The development and applicability of a web-based time-geographic visualisation tool

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ABSTRACT: This article describes the development of an easy-to-use, web-based, time-geographic visualisation tool called the Time-Geographic Interactive Framework (TGIF). The article sets the context of the tool's development into the wider context of time-geography research and the use of web-based applications in GIS, for instance, in geovisualisation work. The article illustrates how this powerful platform enables users to incorporate various interactive text, image and audio data to explore time-geographic paths individually, in groups and as a whole class. We demonstrate that the TGIF is a versatile tool for a broad range of research topics, including emotional geographies and environmental education. The final section describes how university students responded to a small-scale survey on the TGIF. The survey participants indicated the usefulness of the tool for visualising time-geographic paths and for enabling them to understand the relevant social meanings of these paths. The students participating in the survey also indicated that the TGIF could possibly be used effectively in secondary education too. We conclude with a summary of future research and development of the Framework.

Introduction

Since its initial conceptualisation by Hägerstrand (1970), the notion of 'time geography' has received considerable attention from numerous fields (see e.g. Hill, 2014). Giddens (1984), in his structuration theory, for example, noted that social structure is produced and reproduced in the everyday practices that are examined by time geography (Lippuner and Werlen, 2009); therefore, the time-geographic perspective illustrates the importance of routine in daily life.

In acknowledging the utility of time geography, attempts to provide improved visualisations of Hägerstrand's (1970) time-space paths have been made. One widely recognised application is Kwan's (2008) three-dimensional aquarium: a dimensional rectangle in which individual movements are visualised using place (the x and y axes) and time (the z axis) variables; and other diverse modifications have been proposed. The majority of these modified time-geographic visualisations are based on commercial, off-the-shelf GIS applications. Despite its appealing functions, commercial GIS is not easily accessible to the public because it requires sophisticated hardware and complicated interfaces as well as being costly. To address these problems, we developed a time-geographic visualisation tool called the TGIF (Time-Geographic Interactive Framework). The TGIF uses Google Maps and Google Earth as its main platforms. Google tools are freely available and do not require expensive hardware to run. They also provide a user-friendly and interactive interface, which is essential for contemporary geovisualisation (MacEachren and Kraak, 2001) and for the adoption of online tools for educational purposes (Milson and Earle, 2007; Kim *et al.*, 2013).

This article describes the development of the TGIF and its benefits and potential applications. The development of tools for interpreting dynamic, time-spatial data is central to the contemporary field of geographic information science (GIScience, Sui and Goodchild, 2011). In the Web 2.0 era, users themselves are active producers of information (Haklay *et al.*, 2008; Hudson-Smith *et al.*, 2009). The TGIF responds to this widespread trend.

This article also reports on a study that investigated the usability of the TGIF. University students were encouraged to use the TGIF to create daily time-geographic paths. They then evaluated the tool's usefulness and made recommendations for extending the use of the TGIF to secondary school students. In addition, we believe that the TGIF will be useful for practitioners who specialise in spatial cognition, spatial thinking, and geographic information systems (GIS) education.

Time geography

The Swedish geographer Hägerstrand (1970) first presented the notion of 'time geography' in the early 1970s. More recently, time geography has been described as 'a conceptual geographic framework… founded on a matter-realistic ontology that explicitly takes departure from the material eventness of geographical phenomena and processes, in their dynamic time-spatial situatedness on Earth' (Gren, 2009, p. 279). Fundamental to time geography is the assertion that everything on Earth shares a common property, i.e. 'corporeality' (or existing in bodily form), which can only be conceived, understood and analysed by reference to particular time-space material conditions.

Despite its original emphasis on integrated accounts of both human and non-human entities, a more human-oriented approach to time geography focuses on 'the complex interaction between space and time and their joint effect on the structure of the human activity patterns in particular localities' (Kwan, 2004, p. 267). Thus, essential components of time geography include (i) the integration of space and time, and (ii) human daily activity patterns.

