Teaching Topographic Map Skills and Geomorphology Concepts with Google Earth in a One-Computer Classroom

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ABSTRACT

Teaching high-school geomorphological concepts and topographic map reading entails many challenges. This research reports the applicability and effectiveness of Google Earth in teaching topographic map skills and geomorphology concepts, by a single teacher, in a one-computer classroom. Compared to learning via conventional instructional methods, students learning with Google Earth do not develop differing geomorphology concepts because both settings enable students to learn with similar static representation. However, students learning with Google Earth improve topographic map skills significantly compared to conventional instructional methods. This is because of the 3D landscape visualization and prior knowledge connections available with Google Earth.

Key Words: *Geomorphology, Google Earth, Spatial Visualization, Spatial Thinking, Topographic map skills*

INTRODUCTION

Geomorphology is an essential division of geographic education. Learning geomorphology enables students to understand the formation of physical landscapes through knowledge of land-forming processes and geomorphic systems (Huggett 2007). Topographic map reading is another important skill within the discipline of geomorphology; even in our daily lives we require knowledge of terrain for mountain hiking or emergency rescue tasks (Atit *et al.* 2016). However, learning concepts related to geomorphology is difficult. Most students have encountered difficulties in recognizing relationships between topographic features and geomorphological processes (Rickey and Bein 1996; Jurmu 2005; Dolliver 2012). The interpretation of topographic maps has frustrated students as well. (Rapp *et al.* 2007; Clark *et al.* 2008; Reusser *et al.* 2012; Atit *et al.* 2016). To be successful in learning concepts of geoscience, students must effectively develop their spatial thinking ability (Ishikawa and Kastens 2005; Kastens and Ishikawa 2006), which plays a major role in map reading (National Research Council 2006). With the increase in popularity of teaching geography using Geographic Information System (GIS), several researchers have indicated the instructional effectiveness of GIS on spatial-thinking development (Lee and Bednarz 2009; Nielsen *et al.* 2011; Jo *et al.* 2016). Some research has further confirmed the effectiveness of teaching geomorphology with GIS (Wentz *et al.* 1999; Allen 2008).

Despite the noticeable effectiveness of GIS, many studies have identified manifold challenges that hinder teachers from adopting GIS for pedagogical purposes at the K-12 level (Wang and Chen 2013; Hong 2014; Baker 2015). Among perceived obstacles were two widely shared issues: the lack of instructional support (Kidman and Palmer 2006; Marsh *et al.* 2007; Baker *et al.* 2009; Demirci 2011) and the lack of teachers' time to design and conduct GIS lessons (Bednarz 2004; Höhnle *et al.* 2013; Wang and Chen 2013).

The instructional support issues involve hardware and software limitations. Hardware issues were attributed to the lack of students' access to computer laboratories because of the insufficient amount of computer laboratories or the allocation of laboratories to other computer classes (Kidman and Palmer 2006; Baker *et al.* 2009; Demirci 2011). Time-related issues involved teachers' time devoted to learning GIS (Bednarz 2004) and identifying relevant GIS data (Höhnle et al. 2013). The limited geography lesson hours was also an impediment. (Wang and Chen 2013). To investigate efficient instruction of geomorphological concepts and topographic map skills using GIS, while reducing teacher support and time investment, this study explored the instructional effectiveness of Google Earth (GE) in line with the Minimal GIS principle.

Teaching with Minimal GIS and Google Earth

The Minimal GIS principle focused on improving GIS pedagogical value by reducing the learning curve of GIS technology techniques (Marsh *et al.* 2007). This study employed GE as the primary instructional platform. GE is not regarded as a true GIS because it has limited spatial analytical features compared to the traditional GIS (Patterson 2007). However, GE is considered a powerful tool to develop and serve GIS information and learning resources (Hennessy et al. 2012). Using GE for instructional purposes could be an ideal way to practice the minimal GIS principle and mitigate teacher's support and time issues.

GE is a free Web-based geospatial data platform and allows users to observe satellite images of Earth's surface. Users can easily select the location, scale, and direction of observed areas. The GE software is accessible to educators and can effectively engage students in visualization, and inquiry, in a spatially-oriented learning environment (Patterson 2007; Palmer 2013; Wang and Chen 2013). Moreover, GE is user-friendly and can be used in regular K-12 classrooms. The intuitive interface effectively lowers the learning curve and enhances users' geographic concepts and skills. Working with preprocessed data also significantly reduces teachers' needs of support and time to design lessons. The infrastructure for implementing GE-based pedagogy, an Internet-accessible computer with a projector and a screen, is widely available in many classrooms.

