

ENHANCING STUDENTS' ABILITY IN READING CONTOUR MAPS USING GIS

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ABSTRACT:

Terrain relief is an important feature of geographic environment and a major element of topographic maps. Contour lines are widely adopted as representation of terrain relief in traditional maps. In general, contour maps are still indispensable due to the following reasons: 1) Abundant terrain data are still represented by contour maps; 2) Contour maps contain fewer limits for use in different situations; 3) Reading contour maps can train students' logical thinking. Yet, contour maps are difficult to comprehend for most students due to their abstract nature. This research takes into account three essential elements involved in contour interpretation: terrain information, map representation and spatial cognition. We incorporate these elements into the creation of terrain relief using GIS and computer mapping software, such as ArcMap and Surfer. The representation being developed include vivid ones and abstract ones so that students can learn to comprehend abstract representations of terrain relief, such as contour maps, through vivid representation. A teaching module composed of these representations is developed and tested before serving as a teaching supplement to geography teachers. It is anticipated that this will contribute to geography teachers' instruction of contour map reading and facilitate students' map cognition process.

1. INTRODUCTION

Terrain relief is an important feature of the natural environment, influencing human activities and the spatial distribution of many natural and human phenomena. How to represent terrain relief is always a vital theme for discussion in cartography (Imhof, 1982). Traditional paper maps can represent terrain relief in diverse ways, but each way provides different information and has its own advantages and weakness. Among traditional maps, contour maps document rich information, and are widely used for various purposes. The ability to read contour maps is hence broadly considered as a basic map reading ability that students should possess.

Taiwanese junior and senior high schools have hence included contour map reading as a skill that should be cultivated in geography curriculum (Ministry of Education, 2008). Many students, nevertheless, believe this is a difficult theme to learn. Questions about contour map reading also appear very often in Taiwan's entrance examination for high schools and universities. Participants, however, in general do not perform well in such type of questions. For lecturers alike, many feel that teaching contour reading is a challenging task.

During the past thirty years, the advancement in geographic information system (GIS) has enabled diverse representation of topographical information. Three dimensional (3-D) spatial representation, in particular, makes topological representation much more precise and concrete. It is easier for normal people to understand 3-D representation. Despite such development, contour maps are not completely replaced by computerized representation. The crux of this paper lies in introducing a number of examples to show how the representational functions of GIS and 3-D dynamics can help students comprehend abstract concepts of contour lines and further enhance their contour map reading abilities.

2. CHALLENGES OF REPRESENTING TERRAIN RELIEF

Maps provide a medium for information dissemination. The process of conveying geographic information involves the flow of messages between two entities: the real world and maps. Map-makers and map-readers play vital roles in encoding and decoding this information (Robinson *et al.*, 1978; Robinson *et al.* 1995). Below we explain three aspects of factors that affect the dissemination of topographical information (Figure 1).

The first aspect concerns *terrain relief in the real world*. Terrains are 2-dimensional existing in 3-dimensional space. One can thus consider terrains as 2.5-dimensional, changing a continuous smooth dimension. Any point on the earth surface has an altitude. Any such point can be a part of a plain, hill, or mountain. In addition, altitude can be extended to measure features such as the steepness of slopes, aspect of slopes, and topography, etc. Different users require different topographic information. Researchers who study the potential threats of mudslides need accurate data of altitude, slope steepness, slope aspect of a hill. Experts designing the proper management of water resources need topography, ridge lines, and watersheds of a larger scope of area. The content of information that maps need to record and convey vary according to the users' needs.

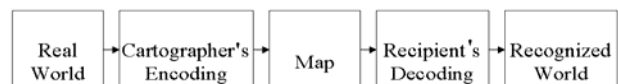


Figure 1. The process of map communication (Robinson, *et al.*, 1978)

The second aspect concerns *terrain relief shown in maps*. Early maps can already accurately document discrete objects such as houses, roads, and rivers because the positions of these features are discrete and clear, and because orthographic projection

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allows cartographers to represent how these features are seen as if they were looked down upon from the sky.

The challenge, however, lies in recording terrain relief. As said, terrain relief is a continuous smooth field (Robinson, *et al.*, 1995). The altitude and slope of every location cannot be completely recorded. Representing terrain relief is much more complicated and difficult than representing roads and houses. This requires a highly abstract way of thinking and representation. As a result, more than ten diverse methods have been developed to represent terrain relief. A summary of these methods can be found in section three of this paper.

