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Best practices on how to design Google Earth tours for education

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ABSTRACT

Google Earth tours (GETs) are recorded flights around Google Earth. They are highly engaging to watch and have great potential for communicating spatially in a teaching environment. They also benefit from being easy for an educator to produce but they can be ineffective if they are designed poorly. With this in mind, in this paper we cover three main topics: (1) we consider how best to produce GETs, (2) we deconstruct them as a communication media and finally (3), we consider the larger educational context in which they are used. By reviewing literature relevant to these areas we produce 19 best practices for using GETs in education. The amount of evidence we can show in support of our best practices varies. Those that were generated by comparing GETs to the well-researched area of educational animations are highly reliable because they are based on empirical evidence. Those associated with the virtual flights between locations within a GET are more open to interpretation as they have been less well studied. We conclude that further work should be focused on investigating virtual flight within a GET.

INTRODUCTION

A Google Earth tour (GET) is a recorded camera flight around Google Earth (GE), which can be saved, replayed, and edited. Similar "tour" functionality has previously existed in geographic information system (GIS) software (e.g., Shephard, 2003) but GETs are much easier to produce when compared to this functionality. To record a tour, the user simply clicks a record button, navigates around in GE's three-dimensional (3-D) browser window as desired and then clicks stop when the tour is complete. An audio narrative can be added and author-created features (e.g., place marks) stored in the Places column can be turned on and off by the tour. The low level of skill required to author a GET is one of the primary reasons for advocating the use of GETs for education as it puts it within reach of the average educator.

A GET within GE can be usefully used to *visualize* spatial data in a narrative format. It is important to differentiate this from teaching involving GIS which is concerned mostly with *analyzing* spatial data. So a sensible use of a GET may well be to take the results from a GIS analysis and output these in a GET for presentation to interested parties.

The literature concerning both GETs proper and other techniques of producing "tours" within GE, such as recording a video of the screen, has generally dealt with them in a positive, non-critical, descriptive manner (Bomar, 2009; Walden, 2011; Green

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and Mouatt, 2008; Stott et al., 2009). The exception is Priestnall and Cowton (2009) who do address some issues of use. This noncritical approach does little to help educators understand the true potential of GETs and what educational contexts they are best suited to. A similar criticism has been leveled at the literature concerning the educational use of virtual worlds by Dalgarno and Lee (2010) as we discuss later. In this paper, we aim to examine literature related to GETs and advocate a set of best practices that educators can then apply to using GETs in the classroom.

We stated above that ease of use for *authors* is an important characteristic of GETs in education. Ease of use for *users* are the next most important characteristic. The user controls a GET through a set of buttons on screen similar to those on a videocassette recorder (VCR). This operation is similar to playing a video clip and is therefore a very user-friendly experience. Figure 1 illustrates a GET using a series of screen shots.

GE has been used in other educational contexts (Heavner et al., 2011; Turk et al., 2011), and in these situations users can

