Analysis of the Spatial Thinking of College Students in Traditional and Web-facilitated Introductory Geography Courses using Aerial Photography and Geo-visualization Technology

by

Ronald Evan Palmer

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Graduate Supervisory Committee:

Ronald Dorn, Chair
Lauren Harris
Niccole Cerveny

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ABSTRACT

Recent advances in geo-visualization technologies, such as Google Earth, have the potential to enhance spatial thinking. Google Earth is especially suited to teaching landforms and geomorphological processes in traditional, online, or hybrid college classroom settings. The excitement for the technology as a learning tool, however, must be tempered by the need to develop sound and supportive pedagogies. A fundamental gap in the geoscience education literature exists because learning experiences with Google Earth, from the perspective of the student, are not completely understood. This dissertation analyzes three case studies in college introductory physical geography (Chapters 2 and 4) and teacher education (Chapter 3) courses at Arizona State University where students completed an online (Chapter 2 and 3) laboratory that used Google Earth as the main tool for landform identification and interpretation, and a hardcopy laboratory and in-field exercise (Chapter 4) that compared Google Earth oblique with traditional stereopair air photo and planimetric perspectives. Gauging student performance in these tasks, along with their formative and summative opinions for 'what it was like to learn this way', provide information as part of a feedback loop to develop and improve instructional scaffolding and best practices so that the focus remains on the content-to-be-learned and not the tool. These case studies show that, in general, prior use of Google Earth is usually not a limiting factor; multiple perspectives and supplemental visualizations of landforms with Google Earth's may enhance the learning experience; the hands-on nature of structured Google Earth exploration in these labs are virtual field trips that increase enjoyment and fit within a learner-centered curriculum; scaffolding landform-learning exercises for aspiring elementary school teachers linked to children's literature assists the development of content knowledge for teaching physical geography and spatial thinking; and, finally, despite a virtual globe's high-quality

visualizations and promising potential for learning, there is still a role for stereopair images in the geomorphology classroom.

DEDICATION

This work is dedicated to my loving grandfather, J. Lynn Shawcroft. Papa, you have been one of my biggest fans and support during the past few years. You were the first person I called when I learned about my selection for this opportunity to earn an advanced degree. I remember our conversation well. Now that I have completed this program I fear you are more proud of me, and the portion of my life's accomplishments that this work represents, than I deserve—but that is what makes you so wonderful.

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INTRODUCTION

The focus of this dissertation rests in exploring the nature of spatial thinking and pedagogies for spatial thinking in response to a prominent and popular virtual globe program, Google Earth. Launched in 2005, it is available as a free download from the Internet (https://www.google.com/earth/). Google Earth is changing the way we observe and explore Earth; from the layperson curious about what their house and neighborhood looks like from above to the scientist or professional choosing it as a research and communication tool. Of all its potential uses, Google Earth has tremendous appeal to the education community because of its relative ease of use and impressive world-wide coverage of seamless of satellite aerial imagery – all streamable at multiple scales and draped over digital terrain data in a way that provides near-real and multiple perspectives of the earth's surface and landforms, ocean floor, and even Martian surfaces. One can explore standard straight down, or planimetric views, oblique side-looking views, and ground views including the Google Earth StreetView ™ from most roadways. Although it lacks the spatial analysis and data handling power of a geographic information system (GIS), ever since its debut Google Earth has been demonstrating its potential to develop and enhance spatial thinking as educators continue to find new ways to incorporate it into classrooms and programs. While excitement over Google Earth is definitely warranted, prudence calls for sound pedagogies to guide the many ways to learn and things to do so that the focus remains squarely upon learning and less upon the tool.

This introductory chapter briefly introduces relevant literature to establish a background for spatial thinking, physical geography instruction using Google Earth, and learning theories before describing a general problem statement that connects the three individual case studies that comprise the body of this dissertation.

SPATIAL THINKING

Spatial thinking is something that we all do, at least informally and subconsciously. We live and function in a spatial world (Stephen, 2003). As infants we begin to develop a basic awareness and understanding of our own and other objects' spatial existence (Bremner, 1989; Golledge, Marsh, & Battersby, 2008) which increases our chances of survival and potential for enjoyment throughout life. As we grow and age through childhood, gender and gender-environment interactions begin to play significant roles in the development of our spatial thinking skills generally (Matthews, 1986). The National Research Council's (2006, p. 3) report *Learning to Think Spatially: GIS as a support system in the K-12 curriculum* has codified spatial thinking as, "…a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning" and greatly rekindled an interest in the topic as evidenced by the surge of related articles appearing since its publication (Gersmehl, 2008; Goodchild & Janelle, 2010; Halpern et al., 2010; Hedley, Templin, Czajkowski, & Czerniak, 2013; Huynh & Sharpe, 2013; Jee et al., 2013; Jekel, Pernkopf, & Hölbling, 2008; Jo & Bednarz, 2009; Kastens et al., 2009; Kerski, 2013; M. Kim & Bednarz, 2013; J. Lee & Bednarz, 2009; Marsh, Golledge, & Battersby, 2007; Milson & Alibrandi, 2008; Schultz, Kerski, & Patterson, 2008; Yuda, 2011) although geography educationists have held interest and pushed for progress in this area for decades prior (Mathewson, 1999; Morrill, 1983). Kerski (2013) also reminds us that the GIS education community in particular has been concerned with spatial thinking education in primary and secondary schools since the early 1990s. Many feel that the old barriers to progress are fading and that technology and computers have opened the door to meaningful spatial education for more school children and young adults than ever before (NRC, 2006).

Training and education in the elements of spatial thinking are essential to the making of a geographer (Kastens et al., 2009). Here we must acknowledge there is a difference between latent spatial thinking abilities that nearly everyone acquires to some degree, according to physical and mental maturation, and more sophisticated spatial thinking capabilities that are the result of training, study, and deliberate development born out of interest and passion. Geographers refer to people of the latter group as 'spatially gifted' individuals; they commonly seek out or are attracted to disciplines, vocations, and hobbies where they can capitalize on their mental aptitude for the spatial domain of knowledge as a "…conceptual and analytical framework within which data can be integrated, related, and structured into a whole" (NRC, 2006, p. 25). Perhaps a better way to describe someone who is spatially gifted (noting that, of course, not all spatially gifted persons are geographers) is to say they have, or are in the midst of developing, a *spatial attitude*:

> A willingness and ability to frame problems in spatial terms, to use the language of space to express the elements of a problem, to think about relations between objects in terms of distances or directions or patterns, to imagine alternative graphical representations, to change viewing perspective or viewing angle, to zoom in or out, to hypothesize and visualize the effects of different rates of change, to predict what might happen to spatial patterns or structures or relations *if*… (NRC, 2006, p. 27)

A spatial attitude asks *what is where?* And *why?* (Schoning et al., 2008). The transition that everyone goes through on their way from latent spatial cognition to being able to view the world around them in spatial terms deliberately is one worthy of study.

There are methods for measuring and assessing spatial thinking (Huynh & Sharpe, 2013; J. Lee & Bednarz, 2009, 2011), but we are still wrestling with understanding how much formal, institutionalized education contributes to the equation. This research approaches the topic on the premise that spatial thinking *can* be taught and it *can* be learned (NRC, 2006), but also seeks to assess the evidence of Google Earth's impact and influence on learning through in-depth, quantitative research (Bailey, Whitmeyer, & De Paor, 2012) .

Google Earth as a tool for learning physical geography and spatial thinking development – Physical geography is the quintessential spatial science. Placement and distribution of objects and features on and below the earth's surface, and the formative processes that sustain or change them, predate and were originally independent of people. It is a great mystery; humans are curious about why Earth appears and functions as it does and thus gaining knowledge of landforms across space is an essential part of the education and intellectual motivation of geographers (Davis, 1902; Lobeck, 1924; Raisz, 1931; Sauer, 1956). As its vastness and wide expanses are too great for any one lifetime to explore, maps and aerial photography communicate spatial information in dense packets and are a universal component of student exercises in learning physical geography. One of the reasons geography instructors harness technology is because it allows them to present landforms via multiple perspectives, in the place of or to supplement field visits (Crampton, 1999; Eusden, Duvall, & Bryant, 2012; Hagevik & Watson, 2003; Heyl, 1984; E. M. Johnson et al., 2011; Lang, Lang, & Camodeca, 2012; Liu & Zhu, 2008; McCaffrey, Feely, Hennessy, & Thompson, 2008; Piatek, Kairies Beatty, Beatty, Wizevich, & Steullet, 2012; Stumpf, Douglass, & Dorn, 2008; Treves & Bailey, 2012). But nobody is advocating that real trips are obsolete – quite the opposite (Fuller, Rawlinson, & Bevan, 2000; Kent, Gilbertson, & Hunt, 1997; Spicer & Stratford, 2001).

Where it is not feasible to observe directly in the field, various forms of spatial representations of landforms and earth features bring snapshots of the physical environment to the student using the same field science and research tools they use (McCaffrey et al., 2005; Thorndycraft, Thompson, & Tomlinson, 2009). Since the 20th Century, aerial photography and satellite imagery in general, and stereopair images of landscapes (Giardino & Thornhill, 1984), in particular, have proven to be a particularly powerful way to help students 'see' in rich detail, as if they were flying overhead. With the development of the computer and computer-generated or computer-hosted visualizations, GIS is a tool initially born out of a need to "help land planners and land resource managers make well-informed environmental decisions" (Anonymous, 2014) and enables us to store, view, and analyze spatial data.

Expert and professional users must have a high proficiency in spatial thinking, but it is generally believed that students and non-experts can stimulate and develop spatial thinking skills by learning to ask questions and solve problems using a GIS (Bodzin, 2011; Goodchild, 2006; Jo, Klien, Bednarz, & Bednarz, 2009; Kerski, 2013; Kulo & Bodzin, 2011; Landenberger, Warner, Ensign, & Nellis, 2006; J. Lee & Bednarz, 2009; Sinton, 2011). One downside to a fully functional GIS, however, is it requires a fair amount of familiarization and is not categorically user-friendly. The need for detailed training has contributed to the relatively unsuccessful integration of GIS into K-12 curriculum (Kerski, 2011). Colleges and universities that teach GIS also struggle to find a balance between teaching the 'button pushing' of the software tool and helping students learn to solve spatially relevant problems with the tool.

Google Earth is a virtual globe and not a GIS, although it has many GIS-like functions. It is relatively easier to use than a GIS because the user does not need to have, search for, or 'add' data layers. They simply need to go—fly—rather, to a point of interest and the data appear. The program streams and displays imagery draped over a digital model of the planet from vantage points of thousands of miles above to mere meters above the surface. This makes Google Earth an appealing alternative resource for the purchasing and storing of hardcopy and digital aerial photography and satellite imagery used in introductory level physical geography and geology college courses (T. R. Allen, 2008; Lisle, 2006; Thomsen & Christopherson, 2010). It is a sophisticated visualization tool that can be used to observe, explore, measure, compare, and document earth surface phenomenon and the human presence at high levels of accuracy (de Vriend, Boves, van Hout, & Swanenberg, 2011; Guth, 2012).

A special edition publication by the Geologic Society of America (GSA) captures the trend of Google Earth becoming *the* tool of choice, where appropriate, for not just geoscience educators but also researchers (Whitmeyer, Bailey, De Paor, & Ornduff, 2012). The papers in this monograph argue that Google Earth does not just improve student knowledge about landforms, but also simultaneously increases their spatial reasoning and thinking skills (T. K. Lee & Guertin, 2012) as is echoed elsewhere (Almquist, Blank, & Estrada, 2012; Bodzin, 2011; Kulo & Bodzin, 2011; Patterson, 2007; Richard, 2009; Schultz et al., 2008). Jensen (2010) describes a user's enhanced spatial and social experience with Google Earth as 'spatial augmentation'.

People just love to play with Google Earth, and learning while 'playing' is a tenet of active and engaged learning – or at least spending time with Google Earth does not always *feel* like the usual struggle of learning. It is fun and visually engaging (Adam & Mowers, 2007; Dordevic & Wild, 2012; Moulder, 2009). If you have downloaded the program, have sufficient Internet bandwidth and can control a mouse you can explore the world with Google Earth. It is virtual visualization but of such high quality that it often gives one the feeling of actually being there. In a structured setting, educators can guide their students on virtual field trips (VFTs) and activities, keeping true to the nature of the discipline as a field science. Of course nothing can completely replace actual outings and field trips for students to touch and see and feel for themselves, but the ability of Google Earth to simulate this through an advantageous view from above and through multiple perspectives adheres to a learner-centered approach to education (Oost, De Vries, & Van der Schee, 2011; Phillips, 2012).

Google Earth requires little to no prior experience and so it is ideal for introductory level physical geography courses and lessons at all levels, and yet is robust enough for advanced students. When going outside is not feasible, or when locations are too far away to permit travel, Google Earth can take an entire classroom out into the field—virtually—in arguably the next best way. Like other strong active learning pedagogies in physical geography, such as fieldwork using the Rock Art Stability Index (RASI) (C. D. Allen & Lukinbeal, 2011), it gets students 'outside' doing physical geography and making observations, not just passively learning about how others practice the science. Similar to students using RASI, carefully designed learning activities and real research based in Google Earth has the potential to give students "…a type of ownership over the process of scientific inquiry – a key principle of learner-centered education" (Lukinbeal et al., 2007, p. 239). Two recent studies reported that teachers and student-teachers who did field work that included both GIS and Google Earth as visualization and analysis tools said they are more likely to use Google Earth in their classrooms (Ratinen & Keinonen, 2011; Sherman-Morris, Morris, & Thompson, 2009). Indeed, students who begin to develop an aptitude for understanding patterns and distribution of earth surface objects and features in the natural, outside world—whether by actual visits or via virtual globes and other geoscience technologies—are, by definition, becoming spatial scientists.

However, many temper their optimism with a caution, warning that, as with all geo-visualization technology (Bednarz & Whisenant, 2000), Google Earth-based activities must be carefully scaffolded (Almquist et al., 2012; Bodzin & Cirucci, 2009;

Johnson, Lang, & Zophy, 2011) because screen views are super-saturated with information that can overwhelm and distract the unguided. Gobert, Wild, and Rossi (2012, p. 466) clarify a possible reason why: "[t]his is likely because students, unlike experts, typically do not know what is salient within rich information sources such as Google Earth, and thus, if unscaffolded […] they might not acquire the targeted information as intended." The need to scaffold implies that students may be functioning at very low levels of spatial awareness and need more training and experience.

Learner-centered education and content knowledge for teaching – Learner-centered approaches to education are not new (Henson, 2003; Lambert & McCombs, 1998; H. Spencer, 1966) but learning institutions are struggling with the lumbering process of change as they seek to reconnect with learner-centered education (LCE) (Bosch et al., 2008). In contrast to teacher-centered education, LCE is constructivist (Bruner, 1990). Here students are the producers of knowledge (Spronken-Smith & Kingham, 2009). New knowledge gained is a subjective reality built upon previous knowledge, experiences, and beliefs. Lombardi (2007) expresses it this way: real learning happens when it is meaningful to the student. Effective spatial thinking instruction and learning tasks are better achieved in learner-centered, inquiry-based environments (Bodzin & Cates, 2002). Several leading geoscience educators recently remarked:

> Students do not learn much just by sitting in class listening to teachers, memorizing pre-packaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences, apply it to their daily lives. Rather than asking 'What do I want to teach?' in a consistently lecture-style classroom setting, teachers are encouraged to ask 'What should our students be learning, and how can I facilitate that learning?' (Paradis, Treml, & Manone, 2013, p. 6)

In LCE, the role of a teacher is still vital but changes to that of a facilitator and co-learner along side his/her students (McManus, 2001). It stresses, instead, "the active and reflexive character of learning and learners and the psychological factors that are controlled by the learner internally rather than through conditioned behavior or physiological aspects" (Ware, 2006, p. 15).

LCE methods may be completely different than the way a teacher was taught while they were in school first learning the subjects at the level they are now teaching (American Psychological Association, 1995). No matter the teaching method, however, experienced and aspiring teachers must acquire adequate content knowledge for teaching (CKT) (Ball, Thames, & Phelps, 2008) as well as pedagogical content knowledge (Shulman, 1986, 1987). In other words, there is specific subject matter needed by teachers for teaching—"knowing how knowledge is generated and structured within [a] discipline and how such considerations matter in teaching" (Ball et al., 2008, p. 402). CKT for physical geography enable teachers to teach *how* they learned instead of just mimicking the way they were taught (Harris, 2012).

THREE CASE STUDIES

This dissertation considers three case studies (Table 1) where two types of college students—the general student and the elementary education major—encounter Google Earth and aerial photography interpretation tasks designed to increase their knowledge of physical landforms and their spatial formative processes. Specifically, these connected studies look at the mental transition that general college students and aspiring K-8 teachers in college experience as they discover and develop spatial thinking skills as a result of structured online, in-class, and out-door learning activities and training in introductory-level courses using aerial photography through geo-browsers and virtual globes such as Google Earth. The extent to which they do so is measured by a combination of performance scores and also by their direct formative and summative feedback and opinions about their experience (Bonk & Cummings, 1998).

Each of these three proposed case studies offers specific and meaningful research questions independently. Together, however, they combine to answer two major questions on two different levels. First, they provide insight as to whether labs using LCE methods and Google Earth are effective ways to teach physical geography. Second, they offer a detectable signature, in terms of performance and attitude, for the transition from a latent spatially gifted person to the beginning of training. The broader theoretical implication is a better understanding of the cognitive processes college-age learners go through at the scale of a single or series of tasks.

TABLE 1

Three Case Studies

Lab	Course(s) and semester	Target population	Medium	Geo-Visualization technology and imagery sources
Aerial Photo Interpretation Lab (Chapter 2)	GPH 111 and GPH 211, Spring 2012	General college student, various majors	Online	Google Earth and supplemental enhancements
Geo 4 Physical Systems Lab (Chapter 3)	GCU 113, Fall 2012	Education majors as aspiring K-8 school teachers	Online	Google Earth and supplemental enhancements
Aerial Photography Interpretation Lab, Parts 1 & 2 (Chapter 4)	GPH 111, Fall 2012	General college student, various majors	Paper hard-copy: Part 1 in-class; Part 2 outdoor activity	Stereopairs and viewers, Google Earth images, GPS receivers

Learning geomorphology using aerial photography in a web-facilitated class – The first case study looks at general college students in Arizona State University's *Introduction to Physical Geography* (GPH111) and *Introduction to Landform Processes* (GPH211) courses, examining their performance in and response to an online aerial photography interpretation lab exercise that features Google Earth and various visualization enhancements to aerial photography to learn about geomorphology and landforms. The basic question is how do individual learning styles and background contribute to the learning experience. This case study also assesses, through student performance and feedback, the effectiveness of scaffolding landform learning online: provide basic information through text, diagrams, videos and links; guide students in observing real example landforms on their own in Google Earth imagery from multiple perspectives and with supplemental enhancements; demonstrate their understanding by crafting, capturing, and annotating a screenshot with an oblique view.

