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## **RESEARCH ARTICLE**

### **Footprints in the sky: using student track logs from a “bird’s eye view” virtual field trip to enhance learning**

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## Abstract

Research into Virtual Field Trips (VFTs) started in the 1990s but, only recently, the maturing technology of devices and networks has made them viable options for educational settings. By considering an experiment, the learning benefits of logging the movement of students within a VFT are shown. The data is visualised by two techniques: “Animated Path Maps” are dynamic animations of students’ movement in a VFT; “Paint Spray Maps” show where students concentrated their visual attention and are static. A technique for producing these visualisations is described and the educational use of tracking data in VFTs is critically discussed.

Keywords: virtual field trip; learning analytics; geovisualisation; Google Earth; tracking

## 1] Introduction

The overriding view in UK Higher Education is that fieldwork training is vitally important in a range of subjects including Geography, Ecology and Geology. Virtual Field Trips (VFTs) have been suggested as a technique to support this field learning trip (Maskall & Stokes, 2008). Examples of enhancement include preparing for a real field trip (Priestnall, 2009), aiding data collation in the evenings of a residential course (Dykes et al., 1999) and student-produced VFTs as a reporting medium (Eusden et al., 2012). VFTs have also been suggested as solutions to problems such as accessibility for disabled students (Stumpf et al., 2008); health and safety issues (Stainfield et al., 2000) and locations that are impractical to physically visit (Granshaw & Duggan-Haas, 2012).

An important, and so far largely overlooked, advantage of a VFT is that it is relatively easy to track students’ movement within it. Such tracking produces a large amount of 4-D data (space with time) but if such data can be visualised effectively then it can provide excellent insights about students’ learning within the VFT. To take a deliberately simple example to aid explanation: where a student is learning to distinguish a volcano from a mountain, a student may be asked to find a volcano in Google Earth (GE). To check that any volcano-like landform s/he finds is not a mountain, the student must zoom in to examine if it has a crater. Examining the student’s 4-D track can prove s/he zoomed in appropriately and applied his/her knowledge correctly.

The technique of tracking students within a VFT is an example of learning analytics: a rapidly growing field in which students’ interactions with learning software are recorded and analysed (Ferguson, 2012). The educational insights gained have the potential to transform higher education (Siemens & Long, 2011). This study represents the first application of learning analytic techniques to 4-D data gathered from a VFT.

The primary purpose of this paper is to illustrate the potential of such 4-D data to enhance the understanding of students’ learning with data from an example experiment. The secondary purpose is to describe two visualisations that can be applied to the data and argue that they are effective. To support the secondary purpose the paper also references a proof-of-concept tool (Treves, 2014b), which readers may use to experiment with the visualisations in a study area of their choice.

Students’ tracks have previously been recorded and analysed in 3-D (2-D space with time) as we go on to describe in detail in the Previous Work section. It is therefore useful at this point to classify VFTs into two groups based on the dimensionality of the learning environment: Avatar VFTs generally recreate the experience of being on a real field trip such as exploration via walking or in a vehicle to study the geology of the

Grand Canyon (Dordevic & Wild, 2012). Tracks produced from an avatar VFT are 3-D (2-D with time). More complex are bird's eye view VFTs (BEVVFTs), which enable navigation in 3-D space with time and are in 4-D.

In terms of visualising tracking data, avatar VFTs producing 3-D logs can be visualised by avatar residence time maps (e.g. Chittaro & Ieronutti, 2004) amongst other techniques. However, these visualisation types cannot be applied to BEVVFTs because of the extra dimension of data.

To date two main techniques have been used to assess the value of VFTs: student surveys (e.g. Dykes et al., 1999; Spicer & Stratford, 2001; Wentz et al., 1999) and/or testing (e.g. Lang et al., 2012; Stumpf et al., 2008). Student track logs within a VFT can produce behavioural insights into learning that are not available from these two techniques. As such, they offer a potentially useful extra source of information by which to judge students' learning.

To be useful in practical learning situations, BEVVFTs have to be easy to create, usable and robust. Technologies have developed that can be used to create VFTs quickly and in high resolution (Granshaw & Duggan-Haas, 2012). In terms of usability, preparing and using VFTs on a platform such as GE is easy enough that it can be set as an undergraduate assignment (Eusden et al., 2012), whilst network speed and hardware requirements of a typical VFT platform such as GE are those of a typical household computer (Google, 2014). This enables educators to implement the use of a BEVVFT in their teaching and be confident it will operate for students correctly.

The rest of this paper is structured as follows: we start by identifying relevant previous work in section two. We then move on to describe the educational task we used in section three including a technical description. In section four, two visualisations are described and in the following section they are applied to the experimental data. This is followed by discussion and conclusions.

## **2] Previous work**

Previous attempts to identify the opportunities and problems with using virtual reality to illustrate geographical data informed our experimental design: Brodlie et al. (2002) discuss a scale of immersion, with low immersion representing an environment such as a series of text web pages and high immersion representing a virtual reality environment so visually detailed that users within one may involuntarily duck as they pass virtual objects (Dykes, 2002). The authors propose that the characteristics chosen for the virtual reality environment (which also applies to VFTs) should depend on the task a map where altitude represents time; choosing a high immersion VFT just because it is possible should be avoided (Gillings, 2002).

Kraak (2002) classifies virtual reality environments in terms of views: plan view (with no tilt view such as a road map), model view (tilted view, such as a perspective view of 3-D buildings in a city) and world view, which is the same as an avatar VFT. The experimental virtual setting we have created represents relatively high immersion with plan views of the ground.

Avatar VFTs and BEVVFTs form a subset of 3-D Virtual Learning Environments (VLEs) as defined by Dalgarno and Lee (2010). The authors criticise the literature on 3-D VLEs for being largely descriptive without showing evidence that the 3-D nature of the environment has produced learning benefits.

Tracking data has been gathered on avatars moving in 2-D virtual space in games, virtual museums and VFTs, with various different techniques used to visualise the data (Börner & Penumarthy, 2003; Coulton et al., 2008; Oda et al., 2009;

Sookhanaphibarn et al., 2011). Most pertinent for visualising our 4-D data, Chittaro and Ieronutti (2004) split the floor of a virtual museum into a grid of cells, recording the tracks of virtual visitors through the grid. They produced a choropleth density map illustrating the residence time of visitors in a particular cell. This approach has similarities to the paint spray map we discuss in greater detail below.

