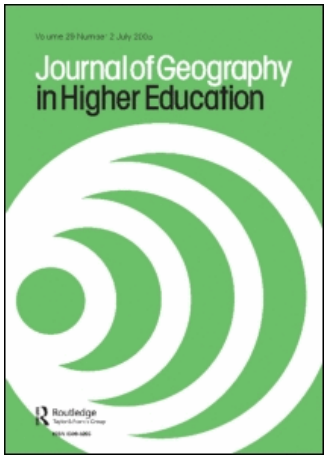

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Developing and Testing an Online Tool for Teaching GIS Concepts Applied to Spatial Decision-making

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ABSTRACT *The development and testing of a Web-based GIS e-learning resource is described. This focuses on the application of GIS for siting a nuclear waste disposal facility and the associated principles of spatial decision-making using Boolean and weighted overlay methods. Initial student experiences in using the system are analysed as part of a research project on teaching GIS concepts to large numbers of students with little or no prior GIS experience. Some general thoughts on the utility of Web-based GIS for learning and teaching are presented. Results from the first cohort of 167 undergraduate/postgraduate geography students using the system indicate that students find it easy to use, a useful aid to learning about the issues involved, and a thought-provoking exercise in Internet-based democracy.*

KEY WORDS: Web-based GIS, spatial decision-making, electronic resource, nuclear waste disposal

Introduction

The use of computer-aided learning (CAL) in higher education gradually increased throughout the 1980s and 1990s, partly in response to better access to computing resources (hardware, software and data), and partly in response to the need to teach more and more students (Timms *et al.*, 1997; Castleford, 1998). Since the advent of the Web as the favoured mechanism for the mass delivery of multimedia information, there has been a corresponding rise in the number of online teaching resources available. The history of this so-called "*e-learning*" revolution has been one that, by its very nature, is technology led as innovations in e-learning are inspired and enabled by innovations in information and communication technologies (ICTs).

The idea of e-learning is not new, however, with fanciful ideas about the future of learning going back as far as 1900 with electronic means replacing the traditional teacher–class–book set-up (Figure 1). Flights of fancy aside, learning and teaching is not something that can easily be automated, if at all. The traditional means of learning through the study of exemplars and solving of

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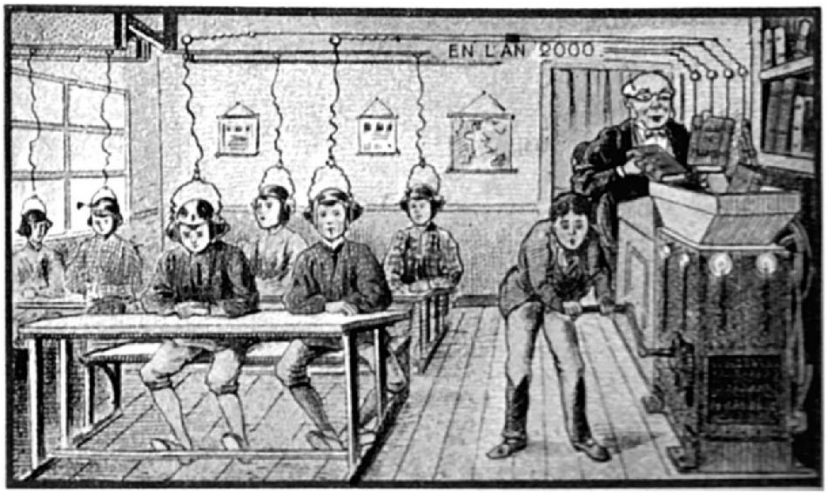

Figure 1. A frivolous French prophecy, dated *c.* 1900, of what teaching would be like in 100 years
Source: From de Bono (1974), reproduced with permission of Thames & Hudson.

problems (whether presented verbally or as text, sound, pictures, objects or practical exercises) has changed little since classical times, rather it is the mode of delivery that is changing in response to the rapid technological advances seen over the last 100 years; photography, film, radio, television, video, the computer and, most recently, the Internet. There are now a great many Internet-based tools and resources, ranging from online libraries and case studies to email discussion forums and interactive demonstrations, that have been set up in support of educational programmes, including both open distance learning (ODL) and more traditional face-to-face degree courses (Davies & Crowther, 1995; Castleford, 1998; Gardner, 2003). These take advantage of the power and flexibility of the Web as a means of delivery of educational materials, namely:

- rapid authoring and publishing of electronic material;
- delivery of a wide range of content type (text, pictures, animations, sound, video, etc.);
- non-geographically constrained '24/7' access allowing 'out-of-hours' entry from any location with Internet access;
- ability to deliver interactive content and instantaneous feedback;
- two-way flow of information from teacher to student and back.