Space and time

Time geographers contend that a phenomenon can be fully understood only when space and time are examined in conjunction with each other. In the time geography field, efforts to recover the temporal dimension have echoed those philosophical and scientific arguments that question the validity of categorical distinctions between space and time first formulated by Emanuel Kant (Strohmayer, 2009). The central principle of time geography states that 'time and space always come together in order to keep track simultaneously of both spatial and temporal dimensions of material geographical events' (Gren, 2009, p. 281). Time geography requires researchers:

> *'to accept that space and time are universally and inseparably wed to one another; to realize that questions pertaining to human organization of the Earth's surface, human ecology, and landscape evolution cannot divorce the finitude of space and time'* (Pred, 1977, p. 218).

Humans' daily activity patterns

Time geographers attempt to examine the activity patterns performed by individuals in everyday life. Daily life patterns form complex webs of social relations and relevant practices (Latham, 2003). Depictions of everyday life uncover the often complex interrelationships between a wide range of social and spatial components. For example, Hill and Woodland (2005) examined the cultural impacts of foreign tourism, migration, and government modernisation on local communities in southern Tunisia via a time-geography framework. The movements of local residents became both constricted and fragmented in time and space, after being affected by external global forces. Therefore, a description of one's daily life is not a trivial depiction of that life. Instead, the description is a window through which underlying social and spatial structures can be examined. Giddens' (1984) 'structuration theory' provides insights into this discussion. Fundamental to the link between time geography and Giddens' structuration theory is the importance of the spatiality of social practices in everyday life. According to theories on ways to resolve the chronic dichotomy between social structure and individual agency, the former should be continually produced and reproduced in actual everyday practices (Lippuner and Werlen, 2009). In this sense, Giddens employs and embraces the time-geographic perspective as a crucial aspect of his social theory, stating that:

> *'time-geography is concerned with the infrastructural constraints that shape the routines of day-to-day life, and shares with structuration theory an emphasis upon the significance of the practical character of daily activities, in circumstances where individuals are co-present with one another, for the constitution of social conduct'* (Giddens, 1984, p. 116).

Gidden's perspective emphasises that examining the daily activities of individuals provide a useful method to investigate underlying social structures.

Geovisualisation

The field of cartography has shifted its focus from printed map communication to an emphasis on 'geovisualisation' (MacEachren, 1995). Increasingly, geovisualisation has become central to scientific visualisation and exploratory analysis (MacEachren and Kraak, 1997). Geovisualisation allows spatial data to be collected, analysed, synthesised and presented effectively. This study focuses specifically on web-based, spatio-temporal geovisualisation.

GIS communities have increased their use of web-based applications. The development of information and communication technologies (ICT) have set the stage for the geospatial web with several online mapping platforms, such as Google Maps, Google Earth and Wikimapia, now available. When using these online platforms, users can create, build and modify their own geographic information datasets on online maps and display information in novel ways. This new web-based approach to geovisualisation is related to social issues, including citizen science and public participatory democracy (Goodchild, 2007; Elwood, 2009), neogeography (Turner, 2006), volunteered geographic information (Goodchild, 2007; Boyd and Foody, 2014) and GIS Wikification (Sui, 2008). Google in particular has introduced two web-based mapping services (Google Maps and Google Earth), which are designed for creating geo-referenced information from geographic maps and satellite images (Zook and Graham, 2007). Through these geovisualisation technologies, customisable, functional and serviceable web-based digital maps can be produced.

One of the main emphases of geovisualisation is the representation of geographic data from a spatio-temporal perspective. In particular, in the context of time geography, human travel behaviours can be represented via space-time cubes. Since the first publication by Hägerstrand (1970), researchers have conducted several studies on the space-time cube – also referred to as the 'aquarium' (Kristensson *et al*., 2009; Chen *et al*., 2011). Early studies on this form of travel behaviour ran into difficulties in visualising complex time-space trajectories. However, ICT and geovisualisation techniques now allow geographers to illustrate activity-travel patterns in a 3D space and interact with them. For example, Kwan (2000) developed the 3D 'space-time aquarium', which enhanced Hägerstrand's time-space path model using real-time data generated through GIS. Kwan's visualisation tool has helped researchers to address diverse topics regarding travel behaviours, including the space-time paths followed by African-American women (Kwan, 2002) and the feelings held by Muslims regarding their residential neighbourhoods (Kwan, 2008). Other researchers (e.g. Kristensson *et al*., 2009) have modified the traditional space-time model (or visualisation), and a broad community of researchers have become interested in developing effective space-time model visualisation methods. This article seeks to extend these endeavours through the TGIF.

