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Concept Maps as a Tool to Analyse College Students' Knowledge of Geospatial Concepts

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Abstract

This study focused on college students' development of conceptual knowledge in geographic information system (GIS). The aim of this study was to examine if and how students developed their conceptual knowledge during their enrollment in an introductory-level GIS course. Twelve undergraduate students constructed 36 concept maps and revised 24 concept maps in three sessions. The author scored those 60 concept maps in two different ways. The first method measured the degree to which concept maps were structurally complex; the second method assessed the correctness of interrelationships between spatial concepts shown in the maps. A statistical analysis of the scores obtained through the second method suggested that there was a significant difference between the maps created in the first session and the maps revised in the second session. Students could successfully revise their original concept maps at the middle of a semester. A mix of the two quantitative and qualitative methods had the potential to examine the development of students' conceptual knowledge through multiple perspectives. Lastly, this study discusses how concept maps can be applied to research and instructions. Concept maps can be used for exploring students' understanding of spatial concepts.

Keywords

GIS Education, Spatial Thinking, Geospatial Concepts, Concept Maps, Assessment

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The purpose of this paper is to make two, related arguments. First, that it is essential that Geographic Information System (GIS) educators pay attention to, and explicitly teach the geospatial concepts that are the building blocks and language of GIS and second, that concept maps can be used to analyze students' conceptual knowledge. To begin, the author briefly discusses the role of geospatial concepts in GIS education. A review of previous research using concept maps follows. Then this paper reports on new research using concept maps focused on whether college students can improve their conceptual knowledge about spatial thinking while taking a GIS course. The paper concludes with a discussion of implications for GIS educators.

Background

When it comes to the effects of computer technology on students' learning, the discussion is varied among education researchers. Computer-based media provide more interactive communication than traditional media; as a result, students can understand difficult concepts easily and solve problems (Guerrero, Walker, & Dugdale, 2004; National Research Council, 2000). On the other hand, some educators anticipate that students tend to learn how to use computer technology and neglect fundamental concepts necessary for problem solving (Barak, 2004; Becker, 1993).

This dichotomy can be seen in GIS education. GIS is supposed to be a useful support system for spatial problem solving and decision making (Baker & White, 2003; National Research Council, 2006; Shin, 2006), GIS education, especially in introductory-level college courses. However, it tends to emphasize GIS operational and marketable skills and teach about GIS rather than with it (Brown, Elmes, Kemp, Macey, & Mark, 2003; Sui, 1995). In an unfavorable case, some GIS novices are overwhelmed by a series of GIS operations in a tutorial. They follow a GIS manual without thinking of what questions might be possible, why a step of an operation was necessary, and what outcomes were available. Even if they successfully obtain full credit for a tutorial, they would neglect the related fundamental concepts that are necessary for reading and interpreting maps and creating maps and spatial hypotheses. Worse yet, some students may complete a GIS course without attaining spatial thinking skills required for problem solving, information retrieval, and critical thinking (Thompson, 1991). As some people blindly trust outcomes brought about by calculators, some students are more likely to believe outputs brought about by GIS software without assessing them critically. Ironically, GIS software as a tool for assisting users' spatial thinking tends to become a substitute for the act of thinking spatially (Downs, 1997).

The advances in real-world GIS data availability, software and hardware usability, and geospatial technology accessibility has attracted a wide range of users and provided them with valuable outputs through spatial problem solving. As a consequence, people recognize that GIS is an effective tool for reinforcing students' spatial thinking competency (Goodchild, 2006; Kerski, 2008; National Research Council, 2006). Even though conceptual knowledge supports higher-order thinking such as problem solving (Howard, 1987), there is little empirical research on college students' conceptual knowledge in geospatial science (Baker et al., 2015). This study examined if university students developed their knowledge related to spatial concepts during an introductory-level GIS course.

Geospatial Concepts in GIS Education

Concepts denote the regularities of objects or events (Novak & Gowin, 1984) by generalizing multiple instances based on common critical attributes (Howard, 1987; Smith & Medin, 1981). For example, the concept of bird is a label that conveys some common characteristics found among the related species; the concept reminds people of the vertebrates that lay eggs and possess a beak, feathers, and wings typically for flying. As a result, concepts enable individuals to mentally separate examples from non-examples (Klausmeier, 1992) and utilize the concepts for communication or higher-order thinking such as problem solving (Ausubel, Novak, & Hanesian, 1986; Howard, 1987; Medin, Lynch, & Solomon, 2000). When it comes to spatial phenomena and relationships that can be observed at a mesoscale, a variety of concepts have been coined and used by geographers (DeMers, 2009). For example, cluster, density, diffusion, dispersion, distribution, and pattern are concepts for understanding and communicating regularities about spatially arranged geographic features. Concepts denoting geographic phenomena are called geospatial concepts (Golledge, Marsh, & Battersby, 2008).

There are three reasons why geospatial concepts should explicitly be taught in educational settings. First, geospatial concepts are one of the three elements that support people's spatial thinking. Geospatial concepts are intertwined with the other two elements of spatial thinking, which are representations and processes of reasoning, essential for decision making and problem solving related to spatial entities for various purposes, contexts, and disciplines (National Research Council, 2006). The second reason is that geospatial concepts are intensively and frequently used for obtaining two types of geospatial information through maps. First, geospatial concepts are used to interpret map features. For example, people identify locations by considering map scale (Liben & Downs, 1991), understanding spatial layouts or relationships (Uttal, 2000) and calculating distances, areas, and directions (Crosby, 1997). Second, geospatial concepts are used to understand geospatial information that is not explicitly represented in a map. Some information can be obtained only through map readers' spatial inference or reasoning. For instance, map readers uncover new relationships by overlaying multiple map features (Battersby, Golledge, & Marsh, 2006).

