Supporting Creativity and Appreciation of Uncertainty in Exploring Geo-coded Public Health Data

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Keywords

Epidemiology, creativity, geographic information systems, visualization, public health

Summary

Background and Objectives: We present a prototype visualisation tool, ADVISES (Adaptive Visualization for e-Science), designed to support epidemiologists and public health practitioners in exploring geo-coded datasets and generating spatial epidemiological hypotheses. The tool is designed to support creative thinking while providing the means for the user to evaluate the validity of the visualization in terms of statistical uncertainty. We present an overview of the application and the results of an evaluation exploring public health researchers' responses to maps as a new way of viewing familiar data, in particular the use of thematic maps with adjoining descriptive statistics and forest plots to support the generation and evaluation of new hypotheses.

Methods: A series of qualitative evaluations involved one experienced researcher asking 21 volunteers to interact with the system to perform a series of relatively complex, realistic map-building and exploration tasks, using a 'think aloud' protocol, followed by a semi-structured interview The volunteers were academic epidemiologists and UK National Health Service analysts.

Results: All users quickly and confidently created maps, and went on to spend substantial amounts of time exploring and interacting with system, generating hypotheses about their maps.

Conclusions: Our findings suggest that the tool is able to support creativity and statistical appreciation among public health professionals and epidemiologists building thematic maps. Software such as this, introduced appropriately, could increase the capability of existing personnel for generating public health intelligence.

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Methods Inf Med 2010; 49: ■–■
doi: 10.3414/ME09-01-0070
received: August 17, 2009
accepted: February 19, 2010
prepublished: August 5, 2010

1. Introduction

When considering the ways software might support creativity, Shneiderman [1] commented that "*The old computing was about what computers could do; the new computing is about what users can do*". This user-focused philosophy has informed the ADVISES (Adaptive Visualization for e-Science) project, in which we have been working with epidemiologists and public health professionals to understand the problems they face in exploiting large, geo-coded datasets and investigating the ways in which visualisation might support exploration of such datasets. In particular, we have focussed on the use of geographical information systems (GIS) in public health research and practice, exploring barriers to the uptake of visualisation software, considering both technical problems such as the complexity of GIS software for occasional users and attitudes within our target community concerning the use of visualization as a technique. Based on this analysis, we developed a prototype tool for rapid, interactive creation of public health maps to facilitate geographical exploration of datasets and thus provide support for users in generating spatial epidemiological hypotheses.

In this paper we discuss the importance of creative thinking in addressing the challenges facing epidemiologists exploring spatial patterns. We reflect on the current use of GIS software in public health research and practice, and the nature of software designed to support creative thinking. The paper presents an overview of the ADVISES visualisation tool and reports on a series of formative evaluations carried out in collaboration with academic epidemiologists and public health practitioners in the UK National Health Service (NHS) and which have helped to refine and evolve it.

1.1 Creative Thinking in Epidemiology

Data collection can be the most expensive and time-consuming stage of epidemiological research. However, improvements in routine data collection by organisations such as the NHS and open access to government-curated resources such as the Health Surveys for England [2] mean that overwhelming amounts of data are now available. These developments are a typical example of what is often referred to as the "data deluge" in science [3]. This is changing the ways in which scientists do research; in particular, it is encouraging the use of data-driven or algorithm-driven approaches where, instead of forming hypotheses and then looking for confirmatory evidence, data is mined for possible lines of enquiry [4].

In epidemiology this has sparked interest in the use of visualisations for exploring datasets and discovering hypotheses. Working in collaboration with epidemiologists, the ADVISES project has been investigating ways to quickly and easily generate simple interactive maps that can be incorporated early into public health analytical processes.

Epidemiologists are today tackling ever more complex concepts of causality, often involving diverse sets of factors. At the same time, the availability of geo-coded extracts of health records and health surveys is increasing. As spatial factors are related to many other determinants of health, there is a need for thought-provoking and interactive visualisations to help epidemiologists explore concepts and data fully – blending abstract reasoning with systematic statistical processing. We have chosen to focus on geo-visualisation, but the principle of supporting both creativity and statistical appreciation applies to other areas of complex, data-rich epidemiology too, for example, genomics.