Children's stories, local landforms, and Google Earth: Assessing a recipe for content knowledge for teaching physical geography and spatial literacy – The next case study examines the learning of college students with a desire to teach in grades K-8. The motivation behind designing this online lab was to help these elementary education majors gain valuable content knowledge for teaching physical geography and various social studies topics. The scaffolding approach is similar to the first case study but tailors it to this audience by appealing to their self-professed interest in teaching and introduces each landform through a children's book with a regional setting except it does not address landforms at the same depth that GPH111/GPH211 received. Here, aspiring teachers in college gain experience using Google Earth to learn about landforms so that they can use this method in the not too distant future. Their performance, combined with feedback on whether they enjoyed learning this way, helped to validate and improve a landform-learning recipe that can be adopted by other teacher education programs.

Is the stereopair still useful?: Comparing student performance and preference for oblique vs. planimetric aerial imagery – The final case study compares an established, older geo-science visualization method—stereopair air photos and stereoviewers—with the relatively new technology of Google Earth. This study again targets the general college student in an introductory-level physical geography course at ASU, but this time landforms are presented through oblique Google Earth, the planimetric stereopair, or a combination of both. The variance between student performance and their emotional reactions to the three different lab versions help to answer the question of whether or not Google Earth views are sufficient for landform interpretation or whether stereopairs still have educational value. This case study also provides insight into the real-world application of spatial thinking skills by these students. The different groups completed an outdoor Global Positioning System (GPS) exercise where they were challenged to locate themselves physically and record the coordinates of points marked on oblique or planimetric (or one of each) Google Earth screenshots.

Chapter 2

LEARNING GEOMORPHOLOGY USING AERIAL PHOTOGRAY IN A WEB-FACILITATED CLASS

ABSTRACT. General education students taking freshman-level physical geography and geomorphology classes at Arizona State University completed an online laboratory whose main tool was Google Earth. Early in the semester, oblique and planimetric views introduced students to a few volcanic, tectonic, glacial, karst, and coastal landforms. Semi-quantitative analysis of student performance compared across prior experience using Google Earth, self-reported learning styles, and math backgrounds revealed no statistically significant correlations. Despite the online nature of the learning experience leading to logistical frustrations such as how to annotate screen captured imagery, qualitative analysis of student feedback agreed with prior similar research on the necessity for scaffolding and that clear learner objectives followed by a sequence of tasks results in superior student learning. Another observation is students do not benefit from prior schema regarding math training or previous use of Google Earth to perform well. Supplementation with Google Street Views, panoramas, topographic maps, and terrain views enhanced student learning in several ways. First, self-declared kinesthetic learners preferred these supplements over self-declared visual learners. Second, these supplements gave the aerial photo experience more of the feel of a virtual field trip experience, which then aided student learning.

INTRODUCTION

The teaching of landforms has long been a part of the education of a geographer (Davis, 1902; Lobeck, 1924; Raisz, 1931; Sauer, 1956). Using aerial photography remains a universal component of student exercises in learning geomorphology, whether it is through the use of stereopairs (Giardino & Thornhill, 1984) or more recently, Google Earth (Google, 2013) in laboratory manuals (Thomsen & Christopherson, 2010) and other forms of learning (T. R. Allen, 2008; Lisle, 2006). The consensus of a Geological Society of America Penrose Conference in January 2011 (Whitmeyer et al., 2012) held that Google Earth and other virtual visualizations advance both earth science education and research.

While aerial photography has been a crucial tool and resource to the physical geographer for decades, other forms of visualizations can enhance its value. When meaningfully arranged, or scaffolded to provide context (Bodzin & Cirucci, 2009), the otherwise foreign language and information-dense nature of aerial photography and imagery becomes more comprehensible and meaningful to the layperson (Katy Appleton & Lovett, 2005) or the student (Kinzel & Wright, 2008). Virtual Field Trips or Virtual Field Experiences (VFTs/VFEs), as part of a structured curriculum or life-long learning, can make use of a variety of geo-visualization technologies and tools to very nearly simulate an actual excursion (Crampton, 2002; Granshaw & Duggan-Haas, 2012; Lang, Lang, & Camodeca, 2012; Stumpf et al., 2008). The realistic feeling that visualizations evoke to supplement and enhance traditional aerial photography is possible largely because of the digital elevation model (DEM). They opened the door to 3D virtual realities (Faust, 1995), photorealistic terrain visualizations (Graf et al., 1994), and digital modelling and mapping (Smith & Clark, 2005; Smith, Rose, & Booth, 2006). In all, the ability to see the earth from multiple perspectives and at multiple scales, with complimentary text, audio, or video media, provides a powerful array of options for geographic learning.

Introductory physical geography courses in the United States are typically general education courses that end up recruiting new geographers into the field (Beck, 1974; Hoisch & Bowie, 2010; Nellis, 1994; Stumpf et al., 2008; Trupe, 2006). As a consequence, students with various preferred learning styles (Bransford, Brown, & Cocking, 2000) from various disciplines—the full spectrum of a university from humanities and the fine arts, business, social science, and natural science end up taking these courses (Hudak, 2003).

Accommodating all students with the best, complimentary instruction is a constant challenge. Online, hybrid, and web-assisted courses alleviate this issue and are a persistent element of the growth of higher education in the United States (I. E. Allen & Seaman, 2005, 2010; Duffy & Kirkley, 2004; Olson, 2013) and globally (Hiltz & Turoff, 2005). In physical geography education, initial research suggests that web-based learning is at least a viable alternative to the traditional classroom (Jain & Getis, 2003).

This chapter explores the issue of using Google Earth and various supplemental visualizations to assist the learning of landforms by general education students in an online physical geography laboratory at Arizona State University (ASU). Over ninety students from more than 30 different majors used different combinations of 360° panoramas, helicopter views, Google Street Views, terrain maps, contour maps, and other supplements to assist in the learning of landforms through both planimetric and oblique Google Earth visualizations. After presenting the methods employed to analyze student learning in the next section, both quantitative and qualitative findings reveal the aerial photography viewed in Google Earth assists in student learning — but there exists greater learning potential when students also view these same landforms with other visualizations.

CONTEXT AND NATURE OF THE AERIAL PHOTO ASSIGNMENT

Introduction to Physical Geography (GPH111) and *Introduction to Landform Processes* (GPH211) are two first-year courses offered in Geography at ASU. I developed a new online aerial photography laboratory to aid in student learning of landforms in these two courses. The objectives of this lab were for them to 1) learn to use aerial photographs to interpret some basic landforms; 2) learn to use supplemental resources to enhance the power of aerial photos in analysing landforms; and 3) gain confidence in having fun exploring aerial photographs. The lab can be viewed as a static supplemental file: http://alliance.la.asu.edu/aerialphotography/AerialPhotoLab.pdf. Students completed the lab using an innovative grading tool, http://www.gradeify.com/, designed to facilitate such student activities as annotating and uploading screenshots of Google Earth. This lab-hosting tool is also extremely time efficient in providing tailored feedback.

Students completed this aerial photo interpretation lab early in the semester. As such, the tool of aerial photography introduced many of the basic landforms that students would explore later in greater detail. The lab consisted of a series of questions and tasks that introduced students to a resource that would aid them in *seeing* and learning to interpret an aerial view and connect those images to formative processes learned through lectures and readings (Table 1). Each section offered brief explanations in text and diagrams, instructional material and links to supplemental information such as online lectures. This online activity required that students take and submit screen captures of imagery they obtained using Google Earth, and in multiple cases to annotate them with labels and symbols. While taking a screen shot is an intuitive task, the laboratory contained instructions and a chance to practice before encountering the first content questions. Several of the tasks also involved students making calculations such as the volume of sinkholes or uplift rates of marine terraces. Students then shared their thoughts on the value of different Google Earth-visualizations-landform combinations after each task.

The research question of analysing the power of Google Earth in concert with supplementary visualizations for different types of students is possible only because of the growth of available enhancements to planimetric aerial photography. Other supplemental visualizations include online 360˚ panoramas (http://www.panoramas.dk/US/), helicopter views (http://www.californiacoastline.org/), terrain (shaded 3D topographic) and online topographic maps (http://mapper.acme.com/).

Student background – In the Spring 2012 semester, 155 students enrolled in ASU's GPH111 or its GPH211 courses — both offered by the School of Geographical Sciences and Urban Planning. Of these, 92 students (evenly split between the two courses) completed the Aerial Photo Interpretation lab as a graded assignment. GPH111 fulfils a quantitative science requirement and thus attracts students from a wide range of majors although it is a required course for geography majors. GPH211 also attracts a wide range of students.

TABLE 1

Sequence of Student Tasks in Online Aerial Photo Laboratory

Topic	Supplemental Visualization(s) used in conjunction with Google Earth Oblique and/or Planimetric Views & Student Question	Screenshots	Annotations	Calculations
Practice	*N/A*	✔	✔	
Basalt flow textures	*Google Street Views* *What do you think about the value of aerial photographs with a planimetric view? Are they interesting to look at? Do you like this perspective? Did it help you to see a ground view of the same location?*	✔		
Volcano types and heights	*Acme Mapper display of topographic map* *What do you think about the value of aerial photographs with an oblique view? Do you like this perspective? Did this perspective help you see the difference between volcano types?*	✔		✔
Faulting landforms	*Planimetric to Oblique (switching)* *When you were switching the view from planimetric to oblique, were you able to see the landforms better? Why? Or Why not? Please let me know if the process of changing the view affected how you were able to see the landforms.*	✔	✔	
Glacial landforms	*QTVR (360 panoramic view)* *I am very interested in whether the ground perspective helped you. Did the panoramic (QTVR) file give you a better feeling for interpreting the landforms you were seeing in Google Earth?*	✔	✔	
Cuesta landforms	*Acme Mapper terrain map / geologic layer overlay and elevation profile view* *How well did the terrain view help you 'see' or better understand cuesta landforms? I am wondering if the terrain view, along with aerial photography, helps you see landforms of sedimentary rock.*	✔	✔	✔
Sinkhole volume	*Acme Mapper topographic map* *I would love to learn your perceptions about how topographic maps and aerial photos work together with making calculations.*	✔	✔	✔
Marine terrace uplift	*Helicopter Views / Acme Mapper topographic map* *I am interested in learning your thoughts on the interplay of different views of a landform like a marine terrace. Did helicopter views help you understand uplift in the formation of this landform?*			✔
Grand Canyon and chosen hike	*Virtual hike* *I am interested in learning your thoughts about the role of aerial photographs in research that you might carry out on a vacation in your future. Do you plan to use these tools as you plan a future vacation?*	✔		

Given an emphasis of quantitative reasoning in this lab, such as estimating the mass lost in sinkhole dissolution, an issue of relevance is the math background of students. Out of the 37 different majors declared by these students, 17 require only the basic college math course (MAT 142), 16 require more extensive mathematics, and the remaining four do not mention a specific math requirement on their department website and/or are in a non-degree program. Of the students who completed this lab, 42 have taken or will take math courses higher than basic as part of their degree program while 44 must only complete MAT 142. Although a freshmen-level course, the majority were upperclassmen; 16 freshmen, 22 sophomores, 36 juniors, and 18 seniors.

METHODOLOGY

Data compilation – All student lab submissions were compiled into a spreadsheet including text answers, screen shots, points awarded to each question, and students' written feedback to post-task questions in Table 1. Student-based input constituted the rows. The complete dataset (large PDF file, 368MB) and a guide are available for review at the following location: http://alliance.la.asu.edu/temporary/PalmerRIGEO/. Student identities are masked with a code (e.g. "Student S24").

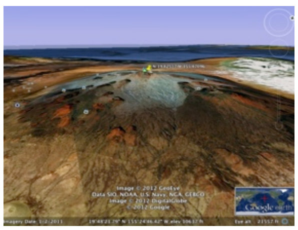
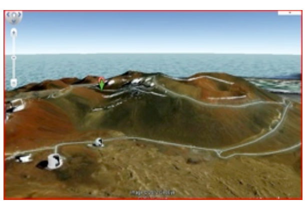
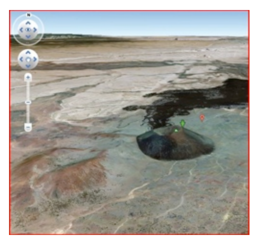
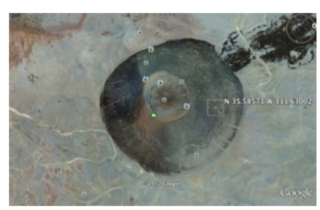
Filtering student responses to questions: Screen Shot-weighted Scores – In reading the raw answers to the questions asked about various visualizations, some students provided feedback to please the instructor. This answer bias was detected if a student clearly did not do well on the task, but then explained how much they enjoyed learning about a landform this way. His/her feedback should hold less weight than those students that did well regardless to whether their reaction to a visualization was positive or negative.

An independent score and rank system served to distinguish more authentic, more sincere feedback that was not part of their grade on the lab. The quality of the product (screen shot and annotations) created by each student was ranked on an ordinal scale from 0 to 3 and then summed as a screen shot score (SSS), both for that particular task and for the lab overall (Table 2). Screen shots of landforms that would be useable in a slideshow or lecture in a classroom setting earned a '3'. Those not suitable for the classroom but indicating a decent attempt at following the instructions received a '2'. This ranking was usually the result of being zoomed in too close or out too far, or not being oblique enough to see the landform's profile. A '2' may also indicate the student did not completely grasp the landform even after reading and viewing instructional material prior to examining it in Google Earth. A '1' was assigned to screen shots that were completely unusable, where the landform was not recognizable, and when they revealed the student clearly did not understand the instructions or was confused about the landform or the imagery. Finally, students that did not submit a screen shot received a '0' score for that task. Whenever a student's responses are referenced in this report they are accompanied by their total Lab SSS and, if applicable, their SSS for that particular lab task.

While also serving as a way to weight student feedback, the formulation of the Screen Shot Score metric also allows for a quantitative analysis of a student's individual performance. Strong students—those who consistently viewed, labelled, measured, and experienced (virtually) landforms in Google Earth in the manner intended—could be expected to have a total Lab SSS in the range 33 to 39. Lab SSS for those whose screen shots received more '2s' than '3s', indicating weaker performance, would fall somewhere between 20 to 32 and a combination of primarily '1s' and '0s' at 19 and below.

TABLE 2

Three students' screen shots identifying basic volcano types and their associated ordinal performance scores (0-3). Because the lab asked for three volcano screen shots, this particular task had a potential maximum score of 9, which could then be used to weight their written feedback. Total Lab SSS possible for the lab is 39 and serves as an overall performance indicator.

Shield Volcano - SSS	Composite Volcano - SSS	Cinder Cone - SSS	Task/ total SSS
			
3	3	3	9 / 37
Student S80: *"I absolutely love looking at the oblique view. They give me an actual feeling of the height of the volcanoes. I think that seeing them as if I were actually in front of them allows me to get a more real feel of the volcanoes."*			
			
2	2	3	7 / 23
Student S122: *"For this particular activity I found the aerial photographs with the oblique views to be very helpful, as well as interesting...these photographs are the next best thing to help me understand the overall shape and features that these specific volcanoes have"*			
			
1	1	2	4 / 25
Student S8: *"I found this perspective to be the most confusing. I am not use to using google earth so it was difficult for me to figure out how to figure out the correct angle for the perspective to be considered oblique. I found it difficult to understand what I was exactly looking at."*			

Statistical methods – This study purposely focused on student feedback and reactions to learning landforms through Google Earth and thus did not incorporate a pre-/post test measurement of learning gains, as is common. Instead, I qualitatively compared categories and groupings of students, and semi-quantitatively compared performance scores (how well they did at producing quality visual images to communicate landforms) against several groups to test their effects. Chi-squares offers a way to compare the many categorical variables of students within the dataset and nonparametric independent-samples Kruskal-Wallis' tests reveal whether a Lab SSS distribution is the same across key variables.

The compiled dataset contains many categorical variables. Student feedback to survey questions throughout the lab enabled grouping and tallying students according to common responses and opinions. For example, after switching between planimetric and oblique perspectives of several faulting landforms, student responses fell into categories such as 'liked switching between planimetric and oblique', 'felt oblique view is sufficient', 'felt planimetric is sufficient', and 'felt negatively about switching'. The final survey question of the lab asked students to reflect on what part of the lab experience helped them the most. From this question, common responses resulted in 14 categorical variables (Table 3) to search trends across the dataset.

TABLE 3

Common responses to lab survey questions and demographic information

Most helpful aspects of lab	•Using aerial photography for the first time to look at landforms •Using Google Earth •Oblique Views •Ground Views (Street View) •Using ACME Mapper •Seeing the Landform-process connection •Using topographic maps •Annotating Screen Shots	Self-declared learning style(s)	•Visual •Auditory •Kinesthetic •Spatial •Interpersonal •Intrapersonal •Naturalistic •Musical •Word •Not Sure
	•Using Google Earth's elevation profile feature •The instructions (text, lectures, diagrams, videos) of the lab •Making Calculations from aerial photographs and visualizations •Learning about volcanoes through aerial photography •Did not like anything in this lab, or did not like this lab overall •Not Sure	Demographic and other information	•Math Requirement of declared major (basic vs. advanced) •Grade level (Freshmen, Sophomore, Junior, Senior) •Prior time using Google Earth more than / less than reported median value (30 min) •Reported time spent on lab (how long it took) shorter / longer than median value (6 hours) for population •GPH 111 vs. GPH 211 student

FINDINGS

Overall, students responded positively to learning landforms and their associated formative processes using Google Earth and supplementary visualizations. Of the 68 students who gave a response (several students' responses fell into multiple common categories, but usually not more than two) to final feedback question (Table 3), 25 students remarked that they enjoyed their first time interpreting aerial photography. 22 mentioned Google Earth specifically as the most helpful aspect of the lab. Additionally, 11 students felt that being able to see landforms from an oblique perspective made a difference for them. Overall feedback from another 11 students related to positive experiences with grasping the landform-process connection as they viewed aerial photography and supplementary enhancements. Only five of the 68 students left negative comments about an aspect of the lab or about the lab overall. Regarding their overall performance, 33% of students had high total Lab SSS (33-39), 59% in the medium range, and 8% were lower.

Influence of prior experience, self-declared learning style and math background – Although a quick glance at the mean Lab SSS for three groupings—prior use of Google Earth, learning style, and the math requirement of declared majors—suggests they do not assert any significant influence on student performance, this descriptor is essentially a summed ordinal metric that is not normally distributed and, thus, nonparametric tests are best suited to detect significance. I used an independent-samples Kruskal-Wallis' test to confirm that a group's Lab SSS distribution is not significantly different than another's.