A third reason for introducing geospatial concepts explicitly in GIS education is some geospatial concepts essential for successful GIS use are not easily or casually learned through experience and should be taught systematically in a formal setting. Some concepts are simple enough to understand and work with. In contrast, other concepts are complicated and are compounds of simpler concepts. The ontology of geospatial concepts in terms of complexity has been studied by several researchers (Golledge et al., 2008; Golledge, 1995; Kaufman, 2004; Marsh, Golledge, & Battersby, 2007; Nystuen, 1968; Papageorgiou, 1969). Although the complexity levels of geospatial concepts are still a matter of discussion and research, Golledge et al. (2008) classified geospatial concepts into five levels and identified complicated or complex concepts such as association, buffer, distortion, scale, and projection. These concepts are essential for basic map interpretation and spatial analysis. However, students are not likely to understand those concepts fully and meaningfully unless they are taught explicitly.

Thus, geospatial concepts have a foundational role in GIS education. However, there is little empirical research on college students' conceptual knowledge in geospatial science. One note of caution: students do not come to the classroom tabula rasa. Geospatial concepts can be attained not only in the classroom but also in daily life. Students utilize their personal, informal conceptual knowledge, whether it complies with accepted and accurate understandings, for further knowledge development in formal settings such as the classroom. When students learn new concepts, they have to resolve and connect them with the concepts that they have already learned. Refining or restructuring conceptual knowledge occurs as a process of students' conceptual development (Ausubel et al., 1986; Rumelhart & Norman, 1978). Understanding what concepts students have attained so far and how they develop conceptual knowledge would give instructors insightful feedback for teaching.

Concept Maps for Assessment

Concept maps have been used by educators (Novak & Gowin, 1984) to evaluate students' conceptual knowledge in a range of subjects. For example, they were biology (Barenholz & Tamir, 1992; Jegede, Alaiyemola, & Okebukola, 1990; Martin, Mintzes, & Clavijo, 2000; Wallace & Mintzes, 1990), chemistry (Ross & Munby, 1991; Schreiber & Abegg, 1991; Wilson, 1994), physics (Roth & Roychoudhury, 1993), medical science (Mahler, Hoz, Fischl, Tov-Ly, & Lernau, 1991), statistics (Roberts, 1999), education (Beyerbach, 1988; Lay-Dopyera & Beyerbach, 1983), history (Herl & Baker, 1996) and geography (Oda, 2011; Rebich & Gautier, 2005; Walshe, 2008).

One of the reasons why concept maps have been used for research and assessment is that these constructions make visible how people connect and understand the concepts that they have learned. The main components of concept maps are concept nodes and labeled links (Figure 1). A concept node is connected to another concept node by a labeled link. This node-link-node composes a proposition, which is the minimum unit that can represent the meaning of a concept. Also, a crosslink is sometimes placed between two concept nodes at the lower hierarchy level. Sets of propositions are arranged in a network form to convey the ideas of the primary concept located at the top of a map. To construct a concept map, people recall concepts related to a primary concept, consider the attributes and relationships of these terms and arrange them meaningfully (Jonassen, Reeves, Hong, Harvey, & Peters, 1997; Wandersee, 1990). As a consequence, concept maps can effectively show how people cognitively interrelate concepts, and in a more efficient fashion for researchers than other assessment methods (Jonassen, Beissner, & Yacci, 1993; Ruiz-Primo & Shavelson, 1996; White & Gunstone, 1992). Although clinical interviews can also reveal students' understandings in depth (Walshe, 2008), a description in a linear fashion tends to be lengthy to convey a complex thought on relationships among multiple concepts. As for traditional assessment methods, multiple-choice exams usually require students to answer a considerable number of questions with little metacognitive reflection (Novak, 1998; Rebich & Gautier, 2005).

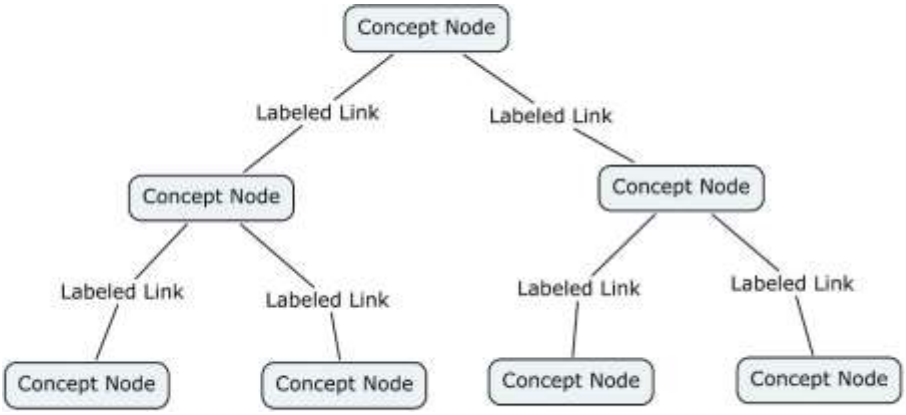

Figure 1. The components of a concept map

Two methods have typically been used to analyze concept maps. The first method (structural) is to count the number of map components such as concept nodes, links, propositions, and crosslinks (Novak & Gowin, 1984). For the Novak and Gowin (1984) scoring method, each level of hierarchy receives five points; each valid crosslink receives ten points. In contrast, both a valid proposition and an example receive only one point each. A valid crosslink is regarded as a good indicator of integration of multiple concepts (Novak & Gowin, 1984). Furthermore, this method has been modified by other researchers (Markham, Mintzes, & Jones, 1994; Stuart, 1985). In short, the structural scoring scheme emphasizes the complexity of hierarchical network forms reflecting well developed conceptual knowledge.

