guided by three related research questions: 1) What are students' perception(s) of the difficulty level of geography and GIS concepts?, 2) What patterns of student perception, if any, exist?, and 3) How do the findings inform instructional strategies in a GIS class?

The literature review provides a broad overview of GIS curriculum organization that sets the stage for past and current ideas on GIS instruction design. This is followed by the methods section which describes the data collection and analysis approaches. The results are presented in the analysis section, followed with a discussion of their meaning and implication for GIS instruction.

Literature Review

A GIS class has competing demands on students: knowledge of geography content, GIS theory, and proficiency with the GIS software. Thus, at least three fundamental instruction issues exist, namely the scope and sequence of course design, method of instruction, and the assessment of effective instruction methods and student learning (Howarth & Sinton, 2011). The task of teaching a GIS class is compounded by new software interfaces and the number of operations available. For example, ArcMap 10.0 has 615 operations in the Toolbox (Goodchild, 2011), making the interface organization a difficult task (Goodchild, 2011) but equally confusing for novice users or even for expert users familiar with an earlier version. In this multitasking setting, instructors rarely have opportunities to think about how students of different levels and learning styles are acquiring the information, about their students' learning process, and about the application of core concepts to solve problems (Howarth & Sinton, 2011).

The introduction of GIS to education began in undergraduate geography 25 years ago, followed by secondary school geography courses, as a new method to teach geographical knowledge through spatial analysis and problem solving (Crechiolo, 1997; Storie, 2000). Early GIS-based geography courses were dominated by such common elements as 1) the nature of geographic data and geographic data collection, 2) geographic data analysis and data display, 3) database management, and 4) types and uses of GIS (Morgan, 1987). However, it was felt that a lack of fluency and understanding of spatial language and concepts created over-reliance on software and lowered the effective use of GIS (Walsh, 1992). By the early 1990s, GIS-based geography curricula integrated components of geography, usually in the form of cartography (Walsh, 1992) and geographical problem-solving and data analysis (King, 1991).

The literature offers suggestions on how to prioritize GIS topics. Since the introduction of GIS to higher education, many teaching models have been proposed, ranging from undergraduate designs taken from a particular university or company practice (Burns & Henderson, 1989; Carver, Evans, & Kingston, 2004; Goodchild, 1985; Mueller, 1985; Nyerges & Chrisman, 1989; Walsh, 1992), to broad theoretical models (Frank & Raubal, 2001; Kemp, Goodchild, & Dodson, 1992; Marble, 1997; Sui, 1995; Wikle & Finchum, 2003), to observations and commentaries (Goodchild, 1985) and tutorial design (Hubeau et al., 2011). These efforts formed the foundation that led to several GIS education and training collaborative movements, providing a roadmap for GIS education: National Center for Geographic Information and Analysis (NCGIA) GIS Core Curriculum (NCGIA, 2000), GIScience and Technology Body of Knowledge (DiBiase et al., 2006), and the Geospatial Technology Competency Model (GTCM) (DiBiase et al., 2010).

Despite such detailed curricula plans devised by expert opinion and experience, there is no standard or defined pedagogy of GIS teaching (Goodchild, 1985; Morgan, 1987) and little consensus on prerequisite courses (Chen, 1998; Goodchild, 1985; Morgan, 1987). A small but growing research niche may provide empirically grounded recommendations on GIS instruction, particularly the sequence of concept introduction. Early suggestions by Golledge and Stimson (1997) provide a link between spatial relations (e.g., overlay, recognizing spatial distributions and patterns) with GIS activities. Studies on a core set of geography and GIS concepts indicate that students have difficulty with such topics as projection (Anderson & Leinhardt, 2002; Battersby & Montello, 2009) and overlay (Albert & Golledge, 1999; Battersby, Golledge, & Marsh, 2006; Huynh & Sharpe, forthcoming; Lee & Bednarz, 2009). These findings lend support to a hierarchy of geospatial concepts, relating to geography and GIS application, ranging from simple to complex (see Golledge, Marsh, & Battersby, 2008; Marsh, Golledge, & Battersby, 2007). This hierarchy is based on empirical data and expert knowledge, however, more research is needed to test the proposed order. This study adds to the literature by examining concepts within the hierarchy using another set of data, students' perception and performance of GIS concepts. This pilot method is being tested here for its value to informing the arrangement of the Golledge et al. (2008) hierarchy. The broad implication of the findings is to suggest interventions, such as in-class activities for complex or difficult concepts. The pilot activities are similar to suggestions from Howarth and Sinton (2011). One example Howarth and Sinton (2011) suggested is to provide a working example and solution as these benefit students without prior experience. The second suggestion is to use physical models to illustrate a concept, a method common in Science, Technology, Engineering, and Mathematics (STEM) disciplines and geography, but less so in teaching GIS.