GE is particularly useful in teaching geomorphology and map interpretation (Lisle 2006). Using GE, students can observe large-scale and small-scale topographic features from different perspectives (Lisle 2006; Palmer 2013). A frequently mentioned constraint to the implementation of GIS is the lack of available spatial data in many countries (Kerski *et al.*

2013). GE enables educators to teach content knowledge with preprocessed data, simultaneously minimizing teachers' time investments. For instance, the United States Geological Survey provides topographic maps of the USA that teachers can download as KMZ profiles for free via the Earth Point website (*http://www.earthpoint.us/TopoMap.aspx*). Teachers can then open KMZ profiles and overlay topographic maps to GE terrain layers to represent topography in 3D (technically in 2.5D). Teaching with GE has proven to show significant potential in fostering spatial-thinking ability (Bodzin *et al.* 2014; Xiang and Liu 2017). Learning with GE, students also develop a strong sense of place with respect to ways in which landforms affect human activities (Ratinen and Keinonen 2011).

Teaching with Google Earth in a One-Computer Classroom

The growing emphasis on GE creates immense opportunities to introduce geospatial technologies (GST) into K-12 physical geography education (Demirci *et al.* 2013; Xiang and Liu 2017). Although previous research has suggested the effectiveness of GE on teaching geomorphology, their instructional exercises were implemented using computer laboratories. Conducting computer laboratory-based activities was difficult for geography teachers (Demirci 2008; Lam *et al.* 2009). However, Demirci (2011) argued that teaching GIS-based instruction in a one-computer classroom produced effective learning outcomes comparable to that of laboratory-based teaching. Countries, such as the United States, have regular classrooms that feature a high percentage of internet and projector accessible computers. (Gray *et al.* 2010). However, the quality of access was insufficient to allow multiple users to use a Web-based platform simultaneously (Baker 2015). Thus, the GIS community needs to seek new strategies for one-computer classroom settings (National Research Council 2006; Baker *et al.* 2009). Although GE is not a true GIS, it is a reasonable way to prepare teachers to use GIS for instructional purposes (Hennessy *et al.* 2012; Rød *et al.* 2012). Moreover, a paucity of research examining the effectiveness of teaching topographic map skills with GE (Demirci *et al.* 2013; Xiang and Liu 2017). Therefore, this study was initiated to explore the instructional effectiveness of GE in teaching topographic map skills and geomorphology concepts.

Research Questions

This study aimed to discover the effectiveness of GE in teaching geomorphology concepts and topographic map skills in a one-computer classroom. Thus, this research compared the pedagogical effectiveness between two different groups of students: one group learned with GE, while the other group learned using the conventional instructional method comprising a blackboard and hanging maps. To evaluate effectiveness more precisely, students' improvements in topographic map skills and geomorphology concepts were compared separately. The main research questions were:

1. Does teaching with GE improve instructional effectiveness of topographic map reading

skills in a one-computer classroom?

2. Does teaching with GE improve instructional effectiveness of geomorphology concepts in a one-computer classroom?

METHODOLOGY

Research Design and Participants

Given the difficulty of random selection and assignment in schools, this study adopted a pretest-posttest quasi-experimental research design to evaluate intervention effectiveness. This study was conducted using an experimental intervention involving two different tenth-grade classes, each with 35 members, at a public high school in Hualien City, Taiwan. The two different classes were randomly selected by the participant teacher from his four classes. One class was randomly assigned to the experimental group and the other was assigned to the control group. The participants of the two groups had similar demographic backgrounds. The two groups comprised normal class groupings, regulated by the Ministry of Education of Taiwan, which theoretically included students with similar levels of prior proficiency pertaining to geomorphological concepts and topographic map skills on average. To identify significantly different levels of prior proficiency between the two groups, this study conducted the pre-test using an independent t-test to compare their prior geomorphological concepts and topographic map skills. The post-test was analyzed using another independent t-test when the two groups performed similarly in the pre-test. A One-way ANCOVA was applied to the post-test when the two groups had significantly different performances.