Finally, an overview of learning analytics is given in Ferguson (2012). She identifies the beneficiaries of learning analytics as students, tutors and institutions. She also explains that learning analytics is currently focused on social interactions amongst students rather than on interactions between students and educational content. She identifies a common problem with tracking in learning environments of how to extract educational value from large datasets.

### 3] Students exploring paleo-landscapes



Figure 1. White border marks part of a swarm of paleo-bank features (Copyright Google, USD Farm Service Agency).

As a basis for our VFT experiment, we prepared materials in GE to be played in the GE API (that is, within a browser) to teach experiment subjects about paleo-landscape features in a study area of USA covering an area of hundreds of square kilometres. The study site is a good example of where an actual field course would be prohibitively expensive to run. Specifically, subjects were taught how to identify paleo-banks: topographical features a few metres high and from tens of metres to several kilometres in length, which are remnants of the topography of dried up lakes. They can be recognised from the air as they form long curves and often occur in “swarms”, running sub-parallel to each other (Figure 1).

There were 45 subjects in the experiment, split equally between the three groups we later go on to describe. Subjects were student volunteers who received an honorarium and the teaching did not form part of any assessed course. Subjects’ answers to questions (discussed further below) and tracking data were logged and recorded on a server.

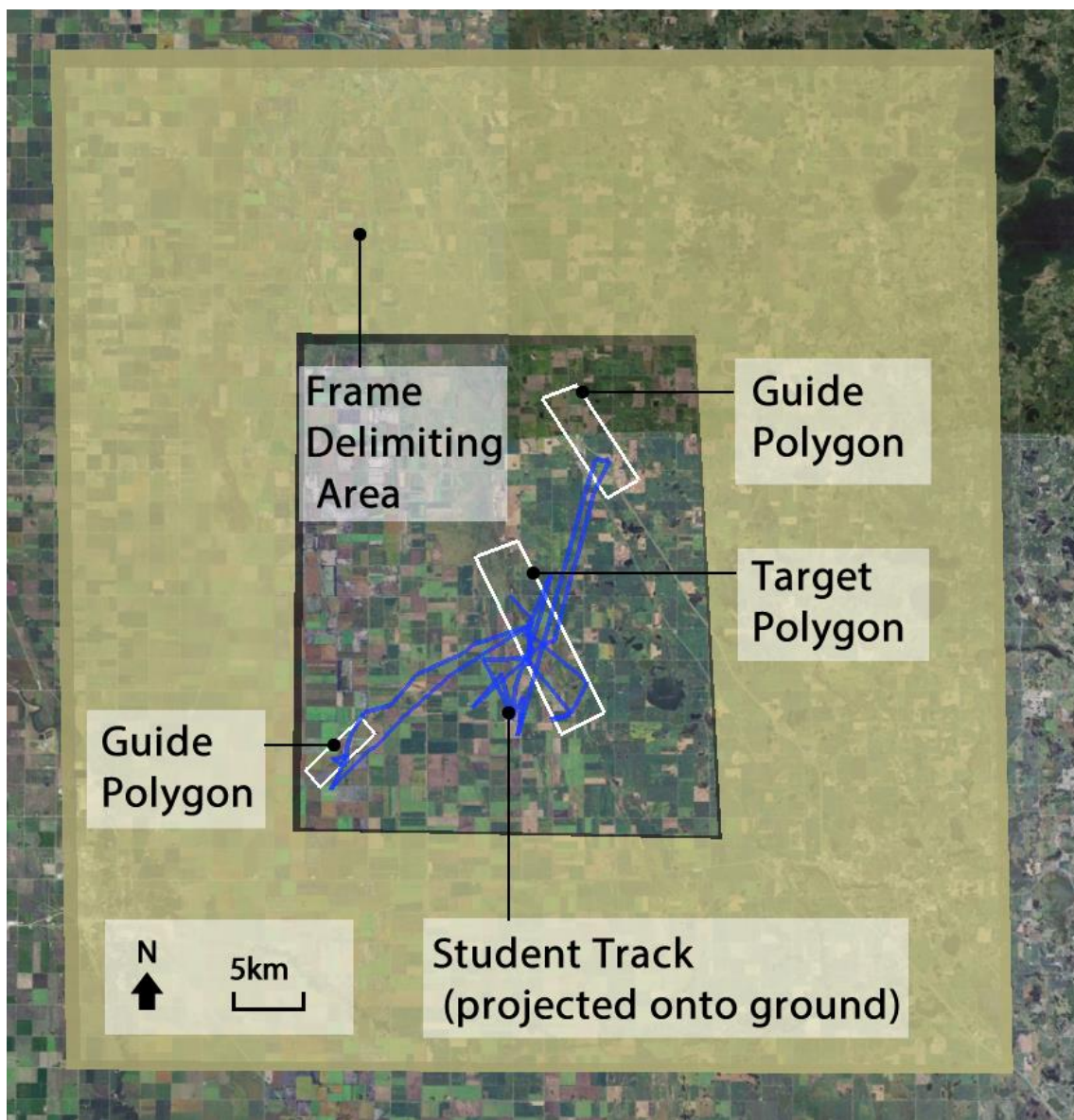


Figure 2. Study site as seen by subjects in the experiment (note that the blue path and black labels were not visible). (Copyright Google, USD Farm Service Agency).

The rest of the detail of the experiment is covered in three sections: basic design of the

experiment, description of the different condition groups and, finally, technical design of the experiment. The steps of the experiment are:

- (1) Students watched a “GE tour” – a voice-narrated zoom-and-pan tour around GE. Layers were turned on and off to explain to students how to navigate in GE and to encourage subjects to zoom in and out in their searching.
- (2) They watched a second tour about the geomorphological history of the study area and how to identify paleo-bank features.
- (3) Students were asked to search for and identify a paleo-bank feature in a marked area of GE that had not formed part of the tour (Figure 2). The area was delimited by a 3-D “picture frame”. During this step, students’ latitude, longitude and altitude was logged with time as they moved around GE.
- (4) Following a prompt, they identified a paleo-bank feature by clicking within GE.
- (5) They completed a test about the educational content. Further discussion of this step is omitted for reasons discussed below.