The third aspect concerns *cognized terrain relief*. The ability to use maps involves the cognitive ability of users; this is related to the users' mental development. Students possess different abilities to cognize the environment and to understand space. This further leads to variation in interpreting and utilizing maps. Age, gender and attitude of students can also explain such variation. Education, however, plays vital roles in minimizing such variation and in assisting students to enhance their map reading abilities.

In the following sections, we begin with a discussion of a number of methods that have been used to represent terrain relief. In the fourth section, we show how GIS and 3-D technology can be combined to assist students in reading contour lines. Section five concludes our discussions.

3. METHODS OF REPRESENTING TERRAIN RELIEF

No single representation method can satisfy all users' needs. With the development of cartographic techniques, nonetheless, more representation methods emerge, and less satisfying methods began to fade. By reviewing secondary literature and maps, we summarize six kinds of 2-D representation of terrain relief (Imhof, 1982).

3.1 2-D Static Representations

3.1.1 Lateral Protrayal: This method directly represents terrain relief perceived in human eyes. It is close to human daily experiences. This type of maps, however, cannot precisely record the many features of terrain relief. Moreover, the data obtained in this kind of maps cannot be integrated with geographical features represented with orthographic perspective.. Hence, such maps cannot present concrete coordinates.

3.1.2 Hachure: Hachure shows the orientation of slopes using different values created by different thickness and density of lines. It is suitable for providing a larger scope of topographical information, but it cannot offer detailed information of a small section of terrains.

3.1.3 Shading: Shading is created using simulation of sunshine projecting onto ground surface. This illustrates shades that are caused by the differences of terrain relief. Shading can represent 3-D terrestrial features. It is suitable for any scale of maps. The downside, however, is that it cannot represent accurate altitude or slope steepness.

3.1.4 Contour maps: Contour maps are illustrated with contour lines that join points of equal elevation above a given level. Topographic maps are generally contour maps. Contour maps provide accurate terrestrial information. However, as said, this kind of representation is very abstract. Normal readers must undertake some training before being able to interpreting it.

3.1.5 Hypsometric Tinting: This method is created on the basis of contour maps. Different levels of altitude are marked with different colors. Although hypsometric tinting differentiates various levels of altitude in a general way, it cannot present further details of terrestrial features.

3.1.6 Colored Shading: Colored shading combines hypsometric tinting, generating colored terrestrial shading. This kind of representation contains rich information, and is easy to read. It is becoming more popular. But it is still not able of offering clear information of altitude, slope steepness, and slope aspect.

3.2 3-D Dynamic Representations

GIS collects, processes and analyzes all kinds of geographic information. It accepts various kinds of data input, offers various types of information products, and shows multifaceted models of geographic features (Guptill and Starr, 1984). Currently, in GIS, digital terrain model (DTM), a 3-D surface composed of a mesh of data points, helps display 3-D terrestrial features. 3-D visualization is closer to human visual experiences, thus facilitating the transmission of information. Many GIS software packages offer 3-D visual simulation. For instance, in ESRI ArcView 3D Analyst, Surfer and ERDAS Imagine Virtual GIS, we can overlay digital terrestrial models with high resolution of terrain images, creating a good visual simulation. Google Earth also has provided similar functions on the Internet, inviting more people to understand terrain relief online. Below we summarize 3-D dynamics provided by GIS into the following four types.

3.2.1 Fishnet Maps: Fishnet maps allow users to observe terrestrial features, altitude, slope steepness, and slope aspect. However, fishnet maps cannot reveal absolute digital data. They also cannot show the terrain relief of an entire area. Since thirty years ago, there had been computerized fishnet maps, but their popularity has gradually disappeared.

3.2.2 3-D Topographic Maps: This representation is similar to that of fishnet maps, but it further combines remotely sensed imagery to show ground covers, offering a much more real effect of terrestrial demonstration. Because the data that needs to be processed is sizable, the development of 3-D topographic maps is behind that of fishnet maps.

3.2.3 Virtual Reality (VR): Virtual reality is a representation method created more than ten years ago. It is demonstrated via the World Wide Web (WWW). At that time, the most widely used way to establish virtual reality is to use VRML language. The way to create virtual reality is similar to that of creating fishnet maps and 3-D topographic maps, but it has an additional dynamic function that allows users to rotate view angles as they wish. Users can observe terrain relief from any angles and distances. It gives a better interactive opportunity. However, due to the limit of speed of that could be carried out by computers and the internet at that time, this kind of representation was not widely promoted. The most widely used Google Earth at this moment has offered effects that virtual reality could provide at that time.