Saxon's discussions about the promotion of creativity in epidemiology are particularly pertinent to our study [5]. While Saxon focuses on the personal characteristics of researchers and the academic processes associated with epidemiological research (for example, peer-review of new study plans), he also stresses the need for new ways to look at existing data, bringing in ideas from other domains and sources, and making use of new technologies.

1.2 GIS and Epidemiology

There have been many reports of uses of GIS tools within public health research and the potential of such visualisations to enrich epidemiological thinking [6]. However, a number of challenges and concerns prevent wider uptake: a US review of the use of GIS by public health practitioners [7] identified problems associated with accessing GIS tools, including expense and complexity, as well as technical problems such as software inaccuracies and difficulties in obtaining precise local geographic data; other concerns about data confidentiality and risks of misinterpretation have also been reported [8].

Jacquez acknowledges the contributions of GIS to epidemiology, noting, in particular, that it has been used effectively for the characterisation of populations and development of models [9]. However, he observes that there has been more focus on descriptive than causal epidemiology – epidemiologists are answering the questions technology allows them to answer, rather than redefining the technology. His proposed solution is the development of GIS specifically designed for epidemiology, incorporating time into models as well as place. Indeed, several epidemiology specific GIS applications exist (e.g. [10, 11]), but these still require specialist skills (for example the need to supply the appropriate geographic boundary files for the region of interest), and provide limited interactivity.

1.3 Designing for Creativity

The human computer interaction (HCI) research community has long been interested in understanding how software tools can aid creativity. Shneiderman [1] identifies three schools of creative thinking – structuralist, inspirationalist and situationalist. The structuralist mode emphasises a planned methodical approach, ordered progress is the key to finding new ideas. Discoveries are made by progressively testing out a series of variations, documenting each small step and being aware of limitations and warnings within the data. The priority for inspirationalists is the Eureka moment, creating conditions in which data can be seen in new ways, focussing on lateral thinking and finding new and unexpected associations through new interactions. The situationalist view is that communities are the key to creativity; challenges and support from mentors and colleagues are crucial to the development of new ideas.

These alternative perspectives suggest software features that are likely to encourage creativity: a tool that enables the user to track progress and store ideas and developments, and identify gaps in their thinking, software that can provide alternative ways of looking at familiar data, and enable the user to find the aha! moment, and then to share that thinking with colleagues and mentors.

1.4 The Prototype ADVISES Visualisation Tool

The ADVISES project is working with a group of epidemiologists to develop visualisation tools to support public health decision-making based on epidemiological analyses. It was clear that the epidemiologists considered GIS tools to be potentially useful, but often too time-consuming and complicated. They also expressed concerns around the dangers of misinterpretation of spurious spatial patterns.

The project focussed on understanding the ways in which epidemiologists make decisions about maps, using a combination of requirements analysis techniques, including observation of individuals and meetings, interviews, paper-prototyping and scenario development (see [12] for a detailed account). From our explorations it became clear that a key reason for the epidemiologists' reluctance to use GIS was the general lack of support offered by standard software for exploring the statistical properties underlying the graphical representations. This lack of support may lead to gaps between observing particular patterns in the presentations, ensuring that those patterns correspond to meaningful structures in the data and being able to explain what those patterns mean. These gaps were referred to by Amar and Stasko [13] as the "rationale gap" and the "worldview gap" respectively. Our epidemiologists pointed out the dangers of misinterpretation associated with these gaps [14, 15] and outlined the types of accompanying statistics they would want to review alongside a map, in order to be confident the map was statistically meaningful. They also described

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frustrations associated with tedious routine map building work, such as acquiring the necessary shape files for specific geographies and accessing databases that enable translation between different geographies for a given set of geo-codes.