The second method (relational) places greater value on propositions than the first method. The fundamental assumption is that a proposition is a minimum unit of the meaning that can be judged regarding the validity of an interrelationship between two concepts (Ruiz-Primo, Schultz, & Shavelson, 1997). There are variations of scoring methods. Rice, Ryan, and Samson (1998) compared three types of proposition-based scoring methods. These three categories have the following different scoring criteria: (1) whether a pertinent concept exists, (2) whether a correct relationship between pertinent concepts exists; and (3) whether an incorrect relationship exists. Rice et al. (1998) concluded that the second criterion is the most useful as a class assessment because the scores obtained with the criteria correlated with scores on related multiple choice tests. Roberts (1999) modified the conventional scoring scheme by weighing the accuracy of propositions. There were several reasons why this modification occurred. Some concept maps included incorrect propositional links and links with no words. In this case, counting the number of map components would not work for incorrect propositions. Moreover, the concepts that could be used in concept mapping were assigned to subjects in advance. This methodological aspect made counting the number of concepts and propositions less significant. Ruiz-Primo et al. (1997) used a square matrix and a propositional inventory to score their concept maps by focusing on the quality of propositions. The matrix included all possible pairs between concepts; the propositional inventory was used to evaluate the variation in the quality of proposition with a five-level scale: valid excellent, valid good, valid poor, don't care and invalid. Rye and Rubba (2002) utilized expert maps in their concept map scoring. For the assessment of propositions, they examined the degree to which a novice's and an expert's map matched. The latter two studies adopted master models such as a propositional inventory and an expert map.

To summarize, students use geospatial concepts intensively in activities involving geospatial technologies like GIS and learn new concepts in formal classroom settings through building on their existing conceptual knowledge. Although some researchers have reported the use of concept maps in geography (Rebich & Gautier, 2005; Walshe, 2008), there is little empirical research on how educators assess students' conceptual knowledge in GIS. This study used concept maps as a tool to explore how students developed their conceptual knowledge and analyzed undergraduate students' geospatial concept maps by adopting the two scoring schemes: the structural and the relational.

Domain

This study focused on undergraduate students who enrolled in either of two introductory-level GIS courses offered at a large state university in Texas. The two courses were "GEOG 390 Principles of GIS" offered by the Department of Geography and "FRSC 461 GIS for Resource Management" offered by the Department of Ecosystem Science and Management. The author observed the lectures and laboratories of the two GIS courses to investigate when students learn specific GIS topics in the classes and when they perform various GIS activities in laboratories.

Although both GEOG 390 and FRSC 461 were introductory-level GIS courses, these courses differed from one another regarding philosophy. The fundamental stance of GEOG 390 was geography as the home discipline of GIS. The lectures and laboratory sessions in this course encouraged students to consider and understand the principles that exist behind knowledge and skills related to GIS. On the other hand, the fundamental stance of FRSC 461 was GIS as an enabling technology for science. This course emphasized scientific inquiry and applications in resource management through lectures about geospatial tools and a final project that involved problem solving. Although the two courses varied in philosophy, there was a commonality regarding GIS topic arrangements in the lectures and laboratory sessions (Tables 1 and 2). Both the courses above focused on GIS core competencies and knowledge and the cartographic aspects of GIS in the first half of the semester. In the latter half of the semester, both courses gradually moved to topics about GIS analysis.

There were further differences in the configuration of the two laboratories. In GEOG 390, each laboratory session had a focus topic and a mini project. In each mini project, students were required to apply the knowledge and skills of the topic. In FRSC 461, the laboratory had a final project. This project required students to choose a project topic with his or her partner by the fifth week of the course. In the final project, students were required to solve an environmental question that did not have a correct answer and to deliver presentations about their final projects.

Table 1
The Lecture Topics Included in the Two Introductory-Level GIS Courses

Week	GEOG 390	FRSC 461
1	GIS components, Data dimensionality, Measurements	GIS definition, Spatial factors, GIS applications
2	Map design principles, Map scale, Coordinate system, Projection	Components of GIS, Spatial data, Attribute data, Cartographic model
3	Thematic map, Geoid, Ellipsoids, Datum	Datum, Projection, Coordinate system
4	Projection, Datum, Coordinate system	Projection, Coordinates, Datum
5	Map data entry	ArcGIS file type, Enterprise GIS
6	GIS data structure, Topology	Data sources, Data standards, GIS operations
7	GIS data types, Database management system	Metadata, Database management system
8	Spatial analysis, Overlay, Boolean, Buffer,	Grids, DEMs, TINs
9	Continuous data, Raster	GPS
10	Raster, Interpolation	Remote sensing, Raster analysis
11	Interpolation	Remote sensing, Raster analysis
12	Raster analysis, Terrain analysis	Remote sensing, Raster analysis
13	Raster modeling	GPS Activity

Table 2
The Lab Activities Included in the Two Introductory-Level GIS Courses

Week	GEOG 390	FRSC 461
1	Become familiar with ArcGIS	Become familiar with ArcGIS
2	Become familiar with ArcMap	Become familiar with ArcGIS
3	Create thematic maps and layout hard copy maps	Manage projections and coordinate systems
4	Manage projections, coordinate systems and metadata	Download online raster and vector GIS data and manage meta data
5	Set georeferences	Work with attribute tables and create maps
6	Work with attribute tables and queries	Work with georeferencing, buffering and interpolation
7	Work with spatial queries and spatial joins	Layout hard copy maps
8	Work with map overlay and spatial query	Perform spatial analysis
9	Edit GIS map data	Perform attribute query and attribute table processing

