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NASA Astronaut Photography of Earth: A Resource to Facilitate Students' Learning and Using Geospatial Concepts

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Abstract
Spatial thinking is considered a fundamental cognitive skill and there has been more focus on it in recent years due to improved geospatial technologies. Teaching spatial concepts to students by using publicly available resources is an appropriate method to increase spatial thinking ability. More than 1.5 million photographs are publicly available through the Gateway to Astronaut Photography of Earth website. We wanted to explore the effectiveness of using photographs to improve students' spatial thinking by using a set of these photographs.

In this research, we selected uncataloged photographs from the International Space Station astronauts' collection and asked undergraduate students in the "Principles of Remote Sensing" course to interpret each photograph and locate it on the Earth by using "Google Earth". They used different spatial primitives, simple-spatial, and complex spatial concepts in their interpretation. We recognized and analyzed the concepts used in three assignments during a semester by using the chi-square goodness of fit test and assessed how significantly students increased or decreased their ability to used different types of spatial concepts.

We tested the utility of astronaut photographs for the acquisition and practice of spatial concepts knowledge and examined whether the use of astronaut photographs in a remote sensing course would support students' understanding and use of higher level spatial concepts. An additional outcome of this research is a guide to select appropriate photographs for teaching specific spatial concepts. The results show that students made progress in spatial thinking skills through their work with half of the photographs. We concluded that by selecting a proper photograph for teaching a specific spatial concept, we can see improvement in spatial thinking skills among students.

Keywords
Spatial Thinking, GeoSpatial Technology, Satellite Photographs

1 INTRODUCTION

The National Research Council (2006: 5 and 12) defines spatial thinking as "a collection of cognitive skills comprised of knowing concepts of space, using tools of representation, and reasoning processes." It requires an understanding of and an ability to use spatial concepts, like position and distance, to visualize and interpret relationships and changes among features in space. Spatial thinking also requires communicating spatial knowledge effectively by utilizing presentation tools such as maps, graphs, sketches, diagrams and photographs (Baker at al. 2015; Muñiz et al. 2015; Sinton et al. 2013; Jo and Bednarz 2011). Schultz et al. (2008) defined three components for spatial thinking, including (1) spatial knowledge (e.g., symmetry, orientation, and scale), (2) spatial ways of acting and thinking ("such as understanding change over space versus change over time and recognizing patterns in data"), and (3) spatial capabilities (ability to use GIS software and statistical data) (Schultz et al. 2008: 27). Spatial thinking is considered as a fundamental cognitive skill for competency in geography and has received increased attention in recent years due to the political and social changes resulting from advances in geospatial technologies and the emphasis on spatial thinking skills in science, technology, engineering, and math disciplines. It is an important part of educational curricula at all levels that can be taught and learned (Baker et al. 2015; Muñiz et al. 2015; Schultz et al. 2008).

Concepts of space necessitate a unique type of thinking and are building blocks for spatial thinking. Some examples of spatial concepts that have been widely recognized among researchers include location, dimensionality, continuity, pattern, spatial association, networks, and proximity (Muñiz, et al. 2015; Jo and Bednarz 2011; National Research Council 2006; Bednarz 2004). Muñiz et al. (2015) claim that geography education is changing very fast because of the introduction of geospatial technologies (GSTs), and GSTs have the potential to enhance students' thinking skills and to stimulate a new way of learning. The availability of Google Earth, web atlases and many other location-based services provide the opportunity for students to explore almost all places in the world anytime, anywhere. Google Earth can support student learning while being entertaining for them. It can foster spatial thinking and develop critical technology and thinking skills. It is a powerful learning tool for students because it incorporates visual and emotional images to communicate to and motivate students (Patterson 2007) The Global Visualization Viewer (GloVis) is another online tool that teachers can use to illustrate geographical concepts. Teachers have access to different images to illustrate a specific concept relevant to their local area (Campbell 2007). Publishing and using maps on the Internet, also known as web mapping, is another important way to develop spatial thinking in the classrooms (Manson et al. 2014). Baker and his colleagues (Baker et al. 2015) also claim that GSTs facilitate the learning and thinking process about what is happening on planet Earth. Literature on spatial thinking suggests that spatial thinking skills can improve with appropriately designed learning experiences and training, and GSTs are powerful tools that support the processes of learning to think spatially (Muñiz et al. 2015; Lee and Bednarz 2012; National Research Council 2006).

Muñiz et al. (2015: 13) define GSTs as "the equipment used in visualization, measurements, and analysis of earth's features, including global positioning systems (GPS), geographical information systems (GIS), remote sensing (RS) and digital globes." Many studies have been conducted regarding the relationship of spatial thinking and GIS education. For example, Lee and Bednarz (2009) found that college students with GIS academic backgrounds achieved higher scores than students without such backgrounds in pre- and post-spatial skills assignments (SSTs). According to Sinton (2009), GIS can facilitate critical thinking and can be used as the "common denominator for sharing data and perspectives from diverse sources" in a variety of interdisciplinary courses. Wakabayashi and Ishikawa (2011), in a review of research studies about spatial thinking and GIScience, stress the potential role of GIS in spatial thinking education. Few studies, however, examined the potential of other geospatial technologies besides GIS to facilitate student spatial thinking skills.