Consequently, while investigating ways to make maps easier to generate, we have combined the maps with other visualizations and statistics to aid the user in assessing whether a pattern is more than random noise. For thematic maps, charts and summary statistics are presented alongside the maps to reflect the uncertainty over regions or categories being significantly different from one another. Regarding continuous variables: to help the user choose an optimal number of categories, the distribution of the data behind the theme (say, body mass index) is shown as a histogram with summary statistics below it – cut-points for the theme categories are calculated automatically – and the user can switch between three, five and seven categories, or the user can place specific cut points along the distribution across the range of data values under the histogram. To show the statistical separation of geographical areas coloured with a theme category a forest plot [16] is displayed, giving the user a quick overview of the data for each area. An example forest plot is shown in the left-hand panel of ►Figure 1. For each area, the mean and its 95% confidence intervals for the theme variable are shown as a square with extended bars, while the relative size of the square gives an indication of the relative size of the sample or population.

An important motivation in the design of the ADVISES tool was the promotion of creative thinking, providing alternative views of data, tempered with enough supporting statistical evidence to allow users to make judgements about the validity of the visualization. At present, the tool provides features which map most closely to the structuralist and inspirationalist schools of creativity. Inspirationalists focus on the need for new ways to view and interact with data. The tool provides a quick and simple way to make a map – a dataset containing 500 post-/zip-codes can be turned into a map in around 2–3 seconds in a single operation. This ease of use provides a very