TABLE 4

Means and Independent-samples Kruskal-Wallis' test of Lab SSS across prior experience, self-declared learning style, and math background of students

Category	N	Mean (Std Dev)	(α = 0.05) Asymptotic Sig.
<30 min prior GE use	48	28.60 (6.89)	0.989
≥30 min prior GE use	39	28.88 (6.65)	
Visual learners	42	28.51 (5.82)	0.171
Other learning types	24	30.77 (5.08)	
Major has advanced math req.	42	29.69 (6.40)	0.263
Major has basic math requirement	44	27.91 (7.25)	

Slightly less than one-third of students reported that they had never used Google Earth before (zero hours of prior use). The median reported time was 30 minutes. The mean Lab SSS for students reporting less than 30 minutes of prior exploration and for those reporting more are nearly identical. Kruskal-Wallis' test confirms that the overall performance score distribution of these two groups is the same (Table 4).

Although there has been some on-going critique of classifying students as visual learners (Reynolds, 1997; Willingham, 2005), a reasonable position is that aerial photography interpretation would be a highly 'visual' exercise (Hennessy, Arnason, Ratinen, & Rubensdotter, 2012). As part of the final feedback section, students had the opportunity to report the learning style that best describes them by referring to an explanatory diagram that included visual learner as an option. Unexpectedly, the mean SSS for those students who reported a learning type other than visual was higher than those students who identified themselves as visual learners. Although they performed better, Kruskal-Wallis' test suggests that their Lab SSS distribution is not significantly different from self-identified visual learners (Table 4). For this group, students who did not provide a response were not automatically assumed to be 'other learning types' and were not included in the analysis.

Thinking that the math background of a student might influence their ability and comfort level with the numerical tasks, I hypothesized those students selecting majors requiring only one basic math class would not perform as well as those with a stronger math background. Although students who take (or will take) more advanced math courses in college performed slightly better, on average there was no statistically significant difference between the distribution of Lab SSS of the two math groupings (Table 4).

Chi Square results comparing categorical variables – Given the many categorical variables available to be compared against each other (Table 3), Pearson's Chi Square provides a way to see if variations within student responses were due to chance or linked to other factors. At the standard $\alpha = 0.05$ level, Chi Square revealed several interesting statistically significant relationships. One student sub-group that had a high rate of predictability was the kinesthetic (hands-on) learner group. They were more likely (Prob>Chi Square = 0.0170) to have the opinion that planimetric aerial photos are not easy to interpret after looking at the color and texture of basalt flows in Hawaii from straight above and from a Google Street View (ground) perspective. After annotating an ACME Mapper terrain visualization (3D shaded contour map) to identify mesas and buttes in Canyonlands near Moab, Utah, kinesthetic learners (0.0487**)** were more likely to remark that they liked the terrain view. Consistent with this, kinesthetic learners (0.0412) were also more likely to say they did not like using traditional topographic maps when used to calculate the volume of dissolved limestone in the McCauley Sinks, AZ. A statistically significant portion of these students (0.0324) remarked positively about helicopter views (large-scale, low-angle oblique sequence of photos) along the California coastline to 'see' rates of uplift. Finally, not by chance, kinesthetic learners (0.0336) stated that the most helpful aspect of this online lab experience was looking at landforms in Google Earth from an oblique perspective.

Another group that had several statistically significant relationships surface in a Chi Square analysis is self-declared visual learners. Visual learners (0.0230), more than others types, liked the 360° panoramic view of Peyto Lake in the Canadian Rockies to help them see and label glacial features in their self-crafted oblique Google Earth screen capture. Like the kinesthetic group, they were also more likely to comment that they liked the helicopter view enhancement to Google Earth's depiction of the coastline, except the strength of this link (0.0009) was at an order of magnitude higher. Stronger yet, it was not by chance that visual learners were more likely (0.0001) to remark positively about their first exposure to and attempts at interpreting aerial photography.

There were several other statistically significant connections between student responses to the lab's feedback questions and student categories in a Chi Square analysis of Table 3. Students that reported they had spent more than 30 min (more than the median for the population) using Google Earth prior to this lab were more likely to find the planimetric view of basalt flows in Hawaii easy to interpret (0.0052) and were also more likely to say they only needed the oblique view (vs. switching between planimetric and oblique) to interpret imagery of faulting landforms (0.0401). Students who reported they spent more than 6 hours (median time for population) completing this lab also found useful the supplemental helicopter view of the marine terrace uplift question (0.0294). Students enrolled in Landform Processes (GPH211) were more likely to express enthusiasm and excitement in using Google Earth to plan their next vacation or hike than students enrolled in the introductory physical geography class (0.0482). Lastly, students who's major requires only the basic math class more consistently found the planimetric perspectives of basalt flows in the lab's first exercise difficult to interpret (0.0232).

All other possible categorical variable combinations were either not statistically significant or did not have enough data points to give reliable Chi Square scores, but this does not mean that the lack of relationships is not meaningful to this study. I had hypothesized that visual learners, higher prior use, and advanced math requirement majors would, more than others, like using Google Earth to learn landforms, however if any of the students in these categories felt this way I cannot rule out that it was due to chance. I had also suspected that math requirement would be a strong predictor of who would enjoy making calculations of landform processes using Google Earth imagery and visualization tools, but again there were no statistically significant relationships here. GPH 211 students, who were taking a course more focused on landform processes, similarly did not have any connection, surprisingly, with the most helpful aspect of the lab common response category 'seeing the landform-process connection'. Finally, assuming older and more experienced college students may have an advantage over freshmen, I was surprised to find that academic grade level was not a reliable predictor of any common feedback responses in Table 3.

DISCUSSION

Google Earth-based virtual field trips as an alternative or supplement to fieldwork – Researchers emphasize the ability of Google Earth and VFTs to provide a tremendous opportunity for learning (Harper, 2004; Hurst, 1998) without the cost and logistical burden of actual field visits, although nobody is yet advocating that real trips are obsolete; quite the opposite (Fuller et al., 2000; Kent et al., 1997; Spicer & Stratford, 2001). Students and classrooms are merely a click away from the 'next best' thing to visiting almost anywhere in the world (Tewksbury, Dokmak, Tarabees, & Mansour, 2012). Also, because of their value, many educators are electing to take their classes on virtual field trips before and/or after actual trips to more fully compete and engage the students in the learning process (E. M. Johnson et al., 2011; Stumpf et al., 2008). Lang, Lang, and Camodeca (2012) provides a wonderful synopsis of creating and incorporating VFTs into an introductory geology course where students' learning gains were measured and compared against the traditional lecture format. While their results were not statistically significant, students who were exposed to a VFT of volcanism in Tenerife, Spain performed better, on average, when comparing pre-/post tests of the two groups. The authors mention that their study indicates that

> …student learning [was] positively impacted with this VFT. This is further supported by student surveys and informal interviews conducted after each study…[M]ultiple students mentioned a preference to hands-on type learning experiences such as this VFT over traditional in class teaching approaches such as lecturing." (p. 332)

While this report's aerial photo interpretation lab was not set up intentionally as a VFT, it shares many similar characteristics and many of the participant's remarks indicate that they felt as if they were really visiting and observing these landforms in person. This is due to the combination of location visits in Google Earth enhanced with supplemental visualizations, the scaffolding background material provided in each section, and their active interaction with the subject by crafting views, annotating, and measuring. Referring to the power of an oblique view to see volcanoes Student S52 (SSS 9/9, Lab SSS 27) said

> *I think they are interesting to look at it because it is kind of like seeing it in person however you are not really there...It's more realistic to look at things like this (even still on the computer) than just regular aerial like a bird...I thought it was really cool and helpful to see the volcanoes so realistically.*

Actual field trips for GPH111 and 211 students to Mt. Hood, SP Crater, and Mauna Kea were not an option, but they were able to visit these and other landforms virtually via Google Earth. Similarly, these students would be better prepared for a day of field work and research to, for instance, McCauley Sinks, Arizona, just a few hours north of campus because of having already familiarized themselves through interpreting aerial photography and from making calculations from their own measurements from a topographic map.

Perception of learning and enjoyment enhanced when students are offered more than one perspective – Research on landforms being presented via multiple perspectives when learning landforms reveals an enhancement of student learning (Hagevik & Watson, 2003; Liu & Zhu, 2008). Multiple perspectives can mean the examination of landforms from different angles, as is possible with Google Earth, or it can more broadly refer to the presentation of supplemental material that offers additional perspectives of a subject or landform. Krzic et al. (2012) reports an online teaching tool called SoilWeb that provides students with a web-based, interactive, 'at-their-own-pace' venue of video and audio recordings, photos, text, and graphics to help place landforms into their geomorphic contexts only to be surpassed by extended visits to the field. Responses from students about SoilWeb were positive and encouraging. Another key study, E. M. Johnson et al. (2011), featured student responses to provide insight on how they were learning in the virtual environment, of which Google Earth and multiple perspectives of landforms were major components. Once some of the frustrations of using a new program were resolved, positive comments like the two below reveal that students benefited and enjoyed seeing land features from multiple perspectives.

> *It makes it easier because you're actually [visualizing] stuff, like real stuff. A topography map has mountains and that's nice, but you actually see real features [on Google Earth], an old flood [plain] and bits of deposits. You can't see that on maps. (p. 506)*

> *It was best when we were looking at beaches cause you could turn it onto its side and work out how steep the geography behind it was instead of looking straight down on it. (p. 506)*

These prior findings among student comments are reflected in this online aerial photo lab. After the California coastline portion of the lab, Student S22 (Lab SSS = 20) remarked that he/she, "...always like[s] the incorporation of other types of images and presentations to see other angles of the landforms. This one in particular was helpful because it felt like I was right there above the landform seeing it from a helicopter." Able to adjust the angle of the Google Earth viewer to one that best fits the faulting landforms, Student S4 (SSS 8/9, Lab SSS = 37) reacted this way:

> *I was able to see the landforms much more clearly at the oblique angle, this was especially apparent with the Dez River as I didn't easily notice the uplifted portion with the top-down view. However, the view of the San Andreas fault*

wasn't made any more clear (but it did provide an interesting point of view). Overall changing the view helped quite a bit as it generally added more clarity to the shape and composition of the landforms.

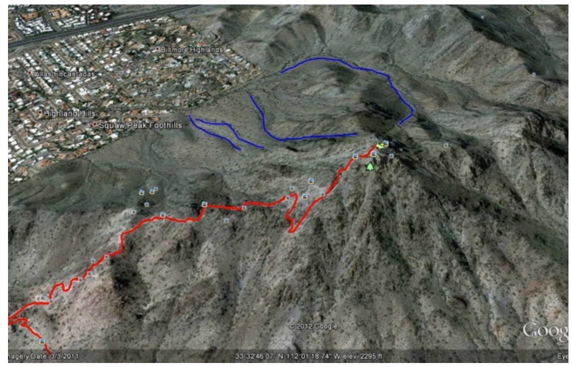
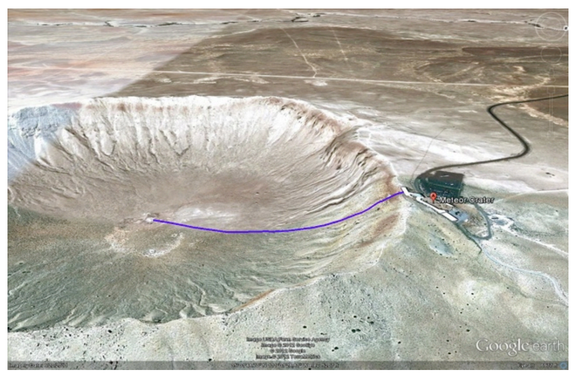
The ability to manipulate, move, swivel, tilt the view in Google Earth, and to compare these views with supplemental visualizations is almost like handing a plaster model of these landforms to the students for them to touch and handle for themselves. It became apparent, however, that learning is enhanced only to the degree students can read, understand, or interpret the supplemental and alternative representations. Although they thought the helicopter views were useful because "...they just gave a more in depth angle for anyone to see what [the coastline] actually looked like from multiple sides", Student 65 (Lab SSS = 32), for instance, reported having difficulty reading the contours and elevation data of ACME Mapper's Topographic view of the coastline, which was necessary for calculating uplift rate. Thus one major challenge in an online setting is how to efficiently instruct students to make sense of all the information and tools available to them on the screen.

Active, hands-on participation and creation fosters learning and ownership – The relevance of student-created products appears in a number of papers (Heyl, 1984; C. Jones & Willis, 2011; Kearney & Schuck, 2005; Manfra & Hammond, 2008; Wake & Wasson, 2011). In essence, this aerial photography lab offered students over a dozen opportunities to craft and annotate screenshots representative of their aerial photography interpretation efforts. Recently, Eusden et al. (2012) presented findings from using of Google Earth 'mashups' in an introductory geology class where students reflected and reported on a field trip to the Presidential Range, NH. Utilizing it's native Keyhole Markup Language (KML), students attached self or group-authored descriptions (text), photos, and YouTube videos to Placemarks (waypoints) in Google Earth of the places they visited on their trip. These mashups embodied the creative reflection of what they experienced and learned in the field in a manner familiar to social networking and have the advantage of being easily shared and downloaded among the class or the entire world online. These researchers report that this project was very successful, effective, and fun for all involved and that "…student feedback on course evaluations was very positive about this experience" (p. 363). This is likely because both the trip and post-trip activities were very 'hands-on', dynamic, and fun; promoting learning beyond the bounds of a formal class structure.

While the lab featured in this study did not involve 'mashups', it was a short step away by having students create a path (as a .kmz file) in Google Earth of their favorite hike (or of some place they would like to visit or hike), take a screenshot, and then briefly describe the geomorphology they see as they experience their hike virtually. Many students seemed to struggle with this as the intellectual leap perhaps was too great or because by this point in the lab they were mentally exhausted as evidenced by their simplistic answers (see Student S76), but the screenshots and descriptions provided by several students (see Students S61 & S105; Table 5) highlight how this type of activity has rich potential to enhance learning as it, in my opinion, more meaningfully links newly acquired skills and knowledge with real experiences, positive emotions, and generates a higher degree of student 'ownership'.

TABLE 5

Student screen shots of their chosen hike—represented as a colored path (line)—and their accompanying descriptions of the geomorphology they see. Map Source: Google.

Student S105: *This is the Squaw Peak, and its corresponding trail, marked in red. This is a very famous mountain in the metro-Phoenix area...I have hiked this trail many times and it gives an amazing perspective of the valley. For this assignment I want to focus on the water channels marked in blue. In this picture you can clearly see how water erosion has formed channels in the side of Squaw Peak and its surrounding mountains. These channels allow water to flow off the mountain in times of rain.* (SSS 5.5/6, Lab SSS 35)	
Student S61: *While I live in Arizona I still haven't seen Meteor Crater. I think I heard that it's not open to the public to hike, but I'd at least like to see it sometime soon, and I can always imagine. Obviously, [it] was formed by a sort of large meteor impact a while back and what we see is the resultant crater. The impact happened recently enough that geological processes have not yet had time to erase it from the landscape and so it's more striking than other, older meteorite impacts. It's just that, stuff from space is so cool.* (SSS 6/6, Lab SSS 38.5)	

Similar to the learning that continued post-trip by Eusden et al. (2012) having their students compile their experiences and knowledge into Google Earth mashups, this lab, because of being web-based and time-efficient to grade, offered a way for learning to extend beyond pressing the ‘submit lab’ button. For instance, because Student S105 (Table 5) described and annotated the erosion-formed channels he had seen in person while hiking and was now interpreting from GE aerial photography of Piestewa Peak in Phoenix, AZ, the grader—a professor who is an expert on the geomorphological processes of stream base-level adjustment in arid environments—was able to offer this student more information about the landform-process connection:

> *This part of the Phoenix Mountains is pretty neat. I agree. And your channels are a great example of how streams adjust to base level change. Let me back up and explain. All of the streams in metro-Phoenix end up at the Salt River. The Salt River is the base level for all of our ephemeral washes, like your blue lines. So when the Salt River "cuts down", all of the tributary washes also cut down. The Salt River was at the level of ASU's Tempe Campus. Then, about 480,000 years ago it cut down to its present position. Your blue channels responded by incising, making narrow mini gorges on the south side. But if you look at the channels on the north side of the Phoenix Mountains here, they are not as deeply incised. This is because the streams go all the way around Dreamy Draw before they get to the Salt River. The longer the stream length, the more gentle the adjustment. I hope this makes sense. This would be a great undergraduate research project, a perfect thesis.*

It is encouraging to see how a student's self-created product—their annotated Google Earth screen—enriches and continues the learning process. This kind of positive interaction is surely to spawn more interest and future motivated scientists in the field.

O*nline Learning* – Learning about landforms online through Google Earth, with all its potential, has many aspects that need thoughtful consideration. Lang, Lang, and Camodeca (2012) said that while VFTs, which must be web-based by nature, increased learning, many students mentioned that they would not have been able to do as well without at least some preparation. "Multiple students indicated that without a lecture they likely would have been lost in conducting assignments on [the] VFT" (p. 332).

Gobert et al. (2012, p. 466) clarifies a possible reason why: "[t]his is likely because students, unlike experts, typically do not know what is salient within rich information sources such as Google Earth, and thus, if unscaffolded (i.e., unguided) they might not acquire the targeted information as intended." Online learning and VFT-centered assignments must be carefully "structured to support students' learning processes" (p. 466).

Students in the landform processes and introductory physical geography classes did have a lecture component, but not necessarily in direct preparation for this trial lab and thus it was structured to stand alone. It presented them with clear objectives, an appropriate amount of background material (some of which were pre-recorded lectures), and step-by-step instructions to guide them. Several students in this lab indicated that this scaffolding was crucial to their performance. Even though earlier he/she had expressed frustration after trying to craft an oblique view (this may not have been a problem in a traditional classroom/lab setting with a TA or helpful peers), Student S8 (Lab SSS 25) remarked: "I liked that the instructions were clear and precise so there wasn't much confusion while trying to figure out these tools or how to complete the assignment." Being accessed entirely online, students used any number of different personal computers or laptops at various levels functionality, with various levels of Internet connectivity, and in different settings (at home, the library, or a common computer lab) to complete this lab. As an attempt to look at how students learn landforms in an online setting, further improving the 'structure' and orienting tasks for future students that complete this lab may well result in more apparent and measurable learning gains.

Learner-centered exercises – Real learning happens more often when it is made meaningful to the student (Lombardi, 2007) and educators continue to discover and share new and effective ways to use Google Earth for learning (Richard, 2009). This not only improves geoscience teaching strategies but also simultaneously promotes the broader pedagogical shift to learner-centered education practices. VFTs, mahsups, and web-based lab exercises that harness geo-browsers are inherently student-focused. The traditional classroom structure and its formal content/instructor-centered format—where the default is passive absorption of information via lecture—is being replaced with more effective methods. Bailey et al. (2012) argue that there is a prominent place for Google Earth and virtual visualizations in geoscience education, but admits that we must first see more evidence of this through in-depth, quantitative research of its influence on learning. This type of research will help us overcome obstacles within academia more than an appeal to the capabilities and potential of these technologies alone. When the numbers confirm what our true customers—the student—are already thinking and saying about learning-focused approaches, the shift is likely to pick up momentum. Both the qualitative and semi-quantitative findings here seem to suggest that learning landforms through Google Earth imagery and media-rich enhancements, when adequately scaffolded, is both enjoyable and effective.