The combination of tour followed by search activity mitigates the problem of students getting lost in virtual environments (discussed by Spicer & Stratford, 2001; Treves & Bailey, 2012) whilst still engaging them in investigative problem solving. It is also suspected that it encourages them to use zoom controls more than they would although there was no control for this in our experiment, so we did not test this conjecture.

The experiment was designed to test learning differences between students split into three conditions: “no exercise”, “non-guided” and “guided”.

Table 1. Summary of differences between condition groups for experimental steps

	<b>Steps 1, 4 and 5</b>	<b>Step 2</b>	<b>Step 3</b>	
<b>Condition</b>			<b>Student Tracked?</b>	<b>Polygon Guides Visible?</b>
No Exercise	No differences	Normal	No	No
Non-Guided		Normal	Yes	No
Guided		Enhanced	Yes	Yes

The subjects in the no exercise condition group did not produce any tracking data so they are not discussed further beyond the summary in Table 1 (see explanation below).

The guided group had step 2 enhanced with extra learning scaffolding about how to identify paleo-banks. A graphical version of the extra advice they received in their GE tour is shown in Figure 3. In step 3, they were shown three polygon guides (see Figure 2) to investigate, one of which surrounded a paleo-bank feature: the “target polygon”.

The non-guided group were shown a less detailed version of step 2 and had to identify a paleo-bank without the polygon guides. The differences between the condition groups are summarised in Table 1.

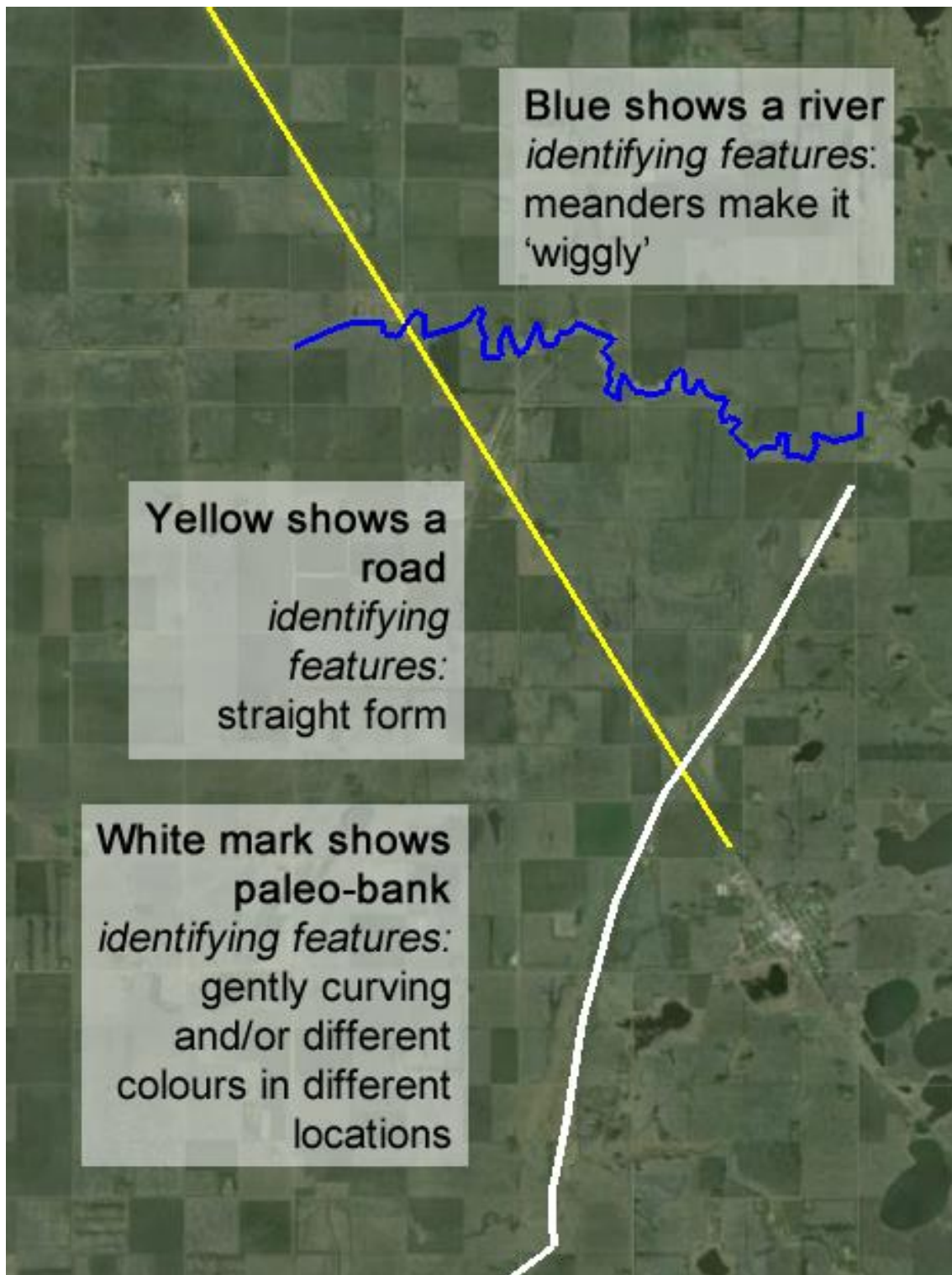


Figure 3. A graphic version of the extra learning scaffolding that the guided group received via the GE tour. (Copyright Google, USD Farm Service Agency).

Technical problems reduced development time for the experiment with the outcome that students all scored highly on the task in step 4 and 5, rendering the test results inconclusive. However, we did collect tracking data successfully in step 3 though not for all students. These results show significant differences between subjects' behaviour and forms the dataset that is discussed in the rest of this study. The experiment delivery, data collection and processing was performed by programming the

GE API in a browser to interact with a server and then processing the data using an Excel® macro. A similar alternative technique suitable for non-developers is detailed in Treves (2014b). This second technique is outlined below:

- 1) The student is instructed on a task to complete within a defined study area in GE (the application).
- 2) The student starts recording a GE tour and attempts to complete a search task. Once done, they stop the tour recording.
- 3) To visualise the 4-D data, the student saves the tour as a GE file. This is sent to the tutor for processing or could be processed by the student themselves.
- 4) The tour is processed using the Excel macro and outputs KML code that produces the two visualisations in GE described in the following section. These are opened in the GE client for inspection.