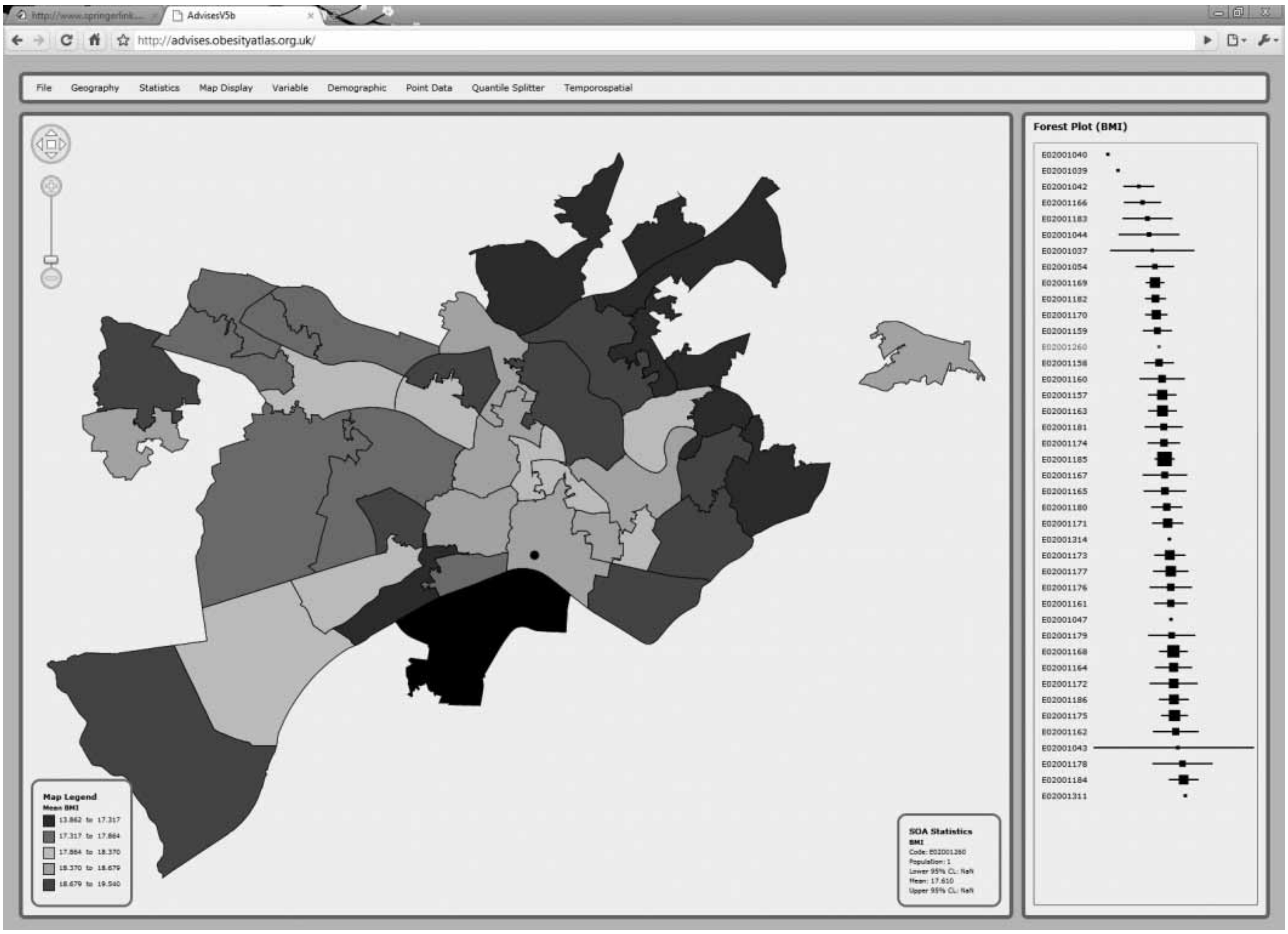

Fig. 1 Screenshot of the ADVISES prototype tool. The map is displayed in a central panel, map controls in the left-hand panel, and the right-hand panel is used to show either a histogram of the theme variable and some descriptive statistics or a forest plot providing a breakdown of the theme variable by map region (shown here). The user has highlighted a row of the forest plot that appears to have a very small population and the corresponding region is indicated in black on the map.

quick way to get a new view of a dataset, while the accompanying forest plot provides an alternate view, dissecting the data by geographical area. Interactive sliders and check boxes let the user modify the map, for example, viewing only males or switching to a new theme variable, allowing changes in the map dynamically to appear.

Structuralist approaches to creativity focus on process and regard for limitations within a dataset. It is easy to make small, incremental changes to the map, and accompanying statistics warn the user of potential invalidities within the map. The ability to save a map, along with descriptive statistics and a list of the parameters currently in use allows the user to track their work.

At present we have not addressed the situationalist approach to creativity – for example, our system does not yet provide support for the sharing of maps between users. While we would like to provide a pool of shareable maps, and allow users to ask questions such as "Show me all maps of North Western England which address childhood obesity", to do so we must first address concerns around privacy and security of personal data[a].

2. Prototype Implementation

The tool has being implemented in Microsoft Silverlight (using C#) to provide a rich graphical environment which supports animation and interaction between components rendered in a web browser. It provides the following functionality:

- *Dataset loading and checking:* loads datasets, carries out initial validation (checking for missing values, incorrect postcodes, etc.).
- *Map displays:* loads geographic shape files and displays maps. Map displays can be overlaid so point data (e.g., location of health clinics, sports facilities, etc) can be displayed.
- *Charts and statistics displays:* runs statistical analysis scripts then displays results in a variety of visualizations, including range split histograms, box-and-whisker plots, etc.
- *Dialogue management:* handles the query interface, interactive query-by-pointing and sliders.
- *Expert advisors:* statistical and visualisation advice, with dataset monitors to trigger warnings.
- *Annotation tagger:* provides for pick lists of terms from a controlled vocabulary of epidemiology which can be associated with map and chart output. The map can be saved as an image file along with predefined tags, system parameters and free-form text comments. The prototype was developed over the course of approximately eight months, by one developer.

[a] The prototype has been designed for use within a trusted public health environment with appropriate information governance.

3. Methods

3.1 Evaluating the ADVISES System

The Advises project has adopted an iterative, user-centred approach; evaluation by users is integral to the design and development [17]. So far, we have carried out a series of three formative qualitative evaluations, investigating user reactions and experiences of the prototype. Users were asked to carry out a pre-defined series of tasks in order to explore whether they were able effectively to engage in data exploration and model building. The intent was to investigate user responses to:

- maps as a new way of viewing familiar data, and a trigger to hypothesis generation;
- the use of thematic maps with adjoining descriptive statistics and forest plots to support the generation and evaluation of new hypotheses – helping to answer the question "Is this a real pattern or an artefact of the visualization?";
- responses to the use of interactivity, such as sub-setting of data and switching between larger and smaller geographic areas as ways of identifying patterns.