This research evaluates the usage of remotely sensed astronaut photographs of Earth and how these photographs can be used for educational purposes. There are more than 1.5 million photographs taken from the International Space Station (ISS) by astronauts since the first Mercury missions, and scientists and the public around the world have access to these Crew Earth Observations (CEO) images (https://eol.jsc.nasa.gov/). The research presented herein, as far as we can tell, is the first attempt to use astronaut photographs for educational purposes and to support student acquisition of spatial thinking skills. We intend to demonstrate the utility of astronaut photographs for the acquisition of spatial concepts knowledge by examining whether their use in a remote sensing course supports students' understanding and application of higher level spatial concepts. We accomplish this by compiling sets of astronaut photographs that can be used to elicit students' knowledge about various spatial concepts. Students then describe and interpret the photographs to determine the location of each photograph.

2 BACKGROUND

The International Space Station is a unique remote sensing platform for several reasons, including that it has a human crew, a low-orbit altitude, and orbital parameters that provide variable views and lighting unlike automated remote-sensing platforms. Human crews working on the ISS use handheld digital cameras as part of the Crew Earth Observations effort to collect unscheduled data showing how the Earth is changing over time, including time-lapse photograph sequences of atmospheric phenomena, floods, hurricanes, volcanic eruptions and glacial retreat, as well as day- and night-time photography of urban and suburban areas. Based on NASA report, "Crew members spend approximately ten minutes a day, five days a week, recording their Earth observations. Some crew members have found Earth observations very enjoyable and have dedicated extra time to photographing the beautiful and extraordinary views from the windows of ISS" (Crew Earth Observations 2017). "A picture is worth a thousand words, but CEO images have value beyond words" (Crew Earth Observations 2017). These publicly available photographs enable anyone to use them for education, entertainment, or to contribute to the acquisition of further scientific knowledge purposes. Multiple, daily ISS passes over the Earth, each pass having unique lighting and viewing angles, provide a unique view of Earth that is not obtainable from robotic imaging platforms that collect image data at the same time of day and with a nadir viewing angle. ISS astronaut photographs inspire curiosity and have potential for scientific research. For instance, high-resolution photographs of cities and natural features such as coral reefs, river deltas and icebergs can help scientists understand urban growth, the impacts of changing land use, and global ocean and weather events (Crew Earth Observations 2017).

When a photograph is downlinked from the ISS, the only metadata that accompanies the photograph is from the camera. The Earth Science and Remote Sensing (ESRS) Unit records the date and time the photograph was taken and other camera metadata, including the focal length, shutter speed and aperture. They additionally calculate the ISS nadir position (i.e., latitude, longitude and altitude) based on ISS orbital characteristics, and the date and time the photograph was taken. These attributes constitute the "uncataloged" photography database, which currently contains about 2 million photographs from 2000 to 2017. Missing from the "uncataloged" database are the Earth coordinates of each photograph and a list of the geographic features contained within each photograph. In an effort to ease accessibility to the photographs for scientific research, the ESRS Unit oversees the manual identification of the latitude and longitude of the center of each photograph and the features contained in the photograph. Once the photograph center and/or geographic features have been identified the photograph is classified as "cataloged." Cataloged and uncataloged photographs are made publicly available through the Gateway to Astronaut Photography of Earth (GAPE) website (http://eol.jsc.nasa.gov) where users may search for photographs by location or feature.

These photographs are a potentially valuable resource for geography education and are likely a good resource for teaching spatial thinking skills. We tested the utility of astronaut photographs from the ISS for improving spatial thinking skills of undergraduate students in the Principles of Remote Sensing course. We also used these photographs for creating a data set of photographs for teaching spatial thinking skills to be used by educators. We are looking at the results of this study as a referable resource for future researchers who want to use NASA photographs in their studies and to provide a guide for evaluating the appropriateness of each photograph for teaching a specific spatial concept.

3 METHODS

In this research, we aimed to observe how spatial thinking skills in 32 undergraduate geography students improved by asking them to complete three assignments involving the interpretation of Earth features in astronaut photographs. We gave students six photographs in three lab sessions throughout the semester to assess their spatial thinking skills and to assess their ability identifying and describing geographic patterns and processes in the photographs. Students used Google Earth to find the exact location of each uncataloged photograph. They recorded their interpretation of the photographed area while they were finding the location of the photograph on the earth. We read all answers and highlighted the spatial concepts that each student mentioned in their interpretation of the photograph location. We grouped the spatial concepts they mentioned into three categories by using the taxonomy of spatial thinking developed by Jo and Bednarz (2009) (Table 1). We tallied the instances where each concept was used and calculated the percentage of instances in each group of concepts. With these data we were able to test for improvements in student's use of a specific concept while interpreting photographs over the course of the three assignments. The details of this methodology are explained in the following sections.

3.1 Participants and Setting

This research was conducted in the "Principles of Remote Sensing" lab, not the lecture, in the Geography Department at Texas State University. Over the course of the semester, 54 undergraduate students met weekly for a period of 16 weeks and completed a series of 10 laboratory assignments. The objective of the labs was to facilitate the acquisition of basic knowledge of remote sensing as a problem-solving tool in physical and cultural sciences with a focus on the acquisition, interpretation, and mapping of aerial photographs and satellite images of the environment. Students learned about several of the spatial concepts in this course. Examples include shape, pattern, color, magnitude, location, and geographical feature. For the purposes of this research, and in addition to the 10 lab assignments, students completed an additional three assignments at the beginning, middle and end of the semester that used astronaut photographs to test student's spatial thinking skills. Thirty-two students completed each of the 3 additional assignments: 10 juniors, 20 seniors, one sophomore, and one certificate seeking student. Among these participants, 11 were GIS majors, five were general geography majors, and the rest of them had other majors.