Methods

Survey development

The survey (Appendix A) includes only topics taught in an undergraduate introductory GIS class and covered in the course textbook [*GIS Fundamentals: A First Text on Geographic Information Systems,* (3rd ed.) by Bolstad (2008)]. The pilot survey, created in Fall 2009, was compared against the NCGIA GIS Core Curriculum and the GIScience and Technology Body of Knowledge to ensure that survey categories or topics were represented in these GIS curricula. The topic sometimes varied in scale but the overall ideas were similar and were covered within the four documents. The pilot survey was then sent to three GIS colleagues to review the logical arrangement of topics within each category. Finally, feedback on the pilot survey was solicited at a department lunch presentation in Fall 2009. Participants, composed of graduate students and faculty, participated (approximately 10 total in attendance) in the process, each with research or teaching experience in GIS or Remote Sensing. The audience was asked to complete the survey which was followed by a round table discussion of suggestions for improvement.

The survey consists of six broad categories and a list of concepts or topics within each category. The categories included 1) Data, 2) Map Projection and Coordinates, 3) Raster and Vector Data Models, 4) Database Models, 5) Non-spatial Raster and Vector Operations, and 6) Spatial Raster, and Vector Operations. Students were asked to rank each concept for its level of difficulty such that each number is used only once within each category. Since the number of concepts within each category is different, the number of ranking options reflects this. For example, Category 2 has 9 concepts, thus, the scale ranges from 1 (easy) to 9 (difficult). This is different from Category 4 which has 4 concepts and a scale ranging from 1 (easy) to 4 (difficult).

Participants

Three sets of data were collected from students enrolled in two introductory GIS classes. Two datasets were collected during the final exam in Spring 2010: 1) perception of concept difficulty, and 2) value of in-class activities. The third dataset included itemized midterm and final exam scores. At the end of the final exam, students were invited to complete an anonymous survey in exchange for attendance credit. Since it was voluntary, all students present received credit regardless of the survey completeness. Sixty-four students participated but surveys from only sixty-two students were sufficiently complete for analysis. Participants came from separate GIS classes, taught by two different instructors. In order to maintain consistency between the classes, identical lessons and in-class work activities were distributed at the same time in the semester. For comparison of student performance, the assessment questions were identical. Class demographics were collected to provide a general description of the participants in the study. The class was primarily composed of an equal number of juniors and seniors (n = 24 or 38.7%) with a smaller proportion of sophomores (n = 14 or 22.5%) at an average age of 24 years old. The class was approximately one-third female (n = 22) and 64.5% male (n = 40). The students' self-reported grade point average was 3.02 (out of 5.0). The racial profile was predominantly white (69.3%), followed by Hispanics (14.5%), Other (8.1%), Asian (3.2%), and Black (1.6%). Compared to student demographic data from Fall 2009, the age and gender distribution of participants in this study are representative of the undergraduate student population in the department. Female enrollment in the geography department is approximately 30.3% compared to the university of 53.4%. In terms of age, juniors (23.8 years old) and seniors (25.3 years old) in the department are slightly older than the university average, 20.6 and 23.9, respectively. Students were primarily geography majors (82%) focused on one of nine broad areas offered in the department and minoring in a related geography topic or a cognate field (e.g., anthropology, biology). A minority of students (18%) majored in other subjects (e.g., mass communication, political science, mathematics) often with a minor in geography.