3.2 Participants

Twenty-one participants have been involved in the series of evaluations to date, 8 male, 13 female; 8 academic epidemiologists, 13 NHS Primary Care Trust analysts. Only one of the epidemiologists had any previous GIS experience. Most of the public health analysts made use of maps produced by colleagues with GIS training but only one analyst regularly made use of GIS tools. A snowball approach to recruitment of academic epidemiologists was used – initial participants were recruited via ADVISES team member contacts and each one was asked if they knew of other colleagues who might make use of geographical information in their work. NHS analysts were contacted via a local public health analysts network.

3.3 Method

Users were asked to interact with the tool to attempt a series of relatively complex, realistic map-building and exploration tasks. We used a "think aloud" protocol [18], a technique widely used in software development in order to gain detailed insights into user reactions to software: users talk as they carry out tasks, describing what they have seen on the display, what they were looking for, explaining what they were thinking, or were trying to achieve. After completing a set of tasks, users were interviewed to explore issues encountered during the evaluation and gauge their reactions to the system. Notes were taken during the session by the experimental facilitator, and, if the participant consented, the think aloud session and interview were audio recorded.

The tasks were developed in conjunction with an epidemiologist to ensure realism and carefully designed so that they would encourage participants to investigate different aspects of the tool, without spelling out instructions or explaining exactly how it was intended to work. Similarly, participants were given a brief introduction to the purpose of the ADVISES system, but were not given detailed instructions in its use, in order that we could understand the usability of the system. The tasks and interview were designed to take approximately one hour in total, though participants were told they were free to take as long as they wished over each task and in exploring the tool, and to let the session

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facilitator know when they felt they had completed the task as far as they were able to. It was made clear to participants that it was the tool that was being tested, rather than their abilities, and that if they found difficulties in completing a task that was a reflection of a problem with the design.

During each round of evaluation users were given an initial map building task, plus two or three more complex tasks focussing on their interaction with particular aspects of the system, such as the use of the forest plot to evaluate which map regions should be excluded due to low population or determining the appropriate level of geographic aggregation for a given dataset. The wording of the tasks can be found in ►Table 1.

In rounds 2 and 3 a semi-structured interview was carried out after the tasks were completed to explore participants' experiences of using the tool. This was also an opportunity to clarify any questions we had about participants' behaviour during the tasks, as well as allowing them to ask questions about the tool. We also investigated whether participants felt the tool might be useful in their work, and asked whether there were other features they felt were missing.

4. Results

►Table 1 presents an overview of the tasks each participant was asked to carry out at

Table 1 Summary of tasks and outcomes

Round 1	**Map creation**	**Map evaluation – categorisation**	**Map evaluation – small area problem**	**Map evaluation – using forest plots**
	You are a public health analyst for the (fictional) Greater Heaton PCT. You are interested in looking at BMI in year 6 (age 11 years) children in your area. Make a new map based on the Middle Layer Super Output Areas, and using your first data set. See if you can spot any general patterns when you look at maps for males only, females only and both together.	You are also interested in obesity levels in Reception Class (age 5 years) children. Create a new map using your second dataset, looking at Local Authority areas, and review the way the data has been split into categories. Consider the effects of increasing or decreasing the number of categories.	You have noticed a 'hot spot' in one region of your Reception Class map which appears to have higher levels of obesity. Investigate whether or not this looks like a genuine hotspot.	You have a third dataset, which provides details of new diabetes cases across your PCT for 2007. Create a new map, using this data and based on the Middle Layer Super Output Areas. Review the mean diabetes levels for each of the Super Output Areas – do you think the areas are correctly coloured?
Success	**5/5**	**1/5**	**3/5**	**2/5**
Round 2	**Map creation**	**Map evaluation – using forest plots**	**Map evaluation – boundary changes**	
	You have just received a new dataset and want to use the Advises system to give you an overview. Start by having a look at the overall distribution of BMI within your data and decide if it looks normal.	You would now like to review the BMI distribution for each middle SOA. Create a graph that gives you a breakdown of the statistics for each individual region.	Finally, create a map which illustrates the distribution of BMI at middle SOA level, and save a copy of this map to your desktop.	
Success	**8/8**	**6/8**	**8/8**	
Round 3	**Map Creation**	**Map evaluation – use of forest plots**	**Map evaluation – use of categories, ethnicity and age**	
	You have recently received a dataset from Littlegrange Primary Care Trust containing height, weight and BMI measures for Reception class (age 5) children and year 6 (age 11 years). The dataset has been cleaned and you want to use the Advises system to get a quick overview. Make a new map showing BMI based on Lower Super Output Areas.	You are concerned that not all the schools in Littlegrange have returned complete sets of measurement data. Are there any areas of Littlegrange you would exclude as under populated?	One of your colleagues at the PCT has commented that whilst cleaning the data they think they've noticed a trend for Asian boys to be more likely to be underweight when starting primary school, but overweight by the time they leave. Can you see any evidence to support this hypothesis?	
Success	**8/8**	**7/8**	**6/8**	

