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Learner Requirements and Geospatial Literacy Challenges for Making Meaning with Google Earth

Lynn A. Moorman
Mount Royal University, lmoorman@mtroyal.ca

Susan Crichton
University of British Columbia, susan.crichton@ubc.ca

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Learner Requirements and Geospatial Literacy Challenges for Making Meaning with Google Earth

Abstract

This research contributes an educational research perspective to teaching and learning with geospatial technologies. This work considers the literacy of a geospatial text that is readily accessible to students, but often assumed to be intuitive to read– dynamic scalable satellite imagery, which often serves as base maps for common navigation, GIS, and virtual globe applications. Within the context of a STEM project, Grades 5 and 6 students were observed and interviewed to identify knowledge and skills that were required to make meaning of Google Earth imagery. A qualitative methodological approach incorporating a thinkaloud data collection protocol was followed to stay true to the breadth, depth and nuances of the student voice and experience. When engaged with Google Earth, the students were observed to employ a range of image interpretation skills, demonstrated various expertise in navigation, and also drew upon their knowledge of the technology. Challenges to understanding the imagery included dominant alignment effect, dimensional translation, and interpreting the nadir view. Students who had an understanding of the underlying technology of the application were better able to overcome these challenges. These results suggest that ensuring students have knowledge about the technology itself, and basic literacy of satellite imagery, is valuable in order to make meaning of the data, critical at this age when students are developing their mental constructs of the world with such geospatial data.

Keywords

geoliteracy, geospatial literacy, image interpretation, Google Earth

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Correspondence should be sent to Lynn Moorman, Mount Royal University lmoorman@mtroyal.ca. This work was supported with funds from the Social Science and Humanities Research Council (SSHRC), Imperial Oil, University of Calgary, University of British Columbia, the Province of Alberta, the Canadian Institute of Geomatics, and the Killam Trusts.

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1 INTRODUCTION

In January of 2010, three Grade 5 and 6 classes in Calgary, Canada began a constructionist inquiry project, in partnership with Science, Technology, Engineering and Mathematics (STEM) researchers from the local university. The overarching theme of the project was valuing appropriate technology through the development of technological solutions for challenges faced in international development projects. Within a week of starting this project, the Caribbean country of Haiti suffered a devastating earthquake that left approximately 300,000 dead and 1.5 million displaced. Suddenly, the theoretical premise of the STEM project in Calgary became a real-world situation. The project focus immediately shifted to Haiti, and the students began learning about the place and its people to provide context for their own work.

These Grade 5-6 students learned together as a combined group, and the three teachers team-taught, using an inquiry-focused, technology-enabled approach, allowing students to conduct their own investigations into the place and people of Haiti (Moorman 2014). Discussions of the geography of Haiti around a classroom wall map were followed by individual explorations of online resources. Students recorded their learning about Haiti and experiences with their projects in project-specific journals throughout the project.

Despite the focus on “place” and the accessibility and familiarity of a geographic technology in the class (Google Earth), the students and teachers did not choose to explore or conduct a geographic inquiry into Haiti with this resource, or talk about place other than showing the location on a wall map. The authors questioned how adding Google Earth to the students' repertoire of resources might affect their understanding of place, specifically Haiti, and the design of their STEM project. A sample of students were selected to explore Haiti with Google Earth. The authors quickly recognized there were limitations in the students’ capacity to use Google Earth effectively and turned their lens to identifying the skills and knowledge students were employing in their meaning-making of Google Earth data, and what skills and knowledge were lacking. This research therefore addresses the foundational concern of how the students came to make meaning with the Google Earth data, and identifies elements of geospatial literacy that allowed the students to interpret the imagery and acquire new knowledge. Further, gaps in geospatial literacy that subsequently resulted in challenges and/or misperceptions of the interpretation of the Google Earth data are explored.

This research lies within the scope of geospatial cognition research priorities identified by the University Consortium for Geographic Information Science (Montello and Freundschuh 2005), on how humans learn geographic information and the mediating effect of technologies and different modes and media of representation on that learning. The research also aligns with the first standard in the United States’ Geography for Life Standards, “how to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information” (Heffron and Downs 2012). The specific research question addressed in this paper is:

> 1. What elements of geoliteracy, specifically geospatial knowledge and skills, are required to make meaning of an unfamiliar place with Google Earth, and how do students show evidence of these elements?

This paper describes the findings from the children's direct interactions with Google Earth as viewed through the lens of image interpretation elements and geospatial literacy, sharing:

- the geospatial knowledge and skills the students used to make meaning of the imagery and application, and
- misperceptions and challenges that were observed during the interpretation process

2 LITERATURE REVIEW

The theoretical underpinnings of this work are drawn from the spatial conception work of Piaget and Inhelder (1956), Vygotsky (1978), Liben and Downs (1989), and Uttal (2000). While Piaget and Inhelder (1956) provided much of the initial understanding of the general progression of spatial understanding by the individual, Vygotsky (1978) shed light on the social construction of knowledge and climbed on Piaget's framework about how children learn. Vygotsky suggested children construct knowledge through social engagement and appropriating structures in interaction with more skilled individuals in the zone of proximal development. This view is relevant to spatial representations because of the social negotiation and subjectivity inherent in creating representations of Earth (Wiegand 2006). For virtual globes, this includes the dates and resolutions of the imagery used, the bands chosen and the colour portrayal, how the images are mosaicked and the provision of temporal viewing, allowing multiple dates of imagery to be viewed and compared.

