Original Paper

Student Led Area Measurement Assessments Using Virtual Globes and Pictometry Web-based Interface within an Undergraduate Spatial Science Curriculum

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Abstract

The use of Virtual Globes and Pictometry continues to expand and develop in undergraduate spatial science education. Spatial science undergraduates measured the area of 30 rectangles on the earth's surface and compared them to Pictometry hyperspectral imagery measurements within a web-based interface and the Google Earth interface compared to ArcGIS Explorer, Map Developers and ArcMap using the ArcMap 10.5.2 interface. An analysis of variance of the absolute mean area errors (p-value of 0.009271) concluded the accuracy of the five area measurements were statistically different at the 95% confidence interval. A Tukey pair-wise test found that the Pictometry and Google Earth methods were more accurate than the ArcGIS Explorer, Map Developers and ArcMap methods. The lowest standard deviation of errors (72.6 sq. ft.) for Pictometry was the most accurate and precise method for on-screen area measurement, followed by Google Earth (SD = 205.0 sq. ft.). The high variation of area measurement error from ArcMap, Map Developers, and ArcGIS Explorer made them less reliable as an alternative to field measurements with ArcMap the worst (SD = 915.1 sq. ft.). The results indicate that Pictometry and Google Earth could both be used to accurately estimate area using on-screen measurements compared to in situ area measurement assessments.

Keywords

spatial science, hands-on, natural resources, virtual globes

1. Introduction

Virtual Globes and Pictometry, which represent ways to display earth spatial features within a computerized environment, assisted undergraduate spatial science students in a capstone course in the Arthur Temple College of Forestry and Agriculture (ATCOFA) at Stephen F. Austin State University (SFASU). Undergraduate spatial science students used Virtual Globes and Pictometry to visualize the world in virtual terms and to process the three content standards of geography. These standards include how to use maps and acquire and process spatial information, how to organize information in a spatial perspective, and how to analyze spatial organization of people, places and the environment. This allows spatial science students to explore the virtual world to facilitate learning essential for long-term learning of spatial science measurements (National Academy of Sciences, 2006; Schultz et al., 2008).

Spatial science students in ATCOFA perform well in applying analytical skills to measure and predict, use geospatial technologies to measure natural resources, use math and statistics for analysis and problem solving, and analysis of priorities to solve real-world problems (Bullard et al., 2014). These are desirable traits in training students for real-world geospatial applications to promote critical thinking, technological knowledge and hands-on engagement (Unger et al., 2016a; Sattar et al., 2017).

Virtual Globes and Pictometry use geobrowser technology to integrate multiscale and temporal data from multiple sources to develop tools for planning for stakeholders (Sheppard & Cizek, 2009; Schroth et al., 2011). The spatial concepts of onscreen measurements combined with *in situ* ground truthing combines the accuracy and precision of the methods for training in natural resource management. Criteria for evaluating landscape visualization for Virtual Globes and Pictometry include the accuracy of measuring features in the landscape, is easily accessible to the public, and be presented in a clear and concise fashion.

Undergraduate spatial science students in ATCOFA at SFASU measured ground rectangles in an urban environment to evaluate tools in Virtual Globes and Pictometry to accurately assess earth surface measurements. After training the students in each method in a senior capstone spatial science course, students measured 30 rectangles clearly visible across remotely sensed imagery in an urban setting. The rectangles were each identified, then measured for length and width on-screen for each of the five techniques analyzed (e.g., Pictometry, ArcGIS Explorer, Google Earth, ArcMap, and Map Developers) to compare the effectiveness of each method. To obtain the actual area of each surface feature identified, as a way to validate each method's area assessment, a measuring tape was used *in situ* to measure the real-world length and width of each rectangle.

Working together, students developed the methodology for spatial science research projects to prepare for their careers (Newman et al., 2007; Bullard et al., 2014; Unger et al., 2016a). The students also learned via one-on-one faculty interactions that while working collaboratively students can acquire and retain information better than working individually (McBroom et al., 2015; Viegut et al., 2018).