This process produces similar 4-D data to that from the GE API tool except for producing a lower position sampling frequency. It should be noted that the Excel tool is a proof-of-concept prototype and should be used with caution.

#### 4] Visualisations

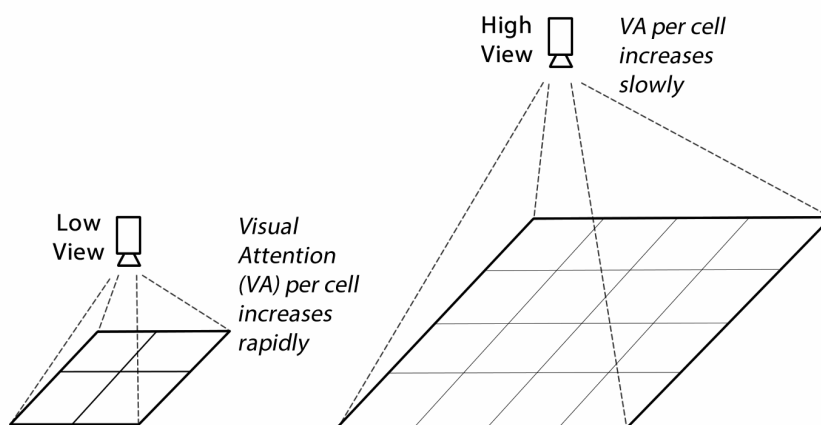


Figure 4. VA changes with altitude of camera



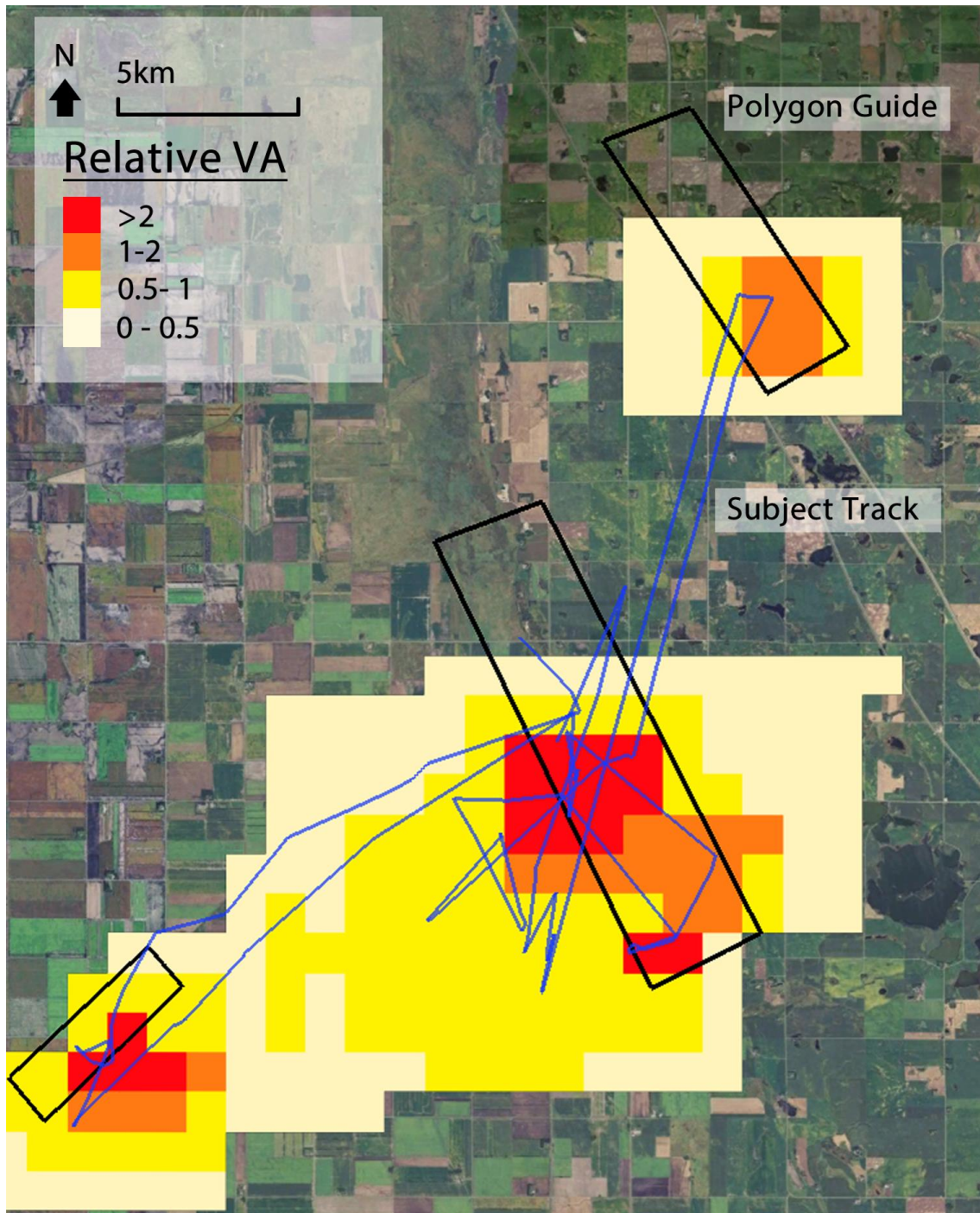


Figure 5. A paint spray map example. VA values are mapped as per the key: other map elements as per Figure 2. Note the polygon guides have been coloured black to aid visibility against the choropleth shading. (Copyright Google, USD Farm Service Agency).

In this section a description of how the two data visualisations are produced is given in order to help interpretation of the results in the following section.

The paint spray map is produced by first splitting the study area into a grid: in our experiment 60 x 64 squares. Then the 4-D tracking data is processed: for every second of the dataset a visual attention (VA) measure of one is evenly distributed amongst all the cells visible on screen. The running total of VA is recorded as a

separate variable for each cell. This is illustrated graphically in Figure 4. An analogy is that the camera is considered to be a paint spray can, which constantly sprays VA “paint” over the map. The depth of VA in each cell is then mapped as a choropleth (Figure 5). Note that the visualisation is effective only if zooming must be used to solve the search task. If it can be successfully completed without any zooming in, VA will remain constant across all cells.