It is Vygotsky's work that has inspired educators to embrace constructionist learning as a significant way to address 21st learning goals as identified by the Organization for Economic Co-operation and Development (OECD) (Schleicher 2018) and others. Specifically, if children are to survive and thrive they must learn to ask authentic and relevant questions (inquiry) and make meaning for themselves (constructionist pedagogy). Asking questions and making meaning also describes the process of image interpretation, inherent in the use of geospatial representations, including virtual globes. Inquiry and constructionism have become central pedagogical orientations to support making, STEM and 21st century competencies (Crichton and Carter 2017).

Liben and Downs (1989) examined the contexts in which Piagetan theory holds true for map competence and confirmed his basic theoretical framework, while questioning his proposed age and development boundaries. Uttal (2000) called for an understanding of the iterative building and reciprocity of knowledge construction that exists between the child and representation of the world. Uttal (2000) argued that geographic representations are a socially constructed media that not only provide us with represented information but influence and affect our own constructions and perceptions of large-scale space. He suggested a reciprocal relationship between spatial cognition and external representations of spatial information exist, that inform and build upon each other, much in the way literal symbols affect language learning (Blakemore and Frith 2008). While much of the research in this area of representation affecting cognition has focused on static maps, very little is known about the mediation effects of virtual globes, despite their prevalence and popularity in modern society since the mid-2000's.

Spatial cognition is a slow, complex phenomena informed by experience and exposure to multiple representations. There is a growing presence of meta-analyses of spatial thinking in the literature, emphasizing the importance of understanding how spatial thinking happens so that we may teach it more explicitly and purposefully (Bednarz et al. 2013; Baker et al. 2012; Anthamatten 2010; Golledge et al. 2008; Battersby et al. 2006; Brophy and Alleman 2006; Anderson and Leinhardt 2002). This area is also recognized as having significant research potential (Bednarz et al. 2013). Liben and Downs (1989) suggested activities involving changes in scale and map alignment in printed maps are typically too difficult for young children. Ironically, flexibility in perspective, scale, and orientation are considered a strength of virtual globes (Goodchild 2008).

In exploring the similarities and differences between how users react to varied representations of Earth, both the mode and medium of representation must be considered. The mode is a "culturally and socially fashioned resource for representation and communication," - how we read information, such as through text or images (Kress 2003: 45). Medium refers to how we engage with it, through analogue book or digital screen for example (Eisner 2008; Kress 2003; McLuhan and Fiore 1967). In many contemporary professional, educational, and personal contexts, the mode for geospatial learning and data exposure has shifted from a predominantly art-like cartographic depiction of Earth typical of atlases and globes, to a blend with photo-like satellite images of Earth, often displayed by a virtual globe. The shift in mode requires a different skill set for interpretation (Plester et al. 2002). While geographic information systems are still making inroads in K-12 classrooms, free virtual globes including Google Earth have become convenient vehicles to investigate the world and associated geographic phenomena through simple access, multi-scale imagery and friendly, intuitive user interfaces.

These interfaces make it easy for users to navigate and to use geographic criteria to make decisions about what the user sees and how they see it. These underlying, implicit, notions of the users' choices as they navigate the application, beg to be deconstructed because they represent naïve geospatial literacy – that is, the knowledge and skills that users draw upon to come to know a place in a virtual context. Users are making choices about scale, geographic extent of their viewing area, and level of attribute data, while not often explicitly knowing they are learning and practicing geography; this lack of cognizance can be considered a strength for interface design and a potential weakness regarding user metacognition and general awareness of our own powers of geography (Patterson 2007). Making the interpretation process more explicit through a deconstruction of choices and actions can reveal what geospatial literacy elements are used and required to make meaning from a geospatial technology such as Google Earth. These identified elements can then be used to inform specific examples, pedagogical strategies, and learning outcomes.

Literacy is the ability of an individual to make and share meaning and knowledge through a representation. Components of literacy recognized in Canada, are knowledge, skills, and dispositions, recognizing that there is an interconnectedness among these (Canada Council on Learning 2012; Government of Alberta 2009; National Research Council 2006). For this paper, geospatial literacy is considered to be an amalgam of knowledge, skills, and dispositions required to collect, comprehend, critically think about, create, and communicate geospatial information (Moorman, in press). The ability to use, analyze, and interpret images and maps is becoming more and more important in many scientific and industrial fields (Solem et al. 2008). In addition, some contend that the ability to use images and spatial technologies intelligently and critically is becoming a requirement to participate effectively as a citizen in modern society (Bednarz et al. 2006). Therefore, there is pressure on K-12 education to include geospatial thinking as a vital part of, or across, the curriculum to ensure that students are competent and comfortable with geospatial information and are empowered to best use the geospatial technologies (e.g., GIS, virtual globes, GPS) available to them. However, the scant research on geospatial literacy at K-12 levels suggests there is much more work to be done to understand how to best facilitate learning and assessment of geospatial knowledge (Anthamatten 2010). This gap creates ample opportunity for the research shared in this paper and for future research.

Procedural knowledge in the context of Google Earth use refers to the specific practices and skills the students use to make meaning from the application. Most critical is image interpretation, as the Google Earth base map is composed of a mosaic of imagery from satellites and aircraft at different spatial resolutions. Interpretation refers to the process of examining an image to identify objects and assess their significance (Lillesand et al. 2015). In the process of reading, comprehension depends on the ability to accurately and fluently identify printed words and a general language comprehension ability (Compton et al. 2009; Gough 1996). Interpreting imagery in Google Earth requires similar skills: the ability to identify features in the imagery and relate them in a spatial and conceptual context. Traditionally there were significant amounts of work and research into understanding how to interpret air photos and develop processes to make the process efficient and effective (as well as reliable and valid), which is important for military and intelligence gathering purposes (Philipson 1997; McKeown 1984). Much of the current image interpretation research focuses on developing automated image classification algorithms and improving classification/interpretation accuracies. Key elements used in interpretation consist of tone, texture, size, shape, pattern, association, and shadow (Lillesand et al. 2015; Jensen 2000). Liben’s (2000) foundational work in children’s map use and work on children’s interpretations of aerial photographs (McAuliffe 2012; Palmer 2011; Plester et al. 2003; Plester et al. 2002) indicated that working with airphotos is an effective scaffold for children to learn about maps and their associated concepts – particularly nadir view. This benefit may be also realized with Google Earth, particularly because it is now easier to access than aerial photographs in classrooms. Phipps and Rowe’s (2010) work in adults’ understanding of satellite imagery identified the confusion caused by clouds, suggesting satellite image interpretation may not be as intuitive as assumed.