3.2.4 Fly: Fly provides the same kind of topographic information that VR can offers. The effect is like when one observes ground features from an airplane. When showing topographic features using Fly, the user has to first choose a flying route. The computer will then simulate what the user could see on that route, and stores it as a flash file. However, since the flying route is fixed, Fly lacks flexibility of interacting with the users like what virtual reality can provide.

3.3 Summary

Dent (1996) believes that a good map should be aesthetically pleasing, thought provoking and communicative. In terms of information transmission, 3-D topographic maps and virtual reality, for instance, are characterized by their readability. But these maps provide limited topographic information. They can only show general terrain relief, not altitude, slope steepness and slope aspect.

In terms of the content of information, contour maps provide the most information and functions, but they are the most difficult to understand. For untrained readers, a contour map is composed of density of irregular lines which are difficult to comprehend.

As we can see, representation of terrain relief has changed from an emphasis of concreteness, to abstractness, and then again to concreteness over time. The earliest representation was close to human's direct experience. The development of hachure, contour maps and others make cartographic representation become more and more abstract. With the development of technology, GIS software's 3-D functions bring us back to concrete representation. Modern concrete representations, however, are greatly different from earlier concrete representations. Earlier representations were rough, and current GIS has accurate DTM as a foundation to generate precise 3-D images, and can be manipulated and calculated. If necessary, 3-D representation can also be turned into 2-D representation. In the fourth section, we show the combination of contour maps with 3-D functions, and make comparisons. We also demonstrate how this combination can assist the interpretation of contour maps in teaching modules.

4. CONTOUR LINE INTERPRETATION

4.1 Contour Line Reading

Every contour line records altitude. After reading altitude, students can further learn to read other advanced topographic information. Students' knowledge is built layer by layer from the simplest concept to the most complicated one. When learning new concepts or skills, students should learn step by

step in order to reduce learning difficulty and reach a higher level of learning outcome.

To interpret altitude, ridge line and valley lines extraction mean different levels of challenges. The objective of the following module is to acquaint students with these concepts:

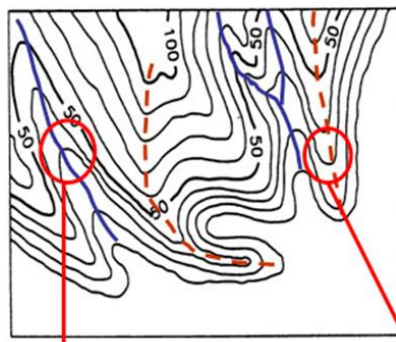
4.1.1 Altitude: Any point's altitude can be estimated from the altitude of the two contour lines below and above this point.

4.1.2 Slope Steepness: Any slope steepness between two points can be estimated by calculating the altitude differences and the horizontal distance of the two points. Density of contour lines can also show the difference of slope steepness. Within the same distance, the more dense the contour lines are, the steeper the slope is, and vice versa.

4.1.3 Slope Aspect: The orientation of a slope can be told by observing the direction that is perpendicular to contour lines. This direction also shows the flows of water.

4.1.4 Slope Pattern: From the density of contour lines of a slope, one can tell the pattern of the slope. When the upper slope is not so steep and the lower slope is steep, one observes a convex slope. When the upper slope is steep and the lower slope is not so steep, one observes a concave slope.

4.1.5 Valley Line and Ridge Line: Valley line is a narrow lower land between two mountain ranges. It is usually the route where a river flows through. It is connected by the lowest point of contour lines. Ridge line, by contrast, is connected by the highest points of contour lines. In contour maps, both terrains appear in V-shapes. If the tip of the V-shape points to a higher location, it is a valley line. If the tip of the V-shape points to a lower location, it is a ridge line. By including ridge lines and valley lines in a map, one can see the water basin and river networks of an area (see Figure 2).



Valley line: V-shape points to a higher location Ridge line: V-shape points to a lower location

Figure 2. Ridge Lines and Valley Lines in Contour Maps

4.2 Contour Representation

GIS software offers diverse representation methods. One can use DTM data to produce hachure, colored shading, contour and other traditional maps. GIS can also produce fishnet maps and 3-D maps, simultaneously using dynamic representation to observe terrain relief from different distances and angles.

In order to let students understand abstract contour lines, teachers can select a number of special terrains, extract their DTM data, and use ArcMap 3D Analyst software to combine colored shading and contour maps. Next, teachers can use Surfer software to create 3-D dynamic representation. Colored

shading shows static 2-D representation, while Surfer allows dynamic representation. Unless the teachers use Surfer in class, students cannot see dynamic representation, but only simulated 3-D static images. Below are some typical examples of terrain relief.

4.2.1 Hill:

Terrestrial feature: Low altitude (mostly within hundreds of meters); little relief.
 Reading skill: contour altitude is within 500 m; relative altitude is below 200 m.