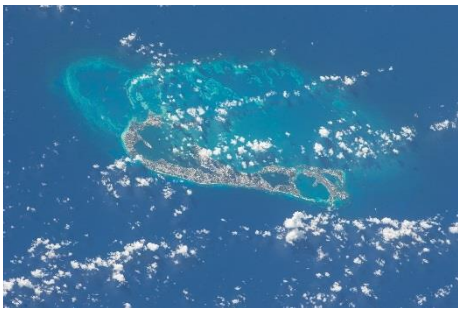
3.2 Task Description

In each of the three lab assignments, students were asked to geolocate six photographs (Figure 1) and to provide a written description of the geographic patterns and processes they recognized in the photograph that helped them geolocate it. In each assignment, students were provided with URLs to the same six uncataloged astronaut photos from the NASA GAPE collection (http://eol.jsc.nasa.gov/). By clicking on an URL, they accessed the photo and found the ISS nadir point latitude and longitude. Using the ISS nadir point latitude and longitude in Google Earth to narrow their search to a specific part of the globe, students were asked to find the exact location of the center of each photograph. Because photographs were often taken at oblique angles, students needed to identify features on the photograph that they could also identify on Google Earth in order to determine the center location of the photograph. Students recorded on their assignment sheet their written interpretation of the Earth features used to locate the image. After finding the location of a photograph center, students recorded the latitude, longitude, country/state and feature name in the table provided to them, so we would have enough information to see if they have found the correct location of the photograph or not.

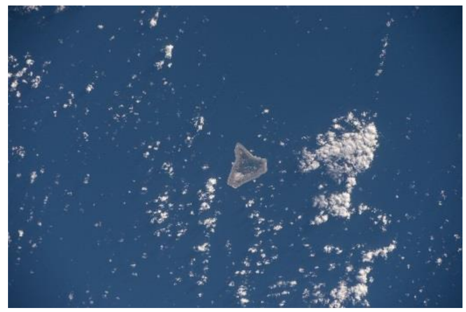
Each of the six photographs were selected to support at least one specific spatial concept. Expected spatial concepts for photographs one through six were: "Color", "Shape", "Gradient", "Magnitude", "Condition", and "Network", respectively. The six photographs provided to students were arranged from easy to difficult to interpret. The difficulty was related to several criteria, including, for example, the scale of the place shown in the photograph, the distance of the photograph center from the ISS nadir location, and the patterns, colors or other complexities of the photograph that provide clues as to its location. For each assignment, students spent about 1.5 hours to find the location of all 6 photographs and to write the description for each photograph in the first assignment. The purpose of asking students to geolocate the same photographs in each assignment was to examine whether and how students made progress in their spatial thinking skills to describe the geographic features in the astronaut photographs.

Photograph 1: Gribben lake, Michigan

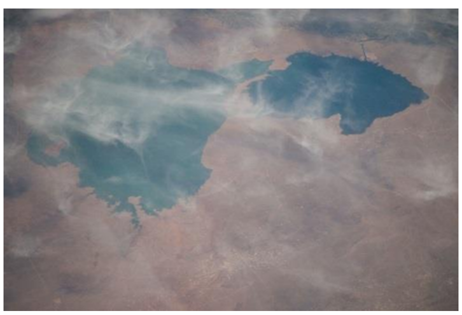
Photograph 2: Richat Structure, Mauritania



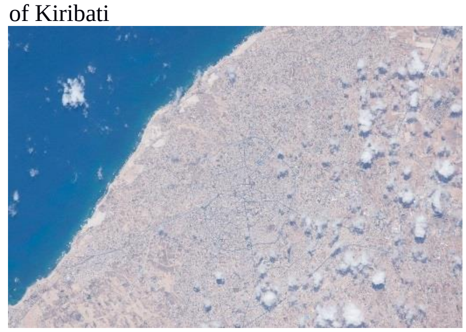
Photograph 3: Bermuda Island



Photograph 4: Malden Island, Republic of Kiribati



Photograph 5: Embalse los Barreales, Argentina



Photograph 6: Misrata City, Libya

Figure 1. Photographs in three assignments[1]

The third assignment was posted at the end of the semester as the last lab assignment. In the last assignment, 22 students simply copied their written descriptions from their first or second assignments, thus invalidating their third responses. We excluded those responses from our data set yielding a set of responses from 32 students for the coding and analysis. We intentionally used the same six photographs for the three intervals because we wanted to assess the students' progress in spatial thinking skills over time, and using the same photographs allowed us to make those comparisons. Because every photograph is unique and only allows for the interpretation of certain spatial concepts, changing the photographs for each interval would make it impossible

[1] Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center. Photo numbers are ISS042-E-2265, ISS044-E-8687, ISS044-E-8672, ISS044-E-19203, ISS044-E-22796, ISS044-E-8687, respectively.

to test for changes in students' spatial thinking skills. In reality, we gave students 6 new photographs for the 2nd and 3rd intervals, in addition to the ones they saw in the first interval. Despite our best efforts to select new photographs with the same level of difficulty and features as the first photographs, the spatial concepts identified by students were so different from the first photographs as to render meaningless comparisons between them. Thus, we report on the spatial concepts identified by students over the three intervals using the same six photographs.