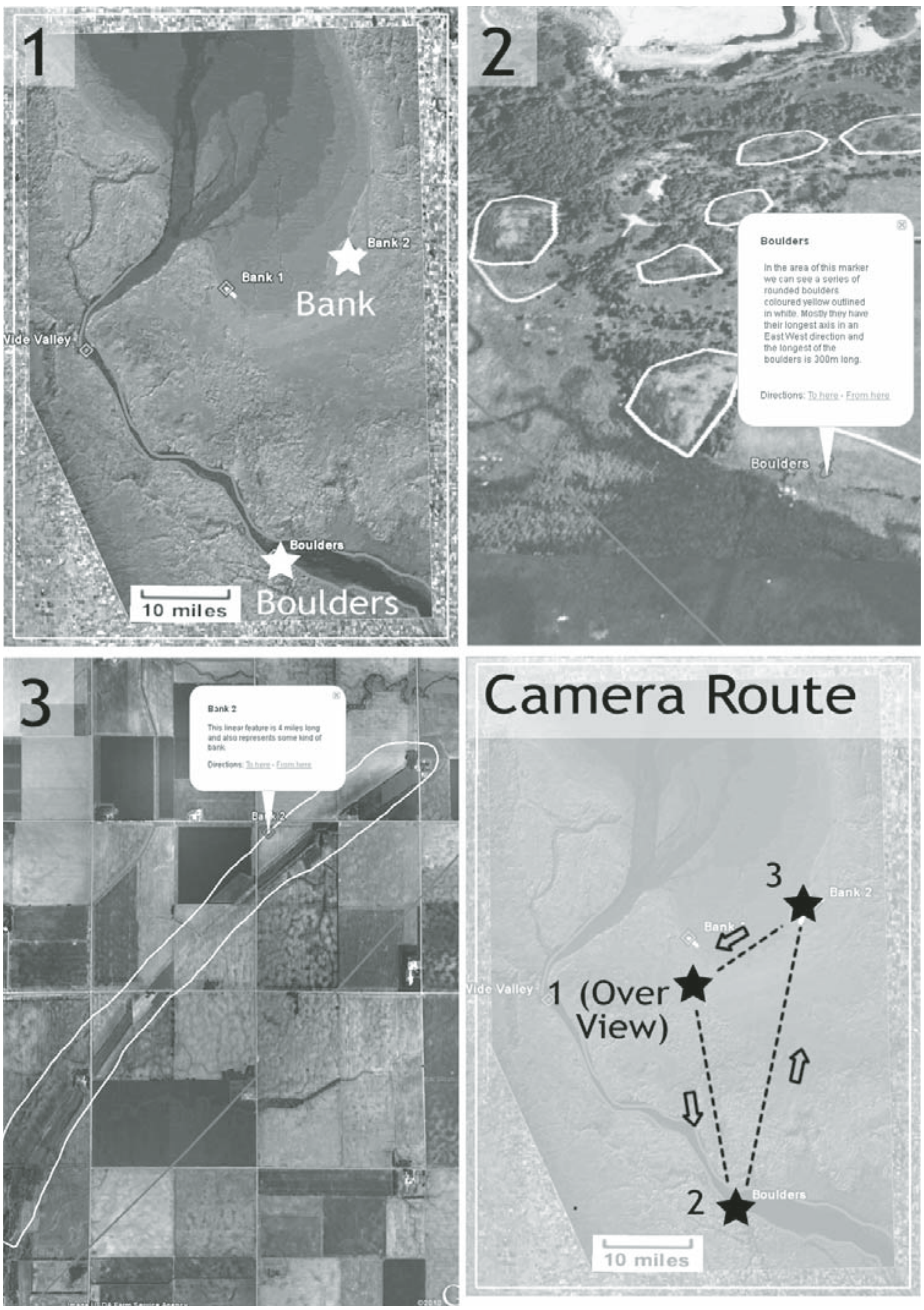

Figure 1. A Google Earth tour explaining paleo-glacial landscape is illustrated by a series of screen shots. In educational use it would be supported by an audio narration. It starts at a high altitude view showing topography (panel 1) with two locations to be visited marked ("Bank," "Boulders"). This initial view is followed by the camera zooming in to visit the Boulders location (panel 2) showing rounded boulders and a feature description. The camera then flies in a looped path out to high altitude and back down to investigate a bank feature (panel 3). After audio description of this feature the camera flies back to panel 1 and the geographical evidence (topography, boulders, bank) is interpreted.

navigate around the globe using five degrees of freedom (altitude, latitude, longitude, camera bearing, camera pitch angle). Within a GET, these five degrees of freedom are reduced to one: play speed (which encompasses play, fast forward, rewind). This is an advantage of GETs because when given multiple degrees of freedom in a 3-D environment such as GE there a number of potential problems for students:

- Getting "lost" in virtual space (Hanson et al., 1997).
- Encountering "desert fog" where all that is shown is a blank white or colored screen with no visual clues to the student's location because they have moved too close to a virtual surface such as a wall (Jul and Furnas, 1998).
- Navigating past key visual information, e.g., flying quickly past the crater of the volcano, failing to notice it and concluding it is a mountain rather than a volcano.
- Flying inside a model, such as a house, that was constructed to be viewed from the outside. Not only is the visualization on the inside confusing, the flight through the wall can be disconcerting.

A well-designed GET using an appropriate narrative and visual annotations either completely solves or at least mitigates these issues. The central purpose of this paper is primarily to outline how to design an effective GET for education using best practices that avoid the above issues, allowing the advantages of 3-D visualization to be leveraged effectively.

The approach taken in this paper is directed toward producing GETs with tangible, educational benefit rather than attention grabbing aesthetic value. GETs can use advanced Keyhole Markup Language (KML) to create "complex" visualizations such as 3-D blocks rising out of the ground to reveal geological cross sections (De Paor And Whitmeyer, 2011; Fig. 2). However, in this discussion we eschew these complex GETs and discuss only "simple" GETs because these are within the grasp of the average educator to produce. We define a simple GET as one which does not suffer from significant view-impeding problems from objects within the tour and which uses functionality that can be produced by recording the tour with GE alone without the editing of any KML code. Important features that require editing of KML code and therefore are beyond our definition include the ability to insert pauses in the GET (so the user is forced to press play to make the tour continue) or functionality such as animated updates, by which objects can be moved or resized during a tour.

In addition to limiting discussion to simple tours, the technical and practical details about how to produce a tour are not part of this paper, for three reasons: first, a number of tutorials are freely available on the web (e.g., http://bit.ly/s82Vem); second, by keeping discussion of technical details to a minimum, the principles outlined in this paper will remain valid regardless of GE interface changes in the future; in addition, they will also apply to GET-like functionality appearing in other virtual globes such as ArcGIS Explorer.

In the rest of this paper we begin by reviewing relevant literature to GETs in education. We then move on to consider the process of producing a GET leading to the first of a set of best practices. Next we explain two self-defined terms useful to our discussion: "GET slides" and "GET flights," and use these to deconstruct GETs as a communication media proposing further best practices. This is followed by a deconstruction of how GET characteristics best benefit the student and then a section exploring the applications of GETs: in what educational situations are

Figure 2. A screenshot of a three-dimensional block that is animated to rise out of the ground in Google Earth. Courtesy DigitalPlanet.org (http://www.digitalplanet.org/API/SOS/index.html).

they particularly well-suited? In the conclusion we review the reliability of our best practices and suggest new avenues suitable for further research.

BACKGROUND LITERATURE

We have searched for discussion of how to best produce GETs or 3-D tours similar to GETs in the literature. We found few examples, so we broadened our search beyond "tour" literature to other non-tour topic areas which we consider relevant. We have grouped the resulting literature into five groups below: pan and zooming, navigation in virtual globes and worlds, tours, cartographic practices, and educational reviews.

Pan and Zooming

There is a significant set of literature on the effective use of "large information spaces" where navigation around two-dimensional (2-D) space such as a map or a graphic such as a family tree is achieved by panning and zooming. The applications used vary widely and are often custom built for the experiment concerned. Furnas and Bederson (1995) discuss a graphical system of representing zoom and pan tracks. They also performed informal tests concerned with flights from point to point; they found that zooming out and then back in with some panning was more popular than routes using pure panning. Ahmed and Eades (2005) discuss automatic camera generation in a zoom and pan environment. They state that it is important to keep landmarks in view at all times but do not offer any evidence for this hypothesis. Igarashi and Hinckley (2000) created automatic zooming so that when scrolling through a large document at speed the user was automatically zoomed out. Conversely, as the scrolling slowed they were zoomed back in again. Informal testing showed that users preferred it to normal scrolling. Hornbaek et al. (2002) investigated pan and zoom searches on maps with and without overview maps. Although users preferred having an overview available, the results from their testing showed that in some cases it slowed down their ability to perform searches.