The instructional content was developed based on a widely recognized standard, proposed by *Geography for life: The National Geography Standards* (Heffron and Downs 2012), and applied to the two groups of students in two different instructional settings. The experimental group learned with GE in a one-computer classroom. The control group received conventional instruction using a blackboard paired with hanging topographic maps and aerial photographs. Both groups were taught by the same instructor and shared the same handouts. The same amount of class time (90 minutes per week for three weeks) applied to the two groups. The instructor was a geography teacher with five years of experience in using technology for instructional purposes.

Development of the Geomorphology Instructional Content

The instructional content mainly regarded fluvial geomorphology, because all research participants were native to Taiwan’s Hualien County which is full of typical fluvial landforms. Teaching students using local landscapes is effective (Hermann 1996), especially with the facilitation of GST (Perkins *et al.* 2010). This strategy enabled students to relate their daily experiences to learning processes. Moreover, the instructional content was designed in line with the standard proposed by *Geography for life: The National Geography Standards* (Heffron and Downs 2012):

1. How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information
2. The physical and human characteristics of places
3. The physical processes that shape the patterns of the Earth's surface
4. How physical systems affect human systems

This instruction was created to enable students to discover and rethink the fluvial geomorphological characteristics and human land use features. This instruction also enabled students to ponder reasons for possible physical processes that create different types of fluvial landforms in different places. Learning how to read topographic maps and to develop students' reasoning of man-land relationships were the other two objectives of this instruction.

The Instructional Design of Experimental Group and Control Group

The instructional content was created to assimilate with requisite, tenth-grade level, geography courses in Taiwan and was shared by both the experimental and control groups. The main difference between the two groups was the different instructional media. The experimental group learned topographic map skills and geomorphological concepts with GE while the control group learned using a blackboard, hanging maps, and aerial photographs. Another obvious difference was related to instructional examples. Students in the experimental group learned with local landform examples, while those in the control group learned using classic landform examples from places other than their hometown (e.g., Huangguoshu Waterfall in China). The reason for chosing this design was to compare GE's instructional effectiveness with that of the regular pedagogical approach in Taiwan. In a regular geography classroom, Taiwanese teachers tend to strictly follow texts and examples provided in textbooks in order to save course preparation time (Yang and Lin 2013). The landform examples of textbooks were mostly cited from classic examples to help teachers deliver information in line with the curriculum standard. On the other hand, when teaching with GE in the experimental group, the teacher might easily use local landform landscapes, in a time-saving way, to resonate with students (Hermann 1996). The instruction was implemented in four sequential sections, in line with the *Geography for life: The National Geography Standards*:

In the first section, the instructor introduced fluvial landform features and general geomorphology theories. As a warm-up activity, the instructor conducted an overview by asking students to recall and state where they had seen fluvial landforms before. During this activity, participants in the experimental group were prompted to view fluvial landforms from a variety of perspectives in order to observe landforms in 360 degrees. For instance, students observed a delta either from apex to toe or from toe to apex. Observing landforms at different scales was also allowed via GE's zoom facility. By reducing the scale and taking a bird's eye view via GE, students observed meanders and sighted evidence of a former oxbow lake (Figure 1). At the end of this section, the instructor introduced important geomorphology development theories and facilitated understanding of systematic descriptions of landforms: concepts of the base level of a stream, the model of landform evolution, and the rejuvenation and cycles of erosion.

The second section covered relationships between fluvial processes and corresponding landforms. The instructor introduced erosion, transportation, and deposition as three primary fluvial processes. Students were then paired to discuss how dominant fluvial processes change in response to different stream segments. For this discussion, students observed practical landforms, using either GE's satellite images (experimental group) or aerial photographs and landform images (control group). Students were also asked to discuss how the river transportation capacity changes in response to channel width and gradient variations. Each pair then answered a question and articulated their inference. The teacher further asked other students to state their perspectives in order to encourage and elicit additional thoughts. When all the questions were thoroughly discussed, the instructor elaborated relationships between fluvial processes and landform features in various stream segments. The instructor particularly focused on how river transportation capacity affects topographic characteristics through analyses of longitudinal and transverse profiles of the same alluvial fan (Figure 2). The profile analysis was also applied to elaborate on the association between the river terrace sequence and the changes of river base levels (Figure 3). After establishing the relationships between dominant fluvial processes and landform characteristics, students were paired to discuss the most probable location, feature, and formation of specific erosional and sedimentary landforms. Various sets of students were called on to answer questions and articulate their inferences. Other pairs were asked to state their perspectives to augment the discussion. As the end of this section, the instructor summarized the locations, features, and formations of depositional and erosional landforms discussed in the lesson.