The TGIF

The time-geographic interactive framework (TGIF) offers an online platform to create interactive, time-geographic paths from user-generated, location-based timetables. In developing the TGIF, we combined the sub-systems for input, process and output data, and employed a loose coupling strategy. This strategy incorporates three interconnected sub-systems that exist as independent systems. We adopted this strategy because existing user-friendly tools (Google Earth for instance) provide useful functions that are important to the TGIF. These include mash-up – a web application that combines information from different sources (Kulathuramaiyer, 2007). We strove to maximise the utility of these tools because it enables the developer flexibly to incorporate powerful functions of pre-existing tools with which students are already familiar, thus decreasing their learning curve. Figure 1 depicts the system configuration for the TGIF, and indicates how the time-geographic path rectangle is created through three steps, each refers to subsequent figures (Figures 2–5) which illustrates that step.

1: Creating a time-geographic table (input layer) using Google Maps or geo-positioning system-based applications (e.g. GPS Essential) (Figure 2)
2: Incorporating the time-geographic table into middleware developed for this study to generate a time-geographic path (Figure 3)
3: Visualising and examining the time-geographic rectangle generated through Google Earth (Figures 4 and 5)

One of the key contributions of our work is the development of 'middleware' that combines the aforementioned steps. The middleware connects Google Maps and Google Earth via keyhole mark-up language (KML). Up to now, no application has been developed specifically for this purpose. The middleware used the Microsoft Windows IIS (version 7) web server and employed JavaScript and Python (version 2.7) programming languages.

The time-geographic path generated through the TGIF can be utilised for a number of purposes. Users can easily, and interactively, create and explore time-geographic paths. Figure 4 provides a visualisation of two individuals' time-geographic paths. The right panel demonstrates that the TGIF creates points and paths across the 3D space (TimePath) and on the ground (GroundPath). The left panel indicates the visualisation options. Using the TimePath (Total) option, the user can change the colour of an entire path or make the path

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toggle between visible and invisible. Here, if the user utilises the TimePath (Segment) option they can modify the colour of each segment and hide/show specific segments. The TimePoint option allows the user to change the colour of each station (or point) and generate a mash-up for each point. The same functions are available for GroundPaths. Using the 'Axis' option, users can change the colours of 3D axes and make them visible/invisible. Finally, users can rotate the time-geographic rectangle onscreen in any direction, and can easily complete zoom-in and zoom-out actions. Using this interface, users can interactively visualise and examine time-geographic paths.

The TGIF allows users to incorporate a wide range of multimedia information in the form of text, images and animated data using the mash-up function. This feature effectively combines time geography with interactive, web-GIS technologies. Figure 5 visualises one graduate student's time-geographic path on a typical day. The student documented his feelings as textual information at every location (point) he visited over the course of the day and recorded relevant images and sounds. When a visitor clicks on a point in the student's path, a pop-up window displays the information posted by the student at that point. For example, Figure 5 shows that the student expressed his excitement at starting a tennis lesson. To demonstrate his excitement, the student posted a photo and changed the corresponding path and point for this activity to the colour red. By way of contrast, the blue segment shown in Figure 5 illustrates his disappointment along this path segment. As this example indicates, the TGIF is a useful multimedia GIS tool in which users can incorporate diverse forms of information to examine their everyday lives.