Van Wijk and Nuij (2003) discussed how best to calculate a zoom and pan path from a close up of map location "A" toward a close up of map location "B." This was done via a looped path, which zooms out and then zooms in again. Unfortunately they make assumptions about the cognitive efficiency of the flight, such as the prime importance of making the path smooth and continuous, without any reference to user tests. They did perform an informal test to find user preferences for speed and shape of the loop between two targets. Their results found there was a wide range of preferences in both variables, but it is noticeable that they did not test users' performance in any way.

Navigation in Virtual Globes and Worlds

There is a distinction between the terms *virtual globe* and *virtual world*. The former are either attempts to mirror the "real-world" (e.g., Google Earth) or present a specialized representation of data (e.g., Software MacKiev's 3-D Weather Globe and Atlas). A virtual world does not follow real-life constraints and creates an imaginary landscape (e.g., Second Life). The common feature between the two is that the user must navigate through a 3-D environment (Bailey, 2010; Warburton, 2009).

A review of Human Computer Interaction literature reveals that researchers in this field are focused on two topics relevant to our discussion. The first is wayfinding tasks in 3-D environments, which is analogous to the task of finding your way to a given location in an unknown city in real space. To be able to follow such a route users have to have far more freedom of movement in these environments than they do with a GET so the literature has limited relevance to our consideration of GETs. However, Darken and Sibert (1993) is relevant, as they investigated how good users were at search and navigation of a 2-D virtual world when provided with a radial grid or an overview map of the world. Broadly, they discovered that both overview maps and grids aided search and location tasks. A grid is a type of landmark that we discuss later.

The second topic area is reducing the degrees of freedom available in a 3-D environment. Hanson et al. (1997) discuss constraining the six degrees of freedom (three location and three camera degrees of freedom) commonly available in a virtual world in various manners. For example, they produce an environment where movement is constrained to two dimensions. An example application is inspecting the features of a tower, user movement is constrained to the surface of a cylinder surrounding the tower at a set distance and the user's view is forced to point at the tower wall. These constraints mean that users avoid navigating through the walls of the tower, which can be very confusing. It also means they cannot turn their camera to look away from the tower and lose sense of where the tower has gone. The informal tests results showed that constraining degrees of freedom proved effective for learning. Drucker and Zeltzer (1994) implement a similar idea, where they designed an interface which uses "intelligent" cameras that align themselves with useful views as users move in 3-D space in order to avoid lost-in-space issues.

Tours

There is a lack of literature on tours in education similar to GETs whether in GE or other 3-D software or in real, rather than virtual, space. Chittaro et al. (2003) briefly discusses tours in a virtual world but their discussion is centered on using avatar tour guides and also discusses problems of tours indoors where avoiding furniture by the best path is important. Object avoidance is not generally an issue in GETs. Priestnall and Cowton (2009) discuss a GET they produced (in video format) showing landscape drawings. Their design-related discussion is limited to noting that during flights a key landmark should be kept in view to help the user fix their movement and the finding that fast, low flights are disorienting.

Wu et al. (2009) discuss wayfinding within an urban virtual world populated with 3-D buildings. They tested their users' ability to navigate virtual streets on foot aided by three different tools: an overview map, text instructions that appeared on screen while the user was moving, and an initial "tour" similar to a GET in which users flew from point "A" to point "B" giving them the benefit of an aerial view. Users then attempted to navigate back from "B" to "A" on foot through streets. The results show that text instructions were the least helpful aid to navigation, and the flying tour was also less useful than an overview map. We think this unfairly measures the efficacy of the GET-like tour because in the tour condition users had to remember spatial information from what they had seen (flying from "A" to "B") as they attempted to return from "B" to "A" on foot. In the overview map condition they could access the spatial information at all times from the overview map.

Goldin et al. (1981) set up an experiment in real space where they sent users on a tour of an urban area and tested their memories of it afterwards. The major conditions were comparing a real bus tour to a film taken from the bus. They also supplemented these two conditions with extra tools; some users used a landmark overview map and others had audio narration that informed users of angles of turns and distances from base while on the real or film tour. Despite the lack of richness of the film, during subsequent testing, users recalled similar amounts to those on the real bus journey. Goldin et al. (1981) explain these finding in two ways. First, on the bus tour, maintaining a clear forward view was difficult. Second, the cameraman taking the film focused the tour view on the correct objects thus minimizing distractions.

Cartographic Practices

Users' understanding of GETs is strongly affected by the effectiveness of symbols and the cartography used within GETs. Of particular interest is the change of symbolization when zooming in or out of a map and how this impacts students' comprehension (Zhang, 2005). We also concur with Harrower (2003) that generally symbolization involved in a map animation should be simpler than on a static map because of the extra cognitive load in tracking the movement of an animation. However, because the same practices apply equally to the educational use of any type of dynamic map system and are not specific to GETs, we do not cover such topics here and refer the reader to Brewer (2005).

Educational Reviews

There are two papers that are relevant to our discussion from the general educational literature: the first discusses virtual worlds and the second, guided learning.

Virtual worlds can be defined as 3-D environments in which user has multiple degrees of freedom to move and the ability to look in whatever direction they choose. They differ from GE by using avatars and representing imaginary landscapes whereas GE usually does not involve the use of avatars and mirrors our own planet's landscape. Dalgarno and Lee (2010) review and comment on the literature relating to education using virtual worlds. They criticize the discussion as being overly descriptive and lacking proper critical appraisal of the strengths of these applications as educational tools.