In the third section, the instructor taught topographic map skills, to participants of the experimental group, using topographic maps overlaid with GE’s terrain layers. The topographic maps were made by the Taiwanese government and are available to the public. Topographic data were converted to KMZ format by the Taiwanese government and could thus be directly represented in 3D on GE. In contrast, the control group learned these skills using traditional 2D topographic maps. This section covered three topics: (1) The introduction and application of map symbols; (2) Interpretation and evaluation of elevation, slope, and aspect of a landform by contour lines; and (3) Introduction to identifying specific fluvial landforms on a topographic map. For the experimental group, the teacher overlaid semi-transparent topographic maps with GE’s terrain layers. Thus, students could see how accurately map symbols represent real objects and make clear connections between abstract symbols and geographic features. The interpretation of contour lines was taught with 3D topographic maps represented by GE. The teacher taught students how to evaluate elevations, slopes, and aspects of local fluvial landforms represented by 3D contour lines. Students could potentially learn how to identify specific fluvial landforms through geographic features on 3D earth. For the control group, the teacher presented satellite images and traditional topographic maps in parallel and taught students how to memorize map symbols through cross reference. The teacher taught contour line interpretation and landform identification using traditional 2D hanging topographic maps. In this section, Students, (either in the experimental group or the control group), were paired and asked to identify ten different fluvial landforms from 2D topographic maps collaboratively. One pair at a time, students were asked to point out a landform and share their map interpretation skills. This activity ended when all ten fluvial landforms were identified correctly.

The last section focused on ways in which physical systems influenced human systems. GE served as a platform to allow the experimental group to observe geographical features and engage in spatial reasoning using 3D topographic maps. The example used in the lesson was agriculture type comparison between apex and apron areas of a local alluvial fan. The teacher taught students how to observe the agriculture types and explained what factors influence the land use pattern with 3D topographic maps. In contrast, the control group learned the same topics through agriculture type comparison of classic alluvial fans of Kaoping River in southern

Taiwan. The teacher taught students to observe the agriculture types and illustrated what factors impact the land use pattern with the help of 2D topographic maps. To measure students' ability in reasoning man-land interactions with a topographic map, the teacher listed six different human activities and presented several different topographic maps. Students were paired and tasked to find appropriate sites to develop the six human activities. Later, pairs were asked to point out the site on a topographic map.

Design of Survey Instrument

Research data were collected through quantitative and qualitative methods. The quantitative measure included pre- and post-tests related to geomorphology concepts and topographic maps, while qualitative methods included student interviews and classroom observations.

To measure learning outcomes quantitatively, both groups received equivalent forms (pre- and post-test) with similar levels of difficulty and discrimination. The difficulty index was 0.61 and the discrimination index was 0.34 for the pre-test, while the difficulty index was 0.60 and the discrimination index was 0.33 for the post-test. Each test included ten multiple choice questions with four options. The first five questions in the two tests were created to evaluate students' topographic map reading skills, while the remaining five questions were formulated to measure geomorphology concepts. The topographic map reading tests required students to read topographic maps and answer questions. These questions involved the identification of relief features, possible human activities, and potential natural hazards in specific locations. One of the questions asked students to choose an appropriate contour interval for a given topographic map. Students were also tested on their ability to find correct longitudinal/transverse profiles and viewsheds from different locations. The pre- and post-geomorphology concepts' tests required students to synthesize the following knowledge regarding the relationship between fluvial processes and relief features in different river segments, knowledge of a stream's base level, models of landform evolution, and the rejuvenation and cycles of erosion, to answer questions. The concept questions also covered mechanisms, topographic features or land use pattern identification of some river landforms: an alluvial fan, stream capture and concave and convex banks. All test content was taken from Taiwan's National College Entrance Examination over the past ten years. These items were revised to reflect local contexts. Item analysis statistics was conducted for each item to evaluate its difficulty index and discrimination index using a pilot test. This study administered the pilot test to 120 11th graders who learned geomorphology concepts and topographic map skills the previous academic year. Four senior geography teachers and professors met four times to evaluate the reliability and validity of questions. The two groups' mean scores from pre- and post-tests were analyzed using the independent two-sample t-test ($p < 0.05$).