2. Background

2.1 Virtual Globes

Virtual Globes display the earth as a three-dimensional globe that one can "fly" above. Virtual Globes run software with spatial data that is streamed from the internet including commercial or public domain satellite, aircraft or Unmanned Aerial Systems (UAS) data. Virtual Globes began in 2001 with EarthViewer from Keyhole, Inc. that was acquired by Google in 2004. This platform allowed users the ability to visualize, locate and navigate through their own geospatial data (Bailey & Chen, 2011). These data can be measured as polygons for area or perimeter assessments (Kerski, 2008; Schultz et al., 2008; Viegut et al., 2018).

These digital spatial data can format directly into ArcGIS Explorer or Google Earth. Virtual Globes are critical for learning to think spatially for points, lines, areas and volumes (National Academy of Sciences, 2006) and are an alternative to traditional Geographic Information Systems (GIS) with data sharing at the global scale (Yu & Gong, 2012). Virtual Globes were downloaded over 500 million times by Google Earth by 2010 and now is a standard method of on-screen data measurement.

2.2 Google Earth

Google Earth can assist in learning spatial skills while students work independently or collaborating with others to solve a real-world question (Patterson, 2007). Google Earth is not a GIS but can incorporate data sets incorporated by users (Schultz et al., 2008). By using Google Earth, students expand their thinking and analytical skills, important in high impact teaching (Unger et al., 2016b). Google Earth enhances the four E's of the learning cycle proposed by Cates et al. (2003) including: engaged in the lesson, explore the earth, explain what they identify, and evaluate the information.

Google Earth on-screen data measurements of a surface object can be ground truthed for validation (Yu & Gong, 2012) and then used in additional locations (Potere et al., 2009). Once polygons are identified and measured on-screen in Google Earth, they can be exported as vector layers into Keyhole Markup Language (KML) format for use in natural resource measurements. These polygons can then be compared overtime for change in the shape or land use of these features (Yu & Gong, 2012).

For measurement in Google Earth, latitude and longitude can be taken at each point on a polygon and used as reference for either distance or area calculations. Since the data are spatially referenced, the polygon can be located either visually in another measuring system or referenced spatially with the coordinate systems for use in the next generation Digital Earth (Goodchild et al., 2012).

2.3 ArcGIS Explorer

ArcGIS Explorer is a virtual globe software that is part of the ESRI ArcGIS software suite. ArcGIS Explorer brings GIS analysis capabilities to a free virtual client with geo-processing support (Kienberger & Tiede, 2008) that can be loaded onto handheld computers (Kerski, 2008). ArcGIS Explorer is part of the Virtual Globes that display spatial data on top of a three-dimensional globe on a computer and is periodically updated with increasing resolution and scale. This includes high spatial resolution satellite data that students can access to integrate and utilize GIS services and geographic

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content (Kerski, 2008).

2.4 Google Map Developers

Google Map Developers (not associated with Google Maps) provides prebuilt Google Maps functionality using free mapping tools from Maptiva. This web-based map can be embedded into GIS applications or provide standalone maps of an area. For area calculations, Map Tools can be used including the Area Calculator or the Draw Rectangle Tool to calculate the area on a map. The use of the tool is intuitive by entering the address of the feature in the Map Developers program, then using the area tools to place a point at each vertex, and then close the area measurement by clicking on the final point. If needed, the measurements can be edited by dragging the edges. A starting point for a polygon can be located using the Latitude and Longitude Finder by placing a point at one corner of the polygon with either decimal values or degree values (https://www.mapdevelopers.com/index.php).

2.5 Pictometry

Area measurement in Pictometry uses the Area tool by clicking on each vertex of a polygon. Pictometry, classified as hyperspatial resolution remotely sensed digital imagery, can be acquired at three or four band options. Images are taken by aircraft include both nadir and oblique angles up to 40 degrees with a spatial resolution ranging from 3 to 6 inches. Pictometry imagery depicts fronts and sides of vertical ground features and the ground surface features in a web-based interface. A composite Pictometry image can be used to accurately measure a polygon size and position using the patented Pictometry web-based interface (Wang et al., 2008). Previous assessment of height indicated no difference between Pictometry and a measuring pole for baldcypress tree height (Unger et al., 2015), building height (Kulhavy et al., 2014) and a UAS DJI Phantom 3 for measuring light poles when the UAS was not landed between measurements (Unger et al., 2016a).