Potential applicability of TGIF

To demonstrate how the TGIF can be used in research, we present two examples from the perspective of 'constructivism'. Constructivism denies absolute truth and emphasises the active production of knowledge by individuals (Kim and Ryu, 2014). This indicates that the TGIF can be employed by students to actively visualise their thinking and learning in the areas of emotional geographies and environmental education.

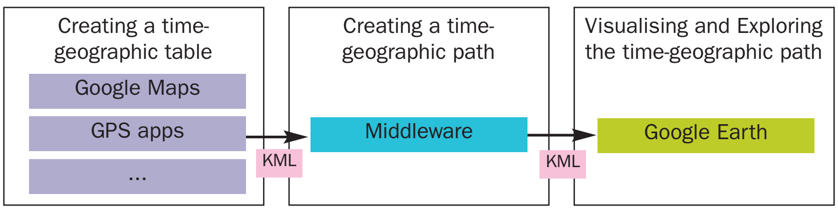

Figure 1: *TGIF system configuration. Note: KML denotes Keyhole Mark-up Language.*

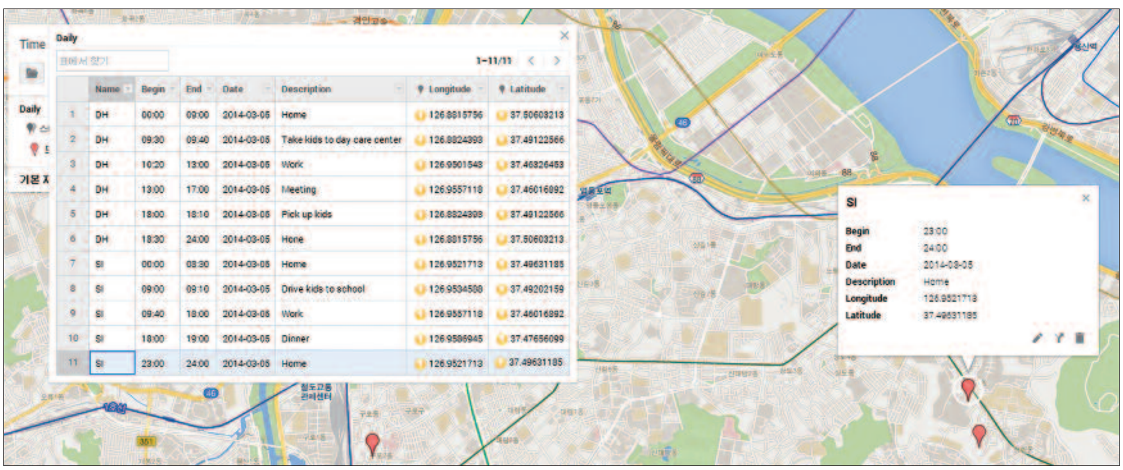

Figure 2: *Time-geographic table creation in Google Maps.*

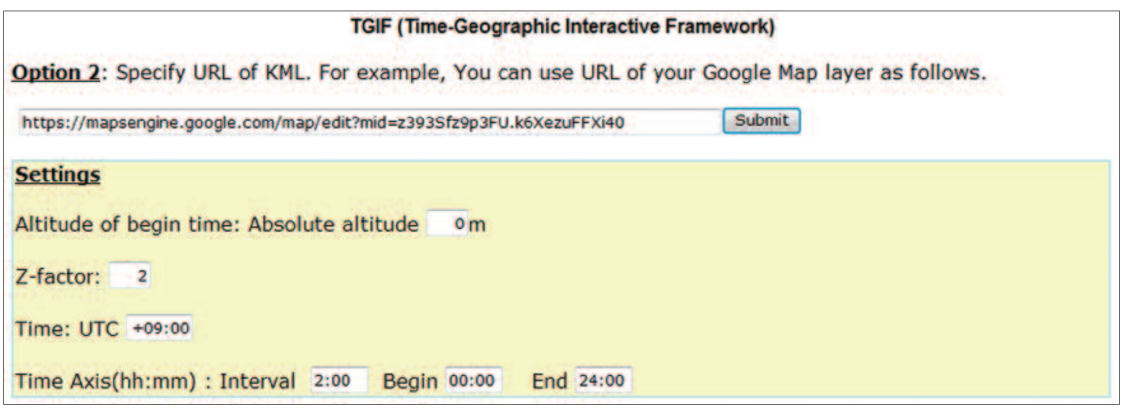

Figure 3: *TGIF middleware user interface.*

GIS platforms for emotional geographies

Geographers have focused on emotion as a significant lens through which students perceive the world (Davidson and Milligan, 2004). As Anderson and Smith state, 'the human world is constructed and lived through the emotions' (2001, p. 7). Therefore, understanding emotions is critical to examine 'how lives are lived, histories experienced, geographies made and futures shaped' (Wood and Smith, 2004, p. 533). Grasping emotional perceptions does not simply involve describing subjective responses; it also involves revealing event contexts, because it is through our emotions that we mediate spatial, social and cultural worlds (Bondi *et al.*, 2005).

Dowler (2002), for example, examined the relationship between emotion and space. First, the researcher described a scenario to American students in which a patient was in critical condition and asked the students whether they would take the patient to a hospital. The student responses differed depending on their location. Specifically, when the students and patient were assumed to be within the USA, the participants reported that they would be willing to take care of the patient. However, the rate of this response