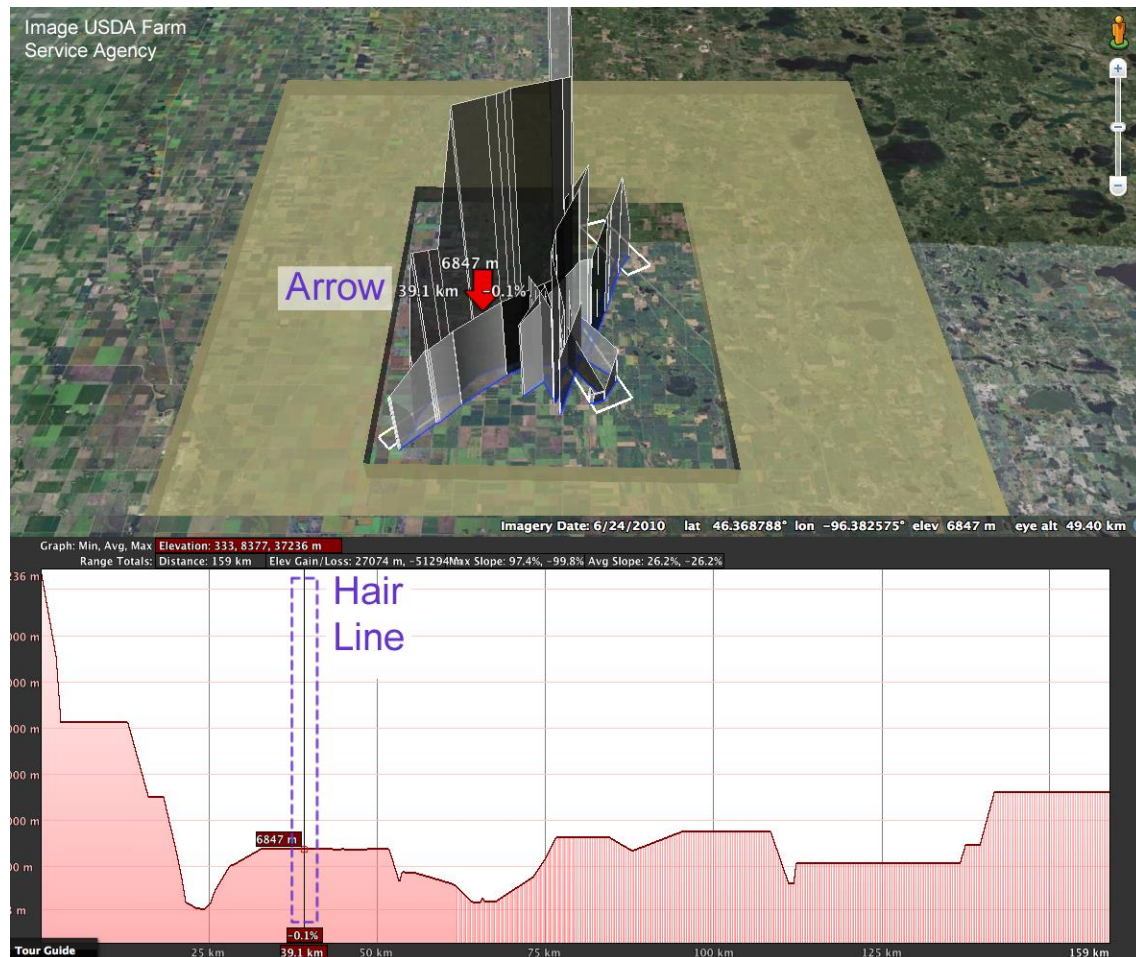


Figure 6. An Animated Path Map. Top: 3-D student track through space is shown as a “fence” and red arrow marks a specific location. Bottom: altitude (vertical axis) is plotted against distance along path with the hairline corresponding to the location of the red arrow on the path in the top section. Note that purple text and annotations were added to clarify the visualisation just for the figure. Other on-screen text is difficult to read but is not necessary for interpretation.

The animated path map produces a 3-D animation of the students’ camera during their search (see Figure 6). It is complex to describe in text so the reader is encouraged to view an illustrative video and download sample data for experimentation in GE (Treves, 2014a).

To visualise the 4-D data, the altitude is important as it allows the viewer to assess if the student who produced the track was zoomed out at a certain point (looking at a general view of the study area) or zoomed in (examining some geographical feature in detail). The animated path map accentuates altitude by use of the linked graph. Note that the altitude was reduced by a factor of 10 to improve visibility of the data at the data processing stage. This improves the visibility of the 3-D “fence” without affecting

the shape of the graph, which is automatically scaled. Also, altitude was plotted against distance along path not against time. We discuss this point in more detail in section 6.

Dragging the mouse across this graph produces a hairline graph and a corresponding red arrow marker in the map screen. A purely static version of the map without the hairline/arrow controls would be difficult to interpret because the path of the camera through space is usually complex.

## 5] Results

The experimental data for the non-guided and guided condition groups were processed to produce paint spray maps for each individual student and also a collated version for each sub-group. Technical problems limited the successful logging of data to seven students in the guided and five students in the non-guided group. The results are shown in Figures 7 and 8. Note that the maps shown were cropped just inside the picture frame shown in Figure 5 and a white base inserted to aid clarity.

The animated path map would be very complex to illustrate in a static figure and, as it has a more minor supporting role to the paint spray map (see later discussion), only data for one student (Figure 6) has been processed.