CONCLUSION

An online aerial photo lab introduced general education students at Arizona State University to landforms in freshman-level physical geography and geomorphology classes. Students from 38 different majors employed planimetric and oblique Google Earth views to explore basic landforms: basalt flow textures supplemented with Google Street Views; volcano types with heights measured through online topographic maps; faulting landforms through annotating landforms like wineglass valleys; glacial landforms supplemented with a 360° panorama; cuesta sandstone landforms supplemented by the terrain view, geology layer and elevation profiles; sinkhole volumes supplemented with topographic maps; marine terrace uplift rates supplemented with helicopter photography; and virtual hikes of the Grand Canyon and a student selected location. Data from student responses facilitated the development of a matrix of 92 rows (students) and 74 columns that contained such data as student responses, annotated screenshots, and calculations for categories of student learning.

A mix of quantitative analysis and qualitative observations of student work products, responses, and feedback tend to support some fundamental observations made in prior research. Google Earth as a learning tool in an online lab was received positively by the majority of students and does not seem to favor one particular group based on math background, learning style, or prior experience with the program. New insight from analyses of general education students reveals that Google Earth exercises with supplemental enhancements can feel like a 'hands-on' exercise even though it is really only virtual, are highly visual experiences, and that an emotional connection with a location or landform allows for learning that exceeds the basic objectives.

Chapter 3

CHILDREN'S STORIES, LOCAL LANDFORMS, AND GOOGLE EARTH: ASSESSING A RECIPE FOR CONTENT KNOWLEDGE FOR TEACHING PHYSICAL GEOGRAPHY AND SPATIAL LITERACY

ABSTRACT. Teaching landforms and other physical geography topics is a good way to cultivate spatial thinking. The development of spatial thinking in children can have side benefits such as improving their potential for success in math, science, and social science topics, but largely rests upon guidance and modeling from a teacher who understands how to teach it the way they learned it. This study examines a sampling of 155 education majors at Arizona State University that completed an online lab based around a landform-learning pedagogy to help aspiring teachers gain experience, confidence, and content knowledge for teaching (CKT) physical geography. The recipe involves introducing landforms and their formative processes through the context of local children's stories before exploring and creating picturesque oblique screenshots using Google Earth. Students reported confidence gains, enjoyment, and likelihood for using this method once they become teachers are compared along with their actual performance. Technical issues and frustrations with their computer, Internet connection, or the Google Earth program proved to be the biggest detriment to a positive experience with this learning approach. Results also inspire a refinement of the recipe so that future teachers in college can get tailored training for content and content knowledge for teaching that is not

typically part of introductory level physical geography courses for general education students.

INTRODUCTION

Everyone thinks spatially (Sinton, 2011; Stephen, 2003). However, the degree to which one spatially reasons and interprets the world around them, and how soon (Bremner, 1989), potentially influences quality of life. Within the practical limits of mental development and maturation, an overarching goal of the geographic education community rests in seeing more young people develop spatial literacy at a greater degree and earlier (Gersmehl, 1992; Gersmehl & Gersmehl, 2007; Hill, 1994; Jo & Bednarz, 2009). Research suggests that early development of spatial thinking in children could be a gateway to learning and success in science, technology, engineering, and mathematics (STEM) (Uttal & Cohen, 2012). It is equally as versatile and beneficial in learning social studies and language arts (Newcombe, 2013).

Deliberately teaching geography—a spatial science at its core—is one solution that should not, theoretically, create more stress for teachers and students as they work through an already over-crowded curriculum (Hinde, Popp, Ekiss, & Dorn, 2011; Hinde et al., 2007). While there are a myriad of good options for how to bring geography into the classroom, this study examines the merits and possibilities of using the STEM subject of physical geography (Dorn et al., 2005), or the study of landforms and their related physical processes in space. This earth science topic exists in science standards, but it also relates to the regional social studies topics such as learning about a state (4th grade) or the United States (5th grade). There should be great motivation for social studies teachers (or teachers that teach social studies, among other things) to know a thing or two about the physical earth before they enter the classroom for several reasons; 1) all human activity plays out on and around its landforms, 2) human activity affects the physical environment, and 3) they will be (or should be!) teaching their students about physical geography. To teach with confidence, pre-service teachers and education majors in college must acquire basic content knowledge for teaching (CKT) physical geography and spatial thinking in tandem with developing pedagogical content knowledge (PCK) and other knowledge types necessary for effective teaching (Ball et al., 2008; Shulman, 1986, 1987).

Physical geography and the teaching of landforms is not a common expertise for elementary teachers. Of course, most will know the difference between mountains, rivers, land, and ocean but few, unless self-taught out of interest or in the rare case of having taken and enjoyed a college-level physical geography course, would not be able to explain to their students, for example, the different types of mountains and rivers or why they appear and behave as they do. Awareness of geomorphology is simply not part of the normal content knowledge of elementary educators (Ken Appleton, 2006; Magnusson, Krajcik, & Borko, 2002). This general lack of knowledge is compounded further by the fact that most are not polished spatial thinkers, where a functioning spatial attitude would naturally lead them to consider the topics they are teaching in spatial terms. Modeling this thinking would make this mental framework contagious to their students. Indeed, there is a strong correlation between a teacher's 'confidence' in spatial thinking—or any subject, for that matter—and a teacher's ability impart it to their students (Gunderson, Ramirez, Beilock, & Levine, 2013). Teachers may also struggle due to a lack of technological content knowledge, understanding that would enable them to harness the most appropriate geo-spatial visualization and analysis technologies as learning tools (Major & Palmer, 2006). Commenting on the integration of Geographic Information Systems (GIS) technology and geographic education in K-12, Kerski (2011) posits that:

> Without a preservice component, GIS implementation will be confined to slow-diffusing in-service training. This is especially true in geography taught in the social studies curriculum where teachers have less computer access and training and their training is less constructivist in nature than their science teacher

> counterparts. Preservice and in-service training for geography teachers needs to be strengthened so that geography teachers feel confident that they can employ open-ended tools. (p. 66)

That teachers need confidence seems all too obvious; in order to teach something effectively they must feel it is a worthy topic, have a reasonable amount of CKT, and have some practical methods on hand for doing so.

This chapter presents findings based on two main research questions involving education majors at ASU that experience introductory learning in physical geography in a unique way:

1) Is this method of learning enjoyable to these aspiring teachers, and
2) How do sequential confidence gains and performance measures in a series of tasks in a single learning event offer insight into spatial thinking and physical geography CKT development?

The answer to the first question is important to know because their positive or negative experience with an online lab that combined children's literature, local desert and Arizona landforms, and structured but self-paced spatio-visual exploration using Google Earth will largely dictate their likelihood of teaching geography in a similar way. Also, if it appears to work for this test group, then there is reason to invest more time and effort into improving and modifying this approach so that other pre-service teacher education institutions and programs can adopt it as a better path to CKT as a vital part of the larger push for greater geography education. The second question is aimed at better understanding the experience and process of acquiring CKT for physical geography and spatial thinking within the scale of a series of tasks in one learning event. In other words, is there a significant signature within the data to suggest the structure and scope of the lab moved these future teachers towards the beginning steps of spatial thinking?

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

The National Research Council defined spatial thinking in 2005 as "an amalgam of three elements: concepts of space, tools of representation, and processes of reasoning" (2006, p. 3). It is the embodiment of a spatial attitude that naturally asks, "What is where, and why?" and then seeks to communicate knowledge gained in the best way possible. Recognized as a distinct and critical way thinking, a host of geographers, cognitive psychologists, scientists and educators are combined in a movement to make spatial thinking and the development of spatial literacy an indispensible part of our national curriculum. This coincides with recent strides in computer technology that has brought new tools into the hands of professionals and the general public alike.

In an overview of the history of progress in understanding spatial thought and education, Sinton (2011) exposes a barrier to progress:

> Many researchers, educators, and the public in general are not familiar with the theories, research, or philosophy underlying spatial thinking and the role that it plays in learning at all levels, from preschool children acquiring knowledge of their neighborhood to scholars interpreting the results from their spatial analyses. (p. 737)

Adding her voice to others' (cf. Bednarz & Whisenant, 2000; Goodchild & Janelle, 2010), Sinton also points out that because of the recent surge of geo-spatial technologies, such as GIS, educators face the challenge of practical use of spatial technology before theoretical and pedagogical wrinkles are ironed out. This is one reason that the NRC (2006) report concluded that, despite its potential as an educational tool, it was (then) still too early to present a comprehensive plan for GIS integration on a large scale in K-12 classrooms.

Others have made the observation that technology alone is not sufficient without a foundational framework. There is a need to measure spatial thinking abilities (Huynh

& Sharpe, 2013; Kerski, 2003). At the cognitive level, aptitude is most commonly measured by psychometric assessments of, for example, mental rotation and “how that ability relates to the use of GIS, such as mentally rotating a three-dimensional image, or a map, on a computer screen” (Sinton, 2011, p. 738) although some research claims the ability to manipulate mental and abstract space does not necessarily transfer into a skill for recognizing different perspectives of a real landscape (Kozhevnikov & Hegarty, 2001). On the other hand, the previous work of Blaut and Stea (1971) found that even young children (ages 3-6) could interpret and identify objects on maps and aerial photographs from different perspectives and at different scales as they learned to navigate their neighborhood. Perhaps this is because children in play naturally toggle between multiple scales in their mind, imagining they are small enough to drive their toy car as they view their make-believe world from directly above and obliquely (Stea & Blaut, 1973). Whether spatial cognition abilities only blossom at a set pace prescribed by age (Piaget & Inhelder, 1956) or are a result of constructive environmental stimulations and learning opportunities irrespective of age, it makes sense that the foci remain upon the principles and not the tools. Radinsky, Hospelhorn, Melendez, Riel, and Washington (2014) used GIS ‘webmap’ census data in a middle school and college social studies unit on Latino and African American migrations, effectively teaching with technology while continuing to keep the subject and ‘why’ at focus. Appropriate scaffolding prevents the novelty of a sophisticated program, such as Google Earth, from taking center stage (Almquist et al., 2012).

One innovative way that learning through Google Earth is entering the classroom is through children’s literature. Google Earth ‘Lit Trips’ are virtual field trips that attach the setting and place of a story with the actual landscape, giving it a very real spatial context (Castek & Mangelson, 2008). Historical events and other topics within the realm of social studies take a fun and exciting twist when examined and ‘re-lived’ through virtual globe visualizations and mashups (Rueger & Beck, 2012). The integration of learning geography through literature is powerful because it opens a door to scientific geography, while at the same time carries with it feelings, perception, and values (Noble & Dhussa, 1990). The number of books with geographic qualities are plentiful (Dowd, 1990; Oden, 1992). The integration of physical geography topics within the larger geographical contexts and settings of both non-fiction and fictional stories, including seeing how landforms and geologic features impact people and characters and vice versa, is a natural next step.

The call to increase spatial learning in our youth may not seem so daunting for K-8 teachers once they realize they can begin through literature already a part of their social studies or language arts curriculum. The real task for them is to become familiar with physical geography topics and visualization technologies; i.e. gain content knowledge and become familiar with this method of learning themselves. Many geoliteracy advocacy groups and educators are influencing teacher professional development along these lines, creating programs that build teachers' geoscience skills (e.g. Almquist et al., 2011; Dupigny-Giroux, Toolin, Hogan, & Fortney, 2012; Ellins et al., 2013), including the critical population—primary and secondary education majors in programs throughout the nation (Cervato, Kerton, Peer, Hassall, & Schmidt, 2013). We can expect Google Earth to play a prominent role both in preparing future teachers and as a tool for learning they will use once in the classroom (Sherman-Morris et al., 2009).

METHODS AND DATA

The Mary Lou Fulton Teachers College, in conjunction with the geography and history academic units at ASU, offers the cross-listed course GCU/HST 113: *United States and Arizona Social Studies* (http://alliance.la.asu.edu/consortium/GCU113Web/2014SpringSyllabi/White113/113_Syllabus_Home.html) as an introduction to social science perspectives to history, geography, and government. This course is designed specifically for aspiring teachers and helps education undergraduate students prepare for general knowledge proficiency certification tests (e.g. http://wwwnestest.com/Content/Docs/NES_ Profile_202.pdf). The course provides a mix of lectures by content experts and assignments to increase their content knowledge in a rather sweeping range of subjects that they will soon be teaching in K-8.

This study focuses on only the portion of GCU/HST 113 related to National Evaluation Series (NES) test objective '0011 *Understand physical features, physical systems, and the interaction between the environment and human societies'*. With permission of course administrators, I helped design the Geo 4: Physical Systems online lab—one of eight geography labs in the course—that features Google Earth as the primary tool for landform exploration and spatial thinking skills development. The basic scaffolding formula 1) first appeals to their professed desire to teach by introducing a region-specific landform through the setting of a children's story, then 2) provides some basic content information through diagrams, pictures, and explanations of that landform (with supplemental links to more information), next 3) uses this background information to ask simple questions about formative physical processes in conjunction with their observing and identifying the landform in Google Earth or similar earth-browser, and finally 4) tasks students to craft, annotate, and submit screenshots of the landforms from an oblique perspective using Google Earth (Figure 1). After repeating this learning

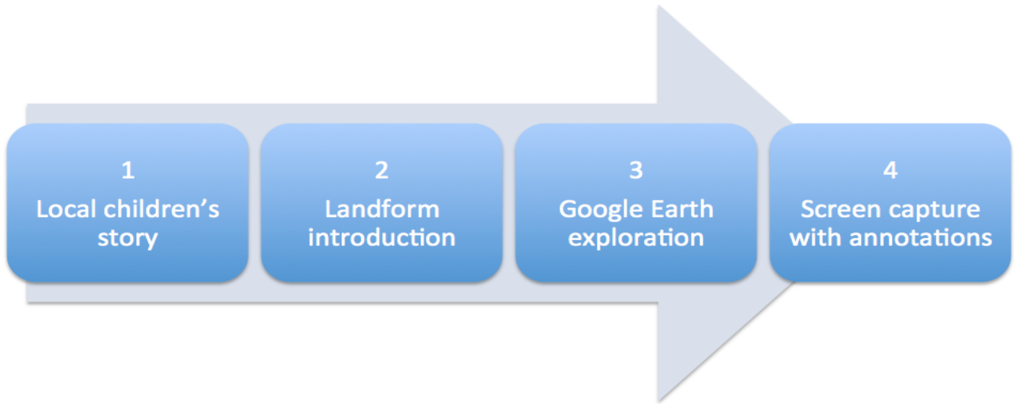


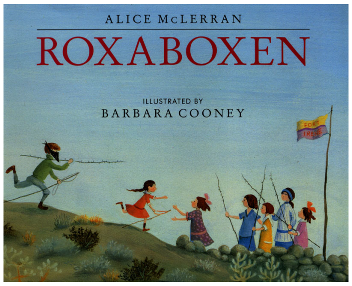
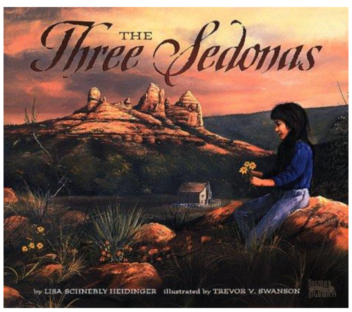
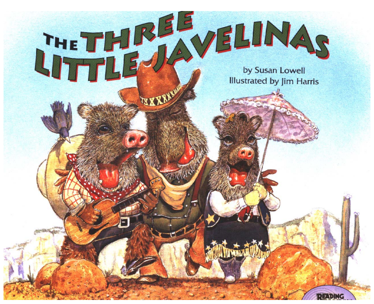
Figure 1. Landform-learning recipe in the Geo 4 lab.

sequence for three key landforms—stream terraces, slickrock and cliffs, and ephemeral desert washes and perennial streams (see Table 1)—aspiring teachers were then tasked with finding two famous Arizona landforms (they could select from a list) on their own and upload attractive oblique views from Google Earth.

Throughout the lab students answered survey questions. After exploring each landform using the steps described above, they were asked whether they felt confident (or gained more confidence) in interpreting views from the air and in identifying landforms in aerial photography. At the end of the lab they answered overall feedback questions relating to Google Earth as a learning/teaching tool, whether they had fun, and whether they felt they might use this method in their future classrooms.

TABLE 1

Three children's books offered as segues to learning about local Arizona landforms

Book Cover	Description	Key Landform
	It looked like any rocky hill, but it was a special place for those with an imagination growing up in Yuma, Arizona.	Stream Terrace
	Sedona Schnebly became a pioneer in the primitive red rock country, told from the perspective of her great-great-granddaughter, 6 year old Sedona.	Cliffs and Slickrock
	An Arizona version of the story of the three little pigs.	Perennial streams and ephemeral desert washes

The entirety of GCU/HST 113 was administered through www.gradeify.com, an online course hosting service that facilitates the ability of students to upload imagery that they designed. A short tutorial and practice opportunity at the beginning of the Geo 4 lab helped remind them of the skills to complete a lab: how to take a screenshot of their computer screen, annotate it using an online photo editing program, and then upload it in the appropriate format and size.

Three instructors facilitated the course; one instructor managed six sections while the other two had one section each. Each section consisted of about 20 students. Only one section met formally with their instructor once a week in a normal classroom setting with a lecture component. I guest lectured in this 'hybrid' section a day prior to Geo 4 being made available to them and used the time to introduce the three children's books and their connection to landforms. They watched a demonstration on how to locate, view, and take a screen capture of a scene in Google Earth. I also emphasized that the purpose of this lab was not just to help them learn more about the physical environment of Arizona, but also to serve as a model they could repeat in their future classrooms. While all 138 students that completed this lab online had access to the same materials, I could not control for such things as work setting, computer quality, or the speed and reliability of their Internet connection.

TABLE 2

Example sequence after students read background information linked to Children's book. In this case the Sedona section responses from Student S30. Map Source: Google.