Data Analysis

The data were analyzed using two mathematical procedures: multidimensional scaling (MDS) as a dimension reduction technique (Buja et al., 2008) and a minimum spanning tree for clustering (Jain & Dubes, 1988). These analyses methods transformed the students' ranking of each concept into a point in a 62-dimensional space, each dimension representing a student (62 students responded). First, MDS compares a category of concepts (e.g., data) across all students to determine the extent of similarity in responses. Similarity is calculated by the distance between the responses of each student. The shorter the distance, the more similar the answers. The data were then reduced to three-dimensions for visualization and clustering. MST clusters similarly ranked concepts as identified by MDS. These analytic methods project and compare the data spatially which allows for a visual assessment of the emerged clusters. Although an average of ranked concepts may be another approach, a limitation is how to determine cut-off scores to group most similar concepts. Hence, this paper suggests another way to group like-concepts together by comparing their similarity with a quantitative approach (MST) as well as interpretation of concept similarity in a three-dimensional space (MDS). An extra step to normalize the data was necessary as the difficulty range of the scales were not consistent (See Appendix B for key steps of this analysis).

GGobi outputs overlaid with student performance in percentage, were computed from the data collected for each of the six categories of the survey (Figures 1 to 6). Points that are connected by lines form a cluster, each cluster indicating that the concepts were ranked more similarly in terms of difficulty level than points within other clusters or isolated points. Points that are not connected to a cluster were ranked too different to belong to a group. Since the images from the three-dimensional space (step 5, Appendix B) are presented here in the plane (two-dimensions), the distances between points in the figures are distorted and do not represent the dissimilarities in levels of difficulty between the points. The dissimilarities are easy to view in GGobi software since it allows the user to interactively rotate and manipulate the network in various ways to reveal patterns and other structural details.

Within each image, a percentage label is adjacent to a concept. This percentage is an average of student performance across both classes. Since some concepts are tested only on the midterm or final exam while other concepts are tested across both, a rule was followed to determine student performance. If a concept appeared in both sets of exams, only the scores from the final exam were used to calculate mean student performance. The rational is that student performance should be at least comparable to the midterm score as this was the second time tested. Furthermore, there is temporal consistency as the survey was taken at the time of the final exam. If a concept appears in only the midterm or the final exam, then the average performance will be taken from whichever exam the question(s) appears in. Some concepts have no performance information because they were not tested explicitly, some reasons are offered: 1) concepts were better evaluated in the lab setting than on a written test (e.g., geocoding), 2) the concept was a minor element in the course, or 3) there was insufficient time to discuss the concept in depth for testing (e.g., SQL).

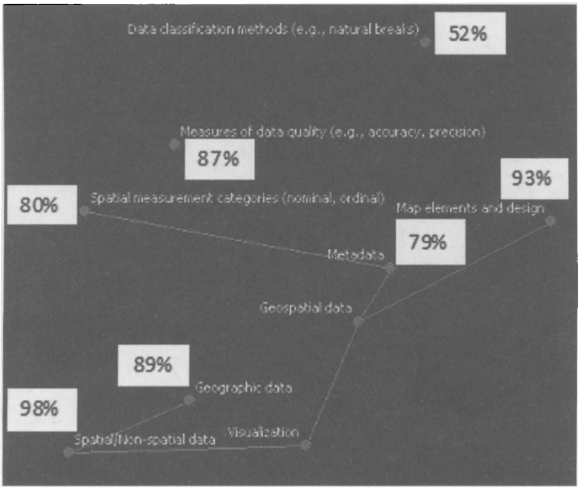
Table 1 summarizes the concepts grouped within each cluster as identified from GGobi, described above. The final row in this table reports the average difficulty score reported by students. The dataset used was that of students' reported perception of concept difficulty. Table 2 reports the average score of students' perceived value of in-class activities. The numbers are calculated by student ranking of four in-class activities for their educative value (1-not relevant, 6-relevant).

Results and Discussion

This section is organized around the three guiding research questions. To support the discussion, Figures 1 to 6 and their corresponding summary table illustrate, 1) clusters of concepts ranked along a similar difficulty level, 2) the average difficulty score for each cluster and each isolated point, and 3) the difficulty ratio is normalized to account for different ranking scores (e.g., 1 to 4, 1 to 9, or 1 to 11).