It is normal to wag the finger of caution at this juncture and point out that e-learning resources should be seen as supplementary to and supporting of traditional methods rather than as a replacement technology (Wentz *et al.*, 1999). There are both advantages and disadvantages to the use of CAL, and more specifically, online learning resources (Newnham *et al.*, 1999; Lemke & Ritter, 2000; Spellman, 2000). While some of the advantages of power and flexibility are alluded to above, the corresponding disadvantages include:

- need for skilled development/maintenance staff;
- the potential for isolation (especially true for ODL teaching staff/students);
- over-reliance on technology and vulnerability to IT-related faults;
- increased opportunity for plagiarism and cheating.

Indeed, some studies have shown that, despite the claims of increased productivity in teaching and improvements in student learning (Davies & Crowther, 1995; Henry & Rafferty, 1995), CAL and its usefulness as an educational tool is poorly understood and can even be unpopular with students (Spellman, 2000). Nonetheless, the advantages are attractive and CAL continues to proliferate along with journals and services dedicated to helping teachers and students get the most out of these resources. This paper describes the development and testing of an interactive, student-centred online resource for teaching basic GIS principles applied to a practical spatial decision-making example without the need for experience in a particular GIS. It is first necessary to review certain aspects of the discipline, pedagogic drivers and enabling technology in this field.

GIS, CAL and the Web

The rise of geographical information systems (GIS), and more latterly geographical information science (GISc), as a research paradigm in geography has placed increased emphasis on quantitative methods, digital maps and spatial data in teaching and learning within geography. GIS is by definition a computer-based discipline and may therefore be regarded as fertile territory for CAL initiatives. The fact that GIS is a technical subject means that it generally requires that students possess a high level of skill with computers. In addition, tooling up for GIS teaching can be very expensive not just in terms of hardware and software, but also in terms of data and expertise in both GIS teaching and technical support. Nor is GIS wholly the preserve of geography departments. It is now part of the curriculum for a range of other disciplines from anthropology to zoology, though it is often taught on a purely conceptual basis for all or some of the reasons outlined above. While there are many CAL tutorial systems for GIS and these are not without their merits, they tend not to be fully interactive and rely largely on pre-cooked examples to demonstrate GIS methods with the result that student input and ability to explore concepts and practical problems interactively and in depth is limited. It is proposed here that Web-based GIS, developed originally as a research tool, and now available as a commercial software product, may well provide a solution to some of these problems. These systems can be adapted to give tutors and students access to a fully interactive GIS and selected datasets through the user-friendly medium of the Web browser without the need to invest heavily in hardware, software, training and support.

While several web-based GIS packages are available off the shelf from the big GIS vendors (e.g. ESRI's ArcIMS or Intergraph's WebMap), they tend to involve high server set-up costs, are focused on online map publishing and often lack the analytical functionality needed for teaching purposes. Bespoke software is often a much better and cheaper solution for academic and public use.

A good example of a decision-making problem in which the public has a vested interest and where Web-based GIS might play a role is that of where to site a new nuclear waste disposal facility (Openshaw *et al.*, 1989; Carver, 1991; Carver *et al.*, 1997). It may be safely assumed that few people would want to live next to such a facility and as such might wish to have access to full information about the site search process and, perhaps, have a say in where it is eventually built. This problem is used as an example later in this paper and has been developed as a case study in developing Web-GIS usable by the public (Carver *et al.*, 1997; Evans *et al.*, in press) since it provides students with an interesting example covering a

controversial topic in which Geography is a key element to the decision-making process.