4.2.2 Volcanic Cone:

Terrestrial feature: Cone-shape mountains; altitude ranges from hundreds to thousands meters.
 Reading skill: Contour lines appear in the shape of concentric circles; central altitude is high and surrounding altitude is low; the difference between middle and surrounding altitudes is hundreds of meters.

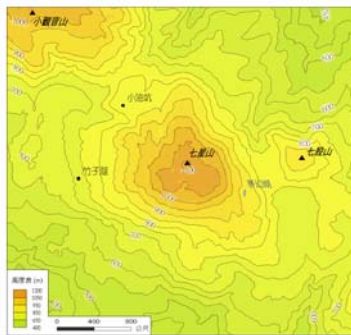


Figure 3. Volcanic Cone Contours

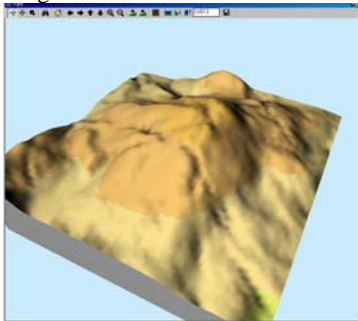


Figure 4. Volcanic Cone 3-D Colored Shading

4.2.3 Tableland:

Terrestrial feature: High altitude in the middle; it is flat and smooth in the middle; surrounding slopes are steeper.
 Reading skill: Values of contour lines in the middle are high; few contour lines in the middle, indicating there is a flat terrain; surrounding contour lines are dense, indicating steep slopes.



Figure 5. Tableland Contours

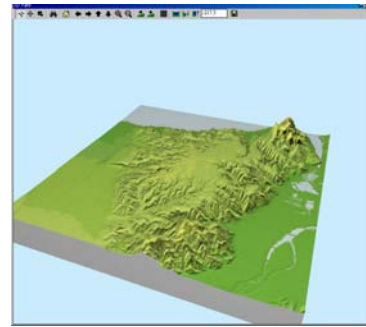


Figure 6. Tableland 3-D Colored Shading

4.2.4 Basin:

Terrestrial feature: A bowl-shape terrain where the surrounding areas are high and the middle is low.
 Reading skill: Few middle contour lines and their altitudes are low; dense contour lines in surrounding areas and their altitudes are high, indicating hills or mountains.

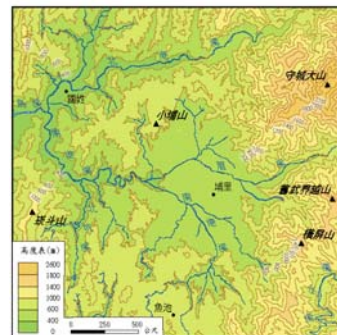


Figure 7. Basin Contours

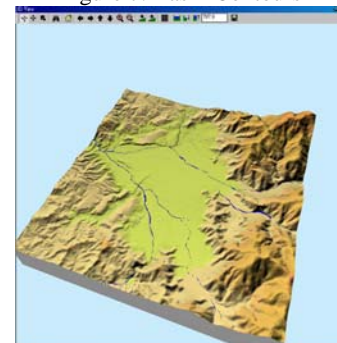


Figure 8. Basin 3-D Colored Shading

4.2.5 Valley:

Terrestrial feature: Elongated lowland between mountain ranges, hills or other uplands.
 Reading skill: Contour lines appear in obvious V-shape. The tip of the V-shape points to higher contour lines. Contour lines are particularly dense near the valley.

4.2.6 Alluvial Fan:

Terrestrial feature: It is a flat landform created by the deposition of sediment over a long period of time by rivers originating from highland regions.
 Reading skill: Where the rivers flow into lowlands, contour lines appear in fan-shape concentric circles; there are few contour lines; the gaps between contour lines are regular, indicating there is a relatively flat and straight landform.



Figure 9 Alluvial Fan Contours

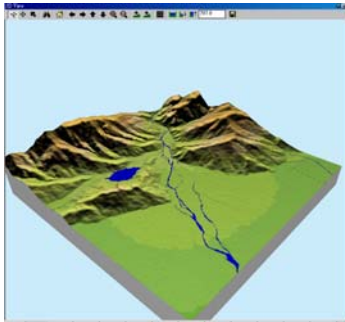


Figure 10. Alluvial Fan in 3-D Colored Shading

4.2.7 River Terrace:

Terrestrial feature: Steps that appear near river valleys, usually displaying discontinuous terrains caused by the rise of landforms or the descend of sea levels.