Question/task	Answer/response
What is the major stream that runs through Sedona?	"Oak Creek"
What is the name of the rock type that dominates the scenery of Sedona?	"Schnebly Hill Sandstone"
Why does a vertical cliff face occur in this picture from Sedona?	"Because that vertical cliff face is composed of a weak layer of rock that collapses and creates this vertical cliff face."
Why does slickrock occur in this picture from Sedona?	"This slick rock occurred because there is no weak layer of rock so it does not collapse. However over time the water from the rain runs over the sanstone [sic] and the surface erodes which creates slickrock"

Use Google Earth to create an image of cliff faces and slickrock from Sedona: • Step 1: In the Google Earth view (using either maps.google.com or the Google Earth program), paste in this location. N 34.86819 W 111.76220 It is the general area of Sedona. You need to "fly around" and find a spot that you like. • Step 2: Using the "eyeball" tool, try to set your view so that you are looking at cliff faces and slickrock at an angle. This is an oblique view, as if you were flying around in an airplane. • Step 3: Take a screenshot of the view you like. • Step 4: Annotate your oblique aerial photo view. You learned how to annotate an image already. Please label a cliff face and slickrock. This is an example of what your view might look like [example screenshot].	
SURVEY QUESTION: I am wondering whether this approach helped you understand how to recognize landforms. In other words, by providing you some basic information about the landform, and then you finding an aerial perspective -- do you feel more confident in your ability to interpret views from the air? Did this second try help?	“I feel confident in telling the difference between sliprocks [sic] and cliff faces so I do think this worked. Also putting the connections of why they form that way together also puts the two different landforms into perspective so I like how you give us enough information to distinguish a difference, but not so much it becomes overkill.”

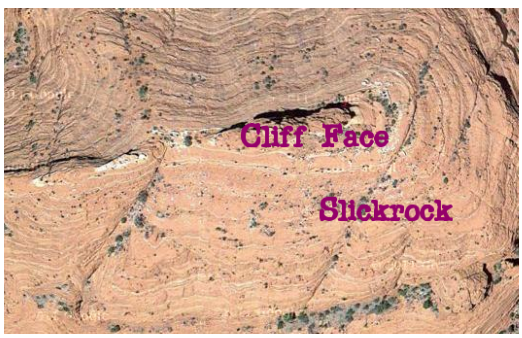
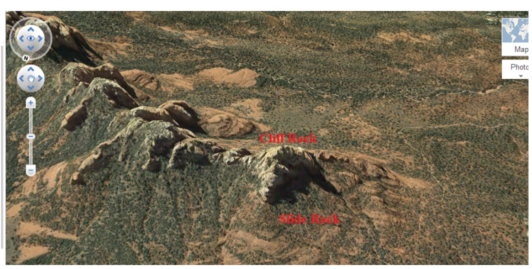
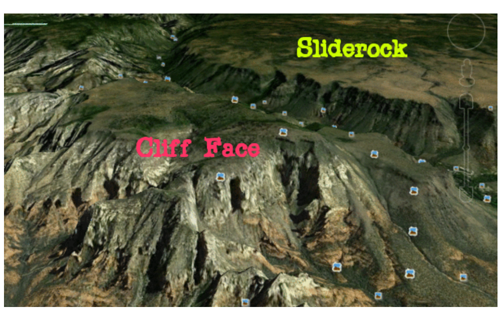
Gradeify’s servers stored student responses electronically and thus it was feasible to sample written answers, annotated Google Earth screenshots, and confidence self-assessments (see Table 2) into an Excel spreadsheet. I excluded those students that were not education majors in ASU’s Mary Lou Fulton Teacher’s College (13) and then, of those remaining, selected 62 using a random number generator. Each student received a numerical designation (S01, S02, and so on) to mask identity within the spreadsheet. Individual students comprised the rows while their answers, including screenshots, and other information comprised the columns.

This large dataset of student responses can be examined both laterally and horizontally, the former providing insight into how a student responded sequentially in the various tasks while the latter allowing meaningful binning and categorizing of student performance and opinions across a single task. For example, scrolling up and down a column and examining all 62 Google Earth screenshot submissions to the Sedona cliff face and slickrock task (Table 3) enables one to detect not only the overall 'grasp' students achieved at this point in the lab and but also allows a categorical performance rating that can then serve as a quantitative comparison metric.

Specifically, student screenshots received a rating of a '3', '2', or a '1' according to their suitability (good, mediocre, or poor, respectively) to be used in a classroom lecture (Table 3). In a similar fashion, I dissected post-activity feedback statements into general categories to detect trends and patterns among this specific group of future teachers. A student's comments could be categorized generally as positive or negative towards the just-completed task and, in most cases, even separated by their accompanying stated reason. For instance, a student who remarked they did not gain any confidence in their ability to distinguish landforms from aerial photography may also indicate that this is because they are not good with computers while another student suggests it is because they did not understand the background information on the landform. Individual screen shot scores (SSS) for each task and summed SSS for the lab, categorized confidence opinions, and basic demographic information (gender, grade level, instructor and section, previous experience with Google Earth or screen capturing or digital photo annotation), in addition to raw answers from each selected student, resulted in a large dataset of 62 rows x 64 columns.

TABLE 3

Vertical comparison of three categories of Google Earth screenshots of cliff face and slickrock near Sedona, AZ. Map Source: Google

Student ID	Screenshot	Screen Shot Score (SSS) and criteria
S62		3 – 'Good' oblique view with cliff face and slickrock correctly and clearly labeled.
S21		2 – 'Mediocre' because not an oblique view although slickrock and cliffs labeling appear accurate.
S51		2 – 'Mediocre' because slickrock is mislabeled as 'slide rock'. Zoom and angle otherwise very suitable.
S41		1 – 'Poor' because both landforms are mislabeled and oblique perspective is too far zoomed out. This would not be an appropriate picture to teach this landform.

It is important to note the various spatial elements of this lab and their associated scales and perspectives. The scale at which students were asked to observe and identify landforms through Google Earth imagery was set at the mesoscale—an intermediate or 'normal' range that matches how they are already accustomed to seeing a mountain or a river from a ground perspective. For example, we can normally see a whole side of a mountain but are unable to see the entire mountain range it is a part of, nor can we necessarily distinguish individual rocks and the clues they hold about the mountain's origins and formative processes while driving past it along a scenic highway.

The free version of Google Earth offers a seamless zooming capability sufficient to view large boulders at the lower mesoscale end of the spectrum (approximately 1-meter resolution in most places) all the way out to entire continents and beyond at the macro-scale. While students inadvertently experienced this range in scales just by using Google Earth (the opening scene is always a whole view of the earth from hundreds of miles in space), the instructions and guidance in the lab deliberately kept students at a zoom level matching the scale of the children's books, or what can be termed a local scale. Manipulating the zoom level of the image on their screen so that they could identify a stream terrace in Yuma, AZ or notice the difference between slickrock and cliffs in the picturesque red sandstone outcrops around Sedona, AZ was an intended part of the experience.

Along with adjusting the scale of the landform, another crucial part of this lab was having students learn to change the viewing angle and perspective of their screen. Giving one the sensation of 'flying' above the earth or looking at the ground from a bird's perspective, Google Earth offers aerial views that can be positioned straight down at 90 degree (nadir) or to side-looking oblique views. The software drapes imagery over digital elevation data so that rises and changes in surface terrain, especially from low-angle oblique perspectives, are distinguishable and appear very realistic even on a twodimensional computer screen. Using Google Earth's navigational controls to pan and zoom, and its camera viewing angle controls to tilt a scene, students experienced something akin to mental rotation of earth objects, which is a foundational tenet of spatial thinking. Looking at landforms for the first time from a planimetric (straight overhead) perspective and, less so from above-ground oblique perspectives, has the potential to be disorienting and a very new spatio-visual experience for these students. Thus, an important question assessed in this research is whether aspiring teachers enjoyed learning this way and if they could complete the tasks at a satisfactory level.

The other context of scale and perspective important to this study rests at the pedagogical level. Unlike most other studies that measure learning gains over a period of time by comparing pre- and post tests, most commonly over the span of one semester, this study attempts to build a foundational understanding of the learning experience from the student's perspective within the scale of just one assignment. This study does not claim to measure learning. Rather, it gauges student performance linked with their opinions and confidence gains for interpreting aerial photography and physical features given the deliberate scaffolding and structure of the lab. In essence, is this a positive experience and does this method appear to work for the majority of education majors in this course? The feedback students provided after stepping through the landform learning 'recipe' three times in a row has potential to offer insight to what their experience was like at the very moment of learning. Unlike the life-like scale and perspective of physical earth objects they encountered in Google Earth, the nature and design of the Geo 4 lab is, somewhat unconventionally, collecting useful pedagogical data at a cognitive micro scale.

FINDINGS

The nature of the Fall 2012 GCU/HST 113 Geo 4 lab dataset described above lends itself to a mix of qualitative and quantitative analysis techniques in determining the extent of student performance, self-reported confidence gains, whether they enjoyed this approach, and if this lab assignment influenced their thoughts on teaching geography in K-8. Reading through student comments, it is obvious that most of the sampled students (80% of those that responded) had a positive experience with the lab. Notably, 50 aspiring K-8 teachers wrote they would like to use Google Earth and this learning approach in their classrooms while only 9 indicated they would not. Distilling their comments down to common categories revealed that they liked using Google Earth as a learning tool, thought that the virtual globe visualizations and imagery made it feel like they were really there, and eventually appreciated the scaffolding—the 'way' or the recipe of the lab. Many remarked they would like to use this approach. The following are typical comments for students. Students S56 and S01 wrote:

> *This was a very interesting assignment, because I have not only learned more about basic landforms but I have also learned how to use several resources new to me. I have never utilized Google Earth before this. I am really excited about this resource. It seems like the perfect tool for my future students to learn more about geography and Earth's landforms. It's truly incredible and we are very lucky to have things like this to use in the classroom. I think that every teacher should take advantage of resources like Google Earth. Additionally, I thought it was fun to annotate my photographs. I enjoyed being able to label, choose fonts, draw on, and play around with the photos I took. This will also be very useful to me in my career. This assignment was challenging at times, but I learned so much and I can't wait to take what I have learned and use it elsewhere. (S56)*

I personally thought this assignment was both fun and a great learning experience. I did learn a lot that I didn't before. I learned about different landforms and I also learned many different ways to look them up on the internet. I think this would be a great activity and a great way for my future students to learn about landforms. I really liked google maps and being able to see my assignment in aerial photos. Thanks for assigning us this homework. I learned something new today. (S01)

Student S03 struggled initially but then got the hang of it:

I thought at first it was a little difficult to use. I really had to get adjusted to the format of Google Earth. However, as I got the hang of it, the use of Google Earth became a fun way to learn. I enjoyed trying to find the different pictures and manipulate them to the correct view point. I thought the best part was looking at the famous Arizona Landmarks. This was fun to look at them and create my own image however I wanted. I think students will really enjoy this. I think this will especially help the students of lower socioeconomic status who have never had the chance to see these landmarks and experience them first hand. It allows for the students to witness and view the cool beauty of the Earth, while learning, and without ever actually having been there. (S03)

Finally, Student S23 was impressed by the ability to take future students on virtual field trips using Google Earth:

I really enjoyed this assignment. I had used google earth once before, just to look my house up. But I had never used it to look up landforms and streams. It was fun to put in the location and then zoom in and really get a good idea of what the stream or landform looked like. I think this is an effective *tool that can be used in a classroom to show kids what landforms look like without having to travel there. It's like going on a field trip without actually leaving the classroom! (S23)*

Of those that did not respond positively to the lab (11 of 62), the majority relate to computer problems and/or technical difficulties while the remaining few just did not like the way it was structured or felt it was tedious and time consuming. Surprisingly, two of the 11 also had attended the in-class lecture. A typical example of other-than-positive comments comes from Student S08 who struggled with Geo 4 because of computer issues—a cost and drawback that is unavoidable in an online learning setting. The difficulty with the lab obviously influenced his/her thinking on whether this method would be useful as a teacher some day.

I think for me personally it was not very easy. I am not very good with computers and it makes an easy assignment very difficult. [I] do not think that my students could learn landforms this way. (S08)

While the overall positive reaction after completing the lab would be encouraging to those advocating learning earth science this way, this research includes ability to track students' attitudes and confidence related to aerial photo interpretation using this learning method as they progressed through the lab. Examining the percentage of students that reported confidence gains after the three iterations of the key landform-learning recipe suggests that confidence levels generally increase within the time scope of the lab. Excluding non-responses, 76%, 88%, and 91% felt confident, or reported feeling more confident, in their ability to interpret views from the air and identify landforms after their first, second, and third opportunities, respectively. Perhaps just as informative is the decreasing of the number of students who reported no gains in confidence after each iteration—14, 7, and 5 out of the randomly sampled 62, respectively. Although these findings do not withstand statistical tests of significance, they do suggest that there is merit to giving new students multiple tries when learning a new skill in a new area.

Because students answered the same survey question immediately after exploring stream terraces, cliffs and slickrock, and then desert streams, sequentially, students acted in a manner similar to consumers rating (i.e. after tasting) a product over a set period of time. In this light, a rater agreement test commonly used in consumer research can detect change through the Bowker p value agreement statistic (Gwet, 2010; Klem & O'Malley, 1998). In the case of this study where the scaffolding method and the associated tasks in Google Earth may be considered the product, there was a statistically significant change in student confidence from their first attempt at using Google Earth for finding 'Roxaboxen' stream terraces in Yuma to their third attempt when asked to identify javelina habitats near desert perennial streams (see Table 4). In other words, the number of students who changed their opinion on confidence gains between these distinct and sequential attempts was not the same for each of the possible symmetric opinion changes.

TABLE 4

Agreement statistics for reported confidence gains after each sequential attempt of aerial photography interpretation

Attempt helped?	Yes	No	Bowker p value
1st attempt	44	14	
2nd attempt	51	7	
3rd attempt	50	5	
Agreement comparison			
1st attempt to 2nd attempt			0.0522
1st attempt to 3rd attempt			0.0348

This dataset also contains a student performance measure that is not connected to scores on individual questions or to a final grade on the lab. As mentioned in the previous section, practicing the skill of crafting appropriate oblique views of landforms and annotating them clearly was a focus of this lab. Comparing screen shot scores (SSS) for each key landform and the sum of these ratings, including their SSS for the two famous landforms submissions, can inform us on how soon within the lab sequence and how well students obtained this skill. As might be expected, the average SSS has an increasing trend. Table 5 showcases student performance as they progressed along the five screen capture opportunities contrasted against the null hypothesis that skill levels are set because of a priori knowledge and will not improve within the time period of one assignment.

TABLE 5

Number of students by rating category (SSS) for each sequential opportunity (in order they appeared in Geo 4 lab) to submit a Google Earth screen shot of a landform and associated significant non-symmetrical change statistics

Key landform	Good (3)	Mediocre (2)	Poor (1)	Total submissions
Stream terrace	22	24	6	52
Slickrock & Cliffs	36	12	4	52
Stream type	31	13	4	48
Famous Landform 1	39	10	1	50
Famous Landform 2	29	21	0	50

Prior rating	Later rating	Bowker p value
Stream terrace	Slickrock & Cliffs	0.0215
Stream terrace	Famous Landform 1	0.0002
Stream terrace	Famous Landform 2	0.0460
Famous Landform 1	Famous Landform 2	0.0252

Suspecting that student perceptions of their performance, even before receiving a final grade or feedback from their instructor, may have had an influence on their enjoyment during the lab and thus their consideration to adopt this method into their teaching repertoire, I compared their SSS totals against their overall emotional reaction to the lab. Not surprisingly, higher SSS totals correlated strongly with positive and excited feelings for the Google Earth landform-learning recipe. Tables 6 and 7 compare mean SSS totals that are statistically significant (at the 0.05 alpha level) using a Wilcoxan/Kruskal-Wallis' 2-sample, normal approximation test and a one-way, Chi Square approximation test that account for asymmetry. Note that a Student's-t or One-way ANOVA test to compare SSS total means is not appropriate given that the SSS measure is essentially a summed ordinal number and is not normally distributed. In contrast, numerous other variables such as having previous experience of looking at aerial photography on their computer, taking screenshots, or annotating imagery had no statistically significant influence on the SSS total performance metric. Also, a student's grade level (ex. freshman, sophomore), gender, instructor/section, and whether they attended the 'hybrid' lecture prior to attempting the lab online had no apparent influence.

TABLE 6

Comparison of means for SSS total and whether student remarked that they enjoyed the lab's learning method. Highest possible SSS total is 18.

	Mean	Std Dev	N
Yes	14.11	4.07	45
No	9.64	6.48	11

p value = 0.0083

TABLE 7

Comparison of SSS total and whether student remarked that they would use this method in future classrooms. Highest possible SSS total is 18.

	Mean	Std Dev	N
Yes	13.80	4.30	50
No	9.89	6.45	9

p value = 0.0331

DISCUSSION

These aspiring teachers experienced learning about local Arizona and desert landforms in a way designed to be enjoyable through meaningful connections to children's stories and 'virtual' hands-on visualization activities with Google Earth in an online setting. Although the intention was to maximize their enjoyment while learning valuable content, whether this landform-learning recipe was actually a positive experience for them, from their own feedback, would be a valuable indication that this pedagogical approach merits continued refinement and development. GCU/HST 113 students sampled in this study responded positively and not only did the majority remark that they enjoyed the lab but also that they would consider presenting physical geography content lessons in their future classrooms using the same or similar approach. This is encouraging in light of Lin, Hong, and Huang (2011, p. 25) who found that middle-school age and adult "students' scientific literacy is significantly correlated with their interest, enjoyment, and engagement in science learning ($p<.0001$)", concluding that positive emotions at the time of learning is more likely to increase their future engagement with science-related topics.

Another piece of research studied college students' reactions to a new approach to teaching theory and analysis (Blunsdon, Reed, McNeil, & McEachern, 2003). Here perceptions of their learning using this new, integrative approach in terms of enjoying the experience was connected to their perception of being able to apply what they learned elsewhere in their academic and personal lives. The Geo 4 study suggests that students who enjoyed the experience did so, in some measure, because they could imagine themselves using the children's literature-Google Earth recipe with, for example, their future 4^{th} or 5^{th} graders. While the term 'enjoyment' may have various meanings to these students, and noting that enjoyment connected to learning is usually the least common type of enjoyment (Lumby, 2010), the assumption is they were using it in reference to their experience with the Geo 4 lab.

Performance measures connected to confidence gains in the Geo 4 lab indicate that this type of learning activity is well suited to college education majors. This study is likely the first to examine education majors in this way and so there are very few, if any, comparable studies where performance progress is tracked through a sequence of tasks in one assignment involving spatial thinking. The increasing SSS are insignificant, and hint at diminishing returns for every repetition of the learning formula for each landform, but the numbers imply they are able to do it. The strong correlation between their performance and whether they enjoyed the tasks and anticipate using it in the future suggest, however, that confidence gains for this population are crucial. Using these results as a springboard, future studies may be able to extract the features and scaffolding elements that contribute to, as in cognitive load theory (CLT), an appropriate intrinsic cognitive load—the "number of elements that must be processed simultaneously in working memory for schema construction (i.e., elemental interactivity)" (Gerjets & Scheiter, 2003, p. 36) and minimizing distracting or unnecessary design features so that learning and knowledge may begin to reach long-term memory (Artino Jr, 2008).