A potential disadvantage of any Web-based GIS is that no one system can hope to approach the full functionality of existing standard (i.e. not Web-based) software packages. However, most Web-based GIS systems are designed to provide online access to digital map information or are focused on specific decision-type problems. As such, Web-based GISs do not require the full functionality of a standard GIS, rather they only require functionality that is relevant to the service provided or problem addressed. Taken in the context of learning and teaching of GIS principles, or more specifically in the context of this paper in regard to exploring the principles of GIS applied to spatial decision-making using map overlays, this 'focused' functionality can in fact be seen as a positive advantage in that it both streamlines system design and operation and additionally ensures that only the correct GIS procedures can be used for the required tasks.

Merging CAL and Web-based GIS for teaching purposes

When used in a participatory decision-making context, a well-designed and Web-based GIS may effectively address Monmonier's (1996) concern over the problem of lack of GIS skills and knowledge on the part of the general public by guiding the user through the data and relevant analyses with structured design and information prompts. The same can possibly be said for applications in the learning and teaching context, where the correct (and incorrect) use of a limited but focused set of GIS tools can be demonstrated through interactive experimentation without the need to pre-process datasets and learn the general 'housekeeping' details of any specific GIS package. Using this approach the student should be able to concentrate on the geographical problem to hand and the principles behind the application of GIS concepts and methods to its solution without undue distraction. Herein lies one of the underlying principles of CAL: that the application of IT to learning and teaching should enhance the learning experience of the student and the ability of the teacher to impart skills and knowledge, not reduce it.

The author's own experience of teaching practical GIS skills is mirrored by that of others (Hearnshaw, 1991, 1993) in that all too often the day-to-day practical 'at the keyboard' problems of using a GIS, including getting to grips with command syntax, file naming conventions, disk space limitations, file formats, projection systems, etc., will preoccupy students and teachers alike at the expense of learning and teaching applied concepts and methods, surely the very the reason for teaching GIS in the first place. It is suggested here that the use of Web-based GIS could significantly improve the learning and teaching of the principles of GIS by providing more students and their teachers with access to GIS software and datasets, and by focusing learning on theory, concepts, methods and application before (or in parallel to) hands-on practical skills with a standard GIS software package. This, it is proposed, should markedly improve the efficiency of the learning process.

The materials described below have been developed directly from research into Web-based GIS and are designed to support student learning about GIS-based environmental decision-making through the medium of the Internet (Carver, 1999; Kingston *et al.*, 2000). This means of delivery makes the product platform

and software independent and takes advantage of the highly interactive nature of the Web and the potential for creative two-way passing of information from tutor to student and student to tutor, even within large and disparate groups. The case study example focuses on problem-based learning, but could equally be used for other modes of student learning by populating the data space with new information, digital maps and other multimedia.

This work forms the basis of a research project aimed at evaluating the role of Web-based GIS in teaching core GIS concepts and substantive applications to large numbers of students with little or no prior experience of GIS and without the need for expensive GIS teaching laboratories. Although results from only one cohort are described, these are used to evaluate system and student performance, and will be used to improve further versions.

Case Study: Siting a Nuclear Waste Disposal Facility

The nuclear waste disposal case study described here is a classic site search and evaluation problem involving multiple stakeholders, multiple objectives and multiple, often conflicting, criteria (Carver, 1991). It is also a very contentious issue that will be of interest to everyone and should generate an enthusiastic and lively debate among students. A Web-based GIS for learning and teaching use has been developed based on existing research-based systems developed as part of the ESRC Virtual Society? Programme by the authors (Carver *et al.*, 2001). The system can be accessed using any Java-enabled browser from http://www.ccg.leeds.ac.uk/teaching/nuclearwaste/. The system incorporates background information on the problem of nuclear waste and its geographical context, an introduction to using the Web-based GIS and the datasets provided, the basic principles of applying Boolean and weighted map overlays to site-search problems, the GIS itself and a feedback questionnaire. The GIS element of the system essentially allows students to display relevant map data, perform map overlay operations and a multi-criteria evaluation (MCE) of potentially suitable areas using selected data layers, display and reclassify results to identify their best-choice sites and finally select a single site for feedback to the tutor. The tasks for the students using the system are to:

- research the issues involved using the online information system and associated Web links;
- explore the geographical dimension of the problem through the digital maps and metadata provided;
- experiment with possible solutions to the decision problem through different combinations (overlay) and weightings (multi-criteria evaluation) of data layers;
- formulate a siting decision based on the above and justify their choices/rationale.