3.3 Coding and Analysis of Data

A taxonomy of spatial thinking developed by Jo and Bednarz (2009) was used to categorize and evaluate the level of spatial concepts students used to interpret the photographs (Table 1). Based on an extensive review of the literature on spatial concepts in geography (Gersmehl 2006; Gersmehl 2005; Golledge 2002; Golledge 1995), Jo and Bednarz (2009) categorized spatial concepts frequently used in geography into three levels: spatial primitives, simple-spatial concepts, and complex spatial concepts. Spatial primitives are those concepts that are the fundamental building blocks of space—basic concepts such as location, place-specific identity, or magnitude. At the next level, simple-spatial concepts, are concepts established by sets of spatial primitives. Distance is an example of a simple spatial concept; it is the interval between two locations. At the top of this classification scheme are complex-spatial concepts. These are concepts derived by assembling sets of simple-spatial concepts or from combinations of spatial primitives and simple-spatial concepts. We adopted Jo and Bednarz (2009)'s categories of spatial concepts as is, but added several concepts to the list of primitives like color, name, condition, and geographical feature that enable us to better analyze the students' answers from a remote sensing perspective. For example, feature color is critical in all interpretations of remotely sensed data, but "Color" is not included in Jo and Bednarz (2009)'s categories of spatial concepts, therefore we decided to add necessary concepts for our research.

We performed content analysis on the student responses, noting each time a student used a spatial concept to interpret the given photograph, and then categorized the concepts against the taxonomy. We should mention that many students used several concepts for describing each photograph, if they recognized the wrong place or they used wrong concepts, we did not consider their responses or did not count the used spatial concepts. Below is an example of a student's response and how the response was coded using the taxonomy (Figure 2).

Table 1. Spatial thinking concepts, adapted from Jo and Bednarz (2009).

Spatial Concepts		
Primitives	**Simple-Spatial**	**Complex-Spatial**
Magnitude	Arrangement	Layer
Place identity	Shape	Gradient
Condition	Enclosure	Relief
Color	Boundary	Profile
Names	Connection	Scale
Geographic features	Reference frame	Density
Location	Direction	Pattern
	Distance	Distribution
	Adjacency	Dispersion/Clustering
	Region	Dominance
	Movement	Diffusion
	Transition	Hierarchy/Network
		Spatial association
		Overlay
		Map Projection
		Buffer

3.4 Statistical Analysis

For each photograph, the number of spatial concepts featured in students' interpretations were tallied. Then, the percentage for each concept category—primitives, simple-spatial, and complex-spatial—was calculated. We compared these percentages by photographs (i.e., Photograph 1 through Photograph 6) and by time of the semester (beginning, middle and end of the semester). Table 2 shows the total count and percentage of each spatial concept. Although we could see a relative increase or decrease in the use of a specific concept over time, we desired to statistically test the changes in the use of spatial concepts over time. We used the chi-square goodness of fit test with a 95% confidence level as calculated below:

$$\chi^2 = \sum \left[\frac{(O - E^2)}{E} \right] \quad (1)$$

where O refers to the observed frequency and E refers to the expected frequency of each category of spatial concepts (Thompson 2006).

ISS042-E-2265

http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS044&roll=E&frame=2265

Latitude	**Longitude**	**Country/State**	**Feature Name**
46°24'49.90"N	87°31'40.07"W	USA/Michigan	Reservoir near Richmond Township

Description of Interpretation:

The location may be a <u>small</u> water reservoir or <u>lake</u>. It is on the <u>northern</u> peninsula of the
Magnitude Geographical Feature Direction
<u>Michigan</u>, USA. The sediment must be some type of clay based on the <u>orange</u> coloration of
Name Color
the water. The area <u>surrounding</u> the location is very <u>green</u>, suggesting <u>dense</u> vegetation and
Enclosure Color Density
not much urban development. Based on the <u>dark brown</u> color outlining the water, it can be
Color
assumed that the water level has decreased due environmental conditions or human use.

Pollution may also be a factor.

Google Earth Screenshot:

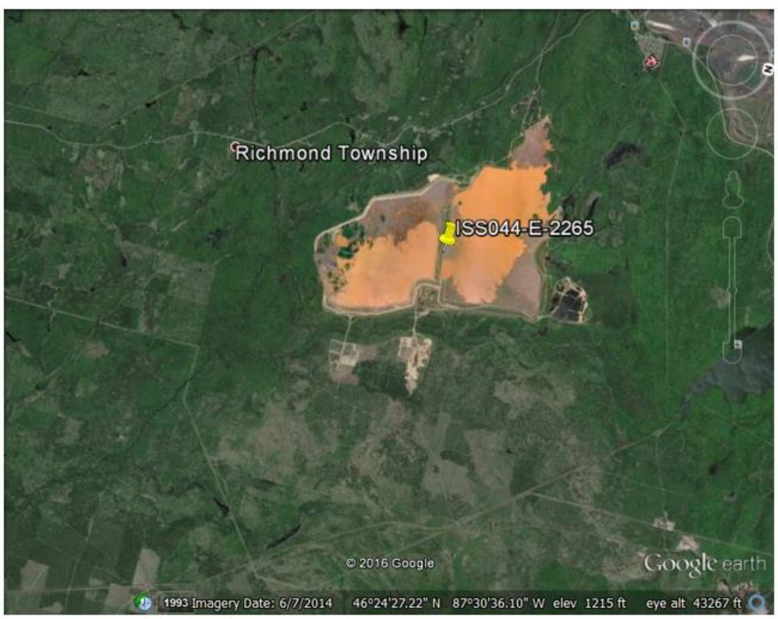


Figure 2. One example of a student's answer (green text) and how researchers assessed the answer (blue text).