2.6 ArcMap

Area measurement within ArcMap, also part of the ESRI software suite of spatial analysis software, starts by first loading a digital image of the area in question into an ArcMap data frame. Once loaded, the scale of the digital image can be adjusted by zooming in and out of the area in question until the area assessment location boundary can be easily identified. After identifying the boundary area in question via a visual assessment, the Measure tool in ArcMap is opened allowing the user to outline the area via the polygon measure tool to measure and record area in the user's choice of real-world units.

3. Methodology

Five measuring tools were used by seniors in a capstone spatial science course to measure the area of 30 rectangles in an urban setting on a computer screen (Figure 1). The tools used were Pictometry, ArcMap, Google Earth, Map Developers, and ArcGIS Explorer. The rectangles were located and measured on-screen in square feet. The actual ground truth measurements were taken with a measuring tape. Measurements were recorded in an Excel spreadsheet and compared using a visual assessment of errors, and then the average and standard deviation distribution of errors for each method were

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calculated and compared. The average of absolute errors and root mean square error (RMSE) for each method were also calculated and compared. A one-way analysis of variance (ANOVA) was conducted comparing the absolute errors for each method with an alpha of 0.05. If a significant difference among the measurement methods was found a Tukey's pair wise comparison on the average of absolute errors was calculated.
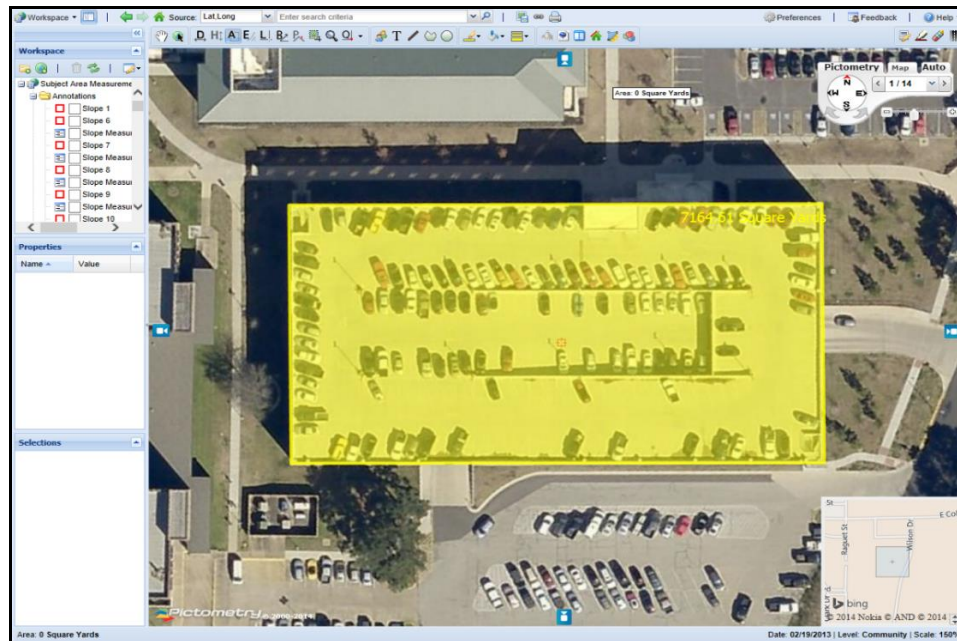

Figure 1. Example of an Area Assessment (e.g., Polygon) Measured on-screen within the Pictometry Web-based Interface

4. Results

A total of 30 rectangular polygons were identified on a computer screen and measured for their area using an on-line area measurement tool. This process was repeated on the same 30 polygons using five different programs (e.g., Pictometry, ArcMap, Google Earth, Map Developers, and ArcGIS Explorer). The actual dimension of each rectangle was measured on the ground using a measuring tape. The area values (square feet) were calculated by multiplying length with width of each polygon for the five methods analyzed (Table 1).