The datasets required are based largely on UK Ordnance Survey digital map data provided through the online Digimap service (Parry & Fox, 1998) and include national (1 km^2 resolution) interpretations of terrain, coastline, road and rail network and protected area boundaries. Other data required include population distribution and basic geology maps. Some input-data layers for student use have gone through some necessary pre-processing, while others are provided more or

less in their raw form. For example, the population data are presented in two ways: as a population density surface (describing the number of people living in any one grid square), and as an interpolated distance and population weighted accessibility surface (describing the proximity to centres of population). Students are helped to recognize the difference between 'factual' data on the one hand (e.g. population density) and 'interpreted' data on the other (e.g. population accessibility), since the way map data are incorporated into an analysis makes a big difference to the decisions it is used to support. This is in itself a fundamental principle behind the application of GIS to spatial decision-making, in that different people will perceive and interpret the problem and its geographical context in different ways.

A client-side architecture is followed whereby all datasets (stored as simple GIF files on the server) and Java applets are downloaded to the client machine when the website is accessed. This makes the system extremely quick because there is no constant passing of instructions/information since all processing is done client side. This makes the exploration of and experimentation with the site-search problem through the medium of this particular Web-based GIS highly interactive and engaging since it allows students to see how their choices affect the maps generated almost instantaneously.

Background information, metadata, map displays and the GIS are all accessed through the Web pages. The initial background information pages give an introduction to the exercise and the problem of nuclear waste disposal followed by more detailed information on geographical aspects of the problem and the potential value of using GIS. These are sequential and are best read in order. These are followed by an introduction to the map datasets and the GIS interface. A user profile form is used to collect information on students using the system (e.g. gender, age group, postcode, highest qualification, etc.) that is used for research and evaluation. The GIS tools themselves are controlled using simple check boxes and slider bars rather than menus or command line syntax as in most standard GIS packages. The GIS interface is shown in Figure 2.

The check boxes are used to perform overlay operations (in Figure 2 the 'High Population Density' box has been checked to remove all highly populated areas from consideration using the equivalent of a Boolean NOT operation), while the slider bars are used to perform criterion weightings in an MCE analysis (the further to the right the slider is moved the higher the priority attached to the selected criteria, while sliders left at the far left get a zero weighting). The MCE method used here is a simple linear weighted combination model that sums the user-weighted standardized input maps to show a location's relative suitability while excluding selected areas by Boolean overlay (Carver *et al.*, 1997). The resulting map shows the excluded areas in black and the relative suitability of remaining areas along a greyscale with lighter shades being more suitable. In Figure 2 a further reclassification operation has been performed using the lower slider bar to 'top slice' the most suitable areas and highlight these in green (shown as dark grey in Figure 2). Here the user has picked at total of 6148 km^2 as representing the most promising areas.

A further task that becomes apparent to students working through the case study is the need to think at a strategic level about the kind of disposal option being pursued (i.e. deep disposal, near-surface disposal or long-term surface storage) as this choice inevitably affects their choice of geographical criteria.