Qualitative data came from in-depth interviews with 18 participant students randomly selected from the experimental group after participating in GE instruction. The interview content mainly focused on the ways in which learning with GE influenced students' learning experiences and outcomes positively and/or negatively. The interview questions were as follows:

1. Does learning with GE affect your learning of topographic map skills? If so, in what aspects? Please provide actual examples to support your statements.
2. Does learning with GE affect your understanding of fluvial geomorphology concepts? If so, in what aspects? Please provide actual examples to support your statements.
3. Compared to previous geomorphology learning experiences, using the lecture/blackboard approach, do you think learning with GE was beneficial to your learning? What parts were most helpful to you? Why?

RESULTS

Overall Evaluation

The overall evaluation was created to compare improvement of geomorphology concepts and topographic map skills from pre- to post-tests between the experimental and control groups. The result shows that the experimental group's overall learning outcome improved significantly, compared to the control group (Table 1). The pre-test was administered to both the experimental and control groups prior to the intervention. No statistically significant difference was found between the two groups in the pre-test. Both groups shared similar knowledge of geomorphology concepts and had comparable topographic map reading skills. After the intervention, emcompassing different approaches, the experimental group (GE pedagogy) exhibited superior performance in the post-test over the control group (conventional instructional method). The t-test result of the post-test shows a significant difference ($t(68) = 2.219$, $p < 0.05$). This finding shows that teaching with GE can greatly impact students' learning. This research study further compared the learning outcomes of topographic map skills and geomorphology concepts separately.

Evaluation of Topographic Map Reading Skills

Teaching with GE effectively strengthened the acquisition of topographic map reading skills in the experimental group. There is no statistically significant difference in the pre-test between the two groups (Table 2). In contrast, there is a statistically significant difference ($t(68) = 2.911$, $p < 0.01$) between the two groups in the post-test. This result indicates that the students of the experimental group showed significant improvement in their topographic map reading, compared to the control group.

Qualitative data collected from student interviews provided another lens to explain the difference in topographic map skills' improvement. The interpretation of topographic maps requires readers to operate spatial thinking ability effectively. The National Research Council

(2006) stated that spatial thinking involves three interrelated components: tools of representation, concepts of space, and processes of reasoning. These three components played essential roles in students' development of topographic map skills.

As the first component of spatial thinking ability, students' skills with using representation tools were strengthened through prior knowledge connections and 3D visualization while learning with GE. In particular, students acquired skills to use map symbols. Understanding the definition of map symbols was the first step toward reading topographic maps. The adoption of GE allowed teachers to present topographic maps and satellite images concurrently (Figure 4). Thus, students could effectively memorize map symbols referring to local objects in satellite images shown on the screen. Given that satellite images mostly covered students' home areas, students could connect prior knowledge of local geography to the process of memorizing corresponding map symbols. Two interviewees reported this learning experience:

> *I felt difficulty when identifying map symbols because I always forgot their definitions before. My teacher showed an (satellite) image and a topographic map at the same time. They covered the same location. I could refer to the (satellite) image for a reminder if I forgot a map symbol's meaning. Gradually, I memorized all the symbols.*

> *My teacher used images of my home area to teach us how to read topographic maps.*

> *I was so familiar with the landscapes in the images…all the schools I ever attended or roads I rode down every single day…even the township I was born in…so I could relate my prior knowledge to the map symbols and know how buildings and roads were mapped.*

One of the most challenging aspects of learning tools of representation is the interpretation of contour lines. An effective strategy to teach contour lines is to use the 3D visualization feature of GE. Using the 3D terrain layer (technically 2.5D) offered by GE, teachers could overlay topographic maps over terrain layers and represent contour lines in 3D. Students could intuitively observe how contour line patterns varied in response to changes in elevation, slope, and aspect . For example, the 3D visualization feature assisted students in learning whether V-shaped contour lines represent a valley or a ridge. Students could take advantage of the 3D visualization of the contour lines to recognize that V-shaped contour lines represented a ridge if pointing directly toward lower elevation, or a valley if pointing towards higher elevation. In other words, GE served as a visualization tool to assist students in the map interpretation process. Two interviewees described their experiences as follows:

> *It is so easy to read 3D contour lines… you can draw contour lines over the earth surface from an aerial perspective…I know if the V-shaped contour lines represent a*

> *valley or a ridge…my teacher encourages us to practice how to follow the direction of the close end (of contour lines) ...I can do this process mentally when reading (topographic) maps.*