Table 1. Area Measurement Results for All Five Methods Analyzed with in Situ Measurements (e.g., Field Column) for All 30 Polygons

Area (sq. ft.)	Pictometry	ArcMap	Google Earth	Map Developers	ArcGIS Explorer	Field
1	2805.1	2452.7	2782.7	2844.0	3982.1	2808.0
2	4228.7	3966.7	3979.3	3901.0	4428.8	4196.6
3	2068.7	2054.1	2109.5	1927.0	2070.9	2138.5
4	177.1	437.5	151.2	132.0	182.3	174.5
5	472.0	640.4	451.1	450.0	534.8	495.3
6	1936.9	3258.4	1947.0	1980.0	1622.6	1940.4
7	65129.2	69259.8	63936.8	62403.0	67304.2	64865.0
8	1293.4	2021.7	1276.9	1276.0	1373.7	1339.0
9	296.9	724.5	298.1	286.0	327.1	290.8
10	1407.8	981.0	1426.9	1404.0	1482.0	1404.0
11	48517.4	47618.8	48046.9	47502.0	47255.0	48415.3
12	16113.0	15543.9	16256.3	16632.0	16367.2	16097.9
13	2909.1	2679.3	2424.6	2485.0	2872.8	2839.7
14	3548.2	4361.2	3583.6	3531.0	3253.6	3647.6
15	333.3	463.7	292.7	297.0	294.5	331.2
16	184.4	318.1	155.4	170.0	422.7	181.0
17	1555.6	1463.7	1517.6	525.0	1497.6	1591.1
18	169.1	179.0	111.3	165.0	167.2	167.5
19	1027.3	1229.7	1001.1	986.0	1050.2	1016.1
20	58835.6	58925.3	59190.3	58644.0	59368.0	59030.6
21	17336.2	17374.7	17486.9	17334.0	17123.0	17335.5
22	2619.0	2930.9	2455.7	2538.0	2643.0	2661.9
23	583.8	758.6	599.8	552.0	592.5	598.3
24	1423.4	2132.8	1577.8	1328.0	1448.9	1498.7
25	4420.3	5923.2	4354.1	4366.0	4168.3	4430.7
26	615.7	646.4	567.1	567.0	598.2	632.3
27	186.7	276.8	205.3	200.0	202.4	199.2
28	217.2	331.4	214.5	210.0	198.5	208.5
29	28.7	122.3	24.6	30.0	47.8	29.1
30	3092.4	2897.0	3122.2	3120.0	3161.5	3138.5

Each polygon's area measurement error was calculated by comparing the on-screen measurement to the actual field measurement. A visual assessment of the distribution of errors by measuring methods

indicates that Pictometry performed better with errors clustered and centered on zero, followed by Google Earth while the remainder of the methods had widespread errors (Figure 2). The average of errors for each measuring method indicates whether or not a method is either overestimating or underestimating the area as a whole (Table 2).
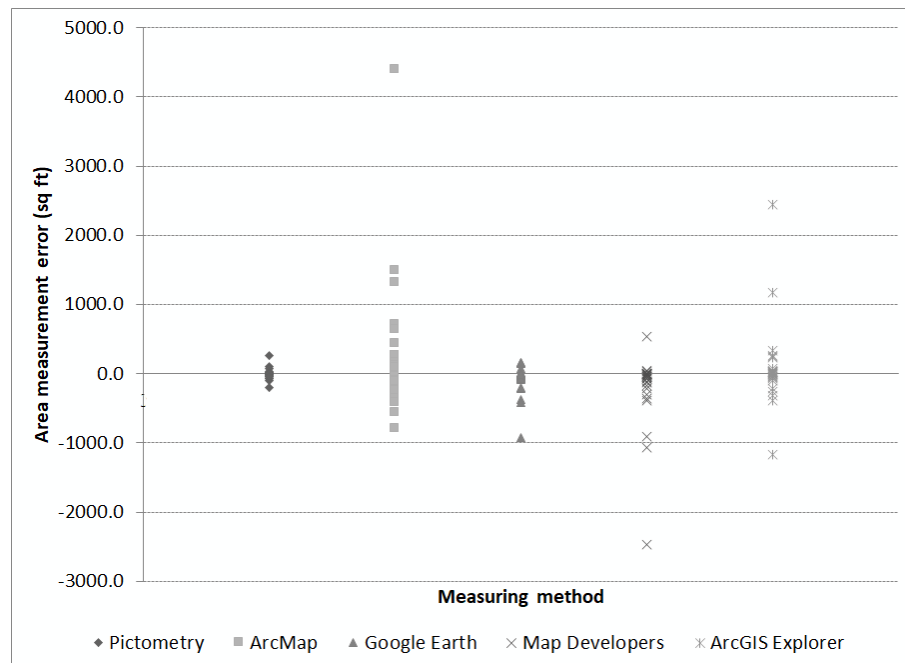