Students and tutors may choose to run through the case study either as

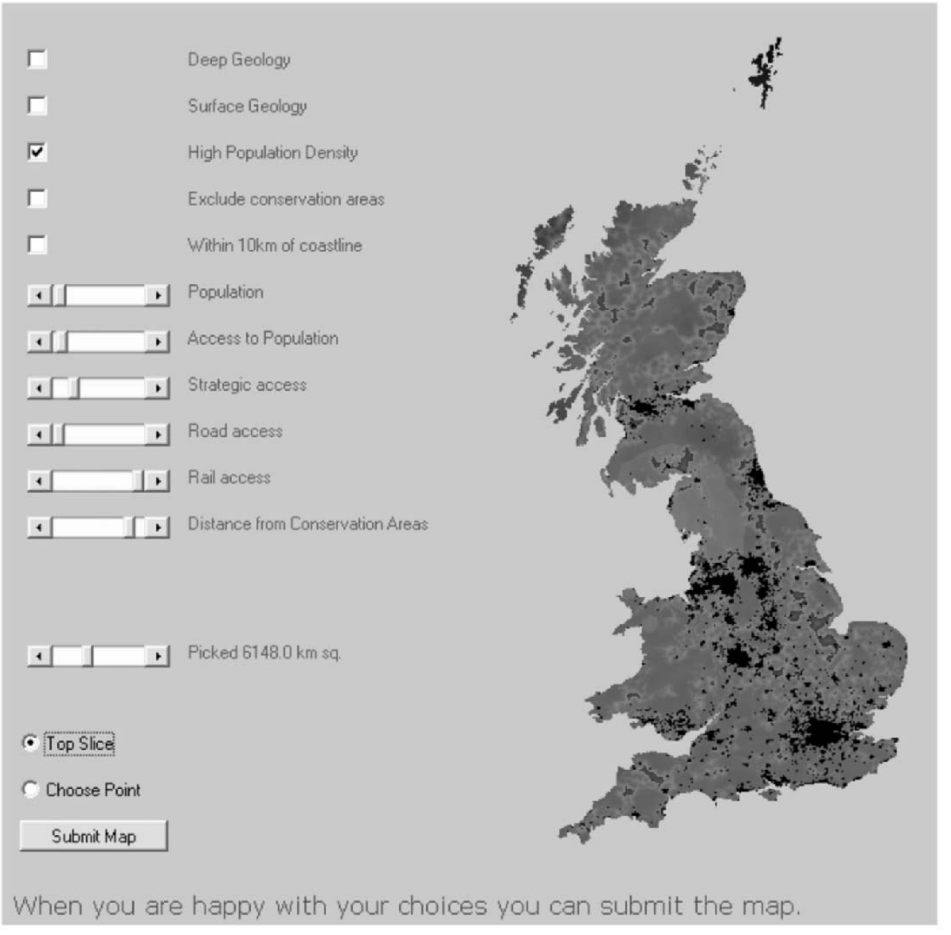

Figure 2. GIS interface

individuals or in groups. Group work allows greater exploration of the problem and issues through role-play. Essential skills in making good decisions can be learnt through practical role-play experience including problem scoping, consensus building, consultation and conflict resolution/minimization. In this mode it is envisaged that students (and tutors) will take on specific roles such as that of the nuclear industry, government, general public and environmental pressure groups. A downloadable student/tutor handout (in PDF format) suggests modes of use, and an online hierarchical help system provides more detailed information as required.

Suggested learning outcomes from the case study are as follows:

- experience in the use of generic GIS operations and digital map data to address a substantive application area;
- knowledge of a difficult environmental decision problem;

- hands-on practical experience of a decision-making process through independent and/or group work;
- understanding of the scope and range of digital map and other spatial data products;
- understanding of the visual (communication) and methodological (data handling and analytical) capabilities of GIS;
- appreciation of the power of GIS and spatial information in helping address environmental decision problems, especially those with multiple stakeholders and conflicting objectives;
- awareness of the possibilities of GIS in extending involvement in decision-making to the general public through the medium of the Internet.

A feedback questionnaire at the end of the case study is included as a way of gathering further information from the students on the nuclear waste disposal problem and the use of the system. These are an essential part of the system's continued development.

Scope for system customization

The source code for the basic GIS engine behind the system is called 'weighter' and is freely available to all academic users and can be downloaded from the Web (http://www.ccg.leeds.ac.uk/software/examples/applets/weighter/index.html). The weighter applet displays a greyscale image, which is generated by allowing the user to weight various different images/maps as per the nuclear waste example described above. This may be used for determining which of several factors influencing any spatial decision should be most important. The user can then choose locations on the image using various tools, and send them to the server for recording. Developers using this applet can populate the decision space with their own map data relevant to the problem they wish to address. The applet can be embedded in a series of web pages like the ones in the nuclear waste example that provide the student user with introductory material, information on the context of the decision problem and a set of tasks that go together to make an online tutorial or exercise. It is not possible for the student to populate the system with his/her own data, rather he/she concentrates on using the data provided and the principles of using GIS and spatial data for decision-making purposes.