The first research question concerns students' perception(s) of the difficulty level of geography and GIS concepts. Their self-efficacy, based on their ranking of concept difficulty, provides information on concepts perceived to be challenging. Self-efficacy is described as a student's belief in their capability to perform a task (Fast et al., 2010). Students generally agree on the difficulty level of concepts. They found data manipulation (e.g., categorization of data, identification as spatial/non-spatial) (Figure 1), geodesy (Figure 2), datum (Figure 2), coordinate systems (Figure 2), geocoding (Figure 3), and neighborhood functions (Figure 6) especially difficult. Students' assessment of "neighborhood functions" can be explained by little class and lab time spent on the topic. In the case of geocoding, students may have ranked it as difficult because it is time consuming to perform in the lab and there are multiple concepts to understand. Geocoding demands precision, time, and general understanding of address assignment thus students may have applied "difficulty" of the task to "difficulty" understanding the concept. It is clear that some concepts, despite formal lecture, class exercises, and hands-on practice on labs, still pose confusion for students. These include data manipulation, geodesy, projection, and coordinate systems (especially false easting and northing).

The second question is about patterns of student perception. Patterns emerge when concepts that are ranked along a similar spectrum are grouped into a cluster. Table 1 summarizes these clusters and the concepts within. Clusters 1, 3, and 4 rank 4.0+ on a scale of 5.0 (difficult). These concept groups may be difficult because they are new to students (e.g., topology, geospatial data), too large a scale to have experienced in daily life (e.g., map projection), and difficult to spatially reason with (e.g., datum). Table 1 is the beginning of a hierarchy of GIS concepts by clusters, simple to complex, as

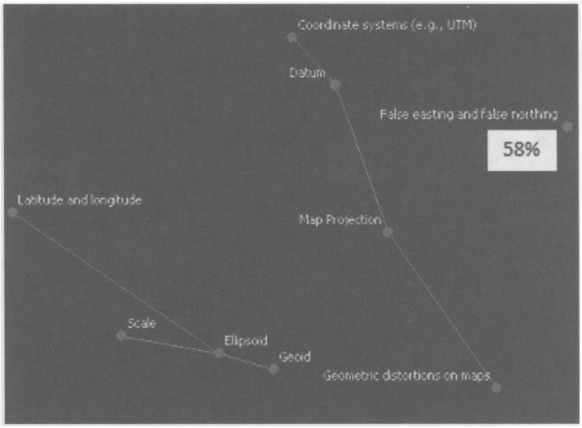


Concept	Difficulty (D) (out of 9)	Difficulty Ratio (D/9)
Data classification methods	3.7	0.41
Measures of data quality	3.9	0.43
Cluster 1	4.9	0.54

Figure 1. Category: Data

perceived by students. The conception is modeled after the work of Golledge et al. (2008) which provides a continuum of primitive (simple) to complex geospatial concepts, however, these are not based on empirical data. Table 1 provides an experimental way to order groups of concepts based on reported difficulty. These clusters may suggest that more time be spent on difficult groups of concepts or perhaps scaffold on a foundational cluster that is perceived to be more simple. Future research in this area requires a more robust and improved dataset to provide a hierarchy of individual concepts.

Another pattern observed is that concept clusters are loosely aligned with overall student performance. For example, students do better on concepts they rank as "easy" compared to those they perceive to be "difficult." For example, Cluster 2 (coordinate systems, datum, map projection, and geometric distortion on maps) in Figure 2 is deemed to be more difficult than any concept in the category, and has the poorest performance. Overall, the concepts identified to be difficult in this study match those identified in the geography literature including buffer (Golledge et al., 2008), coordinate system (Downs & Liben, 1991), projection (Anderson & Leinhardt, 2002;

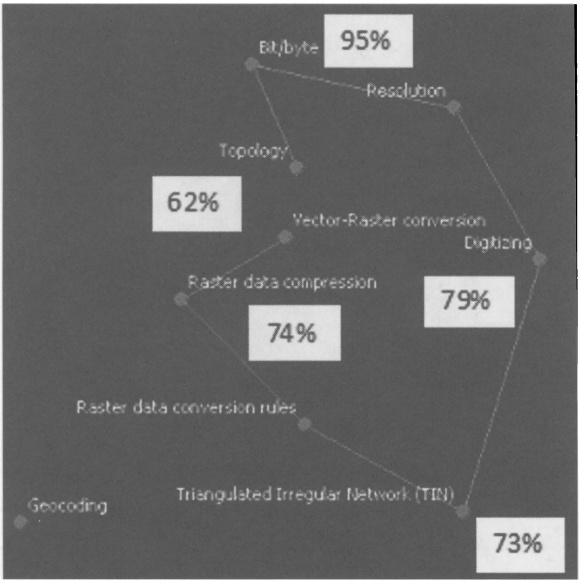


Concept	Difficulty (D) (out of 9)	Difficulty Ratio (D/9)
False easting/northing	4.7	0.52
Cluster 1 (Geoid . . .)	2.8	0.31
Cluster 2 (Coordinates . . .)	4.1	0.46