Figure 2. Distribution of Area Measurement Errors by All Five Methods Analyzed

Table 2. Summary of Area Measurement Errors by All Five Methods Analyzed

Area measurement (Sq. ft.)	Pictometry	ArcMap	Google Earth	Map Developers	ArcGIS Explorer
Mean of errors	-5.7	275.7	-71.9	-197.3	77.9
SD of errors	72.6	915.1	205.0	513.3	563.0
Mean of absolute errors	40.6	480.9	111.8	238.1	255.5
RMSE	71.6	941.0	213.9	541.8	559.0

The error means indicate that ArcMap overestimated the area (average of errors = 275.7 sq. ft.) and Map Developers underestimated the area (average of errors = -197.3 sq. ft.). The close-to-zero error means were Pictometry (-5.7 sq. ft.) and Google Earth (-71.9 sq. ft.). The dispersion of the errors for each measuring method was quantified by its standard deviation. The lowest standard deviation of errors by Pictometry (72.6 sq. ft.) was identified as the most accurate and precise method for on-screen area measurement followed by Google Earth (SD = 205.0 sq. ft.). The high variation of area measurement error from ArcMap, Map Developers, and ArcGIS Explorer made them less reliable as an alternative to field measurement with ArcMap as the worst (SD = 915.1 sq. ft.).

RMSE results show that Pictometry with the lowest RMSE (71.6 sq. ft.) outperformed other methods followed by Google Earth (RMSE = 213.9 sq. ft.). While a close-to-zero mean of errors might be the result of a large magnitude of overestimations and underestimations that cancel each other, the mean of absolute errors provides another approach for accuracy assessment similar to RMSE. Values of the mean of absolute errors indicate the same trend, where Pictometry is the most accurate (40.6 sq. ft.), followed by Google Earth (111.8 sq. ft.), with ArcMap the least accurate (480.9 sq. ft.).

To test the statistical significance on the accuracy of on-screen area measurements, an analysis of variance (ANOVA) was conducted on the absolute errors for each measurement method analyzed (Table 3). The results indicate a significant difference (p-value = 0.009271) among the five area assessment methods. A Tukey pair-wise comparison was conducted to determine which methods are significantly different. Statistically Pictometry performs the same as Google Earth for on-screen area measurement, although Pictometry has the lowest average of absolute errors. While ArcMap has been found the least accurate, its on-screen area measurement accuracy is not statistically different from ArcGIS Explorer and Map Developers.

Table 3. ANOVA on the Absolute Errors of on-screen Area Measurements by the Five Methods Analyzed

SUMMARY					
Groups	*Count*	*Sum*	*Average*	*Variance*	*Tukey*
ArcMap	30	14426.21	480.87	676802.60	A
ArcGIS Explorer	30	7666.23	255.54	255740.27	A B
Map Developers	30	7143.84	238.13	245025.09	A B
Google Earth	30	3353.67	111.79	34421.64	B
Pictometry	30	1216.84	40.56	3596.96	B

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Groups	3402304	4	850576.1	3.498624	0.009271	2.434065
Within Groups	35252010	145	243117.3			
Total	38654314	149				

5. Discussion

An evaluation of Virtual Globes and Pictometry results indicate that Pictometry and Google Earth performed the best for area estimation of rectangles followed by Map Developers, ArcGIS Explorer, and ArcMap. Statistical difference was found between the group of Pictometry, Google Earth, and ArcMap which was the least accurate. Pictometry hyperspatial data had the best resolution at 3 inches and could be viewed at oblique angles to enhance on-screen visualization. The areas of the rectangles

varied from 29 to 64,865 sq. ft. in an urban setting indicating the usefulness of area measurements over these dimensions.