A range of other applets for creating customized Web-based GIS learning and application resources are available from the Centre for Computational Geography, including tools for interactive map display using zoom, pan, query, comment, etc. and fuzzy entity definition using spray-can tools, drawing linked map/histogram displays, drawing and manipulating population/demographic pyramids, etc. (http://www.ccg.leeds.ac.uk/software/).

Results and Discussion

The Web-based GIS for exploring the nuclear waste disposal issue described above has been live tested with students enrolled on a range of undergraduate (Levels 1, 2 and 3) and postgraduate modules in GIS at the University of Leeds. Log files are used extensively to track the choices made by individual users when using the system, principally their initial and final choices in criterion selection and weighting which are then linked to their user profile information and

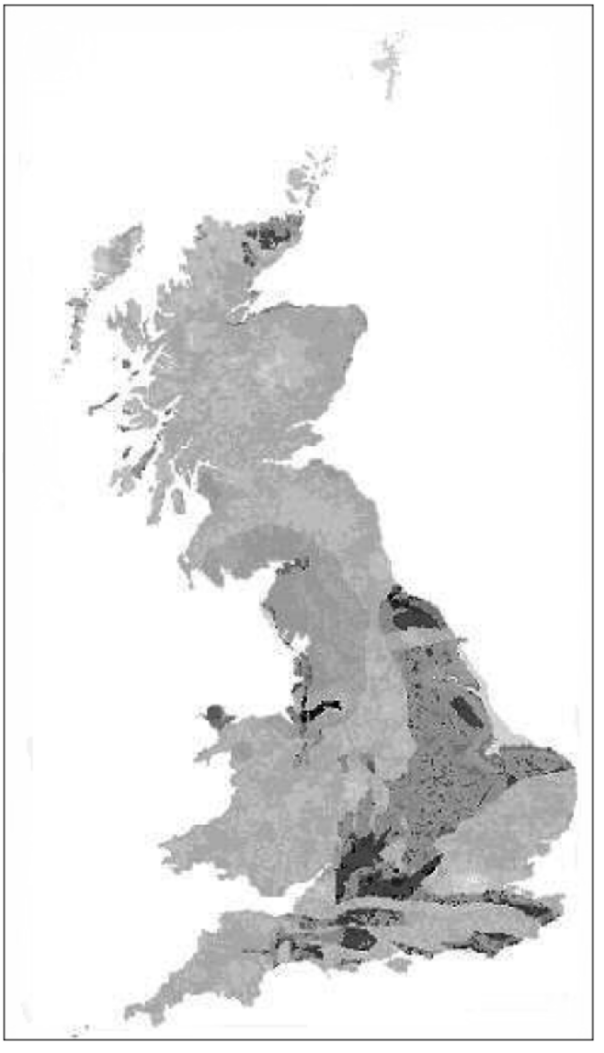

Figure 3 Example composite map created by combining the decision maps of 167 students (black=100% agreement, white=0% agreement)

feedback form responses. Although the maps produced by users are not archived by the server, they can easily be re-created using information from the log files. This is useful in either plotting individual decision-trees or creating composite maps from the final decision maps of many users. An example composite map made up of the final decision maps of 167 students is shown in Figure 3, overlaid to show the level of agreement between users as to where might be a suitable place to develop a nuclear waste repository. Here the darker shading indicates areas more frequently chosen by users as being potentially suitable, while the lighter areas are selected less often. These composite maps are in essence simple consensus maps in that they can be used to identify those areas where the majority of users believe or agree the conditions are suitable for a repository.

A full statistical analysis of the log files evaluating evidence of possible Not In My Back Yard (NIMBY) type effects (i.e. the tendency for people living near to a

proposed controversial development to oppose it because of the potential effects it might have on their environment and general well-being) is given in Evans *et al.* (in press). Here results indicate that students are quite strongly influenced by the results of their GIS decision maps when choosing a final site. Thus students using the system appear to be actively using the maps to inform their choices, illustrating the utility of GIS in exploring the decision space. Student feedback (Table 1) through multiple-choice questions (MCQs) at the end of the system suggests that 87.9 per cent of those who responded felt the system was easy, or mostly easy to use. However, some 32.5 per cent found the GIS component the most difficult to deal with. Possibly of more concern are the 7.3 per cent who found Web links hard to deal with and 4.9 per cent who found the introductory Web pages difficult, as the system has been through several design iterations influenced by a broad lay audience.