Reading skill: A mixture of dense and loose contour lines near river valleys; the loose part represents river terrace, while the dense part represents the slopes of terrace.



Figure 11. River Terrace Contours

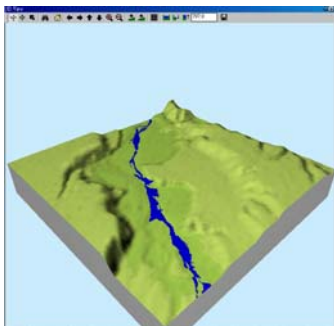


Figure 12. River Terrace 3-D Colored Shading

4.3 Representation by Google Earth

Since the aforementioned two software packages are commercial software packages, it might not be easy to obtain them for teachers and students. If this is the case, one can also consider using Google Earth because it also represents 3-D dynamics. Google Earth contains rich information. It is easy to use and is widely available. Its potential in K12 education is enormous. Recently, Google has provided Web interface's API for advanced users to customize websites. Based on Google Earth, users can add individual images and maps, making Google Earth an attractive platform for educational dissemination. Teachers can integrate kmz files of the above images to Google Earth so that students can try to experience dynamic representation of these static images online.



Figure 13. Tableland by Google Earth

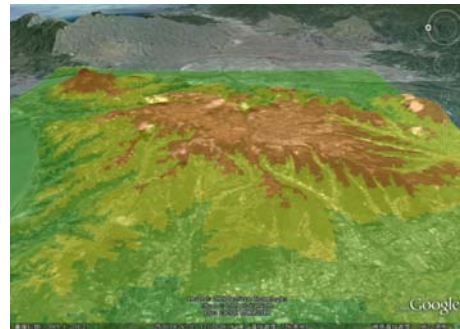


Figure 14. Tableland with hypsometric tinting in Google Earth



Figure 15. Alluvial Fan by Google Earth

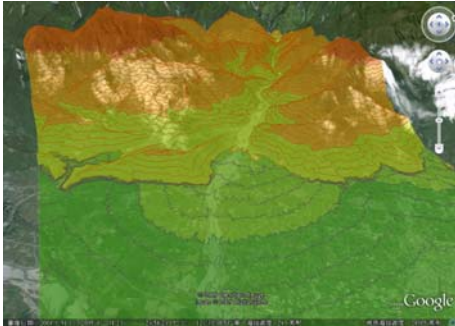


Figure 16. Alluvial Fan with Contours in Google Earth



Figure 17. Basin by Google Earth

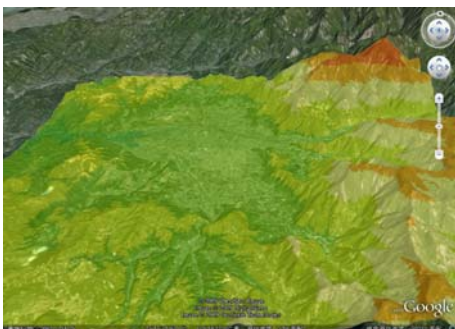


Figure 18. Basin with Hypsometric Tinting in Google Earth

5. CONCLUSIONS

It is an ideal for cartographers to provide rich and easy-to-read information on maps. Cartographic technology has been developed along this line of aspiration. Earlier or even ancient maps are easy to read because their makers usually produced them from the angles of the users. These maps, however, suffered from problems of inaccuracy and deficiency of information. With the diverse development of cartography, such as that of the hachure and contour, we find increasingly innovative ways of representing topography. The increase of information on these modern maps, however, tends to make maps less readable for users.

With the advancement of information technology, informational visualization permits dynamic and real-time style of representation. Users find that they can understand terrain relief from their own experiences, angles, and motives again like earlier maps used to. Because contour maps are widely used and contain abundant information, they are not easily replaceable by other representation manners. That is why in this paper, we exemplify a number of ways of incorporating GIS to help students increase their contour line reading ability. The importance does not solely lie in educational dissemination, but also in research on E-learning.

There is growing concern on the efficacy of E-learning technology in geography education (Lynch et al., 2008) Some argued that information technology may help increase students' interests in learning, but not necessarily change students' learning abilities. It is understandable that if information technology is simply used as a tool to invoke motivation and learning interests, then its effect can only be limited according to its pre-set objective. We believe that apart from invoking learning interests, information technology should also be applied in introducing concepts, helping students to construct and absorb knowledge. Incorporating GIS into the learning of contour maps shows one example of how information technology can help students understand abstract and difficult concepts.

This paper does not discuss further how students and teachers actually benefit from the proposed module. This behoves future study to find out.

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