Mayer (2004) reviews the literature comparing "discovery learning," where students are left with great freedom to effectively teach themselves, to "guided learning," where students are engaged in learning activities but also receive guidance and feedback by an educator. He uses empirical evidence from a number of studies spanning three decades to show that discovery learning is inferior to guided learning. In the background to the paper he gives an overview of the widely accepted theory of constructivism and he also accepts this theory to the extent that to learn effectively students should be engaged in activities rather than just passive listening or watching.

PROCESS OF AUTHORING GETs

In this section, we examine the context of GETs in education before getting into the detail of GET characteristics in later sections. We begin by discussing the process of testing, iterating, and maintaining focus on the educational value of a GET. This process is applicable to any technology-enhanced learning intervention but is particularly important in producing GETs because they are a complex interaction of layers, camera angles, and flight speed. Our discussion, both of this and later sections, is summarized as a collection of best practices (Table 1). GE is a highly usable tool with which educators can produce GETs. Unfortunately, it is still possible for educators to create a confusing tour with poor usability. To understand why this happens, it is helpful to consider usability more generally. Gould and Lewis (1985) outline three principles of usability that should apply to any computer interface design development process:

- *Test the design*—The design should produce prototypes and these should be tested by real users who use them to solve realistic problems.
- *Iterate*—Results from testing should be used to redesign the system in an iterative manner.
- *Focus on users*—Involve the end users of the system in discussion with the designers from the beginning and ensure the designers react to their input.

Although Gould and Lewis (1985) were discussing interfaces and a GET can only loosely be described as an interface we think their discussion is relevant when designing GETs because GETs have the potential to be complex from the user perspective because of the multiple layers, scale, camera angles, camera movement, types of symbology, and labels available. With this in mind, we address Gould and Lewis's (1985) three points in turn below.

For educators, testing the design of a new lesson, or part of a lesson, is often done through the use of student feedback questionnaires. The change is introduced, student feedback collected, and the instructors then reflect on the impact of the change. This

TABLE 1. BEST PRACTICES FOR GOOGLE EARTH TOURS (GETs) IN EDUCATION

No.	Subject area: Major	Subject area: Minor	Best practice description	Evidence
1	Producing process	Iteration and testing	GETs should be generated in an iterative process that incorporates user testing.	Scholarly
2		Student focus	Production of GETs should be student-focused; in particular, educational value should be promoted above flashy presentation.	Scholarly
3	GET slides	Narration, annotations and labels	Within a GET slide, narration should be delivered by audio narration alone.	Empirical
4			Audio narration should relate to what is on screen at the time.	Empirical
5			Labels and annotations should be close in space and time to the map elements they are describing.	Empirical
6			Labels and annotations should be used often but without impacting visual clarity.	Empirical
7		Chart junk	In formal educational contexts, graphical and audio elements not directly connected with the educational message should be removed.	Empirical
8		Personalization	Within a GET narration, less formal language should be used.	Empirical
9		Using animations	Within a GET, rates of change of variables such as population growth are better depicted on a graph than on a map as a changing color or symbol.	Scholarly
10			The visual complexity of GETs should be made simpler than comparative static maps where possible.	Scholarly
11	GET virtual flights	Speed of flight	Speed in flights should be slower with rising complexity on screen and should be in the range of 0.5 to 8 scales per second.	Scholarly
12		Camera angles	The camera in a GET should be kept orientated northwards and vertically downwards, unless the subject of the GET requires viewing from an angle.	Empirical
13		Looped paths and overviews	In GET flights between two low altitude slides, GET flight paths should always pass through a high loop which encompasses both locations in the same view.	Empirical
14			If possible a GET should start and end at high altitude capturing the important points, lines or areas the GET describes in one view.	Empirical
15		Acceleration and deceleration	GET flights between waypoints should accelerate at the start and decelerate at the end.	Scholarly
16	Combined GET slides and virtual flights	Grids for navigation and scale	In a landscape, which has few strong natural landmarks such as roads or coastlines, a static, north-south–oriented grid should be added unless it creates a cluttered view.	Scholarly
17			The grid should have a line separation of a suitable round figure to give a sense of scale. If a grid is not applicable, scale can be included as a line on the ground representing some round figure.	Scholarly
18	Embedding GETs in earth science teaching	Topics that are effective when presented as GETs	The use of a GETs should be particularly considered when illustrating three-dimensional topography, data over a range of scales/locations, and/or introducing a GE map collection.	Logical
19		Creating activities for GETs	GETs should be used to support activity-based teaching.	Empirical

has value but when the change involves introducing a GET we would advocate doing extra testing in addition to the usual feedback and reflection. Our choice would be to set up a test and observe a single student trying out the GET prior to use in the classroom. The methodology outlined by Nielsen (1994) on testing websites is applicable.

In terms of iteration, the single student observation we suggest has the advantage that the results can be used to edit the GET improving it before it is used in a real classroom situation. In our own practice using this technique we concur with Nielsen's (1994) findings that asking students what they thought of an educational program after they have used it reveals less than observing a student using it directly. These two points lead to best practice 1:

BP1] GETs should be generated in an iterative process that incorporates user testing.

Focusing on users' needs is of central importance and we would advocate it as being the most important of the three principles listed above. When introducing a GET, educators need to consider, "What exactly do I expect my students to get from this GET and how is that better than using a familiar teaching medium such as PowerPoint?" A common problem with GETs based on the authors' own experiences is that it is tempting when producing one to focus on flashy and attention-grabbing effects, thereby losing focus on the educational objectives. For example, rapid and extreme camera movements between two camera locations are possible within a GET. These grab student's attention but a more simple curved flight up and down between the two locations is simpler to follow and perceptually gives students important knowledge about the relative positions of the two sites (Priestnall and Cowton, 2009). While an attention-grabbing GET may be appropriate for an informal learning situation like a museum, we think it is inappropriate for a formal education situation. Faced with "flashy" tours in every lecture, students will soon tire of the effect and any attention benefit disappears. This point leads to best practice 2:

BP2] Production of GETs should be student-focused; in particular educational value should be promoted above flashy presentation.