These results indicate that care needs to be taken in measuring spatial area with available tools. Google Earth as a Virtual Globe product performed as well as Pictometry with a 4 inch spatial resolution. Undergraduate spatial science students produced accurate onscreen digitizing of rectangles with minimal instruction, crucial for measuring quantitative data for natural resource planning (Unger et al., 2014; Viegut et al., 2018).

The continued improvement in on-screen measurements indicates their importance in hands-on instruction in these techniques for ATCOFA spatial science students. These techniques can be applied within SFASU and at other universities. The reinforcement of the importance of use of high end technology coupled with analytical skills, use of geospatial technologies and ability to solve problems validates the use of spatial science for multidisciplinary problem solving (Bullard et al., 2014).

The students learned via one-on-one faculty interactions that while working collaboratively students can acquire and retain information better than working individually. Working together spatial science students learned to develop methodology to explore the virtual world to facilitate learning essential for long-term retention of spatial science applications throughout their entire careers.

6. Conclusions

The use of remotely sensed area measurements achieved by undergraduate spatial science students to measure earth surface features within the web-based Pictometry interface, Google Earth interface, Arc Map, Map Developers, and ArcGIS Explorer indicates their use in lieu of *in situ* assessments. The Tukey pair-wise test indicates that the remotely sensed Pictometry web-based interface and the Google Earth interface provided the most accurate measurements while ArcMap was least accurate.

This indicates that both Pictometry and Google Earth can be used for on-screen digitizing of polygons. These results mirror the results of Viegut et al. (2018) that found no significant difference between Pictometry and Google Earth Pro, but both were statistically more accurate than the DJI Phantom 4 Pro UAS. This study reinforces the accuracy of Pictometry and Google Earth for area measurements and the value of student-driven hands on research in spatial science assessments. This interactive hands-on approach of learning with real-world data will prepare the students for their future careers.

Acknowledgements

References

Bailey, J. E., & Chen, A. (2011). The role of Virtual Globes in geoscience. *Computers & Geoscience*, *37*, 1-2. https://doi.org/10.1016/j.cageo.2010.06.001

Bullard, S. H., Stephens Williams, P., Coble, T., Coble, D. W., Darville, R., & Rogers, L. (2014). Producing "Society-ready" Foresters: A research-based process to revise the Bachelor of Science in Forestry curriculum at Stephen F. Austin State University. *Journal of Forestry*, *112*(4), 354-360. https://doi.org/10.5849/jof.13-098

Cates, W. M., Price, B., & Bodzin, A. M. (2003). Implementing technology-rich curricular materials: Findings from the exploring life project. *Computers in the Schools*, *20*(1-2), 153-169. https://doi.org/10.1300/J025v20n01_11

Goodchild, M. F., Guo, H., Annoni, A., Bian, L., de Bie, K., Campbell, F., & Lewis, A. J. (2012). Next-generation digital earth. *Proceedings of the National Academy of Sciences*, *109*(28), 11088-11094. https://doi.org/10.1073/pnas.1202383109

Kerski, J. J. (2008). The world at the student's fingertips. *Digital geography: Geo-spatial technologies in the social studies classroom*, 119-134.

Kienberger, S., & Tiede, D. (2008). ArcGIS Explorer review. *GEO Informatics*, *11*(2), 42-47.