The students were asked questions aimed at elucidating how informed they felt, and whether they saw a need for the public to be allowed more of a say in the disposal of nuclear waste. Their answers suggest they felt the system had given them some additional understanding of the issues (94.7 per cent said they were better or partly better informed), but that they were keen to learn more (75.7 per cent) and thought they had a right to (96.1 per cent). In addition, they believed the public had a right to be involved in the debate (91.3 per cent), though substantially fewer students using the system actually trusted the public to be more involved in the decision-making process (65 per cent). This is perhaps reflected in the fact that the mechanism most students chose as the best method for the public to be involved was the, largely passive, mass media (77.2 per cent). The Internet was students' second choice as a mechanism (65 per cent), and most found the system to some degree useful (90.2 per cent thought the system potentially useful or partly useful).

In addition to the above MCQs, students using the system were invited to give more detailed written answers in free-format text boxes throughout the feedback questionnaire. These allow students to describe alternative choices when "other" is chosen in a particular MCQ or provide further comments on specific aspects of the system, namely the issues raised regarding nuclear waste and its management, the ideas of public participation and the use/usability of the system itself. A selection of responses to these open-ended questions is given in Table 2. Although these are not particularly useful on their own (beyond examining the opinions of individuals), they are, when collated, helpful in evaluating the overall impact of the system on the students' understanding of the various facets of the decision problem, including engineering, geography, politics and ethics, and the potential utility of GIS in trying to find a solution.

Conclusions

This paper has demonstrated how research on developing Web-based GIS for public use in strategic decision-making can be adapted for use as an e-learning resource in learning and teaching. Of particular interest is the use of Web-based GIS as a mechanism for the delivery of GIS tools and spatial data into the classroom or onto a student's PC without the need for expensive software and data. This has obvious appeal and advantages for tutors wishing to teach the principles of GIS as applied to spatial decision-making (perhaps as part of a module covering a topic where GIS might be applied) without incurring the costs

Table 1. Selected feedback answers from users garnered at the end of using the system

System questions	Answers	%
Did you find the system easy to use?	Yes	54.4
	Mostly	33.5
	Partly	10.2
	No	1.0
Which parts of the system (if any) did you find the most difficult?	Introductions to issues	4.9
	The profile pages	16.5
	Links to other websites	7.3
	The online GIS	32.5
	The Help and Information system	10.7
Understanding and participation questions		
Do you feel that you are better informed about nuclear waste management?	Yes	53.9
	Partly	40.8
	No	5.3
Compared to the current system how much information do you want about nuclear waste management issues?	More	75.7
	About the same	23.3
	Less	0.5
Should the public be given access to more information about nuclear waste management?	Yes	96.1
	No	2.4
Should the public be given the opportunity to be more involved in the debate about nuclear waste management?	Yes	91.3
	No	8.7
Should the public be given the opportunity to be more involved in the decision-making process concerning nuclear waste management?	Yes	65.0
	No	34.0
Method questions		
Which of the following methods do you feel are appropriate for helping the public participate in nuclear waste management?	Face-to-face public meetings	59.2
	Paper-based consultation documents	48.1
	Political lobbying (e.g. through local MPs)	47.1
	Media information (newspapers, TV and radio)	77.2
	The Internet	65.0
Do you feel that such a system could be used to help facilitate public participation in nuclear waste management and other issues?	Yes	65.0
	Partly	25.2
	No	7.3
	Don't know	2.4

Source: After Evans *et al.* (2004).

Table 2. Selected responses to open-ended comment questions

Issues of nuclear waste management:

1. Nuclear waste is a very serious issue which requires continued research and development to ensure maximum safety to people and the environment.
2. Everybody has to take some responsibility for it with some taking more than others, like the Government and nuclear industry.
3. A lot more research needs to be funded (preferably by the government) into how nuclear waste can be cheaply and effectively disposed of. We need to make it more economically efficient for nuclear waste companies to clear up their own waste.
4. I feel that in the short term, storage is the best option, providing the facility is able to cope perfectly well with the continued increase in waste it will receive. It is better to have the waste at one site rather than keeping it at its source as it makes it easier to manage and account for. I feel in the long term disposal is the only option as continued storage would lead to problems in coping with the amounts.