SLIDES AND GET FLIGHTS

In order to discuss how to author effective GETs for education we use a framework that splits a GET into two parts, "GET slides" and "GET flights." In this section, we will first define what these terms mean then discuss best practices for producing these two different parts of a GET separately. We then move on to deal with issues that apply to both parts.

Definitions

In presentational software such as PowerPoint, the content is split into slides with transitions between them such as fading or a turning-page animation. In our following discussion a "GET slide" denotes a map-based animation taking place in GE where the camera is static but other layers or elements such as labels may turn on/off. A "GET flight" is a transition between slides where the camera pans and/or zooms to a different position but where other changes, such as layer visibility, do not change. These two concepts are illustrated graphically in Figure 3 and the three panels of Figure 1 also serve as an example of three GET slides.

The definitions of slides and flights are helpful because GET slides are very similar to other animations in education that have been extensively researched. Also, the usability issues of following movement in space are very different from those of an animation where the camera is fixed.

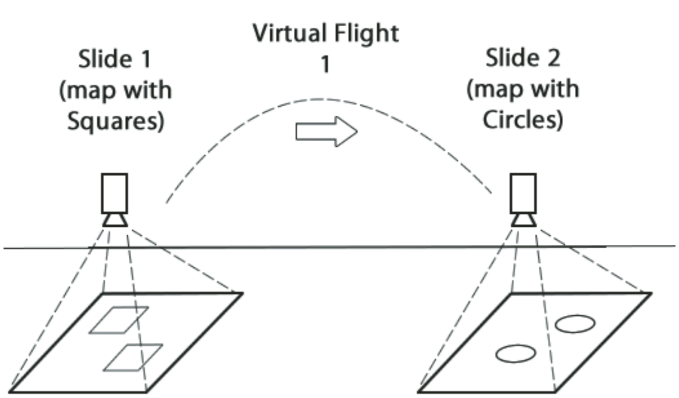

Figure 3. An illustration showing the relationship of Google Earth tour (GET) slides with GET flights. In an imaginary GET, the Google Earth camera first shows a map animation on slide 1 involving squares, then it follows a GET flight to slide 2 where it follows a map animation involving circles.

Best Practices for GET Slides

The use of animations in learning was investigated through a series of empirical experiments by Mayer and Moreno (2003). They produced a series of best practices that can be applied to the GET toolset. Many of these principles have been discussed elsewhere either in whole, or part, but we prefer to use Mayer and Moreno's (2003) framework because of the empirical evidence they have to back up their discussion. We consider their principles in turn below grouping them together for ease of discussion.

Mayer and Moreno (2003) define *multimedia, modality*, and *redundancy principles*, which state that in educational animations, audio narration outperforms on-screen text narration. Just audio narration also outperforms on-screen text plus the same content delivered as audio narration. In this case there is no significant difference between an educational animation and a GET so this leads to best practice 3:

BP3] Within a GET slide, narration should be delivered by audio narration alone.

Mayer and Moreno (2003) also define *spatial and temporal contiguity principles.* These state that linked concepts are most clearly associated in users' minds when watching an educational animation if they are placed close together in space and/or time. Practical examples include map annotations such as a red circle marking certain areas of a complex map being discussed by the audio narrative, labels being placed close to the cities they relate to, and when elements on screen are changing, describing the change happening in real time rather than in retrospect. There is obviously a line to be drawn between what constitutes a label and what constitutes on-screen narration, which would contradict BP1. Best practices 4 and 5 are thus:

BP4] Audio narration should relate to what is on screen at the time.

BP5] Labels and annotations should be close in space and time to the map elements they are describing.

Combing previous discussions, the findings of Drucker and Zeltzer (1994), Mayer and Moreno (2003), Hanson et al. (1997) and Goldin et al. (1981), suggest that annotations and labels have great value in guiding students to what is important within 3-D space, and in our case GET slides. This is particularly true when the map view presented within a slide is visually complex, e.g., a geological map with many irregular polygons (Fig. 4).

However, there is a balance to be struck between the value of annotations and having so many of them that the view becomes confused. Treves and Martin (2008) discuss how geographical material can be presented in simple animations including discussion of what constitutes too much labeling and annotation on animated maps. In a related discussion, Harrower (2003) discusses the advantages and disadvantages of flashing or moving

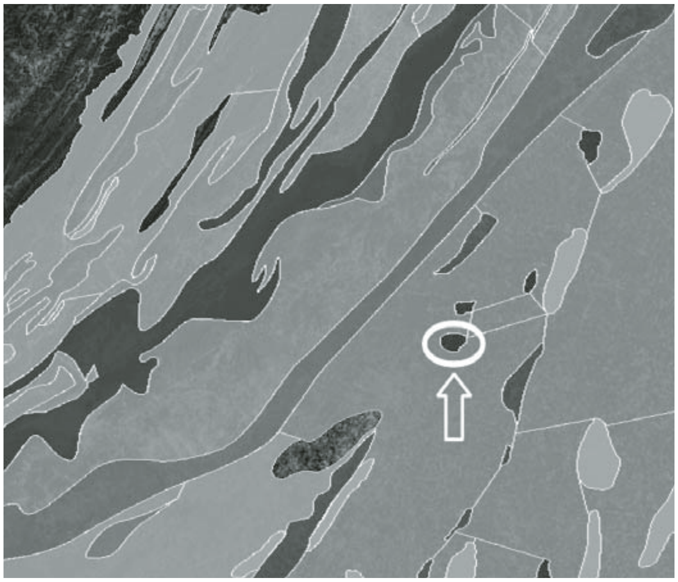

Figure 4. It would be very difficult to pinpoint the polygon shown without the use of an annotation. Image Courtesy DigitalPlanet.org (http://www.digitalplanet.org/API/SOB/index.html).

annotations to direct the users view effectively. This leads us to best practice 6:

BP6] Labels and annotations to guide the eye of the student should be used often but without impacting visual clarity.