Students enjoyed the lab and performance-confidence scores are promising, but in order for these aspiring students to actually be able to apply what they learned it would have been beneficial to add a final step to the landform-learning recipe. A methods task that would bring them back full-circle to the children's book is the next logical piece. Thus, a supplemental exercise to complete a redesigned Geo 4 lab would be one asking them to create a language arts and social studies assignment for their 4^{th} graders (or for whichever grade level they anticipate teaching) that capitalizes on the new aerial perspectives they experienced in connection to the children's story that began the sequence (**Figure 2**). A revised Geo 4 would culminate in the following final task:

Imagine that you are an elementary school teacher in the middle of a social studies unit on Arizona. You just completed one of the above landform-learning sequences above by 1) reading a children's book with your class, 2) discussing that story's key landform and associated processes, 3) helping them find and identify the landform in aerial photography from multiple perspectives, and 4) collecting their oblique Google Earth screen shots for display. Design a short language arts (writing, drawing, or speaking) activity your students could do next to strengthen the story-landform connection you just helped them build.

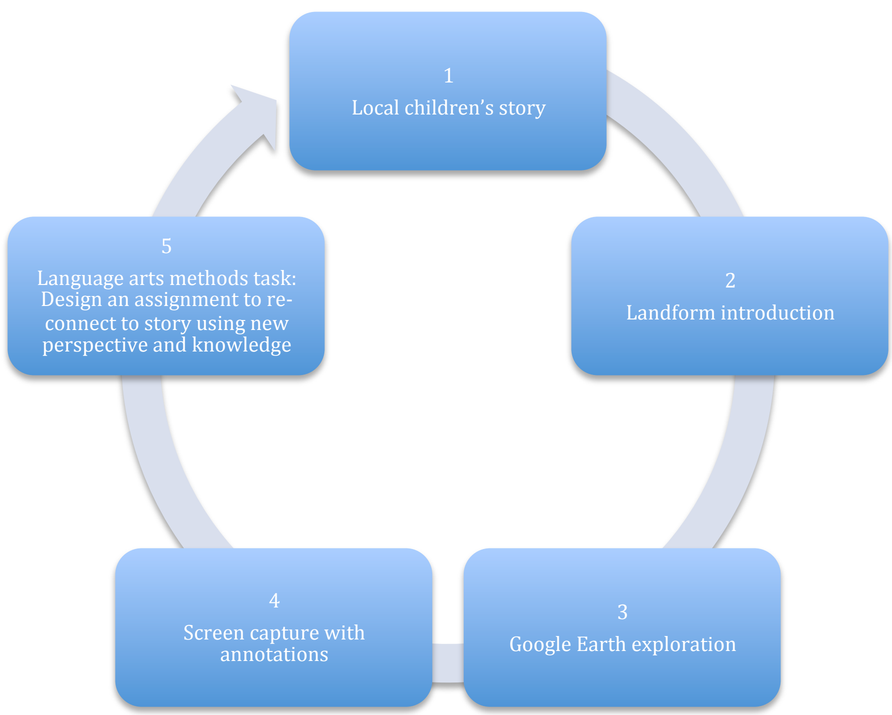


Figure 2. Proposed update to landform-learning recipe with the addition of a methods exercise for aspiring teachers to gain content knowledge for teaching physical geography and spatial literacy

Thoughtful answers to this additional question would vary, but some good examples may be assignments to have the children draw a portion of the story from an aerial perspective and then write a caption. For example, if the teacher-to-be chose the Roxaboxen-stream terrace connection, they might design a fun task to have their elementary students pretend they are a bird flying over a stream terrace in Yuma, AZ where the Roxaboxen kids are playing in the make-believe town made with rounded river rocks, asking them to draw the play village from an oblique perspective and write a caption of what the bird sees and thinks. Or, another writing assignment could be to have the 4th graders write a letter to the author of Roxaboxen, explaining to her what they know about river terraces and even make a suggestion for an additional sentence the author could add in future editions so that other kids could learn what they now know. This adaptation to the landform-learning recipe for aspiring teachers could be captured in a PowerPoint presentation and supporting documentation as a resource for other teacher education institutions.

Elementary teachers may initially lack expertise and confidence in the landforms of their area, but are hopefully familiar with a few children's books (or know where to find them in their school's library), and so the hardest part of the processes is likely deciding which landform(s) to select. To help alleviate this hurdle, I propose the creation of a children's literature and linked landforms database and crowd-sourcing website where educators and geographers could combine their efforts to create a useful resource. One potential feature would be the ability to submit a proposed book title they feel has regional or local geographic significance and request the help and input of geomorphologists and geologists for landform selection and basic information (explanations, diagrams, pictures, links), and especially, the coordinates or place names of real examples of that landform. Book titles could be sorted by region or by landform, and geo-tagged to appear within Google Earth. As student teachers work through the recipe, including the methods step of creating a language arts assignment, whole lessons could be made available, screened by expert consultants, and shared with any who wish to use them.

CONCLUSION

This chapter explored the reactions and performance capabilities of a group of education majors and aspiring teachers in college as they worked through online learning tasks designed to teach them about physical geography and, at the same time, help them acquire CKT. The Geo 4 lab used a novel approach to get them interested in, and perhaps overcome past negative associations with learning about landforms by introducing them through a children's story. Then, after reviewing some basic content information, they used Google Earth to visually explore landforms as directly as possible and from an oblique perspective, with annotated screenshots being proof that they did so.

Results from this study highlight the importance of emotion—enjoyment versus frustration—at the time of 'doing'. Technical problems, not the subject, appear to be the greatest disappointment for these students. While most had no issues with their computer or Google Earth, those that did suffered from an extraneous cognitive load that not only stifled their learning experience, but also negatively impacted their opinion of the landform-learning recipe and their desire and/or confidence to teach landforms using Google Earth in the future. Rather than doing this assignment online, if students completed the Geo 4 lab in a computer lab with ready assistance from instructors and peers then many of technical problems could have been avoided.

The performance, self-efficacy, and confidence gains of students hints that they at least started acquiring content knowledge for teaching physical geography, but this is not quantified. However, reflection upon the data revealed a missed opportunity to immediately channel their minds, motivated by their positive experience with the first four steps of the recipe, with a methods task that gets them to consider ways to help their future 3rd graders process and express their new knowledge through language arts and social studies activities. Analysis of their ideas may have offered a more tangible way to measure CKT. The proposal for a crowd-sourcing database and website based upon the updated landform-learning recipe has the potential to help many more aspiring teachers, and even experienced teachings seeking professional development, gain valuable content knowledge before they enter or re-enter the classroom. Future studies can add to the initial work of this chapter to better understand how specific assignments and their pedagogical underpinnings can assist and prepare prospective teachers still in college to teach the rising generation.

Chapter 4

IS THE STEREOPAIR STILL USEFUL?: COMPARING STUDENT PERFORMANCE AND PREFERENCES FOR OBLIQUE VS. PLANIMETRIC AERIAL IMAGERY

ABSTRACT. Geo-spatial technologies are rapidly improving and are often incorporated into the classroom before their implications on learning are completely understood. However, because of a lag time during a transition period, current teachers and students may suffer if they either 1) delayed using current technology before supporting pedagogies caught up, or 2) if they prematurely dismissed older methods and tools as obsolete and no longer useful to learning. Google Earth is becoming a popular medium for teaching geomorphology for many of the same reasons that stereopair images and stereoscopes have traditionally been used for. Groups of general education students in a freshmen-level introductory physical geography class at Arizona State University completed different versions of an aerial photo interpretation lab that used Google Earth oblique images, planimetric stereopair photos, or a combination of both to learn about basic landforms. Results confirm other studies and show that both technologies and perspectives have value for learning and that student preferences are more likely to vary by landform. They also highlight how a lack of prior knowledge of landforms and a minimal frame of reference for image interpretation limits students to low-level, at best, and inaccurate landform analysis and guessing, at worst. As a practical application, these groups of students participated in an outdoor GPS self-locating scavenger hunt by

referencing points marked on an oblique or planimetric aerial photo, or mix of both. Quantitative measures for accuracy do not favor one perspective over the other while student ratings for each point indicate they felt more confident locating themselves when they could reference their locations against distinct, man-made features.

INTRODUCTION

The storage shelves, file cabinets and closets in physical geography, geology, and remote sensing programs likely contain stereoscopes and stereopair images used for research and course instruction in the twentieth century. This photogrammetric technology and 3D visualization system has proved to be an invaluable resource for the natural sciences (Davies, 1966; Drury, 1993; Kuenen, 1950; Schwartz, 1996). Before the age of computers students often obtained their aerial images of a stratovolcano like Mount Fuji, Japan, or glacial drumlins in Wisconsin in stereo 3D, fascinated by they way they 'jump out' of the flat and off-set photos when viewed together with the aid of a stereoviewer. What was not obvious to the eye with a single planimetric aerial photograph became clear and distinct; changes in terrain and texture, shadows, shapes and patterns appeared tangible and very real, if not exaggerated. In contrast, modern computer technology today offers powerful and sophisticated Earth visualizations from multiple perspectives, and virtual-3D renderings, such that many programs and courses that utilized stereopsis find their equipment collecting dust and taking up valuable storage space. The time has come to ask: are stereopairs and stereoscopes obsolete as a tool for enhancing geography education?

This chapter explores the power of Google Earth and stereopairs in a college level introductory physical geography course where one group of students learned about basic landforms through stereopair aerial photography, another using low angle oblique Google Earth imagery, and a third group viewed both. The oblique angle view, possible in Google Earth and other virtual globe computer programs, maintains many of the advantages of synoptic aerial views but also allows our eyes to detect depth despite being displayed on a flat screen (Boulos & Robinson, 2009). Thus, this research attempts to ascertain whether a combination of Google Earth virtual terrain and stereopair 3D images can enhance college students' understanding in the second decade of the 21^{st}

century. While student learning is the focus, this research can optimize utilization of resources.

In addition, this study goes a step further by also testing whether exposure to one or more perspectives in the classroom translates into practical application in the field. This sub-question addresses a classic problem with real-world benefits to the students in the age of Google Earth: how well can students locate themselves on an aerial photograph?

LITERATURE CONTEXT OF THE RESEARCH

Aerial photography remains an important aspect of earth sciences research and mapping (Ray, 1960) and, especially, in the teaching of landforms. Stereopair aerial photos have been a mainstay in this endeavor and their effectiveness in educational settings upheld in the past (Giardino & Thornhill, 1984). Stereoscopy is possible because of our binocular vision — where a left-eye image of an object is combined in the brain with the right eye's view in a way that allows us to perceive depth and distance within a scene. Made popular in the mid 1800s through double-lens cameras, stereopair photos and 3D motion pictures are still fascinating to young and old today despite their antiquated feel (Klein, 1996). In terms of the utility of stereopair aerial photographs for the study of landform and earth surface processes, photogrammetry can be used to determine elevation using parallax measurements (Toutin, 1995), measure landslides and other changes in terrain (Brown & Arbogast, 1999; Dai & Lee, 2003), and, most commonly, to simply observe all types of landforms from above in three dimensions (MacMahan, 1972). In many ways, the development and application of stereopair aerial photographs was the technological embodiment of earlier block diagrams and physiographic standards (Lobeck, 1924; Raisz, 1931) where cartographic constraints pitted the planimetric map against the more realistic oblique view (Robinson & Thrower, 1957).

Today, however, computer visualizations and virtual globe technologies such as Google Earth (Google, 2013) are increasingly important research and educational tools (T. R. Allen, 2008; Lisle, 2006). A Geological Society of America (GSA) Conference in 2011 resulted in a publication that captured the developments and trends fueled by Google Earth and other virtual visualizations (Whitmeyer et al., 2012). Approximately one third of this edited book deals with the several challenges and many successes of implementing Google Earth-based instruction into geology or geomorphology classrooms for pre-college and college students (Dolliver, 2012; Eusden et al., 2012; Gobert et al., 2012; Lang, Lang, & Camodeca, 2012), and also pre-service teacher programs and resources (Almquist et al., 2012; Granshaw & Duggan-Haas, 2012; Guth, 2012; Hennessy et al., 2012). A common theme among many of the articles, in conjunction with Google Earth's suitability for landform exploration and instruction based merely on the user's ability to craft multiple views and perspectives—one can zoom in and out, pan, rotate and tilt the screen, as well as measure distance and view elevation profile plots (Dolliver, 2012)—touts educational benefits through virtual field trips and student-created mashups (Dordevic & Wild, 2012; Eusden et al., 2012; Lang, Lang, & Camodeca, 2012).

The power of Google Earth, in particular, and of computer generated visualizations in earth science education, in general, is echoed elsewhere (Bodzin, 2008; Crosby, 2012; Hagevik & Watson, 2003; K. Jones, 2001; K. Kim, Oh, Lee, & Essa, 2011; Kulo & Bodzin, 2011; McCaffrey et al., 2008; Pence, Weisbrot, Whitmeyer, De Paor, & Gobert, 2010; Yu & Gong, 2012; Yue, Gong, Xiang, & Chen, 2010). Kinzel and Wright (2008) consider the benefit and impact of multi-media geo-visualizations in the curriculum along with many other enthusiastic advocates as long as geoscience educators couch Google Earth learning exercises within appropriate contexts through scaffolding (Bodzin & Cirucci, 2009; Gobert et al., 2012; Lombardi, 2007), establish a clear way to assess learning via Google Earth (N. D. Johnson et al., 2011), and do not lose sight of role that students' feelings, attitudes, and values play in the learning processes (McConnell & van Der Hoeven Kraft, 2011).

Another important and related aspect of aerial photo interpretation tasks in geoscience education — that could include both stereopair viewing and modern virtual globe technology use — is their influence on spatial thinking (NRC, 2006; Schultz et al., 2008; Titus & Horsman, 2009). Students looking at landforms from multiple perspectives other than ground views, and at different scales, exercise and strengthen their spatial reasoning and cognitive skills, including mental rotation of a landscape (J. Lee & Bednarz, 2011; Lowe, 1993; Piburn et al., 2005; Thankachan & Franklin, 2013). C. Spencer, Harrison, and Darvizeh (1980) studied the affect of the oblique perspective on spatial learning in children. Thompson, Keith, Swan, and Hamblin (2006) provide an example of students providing feedback on their experience of examining landforms through Google Earth 3D and oblique panoramic photos in an introductory-level college geology course. Similarly, Monet and Greene (2012) conducted a semester-long study of students in a introductory physical geology course at California State University, Chico, that used Google Earth and satellite imagery to enhance their knowledge and understanding of key geologic concepts and processes.

Many, if not all of these references to learning landforms through Google Earth visualization imply there is a benefit because of multiple perspectives in photorealistic terrain imagery, such as the oblique angle view (**Figure 1**). However, little discussion in the literature compares the advantages or disadvantages of one perspective over another.

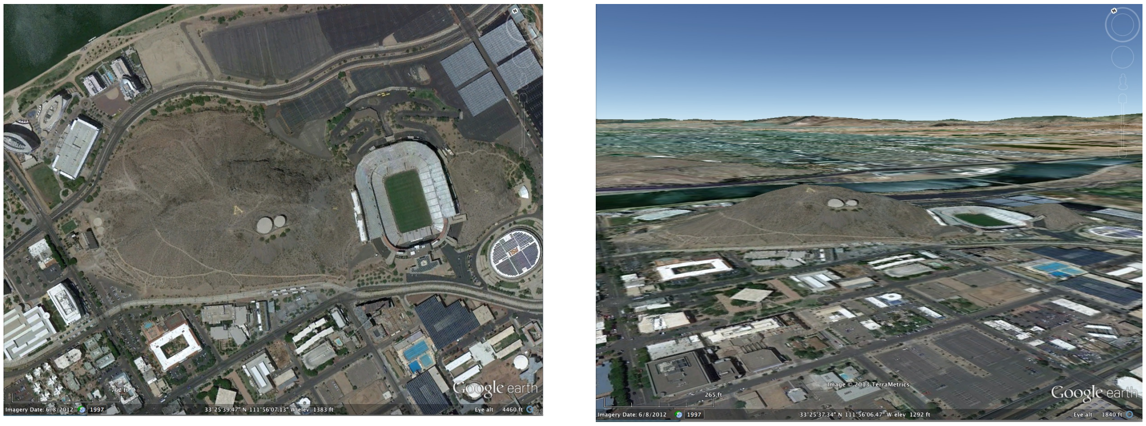


Figure 1. Google Earth planimetric (left) and oblique angle (right) views of Tempe Butte and Sun Devil Stadium in Tempe, AZ. *Map Source: Google, TerraMetrics*

Niedomysl, Elldér, Larsson, Thelin, and Jansund (2013) considered the learning benefits of 3D maps over 2D in an introductory geography class. Hirmas et al. (2014) discussed the effects of seating location and a stereoscopic 3D projection (on a large screen) on student learning in an introductory physical geography course. Horowitz and Schultz (2014) proposed the idea that 3D printers can now create physical models of earth surface objects at various scales that can then be examined obliquely and planimetrically – with the focus that 3D printers might be especially useful for the visually impaired.

What is largely missing, with the exception of a piece of research by Lang, Lang, and Geraghty-Ward (2012), is a comparison of student preferences for Google Earth versus traditional stereopairs, and whether students in training can interpret and orient themselves in space better with oblique angle perspectives versus planimetric. In this light, this study contributes to the geoscience education literature where there is still a need for in-depth, quantitative research to support maturing Google Earth and visualization pedagogies (Bailey et al., 2012).

DATA AND METHODOLOGY

Arizona State University's GPH 111 *Introduction to Physical Geography* is a standard introductory survey course that covers the spatial nature of and functional relationships between earth climates, vegetation, soils, hydrology and landforms. As a science core option it attracts a wide spectrum of students. It has a weekly lab component in addition to lecture. In the Fall 2012 semester, six sections (approximately 170 students) of GPH 111 completed a two-part lab assignment on aerial photo interpretation. The first part was an in-class packet (hardcopy) that introduced them to several landforms using either black and white planimetric stereopair images viewed in 3D with stereoscopes, color Google Earth screenshots from an oblique perspective, or a mix of both. The intent was not to test paper versus electronic imagery, as in Pedersen, Farrell, and McPhee (2005), but to minimize confounding variables. Although images were printed on paper (**Figure 2**), both the oblique and the stereo pair photos (when viewed through stereoscope) appear in 3D or have 3D-like qualities.

Students first read about basic background information and studied simple diagrams for each landform: cone volcanoes, alluvial fans and bajadas, sand dunes, and glacial trimlines, morraines, and crevasses. Then students viewed real examples of these landforms in aerial photography and answered questions about their form and processes. Additionally, students were tasked to label (identify) and annotate the landforms on the imagery in their lab packets using colored markers. They marked the locations of alluvial fans and bajadas in Death Valley, CA; labeled sand dunes of various types and drew an arrow to indicate the predominate wind direction in White Sands National Park, NM; outlined glacial trimlines in the Sierra Nevadas near Mount Whitney, CA; highlighted medial moraines on Alaska's Crillon Glacier. This research analyzes just how well they annotated these images across three different lab versions.