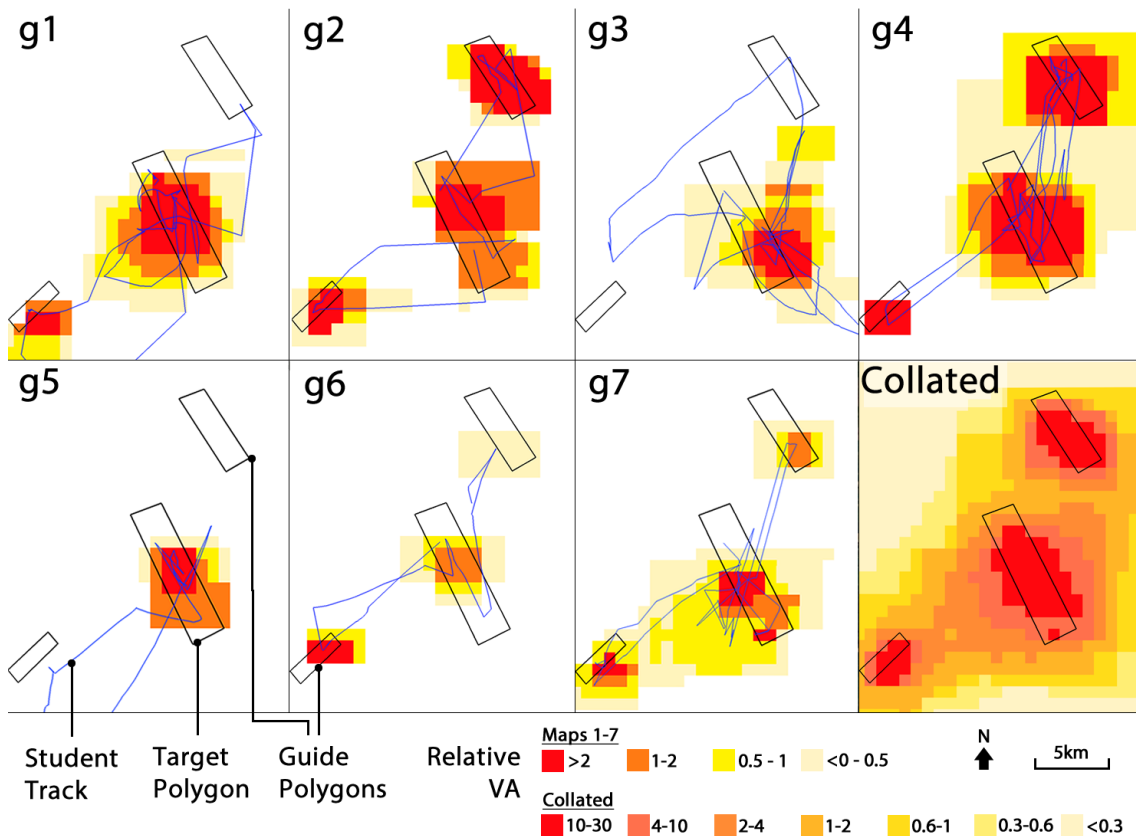


Figure 7. Multiple paint spray maps for the seven students in the guided group. Collated results bottom right. Note that colour palette applied differs between collated and other multiples. The central target polygon contains a paleo-bank whereas the other two 'guide' polygons do not.

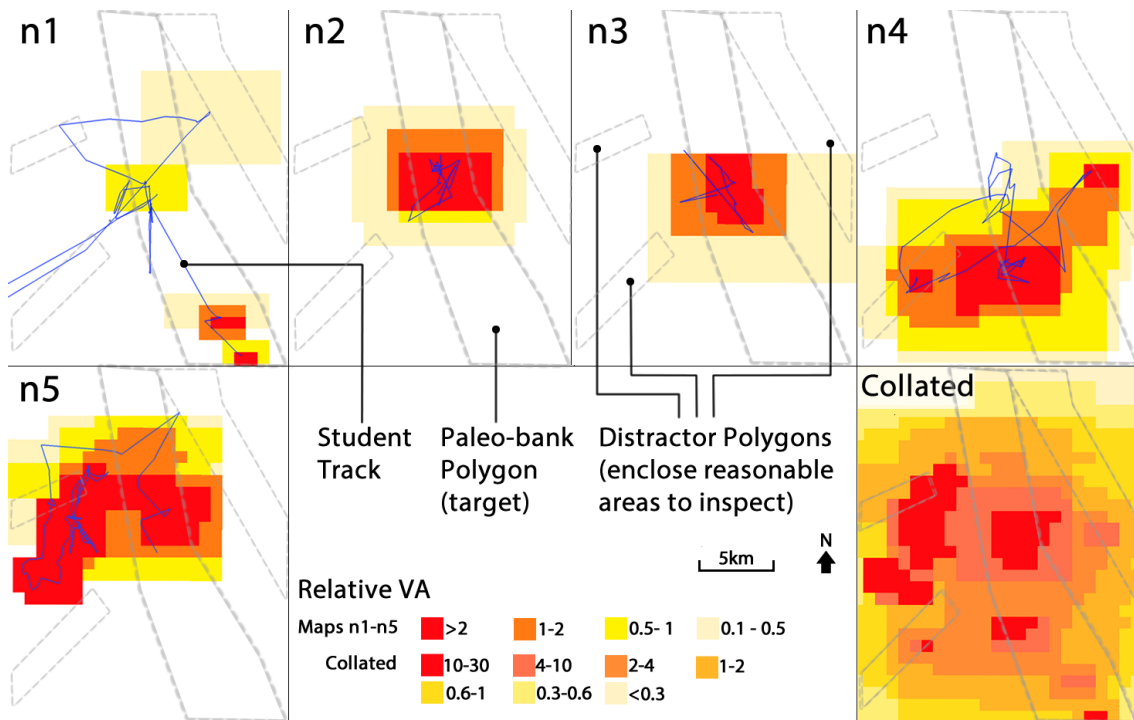


Figure 8. Multiple paint spray maps for the five students in the non-guided group. Collated results bottom right. Note that colour palette applied differs between collated and other multiples. The grey dashed polygons are for interpretation purposes and were **not** visible to this group during the experiment.

## 6] Discussion

Comparison between the guided and non-guided groups visualised in Figures 7 and 8 reveals that the polygon guides visible only to the guided group (black, Figure 7) had a strong effect on the subjects. Subjects in the guided group clearly focused their search within the guides whereas searching in the non-guided group (Figure 8, note that dashed grey polygons were invisible to subjects) was less focused and more prone to occur in unjustified areas (outside the distractor polygons). Counter-intuitively, examining the individual paint spray maps reveals that the subjects who searched the least are in the non-guided group (n2 and n3). The guides appear to have had the unexpected effect of encouraging the majority of the guided subjects to examine all three guided polygons.

Beyond this comparison of the two different groups, Table 2 describes five educational insights that the authors have interpreted from the results that would not have been gained by other techniques.