10	Work with interpolation and geostatistics	Perform digitization, interpolation, and spatial analysis
11	Perform raster analysis	Final Project
12	Perform raster analysis	Final Project
13	Final lab exam	Final Project

Methods

This study analyzed college students' concept maps to examine if and how they developed their conceptual knowledge during their enrollment in one or other of the two courses above. The methodology was a single-group time series design. Each subject attended a training session and three experiment sessions voluntarily in a single semester. The author recruited ten and seven undergraduate students through a flyer at the beginning of the 2008 fall semester and the 2009 spring semester respectively. Each participant received monetary compensation for each experiment session. Of the seventeen participants, four withdrew from the study. One participant constructed concept maps in a linear fashion rather than a hierarchical network form. Since the hierarchy was unclear, the author excluded his concept maps from the analysis. As a result, this study analyzed data provided by twelve participants (Table 3) through two different types of analysis: the structural and the relational. The twelve participants also answered about their map use and confidence in map reading. Their experience and confidence on map reading were relatively high. Five participants responded that they used a map about once a week; six participants used a map about once a month; only one participant used a map about once a half year. As for their confidence, two participants strongly agreed that they were good at reading a map; eight participants thought that they were good at reading a map; two participants neither agreed nor disagreed that they were good at reading a map.

Table 3
Distribution of Participants' Academic Characteristics

Gender	Male 11		Female 1	
Age	20 Years Old 4	21 Years Old 4	22 Years Old 2	23 Years Old 2
Academic Year	Freshman 0	Sophomore 2	Junior 5	Senior 5
Major	Geography 4	Spatial Sciences 3	Marketing 1	Wildlife & Fisheries Sciences 4
GIS Course	GEOG390 7		FRSC461 5	
Spatial Science Course Work Experience	GEOG390 or FRSC461 is the first spatial science course. 7		GEOG390 or FRSC461 is not the first spatial science course. 5	

Procedures

At the beginning of a semester, participants attended a 50-minute workshop and learned how to construct a concept map using specific software designed for that purpose. The contents and activities followed strategies introduced by Novak and Gowin (1984). In the training session, participants learned about concept maps in general and how to use the software, CmapTools, and then constructed a concept map about Earth by using concepts related to ecosystem and following step-by-step instructions. In the last part of the training session, they constructed a concept map about water without any instruction. The author checked their concept maps about water to see if participants properly understood concept mapping and how to use the software. Students participated in three sessions following this training session, roughly five weeks apart (Table 4). In the first session, participants created a concept map. In the second and third sessions, they created a new concept map and revised the map they constructed in the previous session. The average length of each of the concept mapping sessions was approximately 28 minutes.

In each of the three sessions, participants started the mapping software to create a new concept map. The window had already included 30 geospatial concepts (Table 5) at the beginning of their mapping. Participants were asked to use only the concepts they were familiar with and arrange them to construct a concept map. Even though this study aimed at evaluating the development of students' conceptual knowledge in a semester and necessitated multiple mapping sessions, students might have got used to mapping by using the software. The populated 30 geospatial concepts were relevant to the property of geospatial objects, analysis, and visualization. The professor who taught GEOG 390 and the author selected the 30 geospatial concepts to be used in the three experiment sessions by examining two chapters of a GIS textbook written by DeMers (2009). This textbook meant to introduce the GIS concepts and technologies that students should know in an early-stage of learning and used in GEOG 390. A set of the 30 geospatial concepts may not be inclusive, though there were two rationales for the concept selection. The first was that these geospatial concepts should be covered in introductory-level GIS courses. The second was that the concept collection should engage a diversity of mental activities: aerial perception, spatial relationship representations, geometric manipulation, and spatial reasoning. The two chapters of the textbook were "Chapter 0: Spatial Lerner's Permit" and "Chapter 2: Basic Geographic Concepts." They focus on the geospatial concepts that underlie the nature of geospatial phenomena and spatial thinking and introduce the 30 geospatial concepts except overlay and topology. However, these concepts are relevant to some concepts introduced in Chapter 2. It describes how geographic entities such as points, lines, and polygons are represented and stored, and how multiple different types of geospatial entities associate or correlate each other. Moreover, the two concepts tie in with mental activities including spatial representations, geometric manipulation, and spatial reasoning.

Table 4
Activities Conducted in the Three Sessions

Step	Activity	1st Session	2nd Session	3rd Session
1	Answering question about subjects' personal information	X		
2	Making a concept map about the primary concept, space	X	X	X
3	Revising a concept map created in the previous session		X	X

Table 5
Thirty Geospatial Concepts Used

Arrangements, Association, Boundary, Buffer, Cluster, Coordinate, Density, Diffusion, Direction, Dispersion, Distance, Distortion, Distribution, Line, Linkage, Location, Map projection, Network, Overlay, Pattern, Point, Polygon, Proximity, Scale, Shape, Size, Spatial relationship, Three dimensions, Two dimensions, Topology

Assessment of Concept Maps

The author obtained 36 original concept maps and 24 revised concept maps and scored them by utilizing the two scoring schemes: the structural and the relational. For the structural scheme, this study adopted a modified version of Novak and Gowin's scoring method. This method was used by Markham et al. (1994) and counts the numbers of concepts, relationships, branchings, hierarchies, crosslinks and examples. In this study, participants used concepts assigned by the author in advance. Therefore, this study eliminated the count of examples. Each concept and each valid relationship received one point, respectively. Branchings had two scoring weights. The first branching received one point, and a successive branching received three points. Each hierarchy received five points. Each valid crosslink received 10 points because crosslinks can be regarded as evidence of concept map complexity. In each concept map, points were summed up to obtain a total score.