Mayer and Moreno (2003) also found clear evidence that graphical and audio elements not directly connected with the educational message made it less effective. They called this their *coherence principle* and examples would be decorative graphics and background music. This is clearly linked to our previous discussion about being student focused and that "flashy" GETs are attention grabbing but not necessarily effective.

BP7] In formal educational contexts, graphical and audio elements not directly connected with the educational message should be removed.

The final principle from Mayer and Moreno (2003) that we will consider is the *personalization principle*. This says that language within an animation should be informal, e.g., employ the use of "you" and "I." The authors reason that this produces a more effective educational message, as students find it more personal and friendly and so it is more likely to engage them.

BP8] Within a GET narration, less formal language should be used.

Harrower (2003) discusses animations in graphs based on his experiences as a map producer, user, and from some formal tests. Several points he makes deserve discussion here. He proposes that graphs are better at showing spatial patterns rather than depicting rates of change. This idea is exemplified by the Gapminder software (http://www.gapminder.org), which shows changes in world population by country on a graph with links to a map.

BP9] Within a GET, rates of change of variables such as population growth are better depicted on a graph than on a map as a changing color or symbol.

Harrower (2003) also discusses techniques to simplify maps, which is relevant to slides in a GET. We concur with his view that simplification is necessary. Static maps can be more complex because users have time to view them. In a GET, a user has limited time to make sense of the slide before it changes. The author suggests that visual complexity can be reduced by data smoothing, data filtering, and data class collation. His paper predates the recent rapid increase in map mash-ups where data is often plotted over visually complex base maps. This is probably why he does not discuss the importance of simplifying the background map, which is another important way of reducing complexity on a map in a GET slide.

BP10] The visual complexity of GETs should be made simpler than comparative static maps where possible.

Best Practices for GET Flights

Unlike GET slides, there have been relatively few studies that relate to GET flights. We believe GET flights are the key to the power of GETs for education as they can be watched by a student who can track change in location and scale with little effort because the GET flight taps into the student's visual system. By comparison, a traditional textbook must use graphical structure such as overview maps to communicate the same information and as discussed. Results from Hornbaek et al. (2002) indicate that the mental work associated with processing such graphical structures is significant.

Treves and Engelbrecht (2011) investigated the usability of GET flights, including camera angles, camera paths, and camera speed. They did this by placing two place markers in a GE landscape with few clear landmarks. It should be remembered that the satellite data used to make up a GE base map is much more complex visually than other maps such as the road base map used in Google Maps. Users were flown from a close up view of one point to a close up view of the other. The points were then turned off, the view zoomed out, and users had to identify where the points were. Based on the results from these experiments, several best practices, which we discuss below, can be suggested.

When the speed of the GET flight was increased, students became less accurate when identifying the point locations. The impact of changing the speed varied depending on the other factors in the test so the authors do not identify an optimum speed for GETs. However, the middle of the three speed values used by Treves and Engelbrecht (2011) did not appear to cause users performance problems in the test while being twice as fast as the slower speed. Speed in Google Earth is relative, but one way to quantify it is in terms of zoom "scales." The middle speed in the Treves and Engelbrecht (2011) study was 0.5 scales per second, i.e., when zooming out it took two seconds for a 10-pixel-length line to reduce on-screen to five pixels long. This compares with another study (Guo et al., 2000) where the virtual world was much simpler visually than the types of view GE generates and a zoom speed of eight scales per second was found to be optimum.

BP11] Speed in GET flights should be slower with rising visual complexity. They should be in the range 0.5–8 scales per second.

It is possible in a GET to orient the camera at any compass bearing and angle to the ground. A simple flight between two points in GE mimics the behavior in web mapping systems such as Google Maps where the camera is kept vertically downward and oriented northward throughout. A more complex movement could have the camera angle and orientation changing in addition to the zoom and pan changes. Within the Treves and Engelbrecht (2011) test, there was a condition where users were flown from point to point with the camera angle varying through the flight. When compared to the simple GET flight the complex flight made it more difficult for users to remember the points. As before, confusion was increased when combined with other variables, e.g., changing the speed.

However, there are some examples of use where an angled, non-vertical camera view is important, e.g., when illustrating the view down a U-shaped valley. These two considerations lead to:

BP12] The camera in a GET should be kept orientated northward and vertically downward, unless the subject of the GET requires viewing from an angle.

This best practice also makes it possible to enhance the users' locational sense as they are more likely to recognize a coastline (for example) if it is presented in a north upward orientation.

The final condition of the Treves and Engelbrecht (2011) test was that the camera route between "A" and "B," two low-elevation points, was varied. In the "high case" it flew via high point where both "A" and "B" were clearly visible, in the "low case," it also flew to a higher point (than the markers), but from this point neither "A" nor "B" were visible. This condition represents the potential problem of low-altitude flights (Priestnall and Cowton, 2009). Relative to the changing speed and camera angles, the change of altitude had the strongest effect on students' ability to locate the points, which leads to the best practice:

BP13] In GET flights between two low-altitude slides, GET flight paths should always pass through a high loop which encompasses both locations in the same view.

Given this result, the positive reaction of users when given access to overview maps (Hornbaek et al., 2002), and Priestnall and Cowton's (2009) suggestion of keeping key landmarks in view another best practice is suggested:

BP14] If possible a GET should start and end at high altitude capturing the important points, lines, or areas the GET describes in one view.