Figure 2. Category: Map Projection and Coordinates

Downs & Liben, 1991; Olson, 2006;) and overlay (Albert & Golledge, 1999; Battersby et al., 2006; Oda, 2011). Based on student performance below 60%, the minimum passing grade at the authors' institution, other concepts of difficulty found in this study include data classification (Figure 1), false easting and false northing (Figure 2), datum (Figure 2), intersect (Figure 6), and spatial join (Figure 6). Overall, the concepts related to map projection and coordinate systems pose a greater challenge to students than other categories. Hence, there is a need for innovative and novel ways to introduce these theoretical concepts beyond textbook reading and lecture, such as using a model representation suggested by Howarth and Sinton (2011).

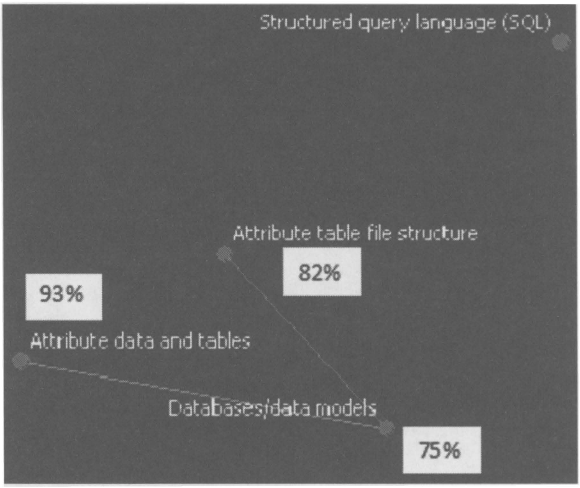
Some interesting anomalies are worthy of discussion. In Figure 6 students ranked geoprocessing operations (e.g., buffer, overlay) to be fairly easy, however, the percentage of performance accuracy is low. The only exception is "clip." A review of both sets of exams reveals that "clip" was assessed with a multiple choice question, straightforward, and similar to some of the activities practiced in class. The other geoprocessing operations (e.g., buffer, intersect, overlay) were also tested in a multiple choice format but the question was problem-based. This suggests that students perceive individual



Concept	Difficulty (D) (out of 9)	Difficulty Ratio (D/9)
Geocoding	5.6	0.62
Cluster 1	4.4	0.49

Figure 3. Category: Raster and Vector Data Models

operations to be simple, but when applied to a problem, students are not as successful. Thus, student performance depends on the question format. These findings lead to the final research question that makes suggestions on how these findings provide effective instructional strategies in a GIS class. Ideas presented are based on pilot exercises, compiled student comments, and two key observations over three semesters. First, students tend to do better on straight forward, isolated and non-contextualized questions, such as the clip question. Second, performance dips when students are asked to solve the same question but within a problem-based setting. The conclusion is that concepts perceived to be "easy" may not actually be such when situated in a problem-based question. Thus, a range of assessments should be used to test students' knowledge on "easy" and "difficult" concepts. In this class, assessments measure a spectrum of thinking levels with three question types: multiple choice, short answer, and problem-based. Below are example questions that test for the concept "projection" across three formats.

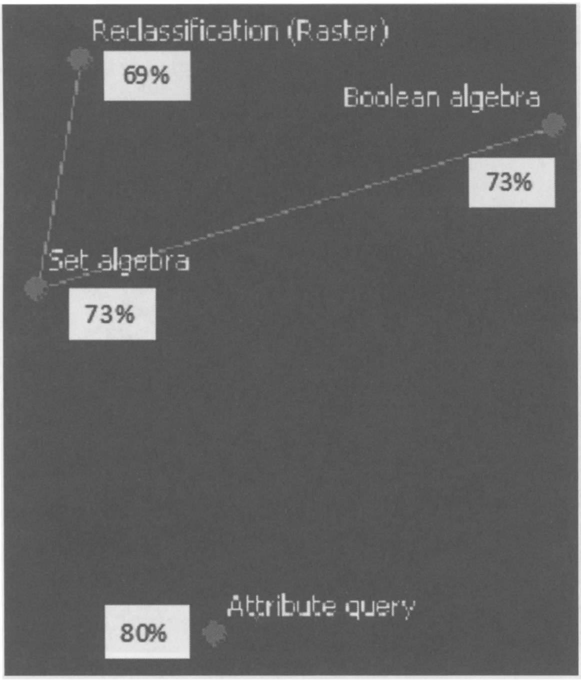


Concept	Difficulty (D) (out of 4)	Difficulty Ratio (D/4)
SQL	2.8	0.70
Cluster 1	2.2	0.55