	Round 2 responses	Round 3 responses
What were your first impressions of the system?	5 positive 3 negative	6 positive 2 negative
Did you find the system easy to understand?	7 positive 1 negative	7 positive 1 negative
Did you enjoy using the system?	8 positive 0 negative	8 positive 0 negative
Do you think this is a system you would use in your job?	7 positive 1 negative	5 positive 2 possible 1 negative

Table 2 Summary of participants' responses: Interviews were transcribed and the participants' answers coded as positive, negative or neutral.

different stages of the evaluation and a summary of the success rate for completing those tasks. ►Table 2 presents a summary of responses to the semi-structured interviews.

5. Discussion

During each round of the evaluation, all participants quickly and confidently created their first map and, without being asked to do so, went on to explore the map, looking at trends, subdividing data into smaller categories, e.g., males and females, switching between geographic boundaries, and then reviewing the associated statistics to help them understand the significance (or otherwise) of observed patterns. Participants found the combination of geographic visualization and descriptive statistics powerful and easy to explore:

- "*I love stuff like this; it's nice having the descriptive stats, when you put data into [commercial GIS package] it can be misleading.*"
- "*It's really easy to figure out; it's at your fingertips.*"

However, during the first evaluation it became clear that the majority of participants struggled with a number of features, including the ability to split a variable range into quantiles, interpreting forest plots and identifying the appropriate geographic level at which to work. To some extent, these issues were a consequence of functionality that was difficult to use or to find, the forest plots proved particularly problematic because most participants were unfamiliar with this mode of data presentation (only one participant commented on having seen something similar before). Following this discovery, the use of forest plots was reviewed with analysts. It was concluded that the forest plots could potentially provide a useful overview of the validity of a dataset but that the current implementation was confusing and not well linked to the map regions. Thus the tool was redesigned to include a simplified version of the forest plot with improved labelling of regions, as well as other revisions based on the results of this evaluation. The improved success rates for the use and interpretation of forest plots in the second and third rounds of the evaluation indicate this redesign was useful.

After working through the set of tasks users were asked about their experiences of the system. The majority of users felt their initial experiences of the system were positive, but some users felt that, although they had successfully created a map, the system was not welcoming:

- "*It's very blank and a bit unfriendly looking. Once the data is in it looks much better.*"
- "*It's not clear where to start, there should be a big 'start here' sign.*"

These comments led to a redesign of the initial map creation process, this redesign was evaluated in round 3, and further mixed reaction to the redesign has led to additional design changes to be tested in the next round of evaluation. Thus, each round of the evaluation directly influences the next iteration of design and development.

The language used by participants suggests they were engaged with the tool, describing it as '*fun*', '*novel*', '*colourful*', '*innovative*'. This reinforces our observation that participants generally spent far longer exploring the system than any of the tasks required them to – having completed the basic requirements of a task they went on to 'play' with their maps. Research into positive emotions and creativity [19] has shown that users who feel positive are better at creative problem-solving, and we consider users' enjoyment in engaging and exploring their maps an encouraging sign that the system could be a useful data playground for hypothesis generation.