dropped dramatically when the participants were assumed to be in Bolivia. In essence, the same scenario presented in different locations induced different emotions (including feelings of unfamiliarity and insecurity in Bolivia), and the students' emotional states caused different reported behaviours. Researchers have noted the importance of emotion in diverse contexts, such as cultural heritage landscape maintenance in Australia (Kearney, 2009), and photographic interpretation (Rose, 2004).

If we accept that emotions play a significant role in shaping our perceptions of the world, geographers must develop methods to examine these processes. Kwan indicates that: 'if the world is imbued with complex emotional geographies, geospatial technology practices are more relevant to real lives if they allow us to take the spatial, temporal, and social effects of feelings into account' (2007, p. 24). In this regard, Kwan and Ding (2008) developed a framework for combining the analytical functions of GIS with narrative analysis tools. A participant's emotional narrative can be incorporated using narrative tools that are supported by GIS time-geographic visualisation. Because these tools utilise commercial GIS software packages and narrative tools this approach is costly. However, using the TGIF described above, students can create time-geographic paths at virtually no cost and embed emotional responses using the mash-up function. As shown in Figure 5, different colour schemes can also be used to express different' emotional states at different points (e.g. red for joy), and relevant images sketches and voice clips can be incorporated into the visualisation to indicate, vividly, the creator's emotional responses along the time-geographic paths. Thus, the TGIF offers an accessible GIS web framework in which students can construct and explore their emotional geographies.

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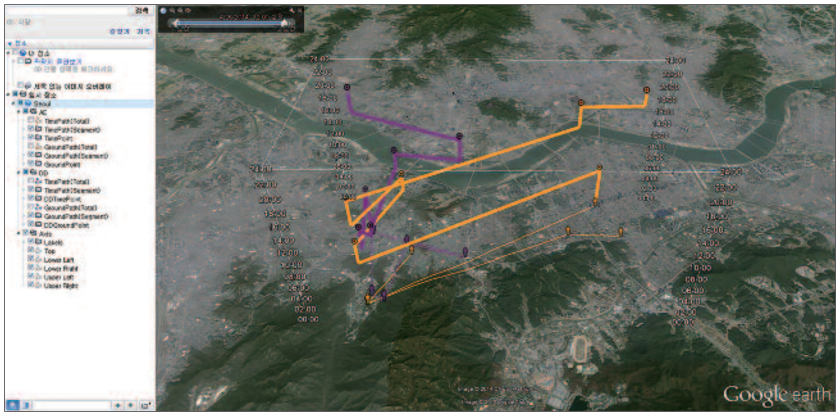