Figure 2. GPH 111 students examining landforms in Google Earth oblique screenshots and in stereopairs with the aid of pocket stereoscopes during Part 1 of the lab. *Photo by author.*

Two sections of GPH111, administered by two different graduate student Teaching Assistants (TA), received a Google Earth oblique-only version while two more sections (also split between the two TAs) had the stereopair/planimetric-only version. The remaining two sections received a version that combined both image types and perspectives. The lab asked them for their experience level with aerial photo interpretation and also gave them the opportunity to give feedback after each landform-image sequence as to which image type they preferred (mixed version) or whether the imagery was useful (oblique and stereopair only versions). Due to the seating arrangement of the classroom around tables, students generally worked and collaborated in small groups of five or six (**Figure 2**).

For Part 2 of the lab, students left the classroom and walked approximately 10 minutes to the Hayden Butte Preserve (referred to as "A" Mountain by students because of the large "A" seen in **Figure 3**) for an in-field activity where they used handheld GPS receivers to locate themselves at several designated points on printed Google Earth aerial photographs. After locating themselves and recording the coordinates for three points on the east end of the preserve (near Sun Devil Stadium), they walked along a trail for approximately one-third of a mile to the west end of the Preserve to repeat the process for three more points.

Figure 3. Setting for GPS exercise at A Mountain near ASU's main campus. The east area (right) and west area (left) are connected by a trail. Sun Devil Stadium is pictured in the top right corner of the image. *Map Source: Google*

To be consistent, students in the Part 1 stereopair sections located themselves using planimetric (orthogonal) Google Earth views and students in the Google Earth oblique-only section for Part 1 received oblique Google Earth imagery again for Part 2. Students in the mixed perspective sections received a planimetric image for the east end and an oblique image for the west end, or vice versa. Both the east image and the west image, for both perspectives, were consistent in camera elevation and scale. To mitigate the potential for student pairs from collecting GPS coordinates without referencing the imagery (ex. going to a point because other students are there), there were twelve points on each end and groups received different versions marked with only three of the twelve points. As students did their best to navigate to the points marked on the imagery and record their coordinates (**Figure 4**), they also indicated whether each point was easy or difficult to find on a scale of 1 (easy) to 3 (hard). After this in-the-field practical exercise, students were asked to reflect and provide feedback on what it was like for them to 'find themselves' on an aerial photograph and, if they were in the group using both oblique and planimetric imagery, whether they preferred the oblique or the planimetric perspective for this activity.

Figure 4. Students using GPS receivers to record the coordinates of points at various sites that are marked on an aerial image. *Photos by author.*

To facilitate the creation of digital dataset, I scanned and saved each student's paper copy lab as a PDF. I then randomly sampled for 32 students for each lab version—oblique, planimetric, and mixed—and transferred both written and graphical answers into an Excel spreadsheet where students comprised the rows (96) and responses to questions and tasks as the columns. Using a scale of '3-good', '2-mediocre', and '1-poor', I scrolled down columns to examine and rate each student's aerial photo annotations for Part 1 of the lab. This vertical comparison along columns rather than horizontal along rows prevented student identity or previous answers from biasing this performance assessment. Summing scores for each student gives an overall performance rating where, in this case, high marks on each of the four landform-imagery annotation opportunities would result in a top score of 12.

The dataset for Part 2 of the lab contained spatial data in the form of student-collected GPS coordinates (DDD MM SS.S latitude and longitude, WGS 84) for 24 distinct points on the east and west ends of the Hayden Butte Preserve. After transferring and confirming each coordinate pair from the scanned labs, 425 out of 527 potential points were suitable for analysis. After importing these point data into a Geographic Information System (GIS), they were first categorized according to general accuracy: within ~10 meters of the intended control point, beyond ~10 meters but within the reasonable search area on the east/west ends of the trail, and well outside of the reasonable area.

The points well outside of the two collection areas are likely the result of recording errors as students copied GPS coordinates onto their worksheets. Points outside of 10 meters but within the reasonable area may also be the result of minor recording errors (i.e. recording the GPS receiver-displayed coordinates correctly but for the wrong point), excessive GPS receiver error, or they may be representative of where the students really interpreted themselves to be.

All three accuracy categories were included when comparing student perceptions of difficulty. Only points within ~10 meters, on the other hand, were measured for their actual distance (Euclidean) from control points using the distance matrix analysis tool in QGIS, an open source GIS software program (www.qgis.org).

FINDINGS

Part 1 of this study focuses on whether one aerial photograph perspective (stereoscope views of aerial photography or Google Earth) is sufficient or if multiple perspectives are better, measured by a performance metric, when learning landforms through aerial photography. Because learning involves feelings and perceptions of gaining new knowledge through experience, another set of results accounts for whether lab versions made a difference in student enjoyment based on voluntary feedback. Part 2 of this study compares the ability of students to locate themselves on different types of aerial photograph through an outdoor GPS exercise.

Student performance measures for Part 1 consisted of objectively rating (1-3) each of the four aerial photo annotation tasks and then summing these scores to obtain an overall performance metric for each sampled student. Because the ordinal weighting scheme results in total performance scores that are not continuous in nature and not normally distributed, any quantitative statistical analyses must employ nonparametric tests in replacement of t-tests and ANOVA. A conservative performance score for mixed version students, who annotated planimetric stereopairs and Google Earth color oblique images within their lab packets, is a summed average so that a max score is also 12.

A less conservative performance score for the mixed group is one that totals the higher annotation score for each landform-image tasking. For example, if a mixed student earned a 7 for stereopair annotations and an 8 for Google Earth annotations their representative performance score would be 8.

The mean score for all three groups is 8.375 (SD=1.469; N=96). The mean scores for the oblique only (8.781; SD 1.237; N=32) and stereopair groups (8.563; SD 1.390; N=32) are higher, and the mixed group (7.781; SD 1.606; N=32) lower than the overall mean. These are significantly different ($p = 0.0190$) according to a Kruskal-Wallis' test, the non-parametric analogue of a one-way ANOVA. The mixed group performance mean is also significantly lower than each in a paired comparison (Table 1) using the Wilcoxon test method, a non-parametric alternative to a Student's t-test.

TABLE 1

Compared group mean differences

Group	-Paired against	p value
Oblique	Mixed (conservative)	0.0075
Planimetric	Mixed (conservative)	0.0394
Planimetric	Oblique	ns

However, the less conservative calculation of performance for the mixed group (mean=8.594; SD 1.241), compared in the same manner, results in no significant difference and thus the stereopair group and the oblique group perform the same as the group that used both types of imagery.

Other variables, such as prior experience and familiarity with Google Earth (for oblique and mixed versions) or stereopairs (for planimetric version), prior exposure to landforms (in another class or in high school, for example), or grade level, did not have any significant influence on performance except in the case of prior exposure to landforms and the conservative mean for the mixed group. Here, the mean for students in the mixed group with no reported prior knowledge of landforms is not lower by chance ($p = 0.0419$).

Whether student-reported enjoyment for learning landforms varied significantly across the three versions of the lab is another aspect explored in this study. A distilled yes/no categorical variable from student responses to a survey question at the end of Part 1 found that approximately 90% of students enjoyed the lab. However, comparing enjoyment to lab version in a Chi Square matrix could not confirm a statistically significant relationship with lab version. In a similar manner, assuming their own perception of how they were doing on Part 1 of the lab may have influenced whether they enjoyed it; I ran a categorized student performance score variable ('good' 10-12; 'mediocre' 8-9, and 'poor' 0-7) against the same enjoyment category and also found no significant relationship.

The structure of the survey questions within Part 1 offered students in the group using both planimetric and Google Earth images to report which of the two aerial photo types they preferred for each of the five landforms. The majority—65.6, 71.9, and 62.5%—of the mixed version students preferred the Google Earth image for volcanic cones, alluvial fans and bajadas, and sand dunes, respectively, but their opinions then switched to favor the stereopairs overall for annotating glacial trimlines and identifying glacial crevasses and moraines which were 62.1 and 56.3%, respectively. Considering the order in which aerial photo and landform interpretation tasks appeared in the lab, a rater agreement change statistic (Gwet, 2010) reveals that the change in image type preference for alluvial fans and bajadas (second in the sequence) to image preference for trimlines (fourth in the sequence) is significant with a Bowker p value of 0.0078. This may indicate that one image type and perspective is better suited for certain landforms because of their shape, elevation profile, colors and textures. For instance, the resolution of Google Earth image may have been too coarse for the untrained to discern more subtle clues such as noticing where the trimline is by where the texture changes from smooth to craggy and not confusing it for mountain crest or ridgeline. The stereopair images, although not in color, had a higher spatial resolution and thus the glacial crevasses were detectable more so than in the Google image. The three landforms for which students preferred the oblique view, on the other hand, had profile signatures (rise or fall in terrain) to help identify them in addition to other color and pattern clues in the imagery.

Part 2 of the lab was an in-field GPS exercise that required students to reference oblique and/or planimetric Google Earth color images, printed on durable cardstock, and locate themselves at various points on the east and west end of the Leonard Monti trail at "A mountain" just north of the ASU campus. The east end is developed with decorative landscaping, walks, benches, trees in planters, and other man-made features while the base of the mountain on the west end is a more natural landscape of desert vegetation and dirt next to an old flour mill. More students rated the west end points with '2s' and '3s' to describe the ease/difficulty of locating themselves and not because of image perspective. A Chi Square comparison matrix reports a likelihood ratio such that the greater number of 'medium' and 'difficult' ratings on the west and the greater number of 'easy' ratings in the east area cannot be attributed to chance ($p < .0001$). In contrast, the influence of image perspective on student opinion of ease/difficulty is insignificant when considering all points and even when isolating the matrix by east/west sides.

How close each student could match themselves to points (dots) printed on their Google Earth aerial photo as recorded by their handheld GPS receivers and compared against the known coordinates collected at the time of the lab's creation, would theoretically be a measure for accuracy. Here, these data show that perspective may play a role as planimetric-only students recorded more points that were typos (outside of the reasonable search area) while the group using both image types gathered more points that were within the search area but not 'close' (within 10 meters) when they were referencing the planimetric view. Chi Square suggests that this cannot be ascribed to chance (0.0004; LR). However, a quantitative distance measurement to test for accuracy across groups would be skewed by student GPS points that are obvious typos and far away, and also likely by those that are within the east/west areas but outside of 10 meters from the intended reference point. Sub-setting the data, the average measured distance (meters) from 'close' student coordinates ($N = 291$) to control coordinates for each dot on the image favors neither side and nor perspective (Table 2). How close students may have come to the control point had no correlation with student perception of difficulty locating themselves. Also, average accuracy error for the GPS location signal was consistent for all students.

TABLE 2

Kruskal-Wallis' test for student accuracy (distance away in meters) by perspective.

Perspective	Mean distance (m) from point / SD	N	H statistic	DF	p value
Oblique only	4.47 / 2.98	128	0.050	1	ns
Oblique (using both)	4.41 / 2.28	58			
Planimetric only	5.51 / 3.37	59			
Planimetric (using both)	4.51 / 2.97	45	2.577	1	ns

DISCUSSION

The ease of use of Google Earth, coupled with its tremendous potential for advancing education in the geosciences (Whitmeyer et al., 2012) make it a clear choice for the classroom. However, determining Google Earth's value relative to stereopairs, which have served geomorphology and similar courses well for many years, is asking whether the baby (i.e. physically handling aerial photographs and using stereoscopes) should be thrown out with the bathwater (i.e. older technology). As technology continues to advance, is there good reason to hold on to stereo pair images and equipment or has Google Earth made them obsolete?

While student performance and the opinions expressed by Introductory Physical Geography students in this study confirm and support the larger body of literature on the value of Google Earth, these findings are not conclusive enough to suggest that stereopairs should be relegated to the dust bin. Quite the contrary; the continued use of stereopair images, in conjunction with modern visualization resources supports the general premise that multiple perspectives of landforms using a variety of media are beneficial to student learning (Hagevik & Watson, 2003; Liu & Zhu, 2008; Stumpf et al., 2008).

Specifically, results from this pilot study confirm the findings of a study by Lang, Lang, and Geraghty-Ward (2012) that compared the use of stereo pair photos and Google Earth in a geomorphology class at Mercyhurst University. Splitting the small class into two groups, they assigned students to construct geologic maps and to derive geologic history from either media, alternating back and forth over eight sequential assignments. Comparing student scores on pre- and post tests administered with each assignment, they found that "Google Earth may be more effective than air photos in achieving a deeper understanding of various geomorphic topics, but when learning to recognize and identify landforms and processes, the examining instrument (i.e. Google Earth or air photos) may not matter" (p. abstract). Because of the small sample size (8), these authors acknowledged the need to expand this research to include more students. While the GPH 111 lab study did not employ pre-/post tests to gauge learning gains, it had a much larger sample size with a group using both image types. Student reactions and performance on both portions, in-class and outdoor, further verifies the Mercyhurst study.

Of note, several qualitative and anecdotal observations from Part 1 provide further insight to student thinking and learning. Some of these observations point out unintentional flaws in the lab's construction and format while others highlight need for adjustments and improvements in future similar studies. First, many students in the oblique and mixed groups were confused by the color Google Earth image of the Sierra Nevada because a portion of the trimline they were asked to trace out happened to cross a stitched boundary of satellite imagery with different temporal resolutions and thus the mountain slope had a change in color and tone. Unaware of how the program streams and combines various images at multiple scales, students misinterpreted this artificial color change as trimline (**Figure 5**).

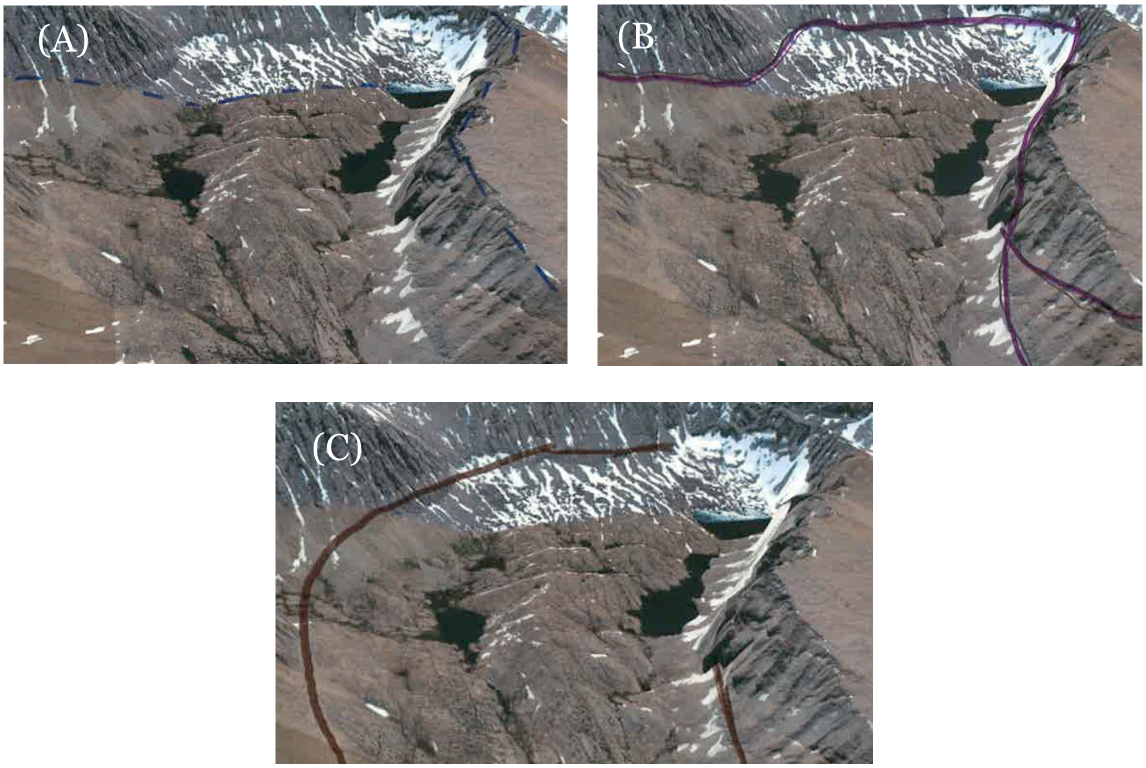


Figure 5. Many students mistook ridgelines and an artifical color change in the imagery as glacial trimline (A), or traced it correctly until the trimline intersected the color change (B). For comparison, the student that annotated the bottom image (C) was not distracted by the artificial color shift. *Map Source: Google*

The students' lack of prior knowledge was also revealed in the White Sands National Park example, because of an accidental misspelling of the term barchanoid as 'barachnoid' in the text of the lab. All students that annotated and labeled that dune type in the lab imagery copied this misspelled term verbatim. Another example of literal interpretations without expert guidance was their inability to understand that a group of merged alluvial fans form a bajada as implied by a block diagram in the lab. Instead, they understood the explanation in the text to mean that the depositional surfaces and overlapping areas *in between* connecting fans are each an individual bajada; rather than outlining a group of fans they circled the areas between. Future versions of the lab will better clarify this landform.

Directly observing and assisting the students (i.e. demonstrating how to use the pocket stereoscopes) as they completed Part 1, but cognizant not to influence their answers and landform interpretations, it was apparent that some students stopped looking at the stereopairs in 3D after the first couple of landforms and elected to just trace the planimetric images in mono/2D. This confused some students in certain instances; they outlined landforms across the double, side-by-side images as if they were contiguous from left to right.

Student comments for Part 1 were overwhelmingly positive. This could be a product of an activity that was different from what they were used to, thus inflated due to a newness or novelty factor. However, many comments appear genuine (Table 3), suggesting that this method of learning was meaningful to them over working with diagrams of landforms in their lab book, for instance, while others were frustrated by how long the lab took or at not being able to see the stereopair images in 3D.

TABLE 3

Typical examples of student comments in response to the question of whether they enjoyed learning about landforms this way?

Written responses	Lab Version
Yes it was interesting and the hands-on-approach was a nice change.	
No, because I can't see the stereo pair.	
I enjoyed using the stereoscope and seeing the different perspective of the landscape.	Mixed
It was definitely a welcomed twist on the subject matter since 3D images made it easier to perceive the actual landforms.	