Current technologies enable geospatial exploration in ways that have previously been impossible, including dynamic scaling and photorealistic views of any place in the world, at a child’s fingertips and a moment’s notice. How this new information and these new ways of acquiring geospatial knowledge will impact a person’s conceptual model of the world and spatial understanding has yet to be fully explored. Virtual globes have been used to introduce geospatial concepts to students, but little research has been conducted determining the success or limitations of this specific technology to facilitate the acquisition of geospatial skills and knowledge, or to determine what geospatial literacy prerequisites are required in the use of the technology.

3 METHODOLOGY

3.1 Participants and Site Context

Twenty-one Grade 5 and 6 students in Calgary, Canada, taught as a mixed cohort by three teachers, were involved in this research, and chosen as a purposeful sample of the 85 students available for maximum variation (Glaser and Strauss 1967) to examine differences in the students' experience of conducting a spatial inquiry on Haiti with Google Earth. In addition to grade and gender representation, the sample selection considered student life experience, academic and English language proficiency levels as informed by the all three teachers. Proficiencies were provided as ordinal data (high, medium, low), and there was representation of all academic and English proficiency levels in each gender and grade (5 and 6). This distribution of grade and gender was eight 5^{th} grade males, six 6^{th} grade males, three 6^{th} grade females, and four 5^{th} grade females.

The students were part of a one-to-one laptop program, and were using their laptops every day. They each had access to Google Earth on their laptops, and had experience using Google Earth, having completed a spatial inquiry about their local watershed shortly before this study. A student teacher also led them on a Google Earth virtual tour of their watershed, from the water source in the mountains to the point where it entered the city.

The administration and staff at the school supported an inquiry-based learning environment and led the school jurisdiction in the use and infusion of technology (Crichton and Yaniv 2007). Teachers were comfortable with integrating technology into their classrooms and teaching practice. The teachers also fostered a strong reflective stance in the classroom, and the students were very familiar with the idea of expressing and recording their thoughts and feelings about a myriad of topics – events, activities, concepts, and processes. This instructional practice was beneficial to this study in order to focus on the use of an application without substantial change in the students' learning environment or basic tools of learning and to have the students communicate their thoughts and ideas to the researchers.

3.2 Data Collection

Evidence required to address the research questions included student interpretations of the data, including strategies of interpretation and elements affecting their decision-making in the interpretation process. The research methodology facilitated the promotion and encouragement of participant voice, reflection on observations, and elicitation of evidence of the students' experience (Westgard 2010; Plucker et al. 2004; Merriam 1998; Stake 1995). The study was a naturalistic case, conducted in the environment in which the students' learning took place, and with the tools, affordances, and limitations common to their typical school experience (Stake 1995). Data were collected using a think-aloud protocol, having students voice their thoughts, ideas, intents, and actions to make their tacit decisions and questions explicit, allowing insight into the participants' cognitive processes (Someren et al. 1994). The think-aloud technique has been referred to as an essential method for education science because it allows us to understand problem solving processes, not just compare answers (Young 2005).

The researchers were familiar to the students, as they had been directly working with the students for three months on their STEM projects. For this study, the students were observed individually. The students were each introduced to the think-aloud protocol and practiced a think-aloud while they explored a place of choice on Google Earth. This allowed the researchers to ensure that the student was comfortable with the navigation controls, user interface of the application, and the think-aloud protocol. The focus of the screen was then brought back to Canada, and students were asked to navigate to Haiti while employing the think-aloud protocol. Any student who had difficulty was given some basic prompts by the researcher to help them eventually locate the country. Once focused on Haiti, students were asked to describe what they could interpret, again using the think-aloud protocol to make strategies and decision points explicit. Then they were asked in a semi-structured interview format about the land cover, the terrain, indications of population distribution, and evidence of the earthquake. The think-aloud protocol in this case was chosen to be concurrent to the Google Earth activity, and the students' actions were observed and video-recorded to create a robust and thorough sense of the subject's actions and reasoning (Jakobsen 2003).

Analysis of think-alouds generally happens from the bottom-up (Ericsson and Simon 1993) with categories developed for analysis and evidence of process derived from the data, and not externally derived and forced on the data. A process of framing and coding (Goffman 1974) of the observations and think-aloud data in this case allowed for a natural categorization of the data into meaningful groupings and themes that responded to the research questions. Themes relevant to the identification of geospatial literacy prerequisites and use-challenges emerged, including the use of interpretation elements, different spatial perspectives required and knowledge of technology.

The technology used by participants in this study was a laptop equipped with a mouse or touch pad cursor control, configured in the same way as their own laptop. Using their own classroom technology ensured the research adhered to a natural case approach.