Given that we are particularly interested in exploring whether our system could support hypothesis generation, it is interesting to note that, as subjects worked through the system, they began, unprompted, to volunteer explanations for, and hypotheses about, the phenomena they were observing, taking account of both the visualisation and the statistics, for example:

- [In response to noting that one area at the edge of the map only had one data point and should be excluded] "*That makes sense, because it's a long way from where most of the children live, maybe in that area more kids go to other schools outside the map.*"

This suggests that the combination of maps and statistics provides encouragement for creativity and idea generation. This vignette also illustrates a tendency for NHS analysts to make heavy use of local knowledge in interpreting maps, often incorporating information that is not encompassed by the dataset being analysed – the example used in the evaluation was fictional but constructed to look like a typical Northwest England region, with smaller, densely populated town and city centre zones surrounded by suburbs and large sparsely populated rural regions. All of the analysts provided hypotheses based on their expectations of the demographics of these types of areas, and this suggests that the ability to overlay additional local features, e.g., transport networks, would be useful.

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6. Conclusions and Future Work

The ADVISES project demonstrates that there is a clear need and demand for new approaches to public health geo-visualisation. The results from our evaluation of the ADVISES prototype visualisation tool suggest that it is able to support creativity and statistical appreciation among public health professionals and epidemiologists building thematic maps and so is a significant step forward in understanding how to meet this demand for new approaches.

By making it easier to generate public health thematic maps, the prototype has removed one of the barriers to making use of maps for data exploration, namely the requirement to learn to use complex GIS software. Furthermore, by providing interactivity, descriptive statistics and meaningful visualisations to accompany the maps, users are supported in making interpretations of maps while reflecting on the underlying uncertainty.

The prototype was evaluated positively, with epidemiologists and public health practitioners welcoming an alternative way of interacting with geo-coded data, and recognising the value of the system as a way to generate hypotheses. Participants also suggested ways in which the tool could be developed further, these suggestions are being incorporated into the next iteration of the design (▶Fig. 2).

It is particularly encouraging that all of the participants expressed a wish to be kept informed of future developments and are willing to test future versions of the tool.

Most of the public health practitioners in our study area (Greater Manchester, UK, 2.5M population) work in small, locality-based teams (primary care trusts or PCTs), and meet together across localities each month for continuing professional development activities. They welcomed the idea of sharing maps: a thematic map built for one PCT is often of interest to others, for example, looking at whether an intervention adopted by one PCT has been successful and might be useful in other regions. Clearly, the professional and social networks of public health practitioners could spread the load of creating thematic maps, then enable their sharing as templates for rapid localisation via ADVISES. The social

