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User engagement by user-centred design in e-Health

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This paper describes the application of user-centred design (UCD) methods and a user engagement (UE) approach to a case study development of a visualization tool (ADVISES) to support epidemiological research. The combined UCD/UE approach consisted of scenario-based design, and analysis of the users’ tasks and mental model of the domain. Prototyping and storyboarding techniques were used to explore design options with users as well as specifying functionality for two versions of the software to meet the needs of novice and expert users. An evaluation of the prototype was carried out to assess the extent to which the expert model would support public health professionals in their analysis activities. The results of the design exploration requirements analysis study are reported. The implications of scenario-based design exploration, participatory design and user engagement are discussed.

Keywords: information visualization; user-centred design; user engagement; participatory design

1. Introduction

This paper describes experience of applying user-centred design (UCD) methods to the ADVISES (Adaptive Visualization for e-Science) project which is developing visualization tools to support public health decision-making based on epidemiological data. In order to encourage epidemiologists to make more use of visualization tools, the project focused on understanding how epidemiologists make decisions using maps (Sutcliffe et al. 2007) while exploring the statistical properties underlying the graphical representations (Thew & Sutcliffe 2008).

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One contribution of 15 to a Theme Issue ‘e-Science: past, present and future II’.
This posed two problems: first, ensuring that visual patterns correspond to meaningful structures in the data; and second, being able to explain what those patterns mean. These gaps have been referred to by Amar & Stasko (2004) as the ‘rationale gap’ and the ‘world-view gap’, respectively.

In addition to the visualization concern, ADVISES had to satisfy the needs of two different user communities: academic researchers interested in causal analysis from epidemiological data; and public health analysts whose concern was local policy decisions. Furthermore, e-Science applications introduce new technology that is intended to change users’ working practices, so a thorough understanding of users’ requirements and their reaction to potential designs was necessary. Consequently, we adapted UCD and requirements engineering techniques to investigate the users’ analytical process (Thew et al. 2008, 2009) and to explore how new visualization tools might be used by academic healthcare researchers as well as by public health professionals.

The rest of this paper addresses two interrelated themes: first, user-centred requirements engineering, with a design exploration process for functional specification in transformative applications, i.e. where no a priori vision of the desired application exists. The second theme assesses the effectiveness of different requirements engineering techniques for promoting user participation and engagement in the design process. The paper is structured in seven subsequent sections. First, related work is reviewed. This is followed by a description of the human–computer interaction (HCI) design patterns, requirements analysis methods and experience with UCD. Then the software architecture is discussed in the light of the design contributions from different user communities. The paper concludes with an evaluation and discussion of the lessons learned from UCD and the implications for user engagement in e-Science and application development more generally.

2. Related work

There have been several reports of the use of geographic information system (GIS) tools within public health research and the potential of such visualizations to support epidemiological thinking (Clarke et al. 1996); however, several challenges and concerns have prevented widespread uptake. A US review of the use of GIS by public health practitioners (Driedger et al. 2007) 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 have been data confidentiality and risks of misinterpretation (Gao et al. 2008). A survey of user requirements for geospatial analysis in healthcare demonstrated the need for geographically based analysis, but also that map-based representations needed to be integrated with other statistical analysis tools; furthermore, that commercial GIS applications did not address many requirements (Scotch et al. 2006). Although GIS tools have contributed to epidemiology, for instance, for the characterization of populations and development of models (Jacquez 2002), the focus has been on descriptive rather than causal epidemiology. One of the few reports of developing tools for geospatial analysis is the Pennsylvania Cancer Atlas, which integrated maps with
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User engagement has been an important focus in the literature on participatory design. In large-scale health informatics projects, the use of design rationale and shared representations of design decisions was recommended, although problems from heterogeneous stakeholder populations, developing participatory processes and administrative overheads hindered cooperation (Pilemalm & Timpka 2008). In a study of user engagement over 7 years, Letondal & Mackay (2004) used a workshop-based approach to foster collaboration among biologists, bioinformaticians and computer scientists, using storyboards, scenarios and design mock-ups. In a wider context, shared representations depicted as informal diagrams have been advocated as an effective means of fostering participative designs in socio-technical systems where work practices are transformed (Herrmann et al. 2004). Agile approaches (Beck 1999) have adopted an interactive user-centred approach with stories being similar to scenarios. Furthermore, agile methods emphasize values and teamwork in development. Another user-centred influence on software specification has been adapting ethnographic analyses to inform software design (Sommerville & Sawyer 1997; Martin et al. 2007); however, few specific processes for translating the knowledge of users into software features have been articulated apart from a few patterns (Martin et al. 2001). Scenario-based approaches have also been used to refine usability features for software architecture in a trade-off analysis (Kazman et al. 1999, 2000); however, the main focus was on user requirements for performance and non-functional aspects such as reliability or generic user interface (UI) functions, rather than considering functionality for supporting users’ tasks. In summary, methods and techniques such as scenarios, storyboards and workshops are well-established techniques for engaging users in requirements engineering and participatory design. What is less clear is how to incorporate initiatives from designers for innovations and process transformation while engaging users.