4 RESULTS AND DISCUSSION

This section is presented as both general results and discussion to respond to the evidence found for the question "what elements of geoliteracy, specifically geographic knowledge and skills, are required to make meaning of an unfamiliar place with Google Earth, and what is the evidence that students have developed these elements?". While image interpretation is informed by *a priori* experience and knowledge, students in this study demonstrated inconsistencies in how and what they actually observed in the image. There was a range of skills of interpretation evident, including the use of image interpretation elements and the ability to contextualize the perspective of the imagery (nadir view, flexible orientation, scale, dimensions). The inconsistencies also related to the students' understanding of how an image of the world was constructed in Google Earth, emphasizing the need for technology knowledge as part of their learning. The misperceptions and challenges observed and the knowledge and skills the students required to make meaning of the imagery and application are presented here, focusing on image content interpretation skills followed by the role of technology knowledge.

4.1 Image Interpretation Skills

Image interpretation refers to the mechanisms of seeing the imagery and making observations, that are subsequently informed by *a priori* knowledge that is creatively extended to become an interpretation of meaning. Interpretation refers to the process of examining an image to identify objects and assess their significance (Lillesand et al. 2015). Key elements used in interpretation consist of tone, texture, size, shape, pattern, association, and shadow (ibid).

4.1.1 Image Interpretation Elements

While students' experience and knowledge affected the personal interpretation of what they observed in the imagery, the students in this study also demonstrated inconsistencies in what they actually observed. Tone was the most obvious element observed and was used primarily to distinguish land cover. All of the students articulated observations about tone but these observations ranged from a simple descriptor of tone (Participant 2 "some brown, some grey, some white") to expert inference about how the tone related to the land cover (Participant 11 suggested a lighter tone might be a mining site, and the tone reflected that the land "might be dusty if it hasn't rained"). Land cover such as farmland and forest were distinguished based on colour, and rubble in Port-au-Prince was identified by a darker tone than the surrounding lighter toned buildings. Bright reds and blues gave the best clues for identifying tarps in Port-au-Prince. Misconceptions around tone involved confusing bare land with snow, water, or clouds because of the bright reflection of all visible light in these features. Participant 11 recognized his mistake later stating, "Maybe I mistook snow for dirt." This second-guessing was a practice of the more expert interpreters, as they sought to logically confirm their interpretation with other evidence. Novice interpreters would not change their initial interpretation even if it did not make sense (e.g., snow in Haiti). One student sought to interpret water quality from the tone of a river, explaining, "The rivers and lakes don't seem to be really fresh water. It looks dark, some water looks black." An understanding of the basic principles of optical remote sensing would help inform students of how the tones are derived and may serve to better inform their interpretation.

Shape was critical for recognizing basic targets. All participants recognized the stadium by its oval shape. Buildings, roofs, and fields were all recognized by shape. Very detailed discernment of shape helped one student distinguish between the crypts in the cemetery and surrounding cars. "Cars normally have mirrors, and this thing doesn't have a mirror" (Participant 6). The crypts were unfamiliar objects to the students and served as focal points for interpretation. Size was used by the students as a secondary element, to test their original interpretation. In many cases, the size of the crypts in the Grand Cimetière convinced many students that they were not houses. Participant 14 explained, "I think these are houses, but these aren't cause they look smaller." While most students decided the crypts were not houses because of their size relative to the houses and adjacent cars, Participant 17 decided that his interpretation of very small houses was still appropriate, without building a more feasible hypothesis in the manner of the more expert interpreters. The students were also able to match size of buildings to their use. For example, Participant 18 inferred that a large building might be a factory after relating the size to a large building housing the newspaper presses in his home town of Calgary.

Shadow was found to be a very useful and supportive secondary interpretation element. Its presence was used for the interpretation of hilly and mountainous terrain, and the length and shape of shadows determined the presence of people (Participants 5 and 6) and of houses (Participant 12). Participant 13 used shadow as a primary element to interpret houses, seeing only the shadow first, then the shape of the houses. Participants 7 and 13 inferred the heights of buildings from the shadow lengths. Participant 12, who was initially confused by the clouds in the imagery, was able to use shadow to determine the true nature of the clouds, stating “The shadow of the mountain would be touching it. ... the shadow over here, they’re not connecting, so it gave it away.” In this case, perceiving shadow correctly as a cloud’s shadow seemed to help in the understanding of the dimensional transformation of the imagery described in section 4.2.1 and thus the interpretation of the feature. Participant 2 struggled reconciling a cloud’s shadow to its source, even after having the cloud and the corresponding similar shadow shape pointed out. Without this understanding, she interpreted the feature as a water body.

Not many students mentioned texture or pattern, and these elements were rarely used in interpreting features, only in describing features after they had been identified. Participant 4 noticed the pattern of the crypts and tombs in the Grand Cimetière de Port-au-Prince cemetery, saying “It looks like an orchestra, the notes, the music.” The patterns of street networks were observed by some students, and their characteristics compared to street networks in other places. Participant 5 was unable to recognize the pattern of urban streets, even when looking in a familiar area. Recognition of the pattern of certain land uses (e.g., streets, golf courses etc.) as an aid to interpretation is a skill honed with experience, and this growing expertise was shown by many students as their experience in looking at Google Earth imagery increased.

The element of association was important for interpretation of familiar environments (e.g., recognizing malls by the lots adjacent parking lots, finding home through association with parks and alleys). In the students’ exploration of Haiti, association was not used as frequently as with a familiar place, but was used to identify a river (Participant 11 noted the association of houses built close to it and lots of vegetation along it). Association was also used in the interpretation of the stadium in Port-au-Prince through the identification of stands, nets, and markings on the field.