A feature not well covered by Treves and Engelbrecht (2011) is that of GET flight acceleration. In a GET it is possible either to fly at a constant speed or with acceleration from the start and deceleration at the end. Mackinlay et al. (1990) describe the advantages of a flight speed that decelerates as it approaches its goal. Zhang (2005) goes further and suggests that there should be:

1. An initial acceleration.
2. A deceleration as the camera reaches its final destination.
3. Deceleration as the mid-point is approached.
4. Acceleration as the mid-point it is passed.

The applicability of parts 3 and 4 depends on if the GET flight follows the high loop mentioned in best practice 13. These stages are illustrated graphically in Figure 5.

Application of this approach represents an efficient use of time within a GET and also helps meet the user's need to track their movement. In the middle of the flight the visual information the student is getting from the flight is low, they just need to track the movement of the GE camera, whereas at the start and end of the GET flight the information needs rise as the student attempts to make sense of where they are and what other layers are being shown on screen.

BP15] GET flights between waypoints should accelerate at the start and decelerate at the end.

Here a "waypoint" indicates either a slide or a mid-point of a high loop as noted in BP13.

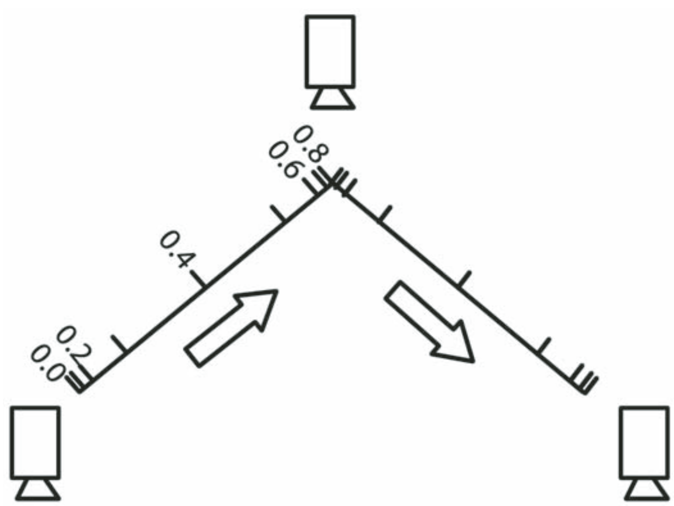

Figure 5. The suggested accelerations and decelerations of a Google Earth tour flight shown as tick marks illustrating camera position every 0.1 seconds.

Best Practices Applicable to both GET Slides and GET Flights

The use of landmarks for navigation in virtual worlds has been comprehensively reviewed by Vinson (1999). A GET differs from his stated problem in that the degrees of freedom are restricted to one dimension but we believe the discussion remains relevant as users in a virtual world or in a GET are trying to make sense of the landscape they view.

One of Vinson's (1999) main recommendations is that a grid acts as a system of landmarks to assist navigation which is in agreement with Darken and Sibert (1993) who tested the effect. In a GET, a grid could be made up of polygon squares fixed to the ground over the study area. GE currently allows a latitude/longitude grid to be turned on via its menu system but we suspect this feature would not prove effective as a landmark system as it is dynamic: as you zoom out labels positions and the scale of the grid change. Darken and Sibert (1993) described how a map grid helps reduce spatial distortions, specifically clustering and axes distortions that impact users. Clustering is where users, without a strong set of alternative landmarks, remember locations based on groupings. An example would be a bus stop: if you tend to remember a location like a café by its relation to a particular bus stop then you are likely to distort the café to bus stop distance to be smaller than it actually is. An axis distortion is the tendency to associate points with line landmarks such as a coastline and then to distort the line landmark as being more vertical or horizontal than it actually is. In distorting the line, the points associated with that line also get distorted to an incorrect position.

Laying a grid over a region will reduce these spatial distortions. However, this presupposes that the map has few strong landmarks such as roads. We hypothesize, that if a grid is overlain on such a landscape it will be less effective because the natural landmarks will compete with the grid for attention. It is our intention to explore this, along with testing our ideas about dynamic grids, as a part of future studies. It should also be noted that a grid might clutter the view creating problems of visual overload instead of reducing the effect of distortions. These points can be summarized as a best practice:

BP16] In a landscape, which has few strong natural landmarks such as roads or coastlines, a static, north-south oriented grid should be added unless it creates a cluttered view.

An additional benefit of a grid is that it can help users gauge the scale of a camera view which shows a scale invariant landscape providing the square size of the grid is a round figure e.g., 500 km. The problem occurs with certain landscapes viewed in GE, for example, along the Antarctic coast, with no roads or houses, there is little visual information to help gauge absolute distances. A grid would provide this visual information, but if a grid is not appropriate a line drawn on the surface of GE, measuring a given length, is also sufficient.

BP17] The grid should have a line separation of a suitable round figure to give a sense of scale. If a grid is not applicable, scale can be included as a line on the ground representing some round figure.

GE version 6 has a scale bar that can be made visible at the bottom of the 3-D viewer. Like the GE grid it is dynamic and (at the time of writing) it cannot be forced to show round figures. Trying to relate the length of an object with a scale bar showing ticks at a non-round figure, intervals (e.g., 648 m) involves a great deal of unnecessary mental effort. For this reason we discourage its use. Scale could be shown as a screen overlay (a graphic that is fixed to the screen rather than the virtual ground in GE), however, a line fixed to the virtual ground in GE is very easy to implement in GE and keeps the correct scale as the camera zooms in and out (which would be problematic to implement for a screen overlay).

Embedding GETs in Earth Science Teaching

In our consideration of best practices so far our focus has been on how to produce effective GETs by deconstructing them. However, a GET does not make an earth science lesson or lecture on its own and we now turn to consider a more holistic view of the place of GETs in education beyond our previous discussion of the process of producing a GET.

Examples of Topics that are Effective When Presented as GETs

Learning benefits depend on what earth science topic is being taught. We believe that GETs are particularly suited to some types of teaching. We identify these areas and give specific examples below. However, it should be noted that our argument rests on logical argument and is not backed up by empirical research.