Figure 4. Category: Database Models

- *Multiple choice:* Which of the following image represents the map projection used to create the UTM coordinate system? (provide 5 images of different projections)
- *Short answer:* The basic projection (state full name) that produces the least amount of distortion for the state of Tennessee. (include image)
- *Problem-based question*: You have downloaded a collection of georeferenced files from various sources. When you add them to a GIS, you notice that some appear on screen in their correct location, some appear but are far from their actual location, and others are absent. Speculate what the problem is and propose a solution.

Each cluster suggests the relative perceived ease or difficulty of a concept compared with related topics (Table 1). Hence, interventions to support student learning on the most difficult concept or a set of concepts within a cluster can be developed. Pilot activities were developed for concepts identified as difficult in the literature and based on the first author's teaching experience. Students' feedback to five such active learning exercises are posi-

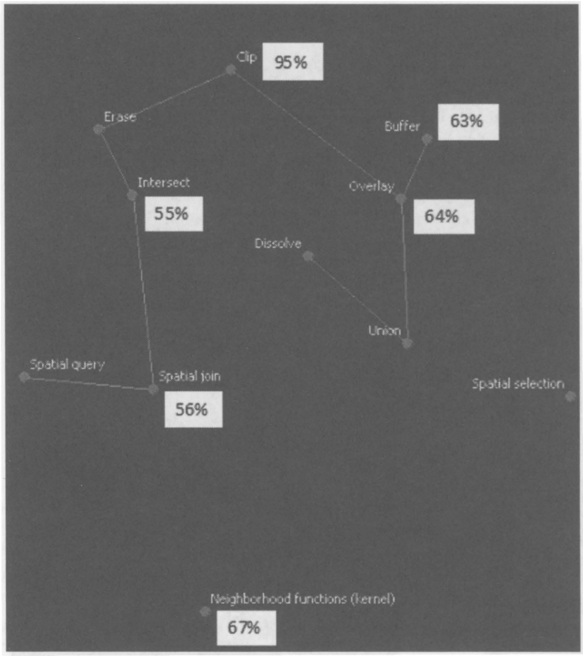


Concept	Difficulty (D) (out of 4)	Difficulty Ratio (D/4)
Attribute query	2.2	0.55
Cluster 1	2.8	0.70

Figure 5. Category: Non-spatial Raster and Vector Operations

tive, each briefly explained (Table 2). The ranking for each activity ranges from 1 (not useful) to 5 (very useful). These four exercises have been piloted along with many other in-class activities and are illustrated here because they are well received by students and provide an engaging way to discuss four challenging topics. Students' comments on these activities are summarized in Appendix C.

- *Projection*: The lecture on projection discusses three types of projection surface (cylindrical, conical, and planar projection) and four types of aspects (polar, equatorial, transverse, and oblique). To translate theory to practice, students work in a small group of three to five peers. Each group is given a piece of tracing paper, a blow-up globe, and a felt-tipped marker. First, a demonstration is given on



Concept	Difficulty (D) (out of 11)	Difficulty Ratio (D/11)
Neighborhood functions	5.5	0.50
Spatial selection	3.8	0.35
Cluster 1	3.8	0.35

Figure 6. Category: Spatial Raster and Vector Operations

how to fold the paper around a globe. Then, each group is given a different projection surface and aspect type to begin drawing. After 10 minutes, students of the same projection type come together to generalize distortions observed on the unfolded tracing paper.

- *Topographic map*: Students generally claim knowledge and ability to read a topographic map. Theoretically, they know how to read a topographic map, but practically, they are confused by multiple coordinate systems on the map (Latitude and Longitude, State Plane, UTM).
    - Students work in a pair, each group is given a topographic map of the local region. They are then asked to locate coordinates from UTM, State Plane, and Latitude and Longitude

Table 1

Summary of easy-to-difficult concept clusters.