3. Application of user-centred design patterns

Rather than starting with a ‘blank slate’ approach, initial designs were motivated by ideas in the HCI research literature. The rationale for adopting this ‘expert-led’ approach was to provide users with preliminary solution visions and thereby engage them in the debate about how our solutions might fit into their application domain. Two solutions to the gaps problems were proposed in early prototypes and storyboards using HCI design patterns for similar decision support functions. The UI had to provide affordances (Norman 1999) or intuitive functions that help users understand representations of the data analysis, and appropriate models of the domain data and processes.

The first pattern, ‘dynamically coupled queries and displays’, recommends that displays are dynamically updated using sliders to express value range queries in an iterative query–view–explore cycle (Ahlberg & Shneiderman 1994). Close coupling of users’ actions to feedback in displays facilitates acquisition of a mental model of the data and an understanding of how features of the representation
correspond to the data. Sliders allow users to change values in queries, leading to dynamic display updates which facilitate sensitivity analysis by ‘micro-querying’. In closely coupled queries, users see changes in the world-view corresponding to their queries, and hence this promotes analysis of emergent visual patterns and their meanings. Consequently, research questions were closely coupled with the displays in the iterative querying–visual feedback cycle.

The second pattern, ‘multi-panel displays’, recommends tiled windows containing separate views on data pertinent to the users’ task (ISO 1998a,b). Users could view concurrent juxtaposed visualizations of maps, graphs and summary statistics, thereby encouraging comprehension of the underlying data models. The third pattern task, ‘appropriate information displays’, advises that information displays should support users’ tasks and decision-making and that only appropriate information should be given, to avoid clutter (Sutcliffe 1997). If the data quantity is large, then overview drill-down details-on-demand controls should be provided (Bederson & Shneiderman 2003).

4. Requirements analysis methods

We adapted scenario-based design (SBD; Carroll 2000) and user-centred requirements engineering (Sutcliffe 2002), both of which advocate the use of scenarios, storyboards and prototypes in iterative cycles of requirements elicitation, design exploration and user feedback to create the process. SBD was chosen because of the often volatile and complex requirements of e-Science applications. SBD is well suited to such circumstances because of its iterative approach which facilitates collaborative design exploration between users and developers. The process is summarized in figure 1.

Unstructured interviews were conducted at the beginning of the project to gain background knowledge on working practices, user preferences and domain norms. Interviews were conducted on site, allowing the epidemiologists to show us existing software they prefer to use, discuss their data management practices and let us view example datasets. Scenarios facilitated exploring possible system designs as well as producing information on the users’ tasks and workflow. Several design representations ranging from simple storyboards or paper prototypes, scripted concept demonstrators to functional prototypes were used. The various prototypes were used in combination with scenarios in task walkthroughs to explore how the software tool might support the steps in the users’ work.

A key orientation to explore requirements as research questions was motivated by the goals–questions–results method (Perrone et al. 2006). Research questions elicited from domain experts were used to create scenarios and use cases that envisioned a new system to support analysis, e.g. ‘What are the characteristics of the GP-registered population in North-West England?’ This scenario described how a user could explore a map of patients registered with primary care trusts (PCTs) in the northwest, stratifying the population by location, gender and ethnicity. Scenarios were supplemented by analysis of the users’ language in interviews, and meetings to develop an ontology describing the process of epidemiological research. The ontology supported analysis and management of data, as well as informing design of the query interface.

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5. Experience with user-centred design

There were 21 participants in the requirements exploration and evaluation session: 8 academic epidemiologists and 13 National Health Service (NHS) PCT analysts (overall 8 males and 13 females). Only one of the epidemiologists had any previous GIS experience. 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 networking group.

Preliminary analysis with academic epidemiology researchers created requirements for a system that supported querying datasets, statistical analyses of differences between populations and trends over time, which produced displays of the retrieved results on maps and graphs with summaries of the statistical analyses. As the application had to serve two user communities, we investigated how the initial expert-oriented system might be used by analysts in the NHS, who had some appreciation of statistics but were not experts.
Figure 2. The paper prototype illustrating a map of a fictitious city including an apparent hotspot indicated by shading the distribution.

The preliminary paper prototype (see figure 2) was used in scenario walkthroughs. The users were PCT health data analysts with varying degrees of experience. The requirements storyboard walkthrough used several scenarios to assess PCT analyst users’ reaction to the prototype and, inter alia, the researcher mode of operation: design of the scenarios was motivated by the world-view and rationale gaps problems, to encourage the users to explore functional requirements as well as investigating their domain-specific practices and workflows. For example, one scenario contained data that were too sparse to produce a statistically sound map, so the data had to be aggregated into larger units. Another scenario asked users to interpret population densities in map regions according to the colour coding, to test awareness of the danger of drawing inferences from small samples. Areas which showed high levels of diabetes had very small populations, making it impossible to confirm whether they were genuine hotspots or not.