Table 2. Learning insights and descriptions for the paint spray maps, refers to Figures 7 and 8

	Learning Insight	Evidence
1	Picture frame construction is effective in mostly limiting students to the study area.	No VA shading outside the inner edge of picture frame on individual paint spray maps.
2	All students zoomed in at least once whilst searching. This is a necessary action to complete the search.	All students produced high density VA shading.

3	Majority of students kept on task and did not show evidence of becoming disoriented.	Only student n5 showed evidence of significant attention being spent outside areas that were worthy of attention: that is, outside of the grey dashed polygons in Figure 8.
4	Students n2 and n3 failed to search beyond the target area. It is possible that the students have not searched widely enough.	VA shading on individual paint spray maps.
5	Compared to n2 and n3, student n1 has been very thorough in his/her searching.	Student n1 has scanned the area at altitude, viewing all the likely features (inside distractor polygons), and investigated the target in detail in two locations (middle and bottom screen).

Such analysis can be easily performed by any tutor if paint spray maps are available to them and may be possible for students as well. Suggestions of how this could benefit learning are listed below, with examples from the experimental results to illustrate the points:

- The tutor could discuss with the student their individual performance using their personal paint spray map; e.g. was student n5 disorientated in the eastern part of the study area?
- A student could use their personal paint spray map to compare their performance with the collated search results of the group and the “answer” (Target polygon Figure 7); e.g. student n2 has not searched enough. By comparing their individual map with the collated map, they can see that there were many areas that their peers examined which they did not.
- The tutor could reflect on how to improve the exercise; e.g. examination of the collated paint spray maps from the guided and non-guided groups shows that the guide polygons used by the guided group (Figure 7) are probably making the task too easy.

A particular benefit of the paint spray map for tutors is that it is static so, once s/he is used to interpreting the choropleth density shading, s/he can rapidly evaluate many students’ paint spray maps. This speed scanning benefit is far less important for individual students who will only really examine their own map.

Turning to consider the educational value of the animated path map, it is less use for a tutor as it must be interacted with to be understood and therefore cannot be evaluated rapidly. However, it may be useful to check interpretations of the paint spray map where the tutor wants more information, e.g. investigating the tracks of specific students listed in insights three and five of Table 2. Marsh (2007, p254) found that non-domain experts are significantly less skilled than domain experts at interpreting geovisualisations. This suggests students will probably struggle to interpret the more symbolised paint spray map and may well prefer the animated path map.

The animated path map could be enhanced by using a time versus altitude graph rather than the distance versus altitude plot that is currently shown. This would allow the user to track periods when the camera was stationary during the search.

A limitation of both the paint spray and animated path maps is that they only work if the camera is not tilted. This is not an issue in flat topography such as in the experiment but in mountainous topography it is useful to tilt the camera to enhance understanding of perspective and scale (Wood, 2002). Visualising VA in a BEVVFT

that allows tilting would be possible but would require much more complex programming to work.

To make the experiment easier, our VFT was kept simple. In a true educational situation it could be criticised as students could learn to identify a paleo-bank by just applying simple heuristics without a deeper understanding of the geographical principles concerned. Johnson et al. (2011) correctly criticises other GE-based VFTs for a lack of attention to the deeper learning needs of students. However, it is believed that 4-D tracking data can also be used to analyse deep learning activities. As an example, students could be organised to search for a paleo-bank and submit examples to a group forum. An activity encouraging deeper learning would be to get the students to assess each other's marked locations and rank them in terms of quality. This would generate paint spray maps of individual students' visits to assess other students' examples and the tutor could view tracking data to judge in what detail they examined each other's work.

## **7] Conclusion**

In this paper 4-D tracking data (three spatial, one time) has been gathered from students moving through a BEVVFT based in GE and has been visualised in two formats: as paint spray maps and animated path maps. Despite the low numbers of students in the study, the data has revealed five learning insights (Table 2) that were gained by analysis of students' track logs visualised by the paint spray map. A simplified technique to collect and analyse 4-D data generated in the GE client has been described that enables others to repeat the important parts of the experiment (Treves, 2014b).

It has been suggested that the visualisations could be best used in three ways: tutors could review student track data in BEVVFTs with individual students; by students reviewing their own performance compared to collated group performance and by tutors reviewing the effectiveness of their BEVVFT design.

The visualisations are considered to be of clear benefit to tutors but the motivation for students to use the visualisations is probably less strong at this stage of development as students' use of feedback is complex (Gibbs et al., 2003); careful pedagogical design and iteration will probably be required to ensure effective student engagement with the visualisations. However, the potential gains could be considerable given the success of student feedback delivered by similar VLE dashboards (Arnold & Pistilli, 2012).

Avatar VFTs, BEVVFTs and other 3-D learning environments have suffered from lack of pedagogical evaluation (Dalgarno & Lee, 2010). Collecting 4-D data and using the visualisations designed for this study provides an important new technique for tutors to assess the pedagogical benefits of VFTs.

Considering the educational effectiveness of the visualisations, they are easy to interpret and capture an objective measure of what students actually did within a VFT. This is a very useful complement to students reporting what they did, which is often useful, but necessarily subjective. The paint spray map is considered to be the more effective of the two maps because tutors need to assess students' learning rapidly and this visualisation is static. In addition, the ability to collate and then visualise data from groups of students is very powerful, especially when a tutor wishes to assess how a BEVVFT could be improved.

A key factor in the success of the experimental tracking was to keep the learning BEVVFT simple, which meant it was relatively easy to filter and visualise the data (cf. Kraak, 2002). Since a significant problem with analysing learning analytics datasets is

their large size (Ferguson, 2012), the tendency to design them to be overly complex (Gillings, 2002) should be avoided.

In the experiment, only one interaction was allowed during the search period: students marked the position of the paleo-bank at the end of their search. A more sophisticated tracking system would gather data on multiple interactions during a search or activity. This would open up the possibilities of introducing online field notebooks and cross-referencing students' note taking with their explorations around a VFT (Spicer & Stratford, 2001) but, as has been noted, this may impact the ability to easily visualise the data.