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Spatial measurement categories	Latitude and longitude	Coordinate System	Topology	Attribute table file structure	Reclassification	Spatial query
Map elements and design	Scale	Datum	Bit/byte	Attribute data and tables	Boolean algebra	Spatial join
Metadata	Ellipsoid	Map projection	Resolution	Database/data models	Set algebra	Intersect
Geospatial data	Geoid	Map distortion	Digitizing			Erase
Geographic data			TIN			Clip
Spatial/non-spatial data			Raster data conversation rules			Overlay
Visualization			Raster data compression			Union
			Vector-raster compression			Dissolve
						Buffer
Perceived difficulty (1-easy, 10-difficult)						
4.2	2.8	4.1	4.4	2.2	2.2	3.8

Table 2

Ranked usefulness of in-class activities.

	N	Minimum	Maximum	Mean (/6)	Std. Deviation
1. Projection	63	1.00	6.00	4.6508	1.10947
2. Topographic map	57	3.00	6.00	4.9474	1.00749
3. Group exercises	64	1.00	6.00	4.9375	1.18019
4. Geoprocessing w/transparencies	58	3.00	6.00	5.1207	.83933

coordinate systems as well as to identify landmarks from given coordinates. Students were also asked to measure the distance between two points using the map scale.

- *Group exercises*: These are activities that engage the whole class of approximately 45 students. For example, a map will be shown on the screen and students will be asked to critique it. This is an excellent exercise to review map elements but also to actively apply cartographic principles.
  - Another exercise is to understand how a raster and vector model represent the same dataset or environment differently. An image is shown on the screen. Students are asked to draw the same image in a vector model using only points, lines, and polygons followed by a raster model using greyscale shading on a grid.
- *Geoprocessing operations*: Students work in a small group to practice identifying geoprocessing operations. The questions range from identifying the operations to drawing an expected outcome given two layers and a geoprocessing operation.

Although some preliminary results have meaning and implication to GIS instruction, the findings may be limited by the sample size and nature of data collected. Since the data and technique is exploratory, it is unknown whether the sample is sufficient to make any general conclusions outside of the two GIS classes. Nevertheless, the authors encourage fellow researchers to replicate and extend this study to probe further best teaching practices in GIS. Another issue is that the Likert scale used to determine concept difficulty was not uniform across each category, thus a normalization calculation was performed. Future data collection should aim for a robust dataset and ensure that the scale is consistent for all categories tested. With these two prerequisites, the mathematical methods and dataset proposed have the potential to complement research on specific geography and GIS concepts, providing further empirical support to Golledge et al.'s (2008) hierarchy.

Conclusion

This study aims to understand how student perception of concept difficulty may be tied to their performance on those same concepts and what instructional outcome is learned. The results suggest several observations. First, student perception of concept difficulty is related to their performance. Second, concepts of similar difficulty level form in clusters and can be used as a gauge to allocate time for instruction. Finally, intervention can be useful to help students' experience through models, activities, discussion, and hands-on play.

It is important that students not only understand the concepts in their most simple form but are also able to apply multiple concepts to reason in a problem. The importance extends beyond a passing final grade; student knowledge and competency are key to securing employment. Many of the concepts taught in a fundamental GIS course are building blocks for advanced GIS courses as well as competency for a professional career in the geospatial technology industry. For example, geoprocessing operations are deemed to be very important (2.5 out of 3, 3 being very important), as are map elements and design (2.34), projection (2.6), scale (2.64), and digitizing (2.5) to list a few examples from a former study (Johnson, 2010). The literature on GIS education is rich in lesson plans and research on best teaching practices. An area in need of more coherent study, however, is the identification of geography and GIS concepts that pose a challenge to students. Only when there is an understanding of this can development of teaching strategies and interventions be tried and tested.

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Appendix A

In your view, please rank the difficulty level of each concept within each category.