Table 2. Concept counts and percentages for each photograph in the three assignments.

		PCC[2]	PCP[3]	SCC[4]	SCP[5]	CCC[6]	CCP[7]	TC[8]
Photograph 1	Assignment 1	83	58.87	42	29.79	16	11.35	141
	Assignment 2	70	59.32	33	27.97	15	12.71	118
	Assignment 3	76	58.02	38	29.01	17	12.98	131
Photograph 2	Assignment 1	75	60.98	34	27.64	14	11.38	123
	Assignment 2	85	53.46	45	28.3	29	18.24	159
	Assignment 3	66	55	25	20.83	29	24.17	120
Photograph 3	Assignment 1	91	52.3	51	29.31	32	18.39	174
	Assignment 2	89	49.72	53	29.61	37	20.67	179
	Assignment 3	90	52.33	46	26.74	36	20.93	172
Photograph 4	Assignment 1	112	64	41	23.43	22	12.57	175
	Assignment 2	101	54.89	52	28.26	31	16.85	184
	Assignment 3	95	55.88	47	27.65	28	16.47	170
Photograph 5	Assignment 1	135	63.38	60	28.17	18	8.45	213
	Assignment 2	132	57.89	67	29.39	29	12.72	228
	Assignment 3	127	60.48	58	27.62	25	11.9	210
Photograph 6	Assignment 1	75	57.69	24	18.46	31	23.85	130
	Assignment 2	85	55.56	26	16.99	42	27.45	153
	Assignment 3	68	55.74	16	13.11	38	31.15	122

In the chi-square goodness of fit test, the null hypothesis is that there is no difference between the percentages of primitive, simple and complex concepts in each assignment—that each assignment was used 33.33% of the time. We use the chi-square goodness of fit test to determine whether observed sample frequencies differ significantly from expected frequencies specified in the null hypothesis. The significance level is equal to 0.05 in our research and if the P-value is less than the significance level then we reject the null hypothesis. Table 3a and 3b are examples to see how we calculated the chi-square goodness of fit test for of Photograph 1, Assignment 1.

2 Primitive Concept Count
3 Primitive Concept Percentage
4 Simple Concept Count
5 Simple Concept Percentage
6 Complex Concept Count
7 Complex Concept Percentage
8 Total Count

Table 3a. Comparing the usage of three spatial concepts.

Concept	Observed Frequency	Expected frequency	$(O-E)^2/E$	Expected Proportion
Primitive	83	47	24.5744	0.3333
Simple	42	47	0.5319	0.3333
Complex	16	47	20.4468	0.3333
Total	141			

Table 3b. Chi-square goodness of fit test result.

Chi-square test statistics	48.5539
Degrees of freedom	2
P-value	< 0.05
Decision at $\alpha = 0.05$	Reject

In above example, we reject the null hypothesis which results in the conclusion that the usage of primitive, simple and complex concepts are statistically different in photograph 1, assignment 1. We calculated the chi-square test statistics 18 times for all six photographs during three assignments and the results showed that the usage of the three concepts was significantly different (Appendix I). We also calculated the chi-square value by comparing spatial concepts two by two. The results show that Primitive and Simple concepts are different in all photographs during all assignments, so the null hypothesis is rejected for all chi-square tests results (Appendix II). We repeat the same process to compare primitive and complex concepts which has the same results as the primitive-simple concepts comparison (Appendix III). We again reject the null hypothesis for equal use of primitive and complex concepts in all photograph interpretations of all assignments. Comparing simple and complex concepts showed a different result. The usage of simple and complex concepts is not significantly different in the following cases: photograph 2, assignment 2 and 3; photograph 3, assignment 2 and 3; photograph 6, assignment 1 and 2 (Appendix IV).

We also compared the percentages of using concepts for each photograph in three assignments during the semester. In this process, we again used the chi-square goodness of fit test to compare assignment 1 and 2 and then 3 (Appendix V). This analysis assumes that the distribution we observed in the first assignment is the distribution we should expect in frequencies from assignment 2, and test the null hypothesis that the distribution from assignment 2 is equal to the distribution from assignment 1. If we fail to reject the null hypothesis, then we follow the same steps for comparing assignment 1 with assignment 3. In another words, if we fail to reject the null hypothesis comparing assignment 1 and assignment 2, then we do not update the multinomial distribution. We keep the observed frequencies from assignment 1 as the baseline. If we reject the null hypothesis, then we have to update the null hypothesis and expected frequencies with the assignment 2 distribution—we update our null hypothesis and now assume that assignment 2 is the baseline. Then, we test the null hypothesis that the distribution observed in assignment 3 is equal to the new hypothesized distribution (from assignment 2). Table 4a – 4d provides an example of how we calculated this chi-square value and how we changed the baseline if we reject or accept the null hypothesis.

In Table 4a and 4b we calculate the chi-square test value for the photograph 2. We assume that the percentages in assignment 2 are equal to the percentages used in assignment 1. So, we use the percentages from assignment 1 as the baseline and for calculating the expected frequency we multiply the observed percentages in assignment 1 to the total number of assignment 2 observed frequency.