Kulhavy, D. L., Unger, D. R., Hung, I., & Douglass, D. (2014). Integrating hands-on undergraduate research in an applied spatial science senior level capstone course. *International Journal of Higher Education*, *4*(1), 52. https://doi.org/10.5430/ijhe.v4n1p52

McBroom, M., Bullard, S., Kulhavy, D., & Unger, D. (2015). Implementation of collaborative learning as a high-impact practice in a natural resources management section of freshman seminar. *International Journal of Higher Education*, *4*(4), 64-72. https://doi.org/10.5430/ijhe.v4n4p64

National Academy of Sciences. (2006). *Learning to think spatially—GIS across the K-12 curriculum*. National Academy of Sciences, Washington, D.C.

Newman, P., Bruyere, B.L., & Beh, A. (2007). Service-learning and natural resource leadership. *Journal of Experiential Education*, *30*, 54-69. https://doi.org/10.1177/105382590703000105

Patterson, T. C. (2007). Google Earth as a (not just) geography tool. *Journal of Geography*, *106*, 145-152. https://doi.org/10.1080/00221340701678032

Potere, D., Scheider, A., Angel, S., & Civco, D. (2009). Mapping urban areas on a global scale: which of the eight maps now available is more accurate? *International Journal of Remote Sensing*, *30*, 6531-6558. https://doi.org/10.1080/01431160903121134

Sattar, F., Tamatea, L., & Nawaz, M. (2017). Drawing the pedagogy: Future prospect of teaching and learning. *International Journal of Educational and Pedagogical Sciences*, *11*, 1649-1664.

Schroth, O., Pond, E., Campbell, C., Cizek, P., Bohus, S., & Sheppard, S. R. J. (2011). Tool or toy? Virtual globes in landscape planning. *Future Internet*, *3*, 204-227. https://doi.org/10.3390/fi3040204

Schultz, R. B., Kerski, J. J., & Patterson, T. C. (2008). The use of Virtual Globes as a spatial teaching

tool with suggestions for metadata standards. *Journal of Geography, 107*, 27-34. https://doi.org/10.1080/00221340802049844

Sheppard, S. R. J., & Cizek, P. (2009). The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualization. *Journal of Environmental Management*, *90*, 2102-2117. https://doi.org/10.1016/j.jenvman.2007.09.012

Unger, D. R., Hung, I., Zhang, Y., & Kulhavy, D. L. (2014). Evaluating GPS effectiveness for natural resource professionals: Integrating undergraduate in the decision-making process. *Journal of Studies in Education*, *4*, 30-44. https://doi.org/10.5296/jse.v4i4.6389

Unger, D. R., Kulhavy, D. L., Busch-Petersen, K., & Hung, I. (2016). Integrating faculty led service learning training to quantify height of natural resources from a spatial science perspective. *International Journal of Higher Education*, *5*, 104-116. https://doi.org/10.5430/ijhe.v5n3p104

Unger, D., Kulhavy, D., Hung, I., & Zhang, Y. (2016). Accuracy assessment of Pictometry height measurements stratified by cardinal direction and image magnification factor. *International Journal of Geospatial and Environmental Research*, *3*(1), Article 4.

Unger, D., Kulhavy, D., Williams, J., Creech, D., & Hung, I. (2015). Urban tree height assessment using Pictometry hyperspatial 4-inch multispectral imagery. *Journal of Forestry*, *113*(1), 7-11. https://doi.org/10.5849/jof.14-020

Viegut, R., Kulhavy, D. L., Unger, D. R., Hung, I., & Humphreys, B. (2018). Integrating unmanned aircraft systems to measure linear and areal features into undergraduate forestry education. *International Journal of Higher Education*, *7*, 63-75. https://doi.org/10.5430/ijhe.v7n4p63

Wang, Y., Schultz, S., & Giuffrida, F. (2008). Pictometry's proprietary airborne digital imaging system and its application in 3D city modelling. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *37*(Part B1), 1065-1070.

Yu, L., & Gong, P. (2012). Google Earth as a virtual globe tool for Earth science applications at the global scale: Progress and perspectives. *International Journal of Remote Sensing*, *33*(12), 3966-3986. https://doi.org/10.1080/01431161.2011.636081