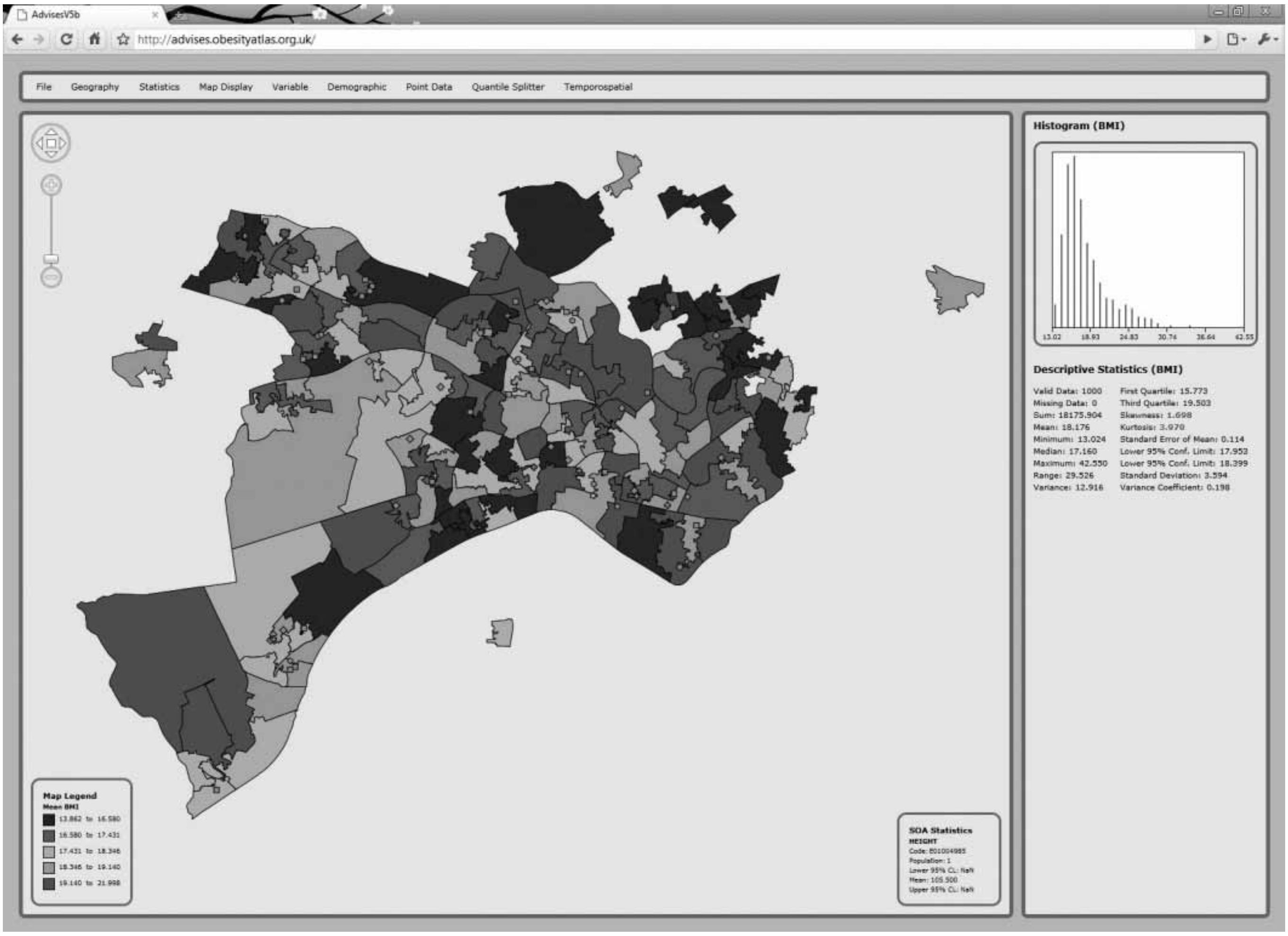

Fig. 2 Screenshot of the latest ADVISES prototype, incorporating new requirements discovered during the course of our evaluation with users. Users are interested in rich detail about their locality and requested the ability to add a second file containing the postcodes and names of locations of interest to a thematic map, the various categories of places, e.g. fast-food restaurants, supermarkets, are shown as different shapes on the map.

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networking of thematic mapping might support creativity by situated means, providing a focus for shared discussion and hypothesis generation.

We recognise the limitations of a short-term study such as this in exploring changes to working practice and evaluating whether people are genuinely able to be more creative. In this next phase we will use a series of diary studies and will work with users over a longer period of time to understand how the use of such systems might promote the generation of new ideas.

The implications of our current findings for public health and epidemiological practice are considerable. Public health professionals are struggling to cope with increasing demands for more population health intelligence from more sources of data and models [20] yet there are not the resources to employ more analysts, however, tools that can support creative and systematic reasoning for public health intelligence could increase workforce capacity with the same number of staff. For the epidemiologist, easier access to spatial visualisation of datasets could increase the objectivity with which hypotheses are shaped. Sharing such tools across academic and service settings could improve the management of spatial epidemiological knowledge for both health science and health service development.

Acknowledgements

The ADVISES project is funded by the UK Engineering and Physical Sciences Research Council under its e-Science Usability programme, grant number EP/D049989.

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