Yes I did because I'm always used to looking at drawn sketches in workbooks or graphs, never really a realistic picture of the actual thing. Yes because it gave me a realistic relation and it was active instead of my looking at a picture and writing about it. I liked the labeling. Yes, it really helps to see the image from an aerial view. It was interesting yes, but I did not enjoy it. GE is really cool though. It's a great way to see topographic images and landforms we cannot just walk to.	Google Earth oblique only
Yes, it was awesome seeing landforms in 3D, however some landforms were difficult to see. Sure, but it was time consuming and headache producing. Yes, I have never used a stereoscope before so I found the new experience very enjoyable. Yes, very hands-on.	Stereopair planimetric only

The GPS exercise of locating oneself on an oblique or planimetric aerial photo has roots in spatial cognition linked to performance. Other studies feature students using GPS devices and Google Earth, as did Martinez, Williams, Metoyer, Morris, and Berhane (2009) where 7th graders went on a scavenger hunt to locate simple machines around campus and then imported and examined those points in Google Earth to improve spatial awareness through a fun, 'doing' activity. In a dissertation at the University of Alabama, Mayben (2010) used non-parametric tests to compare the pre-/post tests of middle school students that experienced instructional vs. traditional geocaching with GPS receivers, but here the focus was on learning styles in addition to enjoyment and engagement. Liben, Myers, and Kastens (2008) tested the spatial thinking skills of adults in connection with their ability to mark their locations (they were taken to various spots on a college campus) on either a round or square planimetric or oblique map. The GPH 111 Physical Geography course did not involve a spatial skills test. However, using

GPS devices to measure accuracy was the corollary to the Liben et al. study; students walked to points marked on aerial photos rather than placing a mark on a map for where they perceived themselves to be.

While I anticipated that the oblique perspective would have offered an advantage to students in the field in being able to orient themselves and 'get closer' to the target points on the images, perspective was not a clear predictor of performance, nor was it a predictor of perceived difficulty ratings. Rather, this practical application found that students struggled on the west side where there were not as many man-made, distinct features to orient from compared to the east side.

One confounding variable for the distance analysis may have been the relative signal error of the GPS receivers, which averaged 4.26 meters (SD 1.49) of accuracy. Furthermore, plotting the points in Google Earth (and also in a GIS) revealed a gridded pattern that suggests, in addition to this error, the sensitivity was at or above a ~1 meter resolution where this exercise needed sub-meter sensitivity by recording another significant digit, a hundredth of a second (ex. DDD MM SS.SS). Higher quality GPS receivers or changing the coordinate readout to Universal Transverse Mercator with 6-digit eastings and 7-digit northings may have prevented this. Similarly, Riggs, Balliet, and Lieder (2009) tracked geology students doing an independent field examination with GPS, analyzing their travel patterns—but not their locational accuracy to known geologic features—to get a sense of their geologic problem solving in the field. Downloading GPH 111 student tracks and time data from the GPS receivers may have offered other quantitative variables such as directness of course, time spent at each point, and re-coursing to further gauge performance. Having students mark and save a waypoint within the GPS may have also cut down on recording errors.

CONCLUSION

One basic message of this study is clear: do not hesitate to keep stereopairs and stereoscopes. The findings of this study cannot advocate throwing them out of classroom instruction solely in favor of modern visualization tools like Google Earth. While this might please the older generation of geomorphology and geology instructors who appreciate this tried and true resource, I also found that Google Earth should be used along with the stereopairs. A future iteration of this study, similar to Lang et al (2012), would be a controlled comparison of student landform interpretation abilities of general college students using stereopair imagery to actually using the Google Earth program to view the same landforms.

Although still very useful and perhaps not entirely replaceable until holographic 3D projection technologies begin to arrive in the classroom, stereopairs proved to be 'old school' technology with these current students. They generally struggled, rather clumsily, to view the images with pocket stereoscopes without training and direct assistance. Unlike previous generations that grew up enjoying View-Master slide viewers (circa 1930's) these students lack a frame of reference for stereoscopy and are more accustomed to computer-generated virtual 3D images. A future study of a large target population will need to provide students more training and experience with stereopairs so that the old and new technologies can be evenly compared.

Another notable contribution of this study is the introduction of a self-locating exercise using aerial imagery rather than a map. With some minor modifications and improvements, this type of in-field practical application repeated in future studies can continue to inform our understanding of students' sense of location, spatial thinking skills, and perhaps indicate whether experience with aerial photography interpretation and visualization technologies, such as Google Earth or stereopairs, does translate into increased abilities to match one's location to visual clues in imagery from different perspectives. With the prevalence of aerial images available on smartphones and portable tablets used, for example, to display driving directions and routes across town or to plan a future vacation or camping trip, this skill will only become more relevant to the post-graduate lives of students.

Chapter 5

CONCLUSION

This dissertation assembles three distinct case studies of general college students and education majors at the largest public university in the United States and their experiences with learning landforms primarily through Google Earth visualization technology. Each case study contributes new supportive evidence to promote and refine spatial thinking and earth science pedagogies so that learning – not the tool – remains the focus. These studies capture student performance metrics for various tasks including the identification and interpretation of landforms and their processes. Quantitative variables, including screen shots and image annotations as a measure of performance, compared with background, prior experience, and reasons for liking or disliking the multiple opportunities to step through these labs' learning sequence, were a common characteristic in corresponding datasets and methodological approach for each case study.

The first case study, *Learning geomorphology using aerial photography in a web-facilitated class*, demonstrated that general college students can learn physical geography landforms in an online setting using Google Earth without any presumption of prior experience, preferred learning style, or an above average background in math. Performance ratings (screen shot scores) for student-created and annotated oblique images of landforms in Google Earth did not correlate with any of these categories.

The second case study, *Children's stories, local landforms, and Google Earth: Assessing a recipe for content knowledge for teaching physical geography and spatial literacy,* will peak the interest of geoscience educators, current elementary school teachers, and program coordinators and specialists in teacher education programs. The enjoyment factor for the landform-learning recipe expressed by college students that desire a career teaching elementary and middle school-aged children in our public schools bodes well for the likelihood that they will seek opportunities to incorporate geography and spatial topics into their lessons. Specifically, their performance in just one lab, linked with feedback, confirms that confidence and their own positive learning experiences are a necessary foundation for content knowledge for teaching.

Is the stereopair still useful?: Comparing student performance and preference for oblique vs. planimetric aerial imagery was the third case study. Unlike the previous two, this lab was not administered through the web but in a traditional classroom/laboratory setting. Additionally, it did not have students use or interact with the Google Earth program directly on a computer but instead structured the presentation of its life-like, oblique aerial images of landforms to match, as nearly as possible, the paper format of stereopair photographs of the same exact location and landform. The motivation for this side-by-side comparison of digital 3D and photogrammetric 3D, and oblique versus planimetric perspectives was to see if Google Earth was sufficient or preferred by today's computer-savvy student, or whether there is still an educational benefit for including stereopairs in introductory physical geography courses. Statistical analysis of student annotations and markings across three groups—Google Earth oblique images only, planimetric stereopairs only, and a mixture—revealed that presentation medium did not matter. The stereopair group did not perform differently, not statistically better or worse, than the oblique only or the mixed group. Similarly, planimetric or oblique perspective aerial photographs did not offer any advantage to these students in the field. Accuracy measures and student perception of the difficulty of navigating to points marked on these two types aerial imagery had no correlation with perspective.

IMPRESSIONS ON STUDENT SPATIAL THINKING

The numbers and categorical variables in the datasets for these three case studies are rich with information. Teasing out a signal for evidence of spatial thinking among these students that would satisfy an objective board of scientific jurors—short of connecting wires to their heads to scan for increased neuron firings in the parts of the brain that are responsible for spatial reasoning while they identified shield volcanoes or slickrock or alluvial fans in Google Earth or stereopair images—proved elusive. Partly this is because each student has a unique background; their mental constructs place them anywhere on a continuum from subconscious to beginning of awareness to high-functioning spatial thinkers.

Still, my speculation is that these activities and learning tasks did enhance their spatial thinking even if performance measures and emotional responses are perhaps only a portion of the equation needed to assess where they are and their relative progress. Learning gains over time may be another important part of the equation that were not a part of these case studies, an acknowledged limitation due to the chosen methodologies and structure of the labs. However, even measures for learning gains, alone or in concert with these and other data, may not have helped me arrive any closer to my goal of assessing how students acquire insight into spatial thinking as learning itself is an abstraction and difficult to quantify.

Learning to think spatially is a process, and it does not happen at once at the will of skillful instructors, or because of one physical geography course in college, and certainly not because of a couple hours of using Google Earth to learn about landforms — although these can all be significant mile markers and stepping stones along the way. Returning to the basic definition of spatial thinking as set forth by NRC (2006), these methods, by their very nature, caused students to draw upon existing conceptual schemas for space through tools that visually displayed and depicted the locations, orientations, shapes, patterns, colors and textures, and interconnectedness of physical earth processes of landforms. The mental reasoning and cognitive processes involved are inherently spatial.

In the case of a student in the first case study working through the aerial photo interpretation lab, their mental journey began with whatever prior impressions and mental images existed for volcanoes and lava types, faulting landforms, glaciated mountain ranges, mesas and cuestas, river-cut valleys—if they had any at all (they were not expected to but may have had some prior knowledge from the lectures or high school)—combined with childhood or recent memories of visiting, hiking, camping, or skiing on or around landforms. Then, through the course of the lab they stepped through a process of attaching visualizations to new words and terms such as a'a and pahoehoe, composite volcanoes, wineglass valleys and normal faulting, arêtes and outwash plains, and buttes, just to name a few.

The lab provided coordinates and/or place names that, when students typed them into the search field on the top left hand corner of Google Earth browser, transported them from a point in outer-space where one can see our planet's blue oceans, and green, brown and white (ice-covered) continents and larger islands (**Figure 1A**) to suddenly barreling down like a shooting star towards the rotating sphere below to deftly stop—hover—several thousand feet above the surface. Now, looking straight down (planimetrically) at SP Crater north of Flagstaff, AZ, and the surrounding area, the student notices color, shapes, and lines but is likely not able to comprehend or interpret such a synoptic view (**Figure 1B**). The four-mile long S-shaped black 'blob' that extends north, and stands out in stark contrast from the tan and brown land floor, may trigger in their minds images of lava and volcanic eruptions. Using the user interface controls, the program responds to their mouse clicks and drags, bringing the student in for a closer view and also shifting to a side-looking oblique view (**Figure 1C**). They might consider its resemblance to an anthill, just much larger.

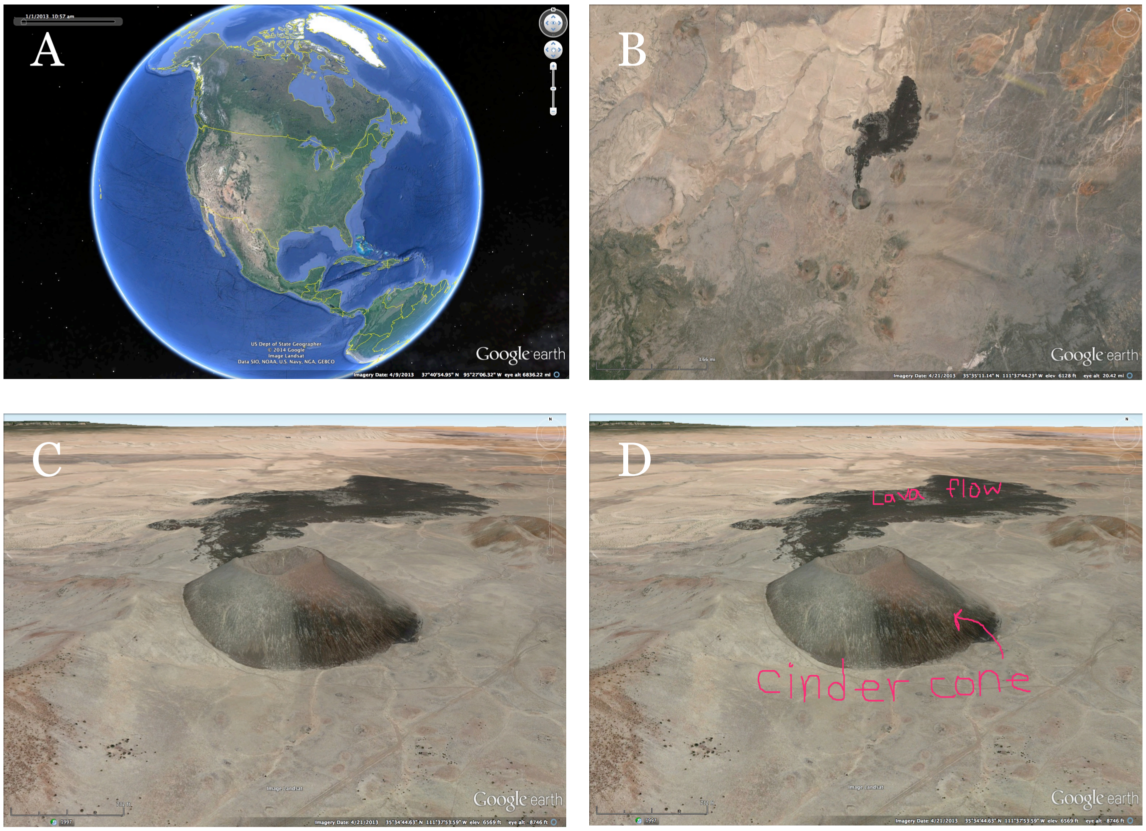


Figure 1. A simple approach to landform exploration using Google Earth, beginning with the opening screen of Google Earth (A), zooming in to a planimetric view above SP Crater, Arizona (B), then observing the landform from an oblique angle and crafting a screenshot (C) before placement of annotations and labels (D). *Map source: Google, Landsat*

Now the student may recognize iconic form and appearance of a cinder cone volcano. They move the screen around—panning, tilting, rotating, and zooming in or out until they are satisfied with the view—then "click" to save a screen shot. Per the tutorial, they learned the skill of adding graphic text and arrows and lines with an online photo editor. They label what they see (**Figure 1D**), a process that combines a sense of personal ownership and feelings of being in control with their newly acquired content knowledge about cinder cones—what they look like, where they are, and how they form and erode over time. They may even, at this point, recognize that this landform is only a 3-hr drive from ASU campus and maybe consider the possibility of visiting the site in person. This basic step-through sequence, with variations, was a part of each case study and is saturated with the “constructive amalgam” of elements that constitute spatial thinking.

For *concepts of space* the scale of a landform is visually comprehended against the enormity of the earth and also against other recognizable natural and man-made features, such as roads, once they zoom in. Landforms are recognized as having distinct locations and also coordinates that pinpoint that location. Visual interpretation of imagery conveys to the mind, “this is a/an [landform X] and it is here in this location and not over there”. The main *tools of representation* for these students was Google Earth imagery, but also include the student-created products of screen shots from multiple views, annotations and markings, and any text or captions they included with their answers.

Their choice of tools were necessarily restricted as inexperienced learners at the beginning stages of training, but their comparative experiences between stereopairs and modern virtual globe visualizations in the third case study, the opportunity to toggle between different perspectives in the first and second, and supplemental enhancements of Google Earth oblique views in the first offered a range of options. Through this they, ideally, gained a frame of reference for the fact that there are choices in geo-spatial tools and technologies for representing spatial phenomena and began to develop preferences for one or the other. The performance metrics of screen shot scores and emotion/opinion categories of like/dislike or easy/hard was an attempt to quantify their combined concept of space and representation and communication methods for landforms. An awareness of these first two elements of spatial thinking, especially, are important for teachers in developing a content knowledge for teaching landforms.

The third element in NRC's definition, *processes of reasoning,* may not have been adequately captured within the dataset. The first case study came the closest because it contained a variable for student preferences for learning styles. But these were self-reported. An actual learning styles survey, separate from the lab, would have been a more reliable data point for analysis.

The methodology in each case study of incrementally surveying after each task or iteration, as well as end of lab solicitations, was another attempt to understand what they were thinking at progressive points. Again, their volunteered comments verified against performance was the best insight I had to metacognition. Their misunderstandings and literal interpretation of landforms, as highlighted by common misspellings and incorrect marking in the stereopair vs. Google Earth lab, highlighted the need to consider that exercises designed to enhance spatial thinking, like the ones featured in this dissertation, may not impact each element equally, at the same time, or at the same rate. Other methods of inquiry and future studies can add expounding (or refuting) evidence to this work's assessment of geo-spatial technology's positive influence on spatial thinking awareness and supportive pedagogies.

To summarize, this research makes a compelling argument for continued development of pedagogies to support spatial thinking and earth systems science education at the college level using visualization technologies. Google Earth is suited for online courses because the program is lightweight, is simple to download and install, and is itself on 'online' resource. Google Earth can also be used in traditional brick and mortar classroom settings as a visualization resource, or also in a computer lab where computer quality and health, and internet bandwidth can be more evenly assured. The case studies of Chapters 2 and 3 showed that, at least for the current generation of college students, prior use and familiarity with the program is generally not a significant barrier to learning through educational activities with Google Earth. In Chapter 2, prior use—zero hours to 30+ hours of reported use—had no influence on student ability to find, identify, craft oblique views, or annotate landforms as part of an online aerial photography interpretation lab. Similarly, education majors' performance in the online Geo 4 lab in Chapter 3 was not influenced by prior experience with Google Earth or having previously viewed aerial photography on a computer. As a learning-enhancing technology, Google Earth is generally easy to use and easy to figure out, even in the scope of one assignment or learning task. Where issues arise, however, is when students have computer issues (e.g., running slow, unstable or out-of-date operating systems, or insufficient Internet bandwidth). In the case of aspiring teachers, a negative experience due to technological or computer issues, often expressed as not being 'good' with computers, was enough to almost entirely taint the learning opportunity; they did not enjoy the landform-learning recipe and likely did not gain any or as much content knowledge for teaching as evidenced by the fact that these students remarked that they did not think they would use this approach once they became elementary school teachers. This points to the need to mitigate, as much as possible, common issues that always seem to accompany computers and technology.

For those who did not experience significant or unresolvable technological difficulties, the active nature of exploring with Google Earth—controlling the program to see the landforms from different perspectives—contributed to enjoyment. Comments expressing that they felt as if they were actually there was a common theme in these case studies. Self-identified visual and kinesthetic learners (Chapter 2) were more likely to comment that they appreciated Google Earth images when supplemented with enhancements, giving multiple perspectives of the same landform. The feel of visiting the field *virtually* contributed to student enjoyment with these labs, although there I could not tell if enjoyment increases for each repetition or iteration of the exploration sequence, like confidence and performance, or whether it is a reflection of their overall impression of the labs. The finding that students hoping to soon become teachers enjoyed the Google Earth learning experience, couched through children's literature, also speaks well for continued use of this approach with this subset of college students.

The case study featured in Chapter 4 came the closest to assessing spatial thinking abilities of students by measuring their in-the-field aerial photo interpretation accuracy with a GPS and by comparing performance between oblique imagery, planimetric stereopair 3D, and a mix. My intuition is that, like Google Earth and related computer issues, knowing how or being trained to use stereopair technology is critical. One suggestion for future studies is the integration pre-/post spatial thinking skills tests, in conjunction to similar methodologies used in these case studies, to further evaluate how supportive pedagogies support the development of spatial thinking in college students in Google Earth era.

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