In addition to using the traditional interpretation elements, the students also made use of temporal change to help in their interpretations. This element was initiated by students who knew historical imagery was available on Google Earth, and were curious about how long a feature had been in place. Scrolling through the previous imagery of Port-au-Prince enabled the students to see how features had suddenly appeared in the stadium after the earthquake, and how those features were growing in number as time progressed. Seeing changes to a feature through a sequence of imagery facilitated its interpretation. In the case of the stadium, Participants 9 and 10 observed the features that suddenly appeared were linked chronologically to the earthquake, leading to the understanding that they were tarps set up as shelters on the stadium field. The digital mode of Google Earth that allows for viewing images through time suggests another image interpretation element, temporal change, be added to the elements list.

4.2 Perspective

4.2.1. Dimensional Transformation

This skill describes the ability to understand how a 3-dimensional (3D) landscape is represented by a 2-dimensional (2D) image. It is relevant to how the students perceived objects in the imagery. Recognizing misconceptions was the key to identifying difficulties in transforming the 2D image into a 3D understanding. Much of the misunderstanding stemmed from the way the 3D image is rendered—the 2D image is draped over a terrain model, so if a student views the image obliquely, they presume it to be a rendering of the actual landscape as in Figure 1. The most common misperceptions were relating heights of buildings and seeing objects that are normally far removed from the ground (high cloud) as ground cover itself. Participant 1 described how he understood that he was seeing clouds, but he couldn't imagine the vertical distance between the clouds and the land from the satellite image perspective. "I can't really see what these are, but I think they are clouds. I thought that clouds were more high off the ground. I think this is a windy day" (Participant 1). In this participant's case, the interpretation of cloud close to the ground and windy conditions stayed consistent throughout his exploration of Haiti, and he tried to portray these on his sketch map of Haiti at the end of the activity.

Figure 1. Clouds can appear to be part of the landscape to novices who see the 2D image draped over the terrain model. ©DigitalGlobe 2014.

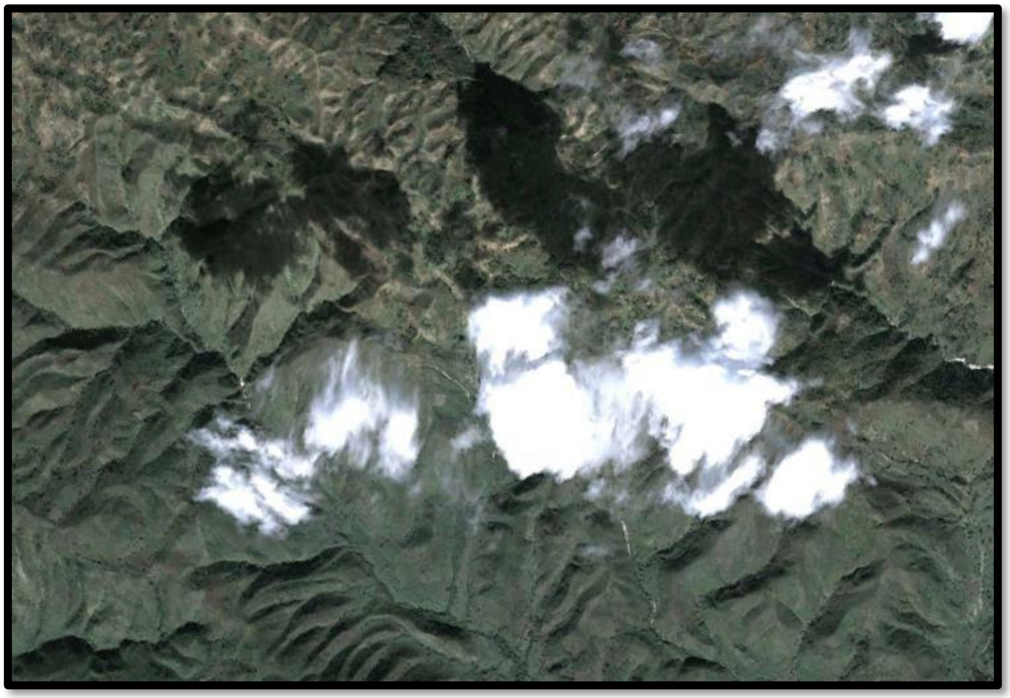

Figure 2. Clouds and associated shadows shown in nadir view, including those visible in Figure 1. In this view, the disconnect between the cloud and shadow indicate an airborne feature. ©DigitalGlobe 2014.

Phipps and Rowe (2010) noted that novices do not necessarily interpret or understand what might be obvious to experts. They also found clouds to be a source of confusion for the teachers and the general public who looked at satellite images as part of public information displays. In this case, multiple students were confounded by the presence of clouds in the imagery. Participant 6 demonstrated this in his description of Haiti as “not a high land, but low, and the clouds are really close to the ground. You might be able to touch them if you climbed a small mountain because the clouds are really close to Haiti.” Students who were unable to separate the aerial features from the ground features were at a disadvantage when it came to interpretation compared to their peers who had strategies to distinguish these features. Participant 12 was able to determine the true nature of the clouds by reasoning that their shadows did not connect to the features (Figure 2), and therefore there must be vertical space between them. This student displayed expert practice by using the interpretation elements of tone and shadow to help understand perspective. While Google has since processed the imagery to remove clouds, it remains important to understand the dimensional transformation, particularly if dealing with historical imagery (with clouds) on the application or looking at imagery away from Google Earth. It is also important to inform students that the images are purposely processed to exclude clouds, to help in their understanding of Google Earth as a rendering of the Earth, not a true “snapshot”.

4.2.2. Nadir View

The nadir view is one that looks directly down at earth, much like one would see looking directly below an airplane. An oblique view is considered to be looking out at the horizon from an aerial perspective, like looking out the airplane window. Though it is accepted that aerial perspectives are cognitively accessible to even young children, there were challenges with it with these participants. The participants in this research much preferred an oblique view to a nadir view because it gave them a better sense of the terrain.