> *I felt impressed with what I learned (in class) when answering a question (in the post-test) that asked me to read the V-shaped contour lines. I could answer this question with confidence... I had an excellent memory about this concept because my teacher led us to follow the ups and downs of 3D contour lines. The changes of elevation were easy to follow, compared with 2D contour lines.*

The 3D visualization also assisted students in learning two-point visibility analysis which requried students to read contour lines. GE's elevation profile function was used to teach this analysis. In this kind of analysis, students were asked to judge if two separate points were visible to each other. Learning two-point visibility analysis with GE might motivate them to self-explore GST and improve their skills with representation tools. This experience was reported by one interviewee:

> *The concept of the two-point visibility analysis was not complicated. I could perform this analysis by myself using Google Earth at home...When answering a question that*

> *asked which location could be seen from a lookout (in the post-test), I processed the two-point visibility analysis mentally, just like drawing images from my brain.*

The second essential component of spatial thinking is concepts of space. The spatial concepts include location, shape, distribution, pattern, density and so on (Jo and Bednarz 2009). Multiple-scale perspectives and prior knowledge connections, enabled by GE, greatly assisted students in understanding spatial concepts. Students might make better sense of spatial concepts when reading maps, given that GE allows students to view local satellite images at different scales. For instance, students could observe a whole county's fluvial landforms and their corresponding locations at the small scale while perceiving settlements gathered in specific areas at the large scale. By observing landscapes at different scales, students might learn how objects' patterns change with scale and understand other important spatial concepts, such as distribution and density. An interviewee stated:

> *The birds' eye view lets me easily observe the settlement patterns in the whole county…I could find where there was a crowd of grey color (buildings) and where there was not. I also identified many familiar buildings from their shapes when the camera got closer. It was so amazing to find that the train station was so close to my school geographically.*

The teacher further prompted students to apply the spatial concepts they learned. Students might apply spatial concepts to logically explore physical and human features represented in topographic maps. The alternate use of topographic maps and satellite images might simultaneously improve students' spatial concepts and the ability to use tools of representation.

Reasoning is the third component of spatial thinking. Reasoning spatially in terms of relationships between physical systems and human systems is an essential task of reading topographic maps. To reason spatially with topographic map data, students needed to manipulate, interpret, and explain structured information (National Research Council 2006). GE enabled 3D visualization and prior knowledge access, which assisted students in the reasoning process. For example, students were asked to reason how settlement distributions change in response to physical characteristics from topographic maps. GE served as a platform to present topographic maps in a 3D model and to enable observation of geographic features at different scales. Based on their knowledge of representation tools, students used spatial concepts to discover that settlement sizes vary in different areas. The next step was to think about possible physical factors that affected settlement patterns. With the facilitation of 3D visualization, students could intuitively find that the apex settlement located at the mouth of a mountain canyon was prone to flooding and mudslides. In addition, they might infer that the small settlement size was caused by limited geographical space. On the other hand, the fan toe areas showed larger settlements because of stable water supply and a wider open area.

Access to prior knowledge was another important element in improving students' spatial reasoning. Teaching about local landscapes proved to be effective in developing students' ability to think spatially (Hermann 1996). Learning about local physical and human features also motivated students to use their prior knowledge and life experiences to reason spatially. One interviewee reported the learning experience:

> *My parents' farm is located in the fan apron area and they planted less water-consuming fruits for many years. Our neighbors almost grew (the same) fruits because of the water shortage…I could now deeply understand environmental factors in agriculture…the environment really affected my family life.*

Fostering students' development of spatial thinking ability was the fundamental reason for applying GIS to teach geography (Bednarz 2004). Learning how to read topographic maps involved three interwoven components of spatial thinking: tools of representation, concepts of space, and spatial reasoning. The employment of GE improved students spatial thinking ability through the use of 3D visualization and prior knowledge connections. With 3D visualization, students had opportunities to understand information conveyed by map symbols to a higher degree. The abstract spatial concepts, such as shape, distribution, and pattern, were represented concretely and connected to students' prior knowledge. Students, therefore, made more sense of spatial concepts of physical features and human activities on topographic maps.

Evaluation of Improvement in Geomorphology Concepts

As seen in Table 3, there is no statistically significant difference in the two groups, in terms of the entry level of geomorphology concepts. Even after learning with different approaches, their performances in the post-test do not suggest a statistically significant difference between the two groups. In other words, teaching geomorphology concepts with GE produced similar outcomes as did teaching with a blackboard.