The relational scheme evaluated each proposition shown in a concept map to decide a made statement was correct or not. For the decision, the author identified correct, partially correct, and incorrect concept pairs and correct propositional statements and use them as a reference. In the first step of this analysis, the author obtained experts' definitions of the 30 geospatial concepts by examining two books and a GIS dictionary on the website of Esri, a leading GIS software vendor. This online dictionary included the terms of GIS technologies and cartography. One of the two books was a GIS textbook (DeMers, 2009) used for identifying the 30 geospatial concepts. The other book (Witthuhn, Brandt, & Demko, 1976) was referred to in a chapter on spatial concepts in the DeMers text and described core concepts in geography for students who had no previous exposure to geography. For example, an identified experts' definition of cluster was "cluster demonstrates a type of distribution with a high density of features." Hereafter, the concept of cluster will be used to explain an example of the following steps in the relational scheme.

The second major step examined each of the obtained definitions to consider which of the other 29 populated geospatial concepts would be candidates for the pairs that can align with experts' definition. In the case of cluster, the candidates of concept pairs were distribution and density since the identified experts' definition included the two concepts. The identified candidates were used to develop the concept pairs that would compose correct propositions. For example, a pair of cluster and distribution and a pair of cluster and density were made and assigned to a correct category. Then, the author formulated experts' propositional statements by referring to the definitions and correct pairs. As an example, the statements about cluster are as follows: (1) cluster demonstrates a high density; (2) cluster demonstrates a type of distribution; (3) density is a measure of cluster; (4) distribution representing a convergent condition is a cluster. Establishing correct pairs and propositional statements enabled each of the 30 spatial concepts to have one or more correct pairs and two or more correct experts' propositional statements. The author used them to decide if students' propositions were correct or not.

In the third major step, the author considered the possible pairs and propositional statements that may not belong to the correct category. For instance, the terms cluster and diffusion may bring the following statement: "cluster is one of the results of diffusion;" the relationship between cluster and spatial relationship can be expressed by the following statement: "cluster can be used to describe a spatial relationship." These propositional statements are not consistent with the definition of cluster formulated by experts, nor are they overarching concepts; however, those statements are correct under certain circumstances. Thus, a combination of cluster and diffusion and a combination of cluster and spatial relationship are partially correct pairs and can formulate partially correct statements. After the author identified the pairs that belong to the correct and partially correct categories, he assigned the possible pairs that belonged to neither the correct nor the partially correct categories to an incorrect pair category. After all, all of the 435 possible pairs composed of the 30 geospatial concepts were categorized into correct, partially correct, or incorrect. The author transcribed these categorized pairs and the corresponding experts' propositional statements into a propositional matrix for assessment.

To initiate scoring with the relational scheme, the author rewrote all of the propositional pairs and the statements shown in each of the participants' concept maps into a matrix. Then, he scored the pairs and statements based on the three categories of propositional pairs and statements. Since this scoring involved only one assessor, it might not have avoided subjectivity fully. The scores for propositional pairs ranged from 0 to 2 points. If a pair belonged to the correct category, the pair received 2 points; if a pair was a partially correct, the pair received 1 point; if a pair was neither correct nor partially correct, it did not get any points. The scores for propositional statements ranged from 0 to 4 points. A correct statement received 4 points; a partially correct statement received 2 points; an incorrect statement and a link without a statement did not receive any points. A combination of pair scores and statement scores established nine different accuracy categories (Table 6). Since a correct statement logically exists in only a correct pair, a score was not assigned to a partially correct or incorrect pair either.

Likewise, a score was not assigned to an incorrect pair because a partially correct statement logically cannot exist in an incorrect pair. As a consequence, the combined scores ranged from 0 to 6 points. If a participant's proposition met the experts' definition, the proposition received 6 points in total.

Table 6
The Relational Score Weight Matrix

	Correct Pair	Partially Correct Pair	Incorrect Pair
Correct Statement	6 points	No assigned	No assigned
Partially Correct Statement	4 points	3 points	No assigned
Incorrect Statement	2 points	1 point	0 point
Missing Statement	2 points	1 point	0 point

Findings

The author obtained the scores of concept maps constructed or revised by twelve students through three sessions. Then, he analyzed the scores through descriptive statistics and non-parametric statistics to examine if there were any differences among the sessions. Most of the students obtained their highest score when they created a new concept map in the second or third experiment session or revised their map in the second session (Tables 7 and 8). In the structural method, the largest number of participants obtained the highest scores when they created a new concept map in the third session. For the relational scores, the largest number of participants obtained the highest scores when they created a new concept map in the second session. Differences between high- and low-score maps were due to the number of map components and valid propositions. For example, Participant C (Figure 2) used 30 concepts in the third experiment session while Participant D (Figure 3) used 17 concepts in the first session. The largest factor contributing to the difference of map scores was the number of crosslinks. Participant C added six valid crosslinks; Participant D did not make any crosslinks. Since the score weight of crosslinks was larger than the other weights, the structural score difference was exaggerated. Differences between the two maps also affect their relational scores. The Participant C map included 35 correct or partially correct statements and 38 correct or partially correct pairs, while the Participant D map contained 14 correct or partially correct statements and 14 correct or partially correct pairs.