## References

- Arnold, K. E., & Pistilli, M. D. (2012). Course signals at Purdue: Using learning analytics to increase student success. In *Proceedings of the 2nd International Conference on Learning Analytics and Knowledge* (pp. 267-270). ACM.
- Börner, K., & Penumarthy, S. (2003). Social diffusion patterns in three-dimensional virtual worlds. *Information Visualization*, 2(3), 182-198.
- Brodlie, K., Dykes, J., Gillings, M., Haklay, M., Kitchin, R., & Kraak, M. J. (2002). Geography in VR: Context. In Fisher, P., & Unwin, D. (Eds.) *Virtual Reality in Geography* (pp. 7-16). London: Taylor and Francis.
- Chittaro, L., & Ieronutti, L. (2004). A visual tool for tracing users' behaviour in Virtual Environments. In *Proceedings of the working conference on Advanced visual interfaces* (pp. 40-47).
- Coulton, P., Bamford, W., Cheverst, K., & Rashid, O. (2008). 3-D Space-time visualization of player behaviour in pervasive location-based games. *International Journal of Computer Games Technology*, 2.
- Dalgarno, B., & Lee, M. J. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, 41(1), 10-32.
- Dordevic, M. M., & Wild, S. C. (2012). Avatars and multi-student interactions in Google Earth-based virtual field experiences. *Geological Society of America Special Papers*, 492, 315-321.
- Dykes, J. (2002) Creating information-rich virtual environments with geo-referenced digital panoramic imagery. In Fisher, P., & Unwin, D. (Eds.). *Virtual Reality in Geography* (pp. 68-92). London: Taylor and Francis.
- Dykes, J., Moore K., & Wood, J. (1999) Virtual environments for student fieldwork using networked components. *International Journal of Geographical Information Science* 13(4), 397-416.
- Eusden, J. D., Duvall, M., & Bryant, M. (2012). Google Earth mashup of the geology in the Presidential Range, New Hampshire: Linking real and virtual field trips for an introductory geology class. *Geological Society of America Special Papers*, 492, 355-366.
- Ferguson, R. (2012). Learning analytics: drivers, developments and challenges. *International Journal of Technology Enhanced Learning*, 4(5/6), 304–317. DOI: 10.1504/IJTEL.2012.051816.
- Gibbs, G., Simpson, C., & Macdonald, R. (2003). Improving student learning through changing assessment – a conceptual and practical framework. In European Association for Research into Learning and Instruction Conference, Padova, Italy.

- Gillings, M. (2002). Virtual archaeologies and the hyper-real: or, what does it mean to describe something as *virtually-real*? In Fisher, P., & Unwin, D. (Eds.). *Virtual Reality in Geography* (pp. 17-34). London: Taylor and Francis.
- Google. (2014). Google Earth system requirements [web page]. Retrieved from <https://support.google.com/earth/answer/20701>
- Granshaw, F. D., & Duggan-Haas, D. (2012). Virtual fieldwork in geoscience teacher education: Issues, techniques, and models. *Geological Society of America Special Papers*, 492, 285-303.
- Johnson, N. D., Lang, N. P., & Zophy, K. T. (2011). Overcoming assessment problems in Google Earth-based assignments. *Journal of Geoscience Education*, 59(3), 99-105.
- Kraak, M. J. (2002). Visual exploration of virtual environments. In Fisher, P., & Unwin, D. (Eds.). *Virtual Reality in Geography* (pp. 58-67). London: Taylor and Francis.
- Lang, N. P., Lang, K. T., & Camodeca, B. M. (2012). A geology-focused virtual field trip to Tenerife, Spain. *Geological Society of America Special Papers*, 492, 323-334.
- Marsh, S. L. (2007). *Using and Evaluating HCI Techniques in Geovisualization: Applying Standard and Adapted Methods in Research and Education* (Unpublished doctoral dissertation). City University, London, UK.
- Maskall, J., & Stokes, A. (2008). *Designing effective fieldwork for the environmental and natural sciences*. Higher Education Academy Subject Centre for Geography, Earth and Environmental Sciences, Plymouth, UK.
- Oda, J., Thawonmas, R., & Chen, K. T. (2009). Comparison of user trajectories based on coordinate data and state transitions. In *Intelligent Information Hiding and Multimedia Signal Processing* (2009). IHH-MSP'09. Fifth International Conference on (pp. 1134-1137). IEEE.
- Priestnall, G. (2009). Landscape visualization in fieldwork. *Journal of Geography in Higher Education*, 33(S1), 104-112.
- Siemens, G., & Long, P. (2011). Penetrating the fog: Analytics in learning and education. *Educause Review*, 46(5), 30-32.
- Sookhanaphibarn, K., Thawonmas, R., Rinaldo, F., & Chen, K. T. (2011, May). Spatiotemporal Analysis of Circulation Behaviors Using Path and Residing Time display (PARTY). In *Digital Media and Digital Content Management (DMDCM)*, 2011 Workshop (pp. 284-291). IEEE.
- Spicer, J. I., & Stratford, J. (2001). Student perceptions of a virtual field trip to replace a real field trip. *Journal of Computer Assisted Learning*, 17(4), 345-354.
- Stainfield, J., Fisher, P., Ford, B., & Solem, M. (2000). International virtual field trips: a new direction? *Journal of Geography in Higher Education*, 24(2), 255-262.
- Stumpf, R. J., Douglass, J., & Dorn, R. I. (2008). Learning desert geomorphology virtually versus in the field. *Journal of Geography in Higher Education*, 32(3), 387-399.
- Treves, R. (2014a). Animated Path Map Media [web page]. Retrieved from <http://is.gd/PtTiXy>
- Treves, R. (2014b). Paint Spray Calculator and Instructions [web page]. Retrieved from <http://goo.gl/kuKfau>
- Treves, R., & Bailey, J. E. (2012). Best practices on how to design Google Earth tours for education. *Google Earth and Virtual Visualizations in Geoscience Education and Research: Geological Society of America Special Paper*, 492, 383 -394.



- Wentz, E. A., Vender, J. C., & Brewer, C. A. (1999). An evaluation of teaching introductory geomorphology using computer-based tools. *Journal of Geography in Higher Education*, 23(2), 167-179.
- Wood, J. (2002). Visualizing the structure and scale dependency of landscapes. In Fisher, P., & Unwin, D. (Eds.). *Virtual Reality in Geography* (pp. 163-174). London: Taylor and Francis.