The geomorphology concepts taught to both groups addressed how the physical processes shaped the Earth's surface patterns. These concepts could be categorized into basic and advanced concepts in geomorphology. The basic concepts related to students' prior knowledge or concepts visible in their daily lives: relationships among physical processes, fluvial landforms types, and stream segments. The advanced concepts, however were those students were unfamiliar with or those that were not visible in students' daily lives: the relationship between fluvial processes and changes of stream base level, landform evolution models, rejuvenation, and cycles of erosion.

The GE pedagogy effectively assisted students in reviewing and learning basic geomorphology concepts. Students were asked to recall river landforms they had ever seen around them. The teacher then presented fluvial landform features and locations using the GE platform. Students were further asked to propose the association between dominant fluvial processes and fluvial landforms in different stream segments. Within this process, the 3D landscape representations served as a bridge to connect students' prior knowledge to basic geomorphology concepts.

Teaching with GE did not effectively support the learning of advanced geomorphology concepts. The interactions between fluvial processes and changes of stream base level were less intuitive. The concepts of landform evolutions, rejuvenation, and cycles of erosion were also beyond students' daily experiences. Students might require dynamics visual aids, such as videos or animations to promote mastery of advanced geomorphology concepts. Compared to the conventional instructional method, the GE approach did not exhibit significant teaching effectiveness. The reason might lie in the comparable levels of visual aid effectiveness between the GE pedagogy and the conventional blackboard pedagogy. This condition was reported by an interviewee:

> *The (concept of) river base level was so difficult. How changes in river based level affected fluvial processes especially confused me. I did not think the static images were helpful…animations might be better.*

Although the employment of GE could provide 3D landscape visualizations as visual aids, the static representation only provided similar instructional effectiveness, as did teaching with the 2D landscape representations of the traditional blackboard approach.

Strengths and Weaknesses of Teaching Geomorphology with Google Earth

The two dominant features that facilitated signification development of topographic map reading skills were 3D-visualization and prior knowledge connections. These two features also provided effective assistance in imparting basic geomorphology concepts, while offering limited support in learning advanced geomorphology concepts.

There were two common weaknesses found in the GE pedagogy. The first weakness was the unfamiliar layout of information presentation from student perspectives. Given that the instructional aid of the GE was based on satellite images and topographic maps, it is likely that a portion of the students did not know how to take effective notes. Most members of the experimental group were potentially already accustomed to the structure of annotations for regular lecture/blackboard based instructional settings. The second difficulty for the students was that the instructional content on the screen altered so quickly that they might have failed to keep up with, and make sense of, the content. In contrast, learning via the lecture/blackboard approach allowed students to have sufficient time to figure out and write down the lecturer's annotation and statements.

CONCLUSION

The purpose of this study was to examine the instructional effectiveness of teaching topographic map reading and geomorphology concepts using GE in a one-computer classroom setting. Based on quantitative and qualitative results, this research indicates that teaching with GE significantly improve students' topographic map reading ability. GE facilitated learning through 3D landscape visualization and prior knowledge connections. On the other hand, teaching with GE did not support significant improvement in student development of geomorphology concepts, attributed to static landscape representations.

There are two limitations to this study. First, the instructional experiment spanned only three weeks. The outcomes might have varied if the duration was extended. Students' learning outcomes may have improved as a result of increased familiarity with GE's layout and information representations. Second, the investigators did not customize a handout for students who learned using local landform examples and GE. The handout designed by the textbook publisher provided students with supplementary word and graphic illustrations of classic landform examples excerpted from the textbook. Students who learned using local landform examples and GE could be confused due to the disconnect between what they learned on GE and what they read in the handout. Therefore, the customized handout should have been designed to provide word and graphic illustrations as well as GE screenshots with crucial illustrations of geomorphological concepts and map skills. Customized handouts could have helped students keep up with the fast-paced information representations in the GE pedagogy. Without this customized design, the acquisition of topographic map skills and geomorphological concepts might have been negatively impacted.

Future research should explore whether an extended period of the GE pedagogy or customized design of handouts influences the instructional effectiveness of GE. This study was limited to measuring the effectiveness of teaching geomorphology with GE in a one-computer classroom context. Future researchers are encouraged to investigate the potential of GE in a similar setting with different topics.

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