Table 4a. Compare the usage of three spatial concepts through the semester. (Baseline=Assignment 1)

Concept	Observed Frequency (Assignment 2)	Expected Frequency (Assignment 1)	$(O-E)^2/E$	Expected proportion
Primitive	85	96.9582	1.4748	0.6098
Simple	45	43.9476	0.0252	0.2764
Complex	29	18.0942	6.5731	0.1138
Total	159			

Table 4b. Chi-square goodness of fit test result.

Chi-square test statistics	8.0732
Degree of freedom	2
P-value	< 0.05
Decision at α=0.05	Reject

Based on the results shown in Table 4b, we reject the null hypothesis and update the baseline and put the assignment 2 percentages value as the baseline. Then we compare the used percentages of assignment 3 with assignment 2. Table 4c and 4d are showing the next steps:

Table 4c. Compare the usage of three spatial concepts through the semester. (Baseline=Assignment 2)

Concept	Observed (Assignment 3)	Expected Frequency (Assignment 2)	$(O-E)^2/E$	Expected proportion
Primitive	66	64.152	0.0532	0.4034
Simple	25	33.96	2.3640	0.2135
Complex	29	21.888	2.3109	0.1376
Total	120			

Table 4d. Chi-square goodness of fit test result.

Chi-square test statistics	4.7281
Degree of freedom	2
P-value	> 0.05
Decision at alpha=0.05	Do Not Reject

Since we rejected the null hypothesis in Table 4b, we concluded that the third assignment percentages are not significantly different from the second assignment. We repeated the same process 6 times to calculate the chi-square test for all photographs. The results show that the percentages used in assignment 3 are not different from the first and second assignments in photograph 1, 3, and 6. In photograph 2, 4, and 5 the percentages used are different in the second assignment compared to the first assignment, but they are not different in the third assignment compared to the second one.

4 RESULTS

According to Table 2, except for photograph 1, students used a larger number of concepts in the second assignment than the first one. In contrast, they used fewer concepts in the third assignment compared to the first and second assignments.
Below we provide more details about the concepts that students used in interpreting each photograph.

4.1 Photograph One

Since the color of the lake is very distinctive in the first photograph, students mostly used "Color" as a primitive concept in all three assignments (30%, 25%, and 26% in the first, second and the third assignments, respectively). "Enclosure" was another simple concept that they frequently used (18%, 22%, and 17% in the three assignments) when they explained that the lake is surrounded by the forest. They used "Pattern" and "Density" among complex concept more than others.

4.2 Photograph Two

For the second photograph, results from the first assignment show that more than 10% of student responses were for the primitive concepts "Color," "Name," and "Geographical feature" respectively. They used the "Name" and "Color" concepts more than 10% of the time in both assignment 2 and 3. They used the "Shape" concept more than other concepts among simple spatial concepts in all 3 assignments. For the complex concepts, they used "Relief" and "Scale" in the first assignment and "Relief" and "Pattern" in the second and third assignment. As it is shown in Table 2, the percentage of use of complex concepts in the third assignment was more than double the percentage of use in the first assignment. These findings suggest that this kind of photograph could be effectively used for teaching the "Pattern" concept. Although at the first sight students might see the circular pattern of the feature, but they did not mention it as a spatial concept in their interpretation.

4.3 Photograph Three

For the third photograph, results show that students used the "Color" concept 16% in the first assignment, but the usage of color reduced to 12% for the 2nd and 3rd assignments. "Name" was used 10% of the time for the first assignment, then it increased to 14% in the second assignment before it dropped to 9% for the 3rd assignment. It seems that they used the "Geographical Feature" concept more in the 3rd assignment than in the 1st and 2nd assignments (22%, 18% and 16% respectively). For the simple concepts in all three assignments, they used "Shape" and "Enclosure" 9% of the time. Among complex concepts, they increasingly used the "Gradient" concept from assignment 1 through three (10%, 11% and 12% respectively). The number and percentage of concepts used indicates that they almost used the same percentage of each concept type for the three assignments. These findings suggest that using similar photographs to this one, with a different color of water, could facilitate learning the "Gradient" concept.

4.4 Photograph Four

Students used 17 different concepts for describing this photograph and among all the concepts used, "Geographical Feature" was used most often—mentioning the island in the photograph. Among Primitive concepts, "Geographical Feature," "Color," and "Magnitude were mainly used (21%, 15%, 15% respectively) and interestingly use of the "Magnitude" concept dropped to 5% and 7% in assignment 2 and 3, respectively. Among simple concepts, "Shape" was consistently used 8% of the time. Interestingly, students used more "Gradient" and "Relief" complex concepts over time in the three assignments (3%, 5%, 7% for the "Gradient" and 2%, 4%, and 5% for "Relief" concept). This photograph shows that, like photograph three, the different blue color tones that indicate differences in subsurface elevation may be a good for learning the "Gradient" spatial concept.

4.5 Photograph Five

Student descriptions for the fifth photograph remained largely the same for each assignment. In so doing, students used the "Geographical Feature" concept among primitive concepts far more than other primitive concepts. Similarly, they used "Direction" more than other simple concepts in all three assignments. Interestingly they increase their use of the "Gradient" concept from 2% to 4% to 6% from the 1st to the 3rd assignment, although the increased percentages are not statistically significant. The increases, however, suggest that students have learned to consider gradient in their description.