Using the 3-D topography of Google Earth. GE is particularly good at showing 3-D topography as its terrain model is detailed and the refresh rate of the screen is rapid, giving the illusion of actually moving above the ground. Examples where this could be useful are illustrating U-shaped glacial valleys and showing how geology outcrops interact with topography (Tewksbury, 2008).

Using GETs to introduce a GE map collection. An excellent resource for education or educational outreach is a GE map collection by which we mean a set of related map layers. Such a collection can be used to illustrate all manner of earth science topics, for example, tracking tropical hurricanes would contain satellite imagery on one layer and a track of the eye of the hurricane on another. Common problems with such a collection are that it is best viewed across a number of scales, and by definition it is multi-layered and requires the understanding of map symbolization (e.g., lightning strikes, wind speed symbols). When first opening such a project in GE, students are likely to be put off by the overwhelming amount of data and affordances that are available to them. We believe that authoring a GET to guide a student through the project can be an effective solution (e.g., Storm Tracking with Google Earth, http://youtu.be/2C8IIzFY-oM).

Multiple scales and locations. When students have to comprehend earth science evidence about multiple locations and across multiple scales, GETs can be an excellent aid. In Treves and Engelbrecht (2011), a GET was used to present geographical evidence from a number of locations which was then interpreted on a larger scale (Fig. 1 is a derived from this GET). We believe that the GET flights between the three slides (in Fig. 1) are highly effective at explaining the changes in location and scale for students.

BP18] The use of a GETs should be particularly considered when illustrating 3-D topography, data over a range of scales/locations, and/or introducing a GE map collection.

Creating Activities for GETs

A key finding from an earlier investigation into GETs in education found that students reacted to them in a passive manner (Treves, 2009). Even when explicitly encouraged to use the VCR pause/play controls in watching a GET, most participants didn't use them and allowed the GET to just play through unhindered. As discussed in the literature section (Mayer, 2004), to achieve optimum learning, students need both an effective communication medium, such as GETs, but also need to make sense of the information in a wider context by taking part in learning activities.

An example of how this can be achieved is a self-assessment question (SAQ). SAQs are a well-used format of learning where students read text and then are asked to problem solve, applying the knowledge they have just gained. Cook et al. (2006) reported empirical evidence that SAQs aided students learning. Our suggestion is that short GETs are accompanied by GE-based activities. For example, having been taught the difference between a V- and a U-shaped valley, students can be tasked with identifying examples of both landforms in a delimited area. However, if an activity within GE cannot be authored easily, a normal text SAQ can still be used in conjunction with a GET.

BP 19] GETs should be used to support activity-based teaching.

CONCLUSION

In this paper we set out to examine how best to author GETs to produce effective learning for students. Our approach was to focus on student usability rather than technical details. We achieved this by deconstructing what a GET offers in terms of educational communication and identifying its important characteristics. These are then cross-referenced with relevant literature to produce the best practice points listed in Table 1. These best practices both promote the strengths of GETs but also represent a critique of them as an educational tool.

The importance of discussing a technology critically in terms of its usability is strengthened by Dalgarno and Lee's (2010) discussion about virtual worlds in education. They argue that the educational literature on the topic could be improved because it has been largely descriptive with little deconstruction and critique of the value of the technology from a user's point of view. We concur with that view, and observe the same pattern in the literature concerning GETs as outlined in the introduction of this paper. We believe our table of best practices (Table 1) meets their call for critical evaluation of 3-D learning technologies.

We introduced the idea that allowing multiple freedoms of movement navigation in virtual worlds can create serious user problems, such as getting lost. Ahmed and Eades (2005), Drucker and Zeltzer (1994), Goldin et al. (1981), Hanson et al. (1997), Igarashi and Hinckley (2000), have all identified the same issue across a range of software using 3-D information space. These five sets of authors have suggested independent solutions to the issue. Our contention is that GETs solve the "too many degrees of freedom" problem for students and, crucially for educational use, do so in a way that is easy to implement by educators without high level information technology skills. This enables educators to leverage the power of 3-D visualizations into their teaching without having to devote an unacceptable amount of time to software-specific training.

Leading on from Gould and Lewis's (1985) usability discussion we also stated that just producing and using a GET in a teaching situation is not sufficient to produce a good educational experience for students. The GET must be produced and embedded into learning in a student-focused manner that demands testing and iteration (see best practices 1 and 2; Table 1).

Following this processed-based view of a GET in education, we moved to deconstruct a GET as a communication media. We defined a GET slide and GET flight, and by splitting the sections of a GET into these two different categories we were able to relate GET slides to the wealth of evidence based literature on animations in learning. Our best practices 3–10 (Table 1) come out of this discussion, and we believe them to be highly reliable because they are based on evidence-based research. In contrast, the best practices associated with GET flights (BPs 11–15, Table 1) are less reliable. They refer mostly to one empirical user experiment (Treves and Engelbrecht, 2011) that directly addresses GETs and some other literature only loosely associated with GETs. Further investigative work in this area is required; for example, the best practice related to tour speed is vague and highly dependent on the complexity of the map view concerned. There are also a huge variety of routes and patterns of acceleration/deceleration that can be used in a GET flight between points, which also needs further investigation.

As well as considering the process of producing GETs and deconstructing them, it is also useful to consider the context of their use in education. There is no direct literature on embedding GETs in earth science education but there is indirectly relevant work on the benefits of guided learning. Our best practices (BP 18–19; Table 1) in this subject area rely on logic and inference from related studies. In the case of active learning, user experimentation is planned (by the authors) but other investigations into the value of GETs are encouraged. A particular experiment of interest would be to compare the effectiveness of a student learning where students produce presentations supported by GETs to when they present the same material using a PowerPoint presentation.

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