There were also uncertainties in interpretation based on the unfamiliarity of the nadir point of view. Participant 2 had a difficult time in her think-aloud practice finding her own home in a neighbourhood she was familiar with, because it was a duplex and what looked like two homes from the ground perspective looked like one from the air. Difficulty recognizing features in a very familiar place indicate there could be issues understanding the nadir perspective. This challenge is what Liben (1999) refers to in her competency model as correspondence mastery, which is identified by Plester et al. (2003) as the key to understanding representations. Participant 5 had difficulty with the nadir view, initially not recognizing streets and then once oriented, could not follow a known route in a survey view. Participants 2 and 9 had similar challenges. Participant 2 also looked for interpretation clues that would not be possible in the nadir view, for example the colour of the brick on the front of the house. This distracted her from seeing what was evident in the imagery.

4.2.3 Dynamic Scaling/Resolution

In traditional image interpretation, the scale of the final interpretation (map) is one of the first things to be considered and decided upon to control the level of mapping and information required for the interpretation (Palmer 2011). In virtual globes, the scale is dynamic, requiring multi-scale interpretation on-the-fly by users. This functionality puts an extra burden on the user in terms of being able to recognize generalized and detailed features; however, zooming in and out and changing scale is one of the most appealing features of the application, according to the student participants in this study, as it gives users control over the detail and area they want to view of the world. This theme is important to this research because it is a functionality that is so different from the geographic representations students typically have access to, such as atlases and printed maps. There is little evidence in the literature suggesting how students might use dynamic scaling or how their learning is influenced by it.

The literature on visual cognition suggests that low spatial frequency features are the first thing viewers interpret, and their attention then moves from a global to local level in interpreting features. In this study, many of the participants showed a propensity to interpret from small scale to large scale, zooming out when needing to get oriented, and then zooming in to a larger scale to discern specific features. This was tied to expert navigation strategies, whereas novices tended to pan across the images instead of changing scale. More advanced users zoomed out to get oriented, as described in Participant 20’s think-aloud. “Where am I? Zoom out, figure out where I am.” The most sophisticated users also recognized that there was different content at different scales, and they reflected on how it affected their interpretation. Participant 19 was expecting complete devastation in Port-au-Prince. He was initially surprised that there were any buildings standing and interpreted from that observation that the impact of the earthquake wasn’t as terrible as he thought. However, he changed his mind again when he zoomed into a larger scale image.

> I'm surprised because I see lots of buildings here. I saw it was good, but now when I zoom in closer… now I'm not surprised, because I see a lot that are tipped over, because I was out so it was good, but now I see buildings tipped over… (Participant 19).

For image analysts, there is the propensity of zooming in gradually while interpreting. While this helps to define features, zooming in too far causes the image to be viewed at a scale that is too large, which renders the interpretation meaningless, as individual pixels are being mapped instead of areas of like-pixels (Palmer 2011). Participant 4 noticed the loss of information at large scales. "If you look back [zoom out] it, looks more real. If you go in too close, then it looks like it's floating… And then what is this? I'll zoom out, it looks more real. Yeah, bushes probably and tents." (Participant 4).

Understanding generalization and pixilation of imagery content at different scales can help with meaningful interpretation. Expert practice consisted of finding a balance between the detail of information required, the field of view suitable for the size of area being investigated and being able to recognize what type of information can and cannot be viewed at different scales. This may be instinctive to some students, and maybe particularly with those who play video/online games where zooming is an element of the game, but it was evident that not all students are at the same level in terms of using scale to facilitate the most meaningful interpretation.

4.2.4. Orientation

Although one of the benefits of Google Earth noted by the students in this study was the multi-directional perspective, as soon as north was rotated away from the top of the viewing frame, all of students became disoriented and many were lost. This challenge illustrates the notion expressed by Uttal (2000) that the representation that we see most frequently becomes our norm. The influence of north oriented maps (north to the top) to the students' mental maps of the world was readily apparent. For these Grade 5 and 6 students, the notion of north as up was so firmly entrenched that they could not even recognize the shape of their province or country in any other orientation. Sun et al. (2004) call this "orientation specific," meaning the spatial memory retains the orientation in which the information was learned. While this is understandable in a learning environment of printed maps that require static text to be read with a certain orientation, students are no longer technologically constrained to the north is up paradigm. However, for some students, there was no question of why north should be at the top, because they thought that is where it belonged, and where it always was. When asked about why he wanted to keep the image oriented with north to the top, Participant 17 answered, "Because north is pretty much – that's where it is, on the north side."

This student had difficulty understanding that representation of the Earth's surface is subjective. Participant 2 understood that the orientation could be changed, but when asked if she would be able to interpret the image if north was not at the top, she replied no. Participant 7 mentioned that it was difficult to navigate if the orientation changed, and Participant 8 became instantly lost when the orientation changed. This mental construct is referred to as the alignment-effect, where mental maps of areas are constrained to the orientation of the representations they were learned from, and are a product of passive learning (Sun et al. 2004).

The students who were able to handle the shift in orientation stated that while they could cognitively understand the image, it still felt uncomfortable and "weird" (Participant 20). Participant 16 described his preference for looking at Google Earth with a fixed north orientation, "I like looking at it like it is a map on a big chart sort of, like a flat map so that I don't have to look at it upside down, because then I don't really understand it." Many of the students made the suggestion that an improvement for Google Earth would be having the ability to "lock north in place" (Participant 16). This was in fact added in later versions of the application. Participant 1's solution was to anchor his view with the Arctic Ocean in the top of the frame. However, this practice was not possible during large-scale viewing or in any explorations in the southern hemisphere.