The descriptive statistic of the individuals' scores suggested some variations among sessions (Table 9). For the structural method, both the mean and median of the scores of concept maps newly created in the third session was the highest among all of the sessions. In contrast, both the mean and median of scores of maps newly developed in the second session was the lowest. Thus, the mean and median decreased in the second session and increased abruptly in the third session. The results obtained through the relational method were different from those through the structural method. Both the mean and median of scores of concept maps revised in the second session were the highest among all of the sessions. When it focused on only concept maps newly created in the three sessions, the mean of the relational scores gradually increased from the first session to the third session. The descriptive statistic also provided different findings when the author compared the mean and median of the scores of maps newly created in the first and second sessions and revised in the second and third sessions respectively. In both of the structural and relational methods, the mean and median increased in all of the cases except the structural median of the scores of maps newly created in the first session and maps revised in the second session. Particularly, the mean and median of the relational scores between the new maps of the first session and the revised maps of the second session increased by 12 points and 12.5 points respectively.

Table 7
Each Participant's Structural Scores

Session	A	B	C	D	E	F	G	H	I	J	K	L
Created in Session 1	92	88	99	65	89	101	78	116	96	94	93	**98**
Created in Session 2	77	73	98	76	**116**	87	**89**	105	81	89	112	72
Revised in Session 2	89	**91**	109	**90**	92	87	84	**140**	86	85	87	**98**
Created in Session 3	**96**	72	**164**	70	97	**103**	72	106	**111**	**100**	98	87
Revised in Session 3	**96**	80	99	83	115	95	85	123	87	90	**115**	71

Note: the scores written in bold are the individual's highest score among the sessions.

Table 8
Each Participant's Relational Scores

Session	A	B	C	D	E	F	G	H	I	J	K	L
Created in Session 1	54	**97**	89	70	93	84	40	109	109	56	66	85
Created in Session 2	**59**	67	90	84	96	102	**67**	67	**125**	62	**90**	**88**
Revised in Session 2	**59**	94	110	**117**	108	102	55	**123**	100	62	79	87
Created in Session 3	52	79	**136**	80	**114**	**104**	64	68	106	**82**	81	66
Revised in Session 3	52	71	98	97	96	102	66	104	118	68	76	82

Note: the scores written in bold are the individual's highest score among the sessions.

Table 9
Mean and Median Values of Participants' Concept Map Scores

	Session	Structural Mean	Structural Median	Relational Mean	Relational Median
Newly created concept maps	1st	92.42	93.5	79.33	84.5
	2nd	89.58	88.0	83.08	86.0
	3rd	98.00	97.5	86.00	80.5
Revised concept maps	2nd	94.83	89.5	91.33	97.0
	3rd	94.92	92.5	85.83	89.0