4.6 Photograph Six

Like other photographs, the usage of primitive concepts is higher than the two other concept categories. In this photograph, "Name" was the primitive concepts that students used most in all three assignments. "Direction" and "Distance" were the most frequently mentioned simple concepts and "Pattern" and "Density" were the most commonly used complex concepts. Photograph 6 is the only photograph that led students to use the "Network" concept when they mentioned the road network in the city center. According to the student answers, they used the "Pattern" concept interchangeably with the "Network" concept. Surprisingly, photograph six is the only photograph where students used more complex concepts in interpreting the photograph than simple concepts.

5 DISCUSSION

As Table 2 shows, students used more primitive concepts than simple or complex concepts in all 18 assignments. This observation was supported by the chi-square test results that indicate significant differences between the uses of primitive versus simple concepts and primitive versus complex concepts. Students' use of primitive concepts was significantly greater than their use of simple and complex concepts. These results suggest, that all of these photographs could be used for teaching about primitive spatial concepts. Results indicate that in one-third of the assignments there was no statistical difference in students' use of simple and complex concepts (Photograph 2, assignment 2 and 3; photograph 3, assignment 2 and 3; photograph 6, assignment 1 and 2) but the use of simple and complex concepts in the remaining photographs is significantly different. This result suggests that many of these photographs could also be used to teach complex spatial concepts.

The chi-square test results show that although repeating the assignment for the second time caused different percentage of concepts used in photographs 2, 4, and 5, repeating the assignment for the third time did not result in any different percentages in concept use. Therefore, we suggest that for future studies only two assignments be made throughout a semester. In all three assignments, students used fewer primitive concepts in the second assignment compared to the first assignment. In photographs 2 and 5, student's usage of complex concepts increased more than their use of simple concepts. For photograph 4, students increased their use of both simple and complex concepts in the second assignment compared to the first assignment. On the other hand, repeating photographs 1, 3, and 6 did not lead to any differences in concept use. Therefore, results suggest that using photographs 2, 4, and 5 led to improved spatial thinking skills during the semester.

Taken together, these findings suggest that choosing an appropriate photograph for teaching a specific concept is very important. The statistical results we found suggest that we could use specific photographs for teaching a specific concept. Assigning an appropriate photograph in a teaching setting could be based on the usage percentages of the concepts in this study.

In this research, we see that in all photographs the "Color" of the Earth feature was one of the main concepts students used in their interpretation. For example, the distinct color of the lake which separates it from the surrounding green area makes the first photograph a good photograph for clearly teaching about color as a concept and for hypothesizing the causes of the specific color. In fact, many students recorded logical hypotheses for the orange color of the lake. Photograph one, is also a good example of the "Enclosure" concept because students described the lake and the surrounding forest area. Other photographs could be used to teach spatial concepts like "Geographic Feature," "Condition," and "Magnitude". The shape of the "Richat Structure" is very noticeable in the second photograph and "Shape" was among the most frequently used concepts. Different shades of blue color in the ocean surrounding Bermuda Island in photograph 3 are good for encouraging students to think about and use "Gradient" as a concept—many students tried to link different blue tones to different depths of the ocean. Since photograph 4 is a small island in the middle of the Pacific Ocean with few proximate features to identify, students were required to describe only those features on the island. They frequently used the "Direction" concept while referring to the features on the island (e.g., "There is what looks like a small lake on the northeast corner of the island"). Student descriptions for the fifth photograph remained largely the same for each assignment. In so doing, students used the "Geographical Feature" concept among primitive concepts far more than other primitive concepts. Similarly, they used "Direction" more than other simple concepts in all three assignments. Interestingly they increase their use of the "Gradient" concept from 2% to 4% to 6% from the 1st to the 3rd assignment, although the increased percentages are not statistically significant. The increases, however, suggest that students have learned to consider gradient in their description. Photograph 5 could be a good photograph for learning about the "connection" of two lakes, in addition to the concepts "Direction" and "Enclosure". In photograph 6, most students recognized the road network in the city and used it for finding the exact city in Google Earth. In this photograph, the beige color of buildings was consistent across the city and matched the color of the surrounding terrain, leading students to identify the concept "Color" and to conclude that the city was located in a desert or arid area.

Results show that students used greater number of concepts in assignment 2 compare to assignment 1, but they used less number of concepts in assignment 3 compare to assignment 1 and 2. Results show that for the second assignment students tried to provide descriptions that showed their progress in recognizing the features on the photographs. The results of the third assignment, however, suggest that students lacked enthusiasm for the assignment, perhaps due to the approach of their final exams. The results suggest to us that courses like "Principles of Remote Sensing" improve students' spatial thinking and reasoning skills.

6 CONCLUSION

In this research, we explored the potential of astronaut photographs in a college level introductory remote sensing course to help students acquire and appropriately use spatial concepts. This research was created to evaluate the usage of remotely sensed astronaut photographs of Earth and how we can use them for educational purposes. Our research question was: "how do astronaut photographs in an introductory remote sensing course help students acquire spatial thinking skills." Our findings suggest various ways in which students can learn spatial concepts and improve their spatial thinking skills using astronaut photographs. An additional outcome of this research is a guide to select appropriate photographs for teaching specific spatial concepts.

Using GSTs has great advantages in education, since they make it easier to access geodata and processes geodata more accurately and quickly. GSTs have the potential to enhance students' skills and stimulate a new way of learning, or at least to offer better opportunities to develop higher order thinking skills. Having free access to the astronaut photographs on the NASA website is a great resource for educational purposes.