4.3 Technology Knowledge

It became apparent that students had varying knowledge of how the virtual globe was constructed, and this *a priori* knowledge influenced interpretation of the imagery. Just as Mishra and Koehler (2006) described the importance of considering technology knowledge as a critical element of the technology pedagogy content knowledge model (TPACK) for instruction, knowledge of the technology was important for student learning in this research, and it played a role in how students were able to make meaning of imagery in Google Earth.

Knowledge of the technology manifested in a more comfortable and more realistic interpretation of the imagery. Misinterpretations stemmed from a lack of understanding of how the imagery data was collected and presented. In the most common case, students did not understand the temporal dimension of the imagery, and they made assumptions about the imagery dates to inform their interpretations. A common question was whether the imagery was real-time. Another aspect of the technology that was unknown was how multiple scenes of imagery were mosaicked and displayed as a composite product.

Many students were caught off guard when they were told the imagery they thought was pre-earthquake was in fact, immediately post-earthquake. Some students tried to interpret the imagery while ignoring the context of the new information when they had difficulty believing the imagery was taken after the earthquake. Participant 10 was told the imagery was post-earthquake explicitly three times and continued to explain the elements on the image as pre-earthquake before she hesitated and accepted the new temporal perspective. Without knowledge of the context of the imagery and the technology, any subsequent knowledge creation can be fallacious.

Participants 9 and 20 used their knowledge that Google Earth had a temporal series of imagery to facilitate their interpretations and looked at how certain targets changed between pre-quake and post-quake images. Participant 9 remarked viewing the changes to the landscape through the multi-temporal images "is like the march of time." Spatial resolution was a concern of all participants in this study. When they zoomed into pixel resolution, they assumed the application was just taking time to resolve, or that there was a user function that would improve the detail. A basic explanation of the concept of pixels and spatial resolution was helpful to balance expectations of the users with regard to discernible image detail.

The structuring of the images in Google Earth to effectively cover the Earth's surface created mosaicking artifacts such as seam lines and abrupt changes in tone and resolution that were misunderstood by the participants. Students with knowledge of that structure were able to incorporate the knowledge into their interpretations, realizing they were seeing an artifact. Students without that knowledge created interpretations of features that were not actually part of the landscape. In this way, technology knowledge affected the procedural knowledge of interpretation. The students who were more knowledgeable about how the images were generated and structured were also the ones who moved the most comfortably within the application, with smooth zooming and panning across the imagery, as if the cursor was a natural extension of their own bodies. They used the dynamic nature of the application to help in their interpretation process.

Technology knowledge also related to how the students felt about interacting with Google Earth. Students with a greater knowledge base and experience with the technology did not question the use of the technology, as did students without the experience and knowledge. In this case, technology knowledge related to the trust that was shown in using Google Earth, therefore playing a role in the affective component of learning.

5 CONCLUSIONS

The authors worked with 21 grade 5 and 6 students initially with the premise of exploring how Google Earth might inform their sense of place in a place-based larger STEM project. Though Google Earth was familiar, accessible on their laptops, and easy to manipulate from a user-interface perspective, the students showed a diversity of capacities to make meaning of the imagery and were challenged with interpretation elements, perspectives, and technology knowledge. These foundational challenges suggested an in-depth look was required to explore the students' geospatial skills and knowledge in using and interpreting Google Earth imagery. While the ability to extract information from map-like representations of the Earth has been shown to be evident in children as young as two (Rieser et al. 1982), the different mode and medium of a virtual globe such as Google Earth in a classroom demands that some attention be paid to issues and procedural knowledge that might otherwise limit some students from using the tool effectively, despite its intuitive nature. This research ultimately looked at the geospatial literacy required to making meaning of an unfamiliar place from Google Earth.

In this research, all seven interpretation elements (tone, texture, pattern, shape, size, shadow and association (Lillesand et al. 2015) were used by the students to varying degrees, to identify targets on the Google Earth imagery. Tone and shape were used as primary interpretation elements, providing the first clues as to what the students were seeing. Size, shadow, and association were used as a secondary means of interpreting features to confirm or refute their initial interpretation. Pattern and texture were used primarily as a means to describe a feature, and patterns were not recognized by all participants. A few students viewed the change of a target's appearance through multi-temporal imagery in Google Earth to support their interpretation, claiming a new interpretation element relevant to virtual globes.

Understanding perspective was critical to the students' success in interpreting geospatial content. Four skills were evident around perspective understanding: dimensional transformation between 2D and 3D, nadir viewing, dynamic scaling, and orientation. Students had difficulty realizing that Google Earth imagery is really a flattened view (2D) of 3D earth draped over a terrain model. The result was the vertical dimension of the imagery content was lost, and clouds appeared to be part of the ground cover or landscape. Research into public perception of displays of satellite imagery and visualizations indicates that adults also have this confusion (Phipps and Rowe 2010). Students with more expertise in interpretation used shadows to determine the true nature of the clouds, by identifying a displacement between the feature and its shadow. The nadir view posed problems for some students in recognizing objects like street patterns and houses, even if they were familiar targets. Students with more experience had expertise around recognizing patterns and found the interpretation task more comfortable overall.

Objects and scenes are processed from a global to a local level, and this has implications for how imagery was seen and how dynamic scaling was used. Information processed at the global level acts as a framework to situate local information. Students demonstrated this by zooming out to get the big picture when becoming disoriented or lacking in context. According to Bar (2004), low spatial frequencies can provide the global, contextual information that facilitates object recognition, allowing for a faster recognition response. The more experienced students displayed this multi-scalar ability, zooming in and out of an area while quickly gathering information. Less experienced students tended to pan the imagery, keeping a consistent scale.