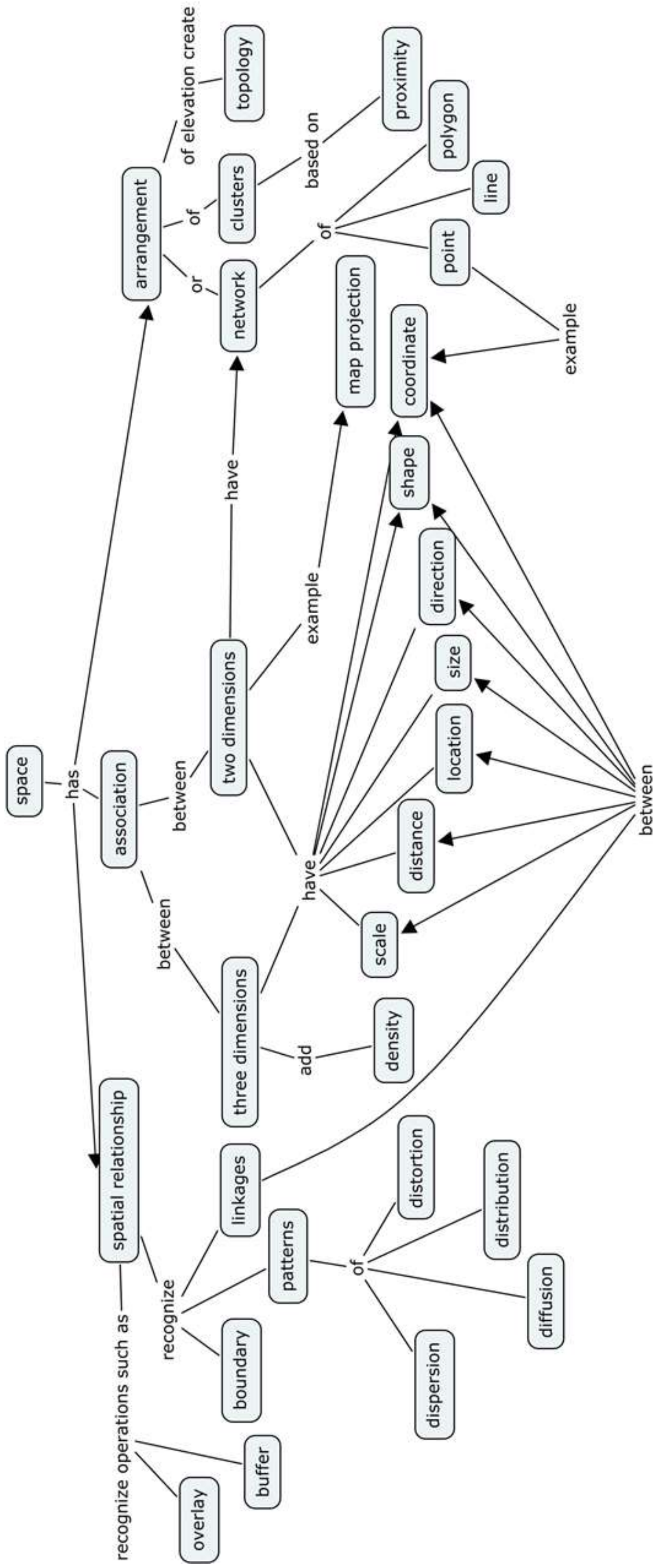

Figure 2. Participant C map

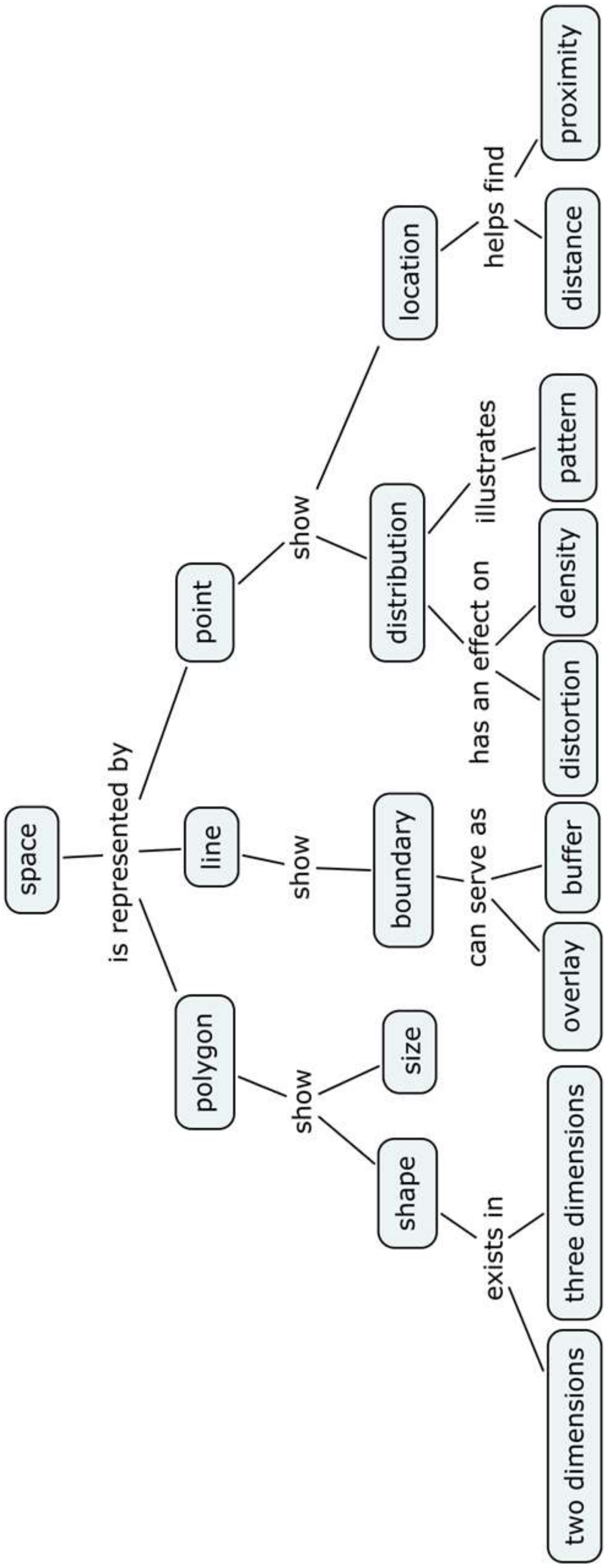

Figure 3. Participant D map

The research aimed to clarify whether differences existed between students' understandings of spatial concepts at the beginning, middle, and end of two introductory-level GIS courses. To answer this research question, the author analyzed differences between the scores of concept maps that were created and revised in three experiment sessions by conducting the Friedman's ANOVA test and the follow-up Wilcoxon signed-rank test. The Friedman's ANOVA test is a non-parametric test and for testing differences between two or more experimental conditions to which the same participants contribute. The Wilcoxon signed-rank test is a non-parametric post hoc test for the Friedman's ANOVA test. The first analysis was the Friedman's ANOVA test. For the concept map scored with the structural method, the scores did not change significantly over a semester (Table 10). For the concept map scores with the relational method (Table 11), the scores for concept maps created originally in the first session and the concept maps revised in the second and third sessions changed significantly ($\chi^2(2) = 6.68$, $p = 0.04$). The Wilcoxon signed-rank test was next used to confirm whether results of the analysis of scores evaluated by the relational were significantly different (Table 12). A Bonferroni correction was applied, and so all effects were reported at a 0.0167 level of significance. It appeared that scores changed significantly in a comparison between the maps created in the first session (Mdn = 84.5) and the maps revised in the second session (Mdn = 97.0), Z = -2.51, p = 0.012.

Table 10
Result of the Friedman's ANOVA Test of the Structural Scores

Combination of Three Groups	χ^2	*p*
Created in session 1 - Created in session 2 - Created in session 3	1.50	0.47
Created in session 1 - Created in session 2 - Revised in session 3	3.36	0.19
Created in session 1 - Revised in session 2 - Created in session 3	1.32	0.52
Created in session 1 - Revised in session 2 - Revised in session 3	0.30	0.86

Table 11
Result of the Friedman's ANOVA Test of the Relational Scores

Combination of Three Groups	χ^2	*p*
Created in session 1 - Created in session 2 - Created in session 3	3.50	0.17
Created in session 1 - Created in session 2 - Revised in session 3	4.87	0.09
Created in session 1 - Revised in session 2 - Created in session 3	3.17	0.21
Created in session 1 - Revised in session 2 - Revised in session 3	6.68	0.04

Table 12
Result of the Wilcoxon Signed-Rank Test of the Relational Scores

Pair of Two Groups	*Z*	*p*
Created in session 1 - Revised in session 2	-2.51	0.012
Created in session 1 - Revised in session 3	-1.65	0.099
Revised in session 2 - Revised in session 3	-1.51	0.130

In an extended analysis of the first research question, the author statistically analyzed differences between participants enrolled in GEOG 390 and FRSC 461. This statistical analysis examined if there was any significant difference in the two courses regarding concept map score increase/decrease. To conduct this analysis, the author calculated the differences of two concept map scores by using the following five equations: (1) the score of the map created in the second session – the score of the map created in the first session; (2) the score of the map created in the third session – the score of the map revised in the first session; (3) the score of the map created in the third session – the score of the map created in the second session; (4) the score of the map revised in the second session – the score of the map originally created in the first session; and (5) the score of the map revised in the third session – the map originally developed in the second session. The results of the Mann-Whitney test indicated that there was not any significant difference between the two groups in either of the structural and the relational scores.