1. Data

Very Easy 1 2 3 4 5 6 7 8 9 Very difficult

Spatial/Non-spatial data _____
Geographic data _____

Visualization _____
Geospatial data _____
Metadata _____
Measures of data quality (e.g., accuracy, precision) _____
Data classification methods (e.g., natural breaks) _____
Spatial measurement categories (nominal, ordinal) _____
Map elements and design _____

2. Map Projection and Coordinates

Very Easy 1 2 3 4 5 6 7 8 9 Very difficult

Latitude and longitude _____
Coordinate systems (e.g., UTM) _____
Datum _____
Map Projection _____
Ellipsoid _____
Geoid _____
Geometric distortions on maps _____
False easting and false northing _____
Scale _____

3. Raster and Vector data models

Very Easy 1 2 3 4 5 6 7 8 9 Very difficult

Vector-Raster conversion _____
Raster data compression _____
Raster data conversion rules _____
Triangulated Irregular Network (TIN) _____
Digitizing _____
Resolution _____
Bit/byte _____
Topology _____
Geocoding _____

4. Database models

Very Easy 1 2 3 4 Very difficult

Attribute data and tables _____
Databases/data models _____
Structured query language (SQL) _____
Attribute table file structure _____

5. Non spatial Raster and Vector operations

Very Easy 1 2 3 4 Very difficult

Attribute query _____
Set algebra _____
Boolean algebra _____
Reclassification (Raster) _____

6. Spatial Raster and Vector operations

Very Easy 1 2 3 4 5 6 7 8 9 10 11 Very difficult

Spatial selection _____
Buffer _____
Overlay _____
Dissolve _____
Union _____
Clip _____
Intersect _____
Erase _____
Spatial join _____
Spatial query _____
Neighborhood functions (kernel) _____

Appendix B

Step-by-step analysis of data with Multidimensional Scaling and Minimum Spanning Tree

1. For a category with n concepts, the i'th concept was modeled as a point (p_i) that exists in 62-dimensions (i.e., one response per student for 62 students);
2. The Euclidean distance $d(p_i,p_j)$ was computed for every pair of concepts i, j within a category to produce the matrix $(d(p_i,p_j))$; where $i = 1,\ldots,n$, $j = 1,\ldots,n$;
3. The matrix was input into GGobi as a dissimilarity matrix. GGobi is a graphical software tool for the exploratory visual analysis of graph data (Swayne, Buja & Lang, 2003);
4. Using the dissimilarity matrix GGobi maps the points (currently in 62 dimensions) into a space of lower dimension using multidimensional scaling (MDS), thus producing 3-dimensional coordinates for each concept. Three-dimensional coordinates were chosen as this dimension is easier to visualize and manage for interpretation, yet conserves scale of data. In particular, MDS attempts to find a configuration of points so that points that were far in the 62-dimensional space are also far apart in the 3-dimensional space;
5. For consistency between categories where the number of concepts was not the same, the data were normalized. For each category, the new distances generated by applying MDS in the previous step were divided by the largest distance between pairs of concepts in that category. Thus, the maximum distance for each of the six categories equals 1.0 which allows for a uniform method for finding clusters in a category. It should be noted that clustering is debated and is an open problem for data analysis as there is no generally accepted way to group or cluster points;
6. A minimum spanning tree (MST) was computed along with the mean and standard deviation of edge lengths in the MST. A MST (say T) of a network G is a subnetwork that has a minimum total weight among all subnetworks of G which span G (i.e., every point of G is incident with some line of T) and are connected (i.e., there is a sequence of point-edge-point moves connecting any pair of points). For example, if there are 9 concepts, T will have 8 lines (Chartrand & Zhang 2004).

At this state, any edge that is too long (i.e., if its length is greater than the mean + 1 standard deviation) were deleted.

Appendix C

Students were asked to answer "Comment on how the following exercises helped with your understanding of the concept/topic?" (direct quotes from students):

Q.1 Projection with globes and tracing paper

- Helped me visualize the distortions associated w/ different projections.
- It physically showed how projections affect the trueness of the world.
- It helped me view the concepts more spatially and practically as opposed to just reading it out of a textbook.

Q.2 Topographic Map Exercises

- It was good to really examine a topo map and get to answer questions.
- As a geographer, the ability to read/use maps is essential.
- Understanding topography is necessary for a geographer, so a quick update helped when in the lab.

Q.3 Group Activities

- Fun exercises. Helps to visualize and see how other students grasp concepts.
- Practical application and interactive.
- Elaborated, showed multiple perspectives on the topic.
- Made for a much more relaxed learning atmosphere.

Q.4 Overlay exercise/overlay with transparencies

- Good for visual learners.
- Helped to see what other GIS students made and their ideas, somewhat inspirational.
- Very useful exercise and I understood overlay much better after doing exercise.

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