The specific results of this research show that although spatial concepts usage increased in most cases during the semester, the percentage differences were not significant in half of the assignments. We observed that students used more primitive concepts in interpreting all six photographs in all three assignments than simple and complex concepts. Among primitive concepts, they frequently used "Magnitude," "Color," "Geographical feature," and "Name". Using the chi-square goodness of fit test helped us to statistically confirm if the percentages of concepts used were significantly different or not. Results from half of photographs indicated improvement in the spatial thinking skills of students and suggest that selecting a proper photograph for teaching spatial thinking skills increases the likelihood of learning success. We conclude that astronaut photographs are a uniquely valuable resource for teaching spatial concepts and spatial thinking.

We further conclude that our findings suggest ways that teachers, professors and scientists can select photographs to be used for teaching a specific spatial concept. We think that these photographs could be used for creating a data set of photographs for teaching spatial thinking skills. We are looking at the results of this study as a referable resource for future researchers who want to use NASA photographs in their studies and to provide a guide for evaluating the appropriateness of each photograph for teaching a specific spatial concept. In the future paper, there are a collection of 18 different photographs which will be categorized for teaching different spatial concept based on students respond in interpreting each photograph. It would be beneficial if other researchers can follow the same procedure of selecting a proper photograph taken from ISS and share them with the students for educational purposes. Then the educator can analyze the results and use them to contribute creating a good database for teachers to teach spatial concepts to improve spatial thinking skills of students.

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Appendix I. Comparing the usage of three spatial concepts (df = 2).

		Assignment 1	Assignment 2	Assignment 3
Photograph 1	χ^2 statistics	48.55319	39.98305	40.96183
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 2	χ^2 statistics	47.17073	31.39623	25.55
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 3	χ^2 statistics	31.27586	23.77654	28.7907
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 4	χ^2 statistics	77.15429	42.07609	42.08235
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 5	χ^2 statistics	98.95775	71.39474	77.4
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 6	χ^2 statistics	35.27692	36.5098	33.5082
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject

Appendix II. Comparing the usage of "Primitive" and "Simple" spatial concepts (df = 1).

		Assignment 1	Assignment 2	Assignment 3
Photograph 1	χ^2 statistics	13.448	13.29126	12.66667
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 2	χ^2 statistics	15.42202	12.30769	18.47253
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 3	χ^2 statistics	11.26761	9.126761	14.23529
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 4	χ^2 statistics	32.94771	15.69281	16.22535
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 5	χ^2 statistics	28.84615	21.23116	25.73514
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject

Photograph 6	χ^2 statistics	26.27273	31.36036	32.19048
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject

Appendix III. Comparing the usage of "Primitive" and "Complex" spatial concepts (df = 1).

		Assignment 1	Assignment 2	Assignment 3
Photograph 1	χ^2 statistics	45.34343	35.58824	37.43011
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 2	χ^2 statistics	41.80899	27.50877	14.41053
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 3	χ^2 statistics	28.30081	21.46032	23.14286
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 4	χ^2 statistics	60.44776	37.12121	36.49593
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 5	χ^2 statistics	89.47059	65.89441	68.44737
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 6	χ^2 statistics	18.26415	14.55906	8.490566
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject

Appendix IV. Comparing the usage of "Simple" and "Complex" spatial concepts (df = 1).

		Assignment 1	Assignment 2	Assignment 3
Photograph 1	χ^2 statistics	11.65517	6.75	8.018182
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 2	χ^2 statistics	8.333333	3.459459	0.296296
	P-value	< 0.05	0.062891	0.586214
	Decision (α=0.05)	Reject	Do Not Reject	Do Not Reject
Photograph 3	χ^2 statistics	4.349398	2.844444	1.219512
	P-value	< 0.05	> 0.05	> 0.05
	Decision (α=0.05)	Reject	Do Not Reject	Do Not Reject
Photograph 4	χ^2 statistics	5.730159	5.313253	4.813333

	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 5	χ^2 statistics	22.61538	15.04167	13.12048
	P-value	< 0.05	< 0.05	< 0.05
	Decision (α=0.05)	Reject	Reject	Reject
Photograph 6	χ^2 statistics	0.890909	3.764706	8.962963
	P-value	> 0.05	> 0.05	< 0.05
	Decision (α=0.05)	Do Not Reject	Do Not Reject	Reject

Appendix V. Comparing the usage of three spatial concepts through the semester (df = 2).

		Assignment 2 to 1	Assignment 3 to 1	Assignment 3 to 2
Photograph 1	χ^2 statistics	0.328685	0.348739	
	P-value	> 0.05	> 0.05	
	Decision (α=0.05)	Do Not Reject	Do Not Reject	
Photograph 2	χ^2 statistics	8.073231		4.728119
	P-value	< 0.05		> 0.05
	Decision (α=0.05)	Reject		Do Not Reject
Photograph 3	χ^2 statistics	0.739321	0.989878	
	P-value	> 0.05	> 0.05	
	Decision (α=0.05)	Do Not Reject	Do Not Reject	
Photograph 4	χ^2 statistics	6.896789		0.067623
	P-value	< 0.05		> 0.05
	Decision (α=0.05)	Reject		Do Not Reject
Photograph 5	χ^2 statistics	140.2272		0.576445
	P-value	< 0.05		> 0.05
	Decision (α=0.05)	Reject		Do Not Reject
Photograph 6	χ^2 statistics	1.130932	4.69298	
	P-value	> 0.05	> 0.05	
	Decision (α=0.05)	Do Not Reject	Do Not Reject	