Discussion

The statistical analysis of the structural scores suggests that the structural scores did not change significantly over the course of the semester. A possible interpretation is that the structural scoring scheme could not detect the development of the participants' conceptual knowledge structure. Participants arranged spatial concepts assigned by the researcher even though they were advised to use only the concepts with which they were familiar. If they were allowed to use freely the concepts that came to their minds, the scores might have had more variation and included more weighted map components such as crosslinks. This may have enabled the structural scoring scheme to detect participants' knowledge structure development. Another possible interpretation is that a single semester is too short a period to detect the development of participants' conceptual knowledge structures. The development of cognitive structures may gradually progress over a longer period than a single semester, or radical structural changes did not occur in a single semester. These possible factors may have hindered the improvement of map scores assessed by the structural. Since a radical or fundamental change in conceptual knowledge is a complex cognitive phenomenon, examining the process of the change may require different approaches (Rusanen, 2014).

On the other hand, the statistical analysis of the relational scores showed that there was a statistically significant difference in score between the maps created in the first session and the maps revised in the second session (See Table 12). Students could improve their first concept maps at the middle of a semester. Thus, it could be said that the development of participants' conceptual knowledge mainly occurred between the first and the second experiment sessions. A possible reason is that participants mainly learned concepts in the first half of the semester when both introductory-level GIS courses focused on fundamental geospatial concepts. In the latter half of the semester, the instructors mainly emphasized geospatial concepts applied to the spatial analysis. The relational scoring scheme is supposed to be sensitive to students' understandings of concepts covered in instruction (Rice et al., 1998; Rye & Rubba, 2002). The relational scoring scheme may have detected the development of students' conceptual knowledge, suggesting that instructors use concept maps to assess students' conceptual development in a time-series framework.

Four avenues of future research could be fruitful. The first would be to repeat the work at hand using a larger number of participants. The small number of participants used for the current study were split across two introductory GIS classes, and may not have been sufficient to find modest but significant shifts in student's understanding over the course of a single semester. A larger sample under full control of sampling would improve statistical rigor. The second would be to consider if and how instruction affects students' geospatial concept learning. A researcher might conduct a multiple-group experiment including a control group and groups who receive special instruction to assess the effectiveness of teaching on concept learning. The third would be to consider if and how students' spatial representations and reasoning improve as a consequence of the development of concept knowledge. For example, a researcher might compare students who appropriately understand the concept of map projection with students who do not understand in terms of their competency in spatial tasks that involve the concept. The fourth would be to clarify what kinds of geospatial concepts are complicated or simple for students in various circumstances. If researchers probe the complexity of geospatial concepts extensively in different settings, the results will identify which geospatial concepts should be taught before they teach a specific, more complicated geospatial concept. These four research themes would shed light on the improvement of spatial science curriculum and pedagogy.

Concept mapping is a feasible way for a thorough understanding of concepts. Students analyze a topic, relate the relevant concepts, and reflect their understanding when they construct a concept map. Concept maps have potential in investigating how students develop their conceptual knowledge. This study adopted two scoring schemes: the structural and the relational. Most educators have assessed students' concept maps by counting map elements and through quantitative methods. That being said, a quantitative method may evaluate a limited aspect of students' learning. Evaluating statements shown in concept maps and adopting a qualitative method are viable approaches to assess the level of students' development of conceptual knowledge (Draper, 2015; Miller et al. 2009). Use of a mix of quantitative and qualitative methods in this study suggested another course of action in evaluating students' concept maps. A concept map is also a useful tool in teaching concepts. Instructors ask students to construct a concept map through collaborative work. This enables students to share knowledge and reach a consensus on the understanding of concepts through critical thinking (Draper, 2015; Schwendimann & Linn 2016). In another scenario of use of concept maps in education, pre-service teachers are recommended to learn how to use concept map for their instructions and assess students' concept maps and how concept mapping impacts students' learning (Subramaniam & Esprívalo Harrell, 2015). In such educational settings, evaluating students' concept maps through the mixed methods would clarify the multiple aspects of students' understanding of concepts.

Conclusion

In this exploratory study, examining concept maps provided insights into if and how college students develop knowledge of geospatial concepts. Geospatial concepts are essential for spatial thinking through a wide variety of geospatial applications and technologies. These used to be taught exclusively through professional development for GIS experts but are now being taught by diverse disciplines and for learners of all ages (National Research Council, 2006; Sinton, Bednarz, Gersmehl, Kolvoord, & Uttal, 2013). This allows everybody to have the opportunity to develop spatial thinking proficiency to become good decision makers in real-life situations (Kerski, 2008) and potentially obtain various jobs (Bednarz, 2004). Considering the significance and pervasiveness of geospatial technologies, it can be said that it is beneficial for educators to examine research and assessment methods for the development of students' conceptual knowledge of geospatial sciences. GIS instructors should not assume that students automatically attain GIS conceptual knowledge. Rather, instructors should strategically introduce and reinforce geospatial concepts.

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