All students were uncomfortable with a flexible orientation, where north was not always at the top of the screen. In online GIS and mapping applications, most base maps are oriented north-up and static. This may be more user friendly because students prefer maintaining a static orientation, however, mental rotation, which is a spatial skill highly valued in art and STEM disciplines, could be practiced with geospatial representations. Visualization of structures and building objects require the ability to mental rotate an object to consider it from a different perspective, as stated in the Alberta science curriculum for grades 1-3 (Alberta Education 1996). Google Earth is easily able to support activities relating to interpretation of 2-dimensional rotation and recognition of familiar areas of Earth. In the current environment of nurturing knowledge of global connections and interconnectivity, it seems important to offer the ability to see the world as a true sphere with many perspectives. Virtual globes allow this, and the imagery is responsive to any orientation, and as such, seem a natural entry point for students. However, if the students are constrained by the orientation of their mental maps, they will be unable to take advantage of the flexibility of a virtual globe.

Research conducted by Sun et al. (2004) into navigation ability showed the alignment effect was dependent on whether the learning of the route was active or passive. Using a virtual environment, they showed that active learning produced no alignment effect, whereas passive learning in the same environment did create an alignment effect. Sun et al. (2004) suggested when the navigator is actively controlling their own movements to learn the space (even with a mouse), versus passive learning, where the navigator visually studies the environment, proprioceptive information acquired through active learning creates a stronger spatial framework. This has implications for education and for developing less subjective perspectives of the world. Instead of typing in a location and having the application zoom directly there, students could actively navigate through regions of interest on Google Earth to view their area of interest, to build an orientation-free mental representation while minimizing the alignment effect in their conceptions of the world.

Knowledge of the technology, particularly with regard to the temporal characteristics of the imagery and how the images were mosaicked to create a continuous coverage of the Earth's surface, manifested in the students' ease and comfort of use of the application and the accuracy of the interpretation. As intuitive as Google Earth is to use, for these children, knowledge of the technology was vital to increasing content knowledge through stronger interpretation and affective response. Technology knowledge should be considered as a distinct type of knowledge that complements such technology use. This relates to the idea of TPACK model for teaching with technology (Mishra and Kohler 2006) but applied to learning.

The range of capacity demonstrated by the students is suggested to be an example of novice to expert practice. Novice to expert levels were noticed in navigation, with novices randomly panning across imagery maintaining a uniform scale to find a location while experts, who were comfortable at multiple scales, zoomed out to a small scale and then pinpointed their location and zoomed back to a detailed view. Experts used multiple interpretation elements to help narrow an interpretation of a feature to a satisfactory choice. Novices used the interpretation elements for description, not to aid in interpretation, and were often satisfied with their first explanation of a target, whether it made sense or not. In orientation, flexibility characterized the experts. Although all students found it uncomfortable to view the imagery when north was not at the top of the screen, the expert users created strategies to help them orient, and could recognize shapes of countries or terrain with a different orientation. Expert use included having a sense of the vertical displacement of the clouds from the ground and recognizing artifacts from the mosaicking process. Identifying characteristics of novice to expert practice can inform learning progressions to support pedagogical strategies and inform curricula developers and teachers of what we can fairly expect of children when using virtual globes and identify what supports are required.

The procedural knowledge investigated in this work is important because it represents the skills sets and practices that can enhance or confuse the mediated learning of the world that is feasible with Google Earth. Many of the challenges observed with the children in this study around procedural knowledge can be addressed through enhanced and explicit geographic teaching about how to read and interpret an image, a fundamental component of geospatial literacy. An overview of how the Google Earth model of the world is created would also be effective in helping students identify artifacts, to better inform their interpretations.

The students and school in this research followed the Alberta Program of Studies for Grades 1-6, as there is no national curricula in Canada. In the Alberta Program of Studies for Social Studies, there are no references in the current curricula to skills of image interpretation or specifically understanding the survey/nadir perspective (Alberta Education 2005). There are, however, benchmark skills for generally using and creating maps that infer the ability to employ the nadir perspective. With the plethora of imagery available to students at home and school, and maps to provide direction to the general public, including interior floor maps of buildings and fire escape routes, it is critical that students develop a strong understanding of the nadir perspective. This skill, and being able to understand information content of satellite imagery is described within the 1st Geographic Standard of the United States' National Geography Standards as a grade 4 benchmark- "identify and describe the properties (position, orientation, symbols, scale, perspective, coordinate systems) and functions of geographic representation" and specifically "compare the similarities and difference of information presented in online road maps, satellite images, or street-view data" (Heffron and Downs 2012).

The responsibility for instruction of geographic representations often resides in the discipline of social studies or geography. It would be impossible to include all elements of geospatial literacy in the outcomes for each grade; however, there are some fundamental geospatial literacy skills that, if addressed in the curricula and classroom, would enhance students' abilities to make meaning from current geographic representations such as virtual globes. These skills include practicing different perspectives of the world to include a bird's-eye view (which is dependent on development of cognition from an egocentric to allocentric point of view), understanding how content changes through generalization at different scales, and practicing mental rotation of geographic images to more easily access imagery and to understand the subjectivity of geospatial representation. This research supports the idea that these skills have novice to expert levels, which may inform future work in learning progressions. The research also supports the idea that foundational geospatial literacy skills need to be revisited and practiced in order to have them become a tacit understanding and a habit of mind, which is another important element of literacy. With reading and writing literacy, there are numerous assessment and intervention strategies to support students if they struggle through elementary grades. Ensuring teachers have access to guidelines around geospatial literacy expectations and access to proven assessment instruments, along with remedial strategies and resources would help to support learners struggling with basic skill development. Development of age appropriate assessment instruments and resources relevant to the curricular context of the teachers is also required.

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