Public participation:

1. I want to live in Sweden, at least they are honest about confronting the issue.
2. If more information were given to the public about nuclear waste disposal instead of allowing this perception of secrecy and mystery to develop, then perhaps peoples' ideas about the industry would change.
3. If you give all of the facts to the general public then if they don't like them it could create public hysteria, and it wouldn't work as the Government never gives the general public ALL the information.
4. Regarding the topic of nuclear management, much of the public may wish to be involved in the matter. However, due to a lack of accessibility, they fail to do so.

System usability:

1. More help could be provided about whether you are actually excluding or including factors using the check boxes, and the weightings sliders could display better information as to whether you're adding weight to a factor or taking it away—it's not obvious what exactly you are putting in to the model.
2. As many different methods as possible should be used to keep the public informed.
3. It is necessary to advertise this medium. The general public do not mostly know about this Website. If there is an official site location Website, it will be necessary to advertise it to the public, otherwise the whole point of this system is lost.
4. I think it helps to facilitate public participation, but most people don't have access to it.

of 'tooling up' for a full-blown GIS programme. The approach described will also appeal to tutors running primer courses that introduce GIS concepts to large numbers of students before they take further practical modules where the use of a standard GIS is taught.

The nuclear waste disposal case study emphasizes the use of spatial data and demonstrates a range of GIS-based analyses and how they might be combined and brought to bear on a difficult multifaceted spatial decision problem. The initial results from the first cohort of students using the system as described by Evans *et al.* (2004) indicates that students found it easy to use and a useful aid to learning about nuclear waste management and spatial decision-making. While almost all students using the system will have had prior exposure to the Internet and the Web (and are therefore familiar with the Web browser interface), a significant proportion of students using the system (32.5 per cent) found the Web-based GIS the most difficult aspect of the system. This might realistically be interpreted in two ways. In the first instance, it is perhaps not surprising that almost one-third of students responded in this way because (a) this *is* the most technically difficult

part of the system, and (b) most of them have only a basic knowledge of GIS from their undergraduate studies and little or no knowledge of the advanced methods of spatial analysis being used. Alternatively, this result may indicate that the instructions and the GIS interface itself need to be looked at again, and further simplified if possible. Further cycles in the action research project need to clarify this point through a redesigned feedback questionnaire and/or the use of focus groups.

Looking from the perspective of improving students' understanding of the substantive issues regarding nuclear waste disposal and spatial decision-making, the results are perhaps more conclusive. In all cases, students seemed to be genuinely enthused about the problem (53.9 per cent considered themselves better informed after using the system and 75.7 per cent wanted to know more) and came to very definite and almost unanimous conclusions about the need for more and better information, and about the future role of the public in helping arrive at an acceptable solution. This vote of confidence notwithstanding, it is interesting to note a healthy scepticism among some students as regards the utility of the Internet and Web-based GIS in reaching out to the wider public on nuclear issues, with only 65 per cent voting for these methods as a good means of informing the public debate and enabling participation in the ensuing decision-making process. These results appear to indicate that the students in this first cohort have actively engaged in the problem, improved their understanding of the issues, and drawn on their findings to arrive at informed conclusions about GIS, the Internet, decision-making and the democratic process.

Future versions of the system will incorporate improvements suggested by users and gathered from feedback log files with the aim of making it easier to use. Further research on usability and student learning outcomes will be facilitated through a more detailed feedback questionnaire and focus groups. As a general observation it is envisaged that further examples of this kind of system, focusing on a wide range of different subjects and uses, have the potential to greatly improve the knowledge and understanding of GIS theory, concepts, methods and application across a range of disciplines and encourage more students to study GIS in greater depth. It is important, therefore, that the relative merits and the potential pitfalls of such Web-based systems in the learning and teaching of technical subjects like GIS are properly researched and fully understood before they are rolled out on a much wider scale.

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