Figure 4: *Time-geographic rectangle created using the TGIF.*

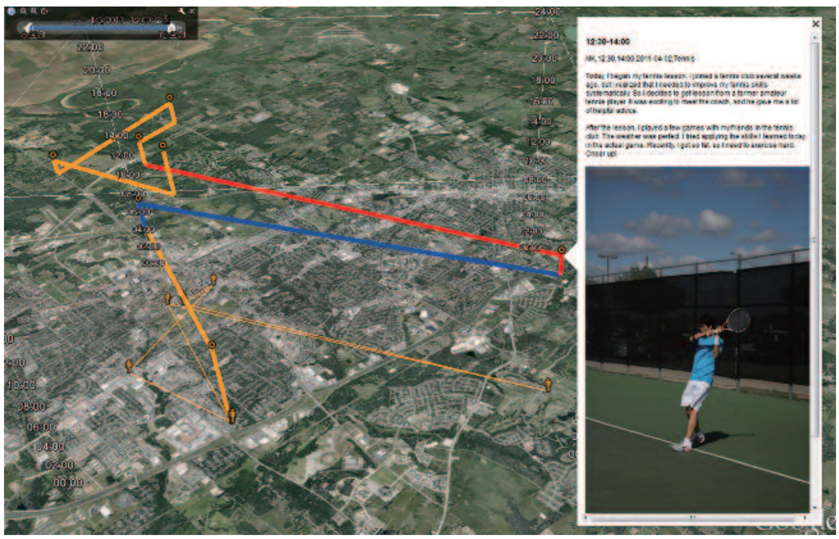

Figure 5: *Interactive TGIF mash-up.*

Visualisation in environmental education

With respect to applications of the TGIF in environmental education, we draw attention to a study by Tani and Surma-aho (2012) which combined the concepts of time geography and environmental activities. The researchers asked students to observe their environments and to construct a visual diagram that indicated their time-spatial paths through narratives. Students created diagrams using the Microsoft PowerPoint software or by hand. Through this activity, students carefully observed their environments and, in turn, noticed

certain aspects of their surroundings that they had not previously noticed. The student-generated, time-geographic diagrams can be regarded as visual narratives (Bach, 2007), which involve constructing knowledge and gaining meaning by visualising daily experiences with stories.

At the time of Tani and Surma-aho's study (2012), no adequately tailored geovisualisation tool for students to create time-geographic paths was available. If those researchers had access to the TGIF, the question arises: could those students' observations have been more effectively visualised? We would argue that, using this tool, students can include information on locations, movements, relevant environmental images and narratives. Furthermore, students can export their data as KML (or the zipped version, KMZ) files. Thus, even novices to the Framework can share their experiences with others, which enables teachers to extend class discussion activities. Specifically, each student could record their daily observations and incorporate them into the TGIF. The teacher could gather the data and visualise all of the students' data in class. (As shown in Figure 4, numerous paths can be simultaneously visualised and interactively explored in the TGIF.) Thus, students can compare their daily movements and activities with those of others, enabling discussions on various topics regarding environments observed and the times they were observed, potential differences between environmental boundaries between students and the typical lived environments occupied by them. Through this, students may come to understand concepts of time geography and its relationship to environmental education through the context of their own experiences. The TGIF offers a dynamic learning platform through which students can create their own data, thereby extending and diversifying pedagogical activities.

Small-scale survey

After using the TGIF themselves, a group of undergraduate students (n=14) in the Department of Geography Education at a large university in Seoul in South Korea gave their opinions on its usability. We introduced the TGIF functions and demonstrated its use to the students. Then, the participating students were asked to experiment with the tool for one week, and create their own time-geographic paths for practice. Finally, the students submitted their opinions regarding the usability of the TGIF. We used a thematic analysis to evaluate their responses. Three themes identified in the student responses are described here.

Meanings of the visualisations

The participants understood the meaning of their TGIF visualisation. The students grasped that their time-geographic paths are not a trivial description of their activities. They recognised that the TGIF visualisation can have implications for understanding wider social meanings of individual movements. Their comments included:

> '*I compared my TGIF visualisation with those of my friends and came to the conclusion that the different boundaries were related to different extents of power or influence. My spatial boundary does not extend beyond the university campus. However, what would the TGIF visualisation of a diplomat look like? It should be wider and more dynamic.*' (Student A)

> '*I created my individual daily time-space paths. However, the applicability could be widened. I think that the TGIF visualisation can play a role in understanding various social groups. For example, an ever-increasing number of foreign workers pose critical social issues in contemporary Korean society. Using the TGIF, we can visualize the places where foreign workers frequently visit and at what time. Their daily activities can be incorporated in this framework. Through this visualisation, we can understand what social activities are conducted by foreign workers and whether they adapt to Korean society.*' (Student B)

TGIF for fieldtrips

The participants noted the usefulness of the TGIF for visualising fieldtrips. These responses may be due to the fact that the participants were geography education majors. The students noted:

> '*The TGIF is a useful tool for geography students who frequently participate in fieldwork. The TGIF makes it possible to more clearly and holistically visualize field sites.*' (Student C)

> '*The TGIF visualisation can be helpful for understanding fieldtrip routes. Whenever I do fieldwork, I take a note of what I learned at a specific place and time. If I do this using the TGIF, I can record my fieldwork with text explanations, photos, and videos. This would help to more clearly understand my trips. Furthermore, the tool would make it easier for me to maintain records.*' (Student D)

Usability for other age groups

The participants reported that the TGIF was easy to use and could be employed at the secondary education level.

'*I enjoyed using the TGIF. With basic computer knowledge, anybody can easily use the tool. For the public, Google Earth has been perceived as a tool for only viewing 3D images of the Earth. However, the TGIF enables students to use Google Earth for more interactive and diverse purposes, such as a digital diary.*' (Student E)

'*When I was a high school student, my geography teacher asked us to draw a map of surrounding areas. If the TGIF were used for this type of activity, students would show more interest and produce vivid descriptions of their local communities. I hope the TGIF is incorporated in geography classrooms at the secondary education level as soon as possible.*' (Student F)

'*I believe that the TGIF has the potential to be employed in geography classrooms at the secondary education level because it is based on a well-known, easy-to-use program, Google Earth, and does not require other software. Young students are attracted by interactive programs like Google Earth. If mash-ups of video clips or photos are also used, students would like the TGIF activities.*' (Student G)

To summarise, the participating students perceived the TGIF as a useful and easy-to-use tool. It offered these students opportunities to observe their everyday lives and surroundings in relation to wider social meanings. The TGIF was also seen as an effective tool for visualising and recording fieldwork. Finally, the participants believed that TGIF could play useful a role in secondary geography education.

Conclusion

The time-geographic visualisation tool 'TGIF' uses Google Maps and Google Earth as its main platforms because they have been widely adopted in educational settings. Thus, teachers and their students are unlikely to encounter a steep learning curve or master difficult techniques in using the tool for the first time. Nor will institutions need to invest in costly software and hardware in order to run it. The TGIF is powerful in that it allows students to employ various types of data, such as text, images and audio information, to interactively construct and explore time-geographic paths. We argue that the TGIF is versatile because its use can be extended to research a variety of topics.

The small-scale usability survey, reported here, indicates that undergraduate students see the TGIF as an effective tool for visualising time-geographic paths and understanding relevant social meanings. The participants of this survey (geography education undergraduates) noted the usefulness of the TGIF in recording their fieldwork. Finally, the participants thought that, because of its easy-to-use interface and motivating outputs, the TGIF could be employed in geography classrooms at the secondary education level.

We would argue that further empirical research could be conducted to illustrate the utility of the TGIF, and the objective of our future research is a more systematic investigation of TGIF uses to increase the package's versatility. We plan to extend the use of the TGIF to a broader range of sample populations, including secondary school students. We also intend to investigate the benefits of the tool in emotional geographies and environmental education. Finally, we will devote further effort to refining the TGIF interface and functions to render them yet more user-friendly and powerful.

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