The users approved of the basic design concepts: multi-panel displays, query sliders coupled to dynamically updated displays and a high-level research question interface rather than structured query language-style queries. New requirements emerged for comparison between areas using two maps as well as complex association questions between two or more variables, e.g. ‘What is the link between asthma and obesity?’ The PCT analysts used local geographic knowledge when interpreting maps and requested support for understanding the implications of local geography, e.g. adding overlays of the street network or adding point locations of schools or hospitals. However, the users’ actions did show potential errors in walkthroughs with expertise-probing scenarios. For example, the majority of users did not notice the data density problem associated with coloured regions; furthermore, only one user explored different boundary levels in order to examine the hotspot apparent on the map.
The requirements analyses with both user groups were summarized in two workflows to reflect PCT analyst and academic researcher practices (see figure 3). Researchers progressed through checking and validation tasks to satisfy themselves that the patterns on map displays and accompanying statistical analysis would support valid conclusions, rather than being misled by hotspots in small areas or by inappropriate and sparse distributions. In contrast, PCT analysts did not appear to be concerned with such validation steps; instead, they were more interested in exploring the implications of visible patterns on the map display.

In summary, the results of the evaluation study pointed to three main conclusions.

— PCT analysts adopted different workflows from the expert epidemiologists. This reflects different research questions; for example, academic epidemiologists are interested in finding general trends and causal
influences between several variables, whereas public health professionals requested simpler, location-based questions reflecting their concerns with local health issues.

— Use of the statistics was often incomplete and sometimes even incorrect, depending on the level of statistical expertise. In particular, some users exhibited a ‘confirmation bias’, employing statistics that confirm rather than contradict their hypotheses. Some participants appeared incapable or unwilling to engage in data analysis, assuming that the system would ‘know best’. As a result, they could misinterpret data and draw incorrect conclusions (rationale gap).

— There is a need for more local geographical detail so that PCT analysts can exploit their detailed local knowledge to interpret patterns apparent on the maps (world-view gap). For example, PCT analysts were interested in plotting the locations of particular services or amenities to see if these relate to the occurrence or outcome of diseases.

The development of two software advisors was motivated by these requirements to caution against unsafe inferences being drawn from sparse or awkwardly distributed data in map displays and to save the user’s effort in choosing visual display coding.

6. Software architecture and implementation

The workflows from the two user communities posed problems in how to allocate somewhat different sets of the requirements to each user community. Producing two versions of ADVISES would lead to maintenance concerns and incur the additional expense of duplicating software processes. The solution adopted was to develop a layered architecture with a core functionality targeted at the PCT users, with an outer layer of functionality for the domain expert users who required additional statistical analysis. Exposure of the functions was controlled by menu configuration on the UI.

To bridge the rationale gap, we yoked the research questions and workflows to preset configurations of displays. This design was also motivated by the display combination pattern, so users could view concurrent juxtaposed visualizations of maps and graphs, to encourage comprehension of the underlying data models. Users form queries by first picking a high-level question type. Then, queries are elaborated by selecting one or more subject populations from the available datasets with variables such as age, gender, socio-demographics, lifestyle, medical history, etc., followed by the desired measures which were usually body mass index (BMI) and other obesity metrics. Queries are organized menu-picking lists configured with constraint rules so that only appropriate choices are offered as the query develops, e.g. trend questions prompt for the time period and intervals; location questions request areas or proximity to displays; and comparison questions prompt for between-population or within-population (e.g. gender) variables.

All queries can be constrained by map areas, with overlays selected for additional spatial data, e.g. point location of health centres, sports facilities, etc. Query range sliders become active once the population and measures variables are
selected, e.g. for age, the BMI range, and the distribution, graphs and maps are displayed. The display for the ‘check area density’ task in the current prototype is illustrated in figure 4.

The multi-panel display affords rapid data inspection and exploration of epidemiology datasets, while colour and patterns in the charts indicate sparse and non-normal distributions when statistical analyses and other inferences may be invalid. Incremental analysis is supported by sliders for value-range queries, so analysts can carry out sensitivity analysis by changing range values, e.g. inspect obesity by area by age.

Range-category histograms and descriptive statistics support the ‘check the data distribution’ task. Users can segment a continuous distribution into discrete categories (e.g. extreme, high, medium, low BMI) using sliders to subdivide the range. This enables sensitivity analysis of range-category subdivisions to ensure, for instance, that distribution tails have sufficient data points for valid statistical analysis.

Box-and-whisker plots support the ‘check area distributions’ task; for example, long thin or short fat boxes indicate sparse distributions with high standard deviations (long thin) or high kurtosis (short fat). The graphs and maps are coordinated and queryable surfaces, so users can point and click on subareas of the map to express a location query. The multi-panel display affords rapid data inspection and exploration of epidemiology datasets, while patterns in the charts indicate sparse and non-normal distributions when statistical analyses and other inferences may be invalid.

\[(a) \text{Statistics advisor}\]

The aim of the statistical advisor is to warn users about sparse distributions where false inferences may be drawn from low numbers. However, there are occasions when looking at low numbers is unavoidable, for example when investigating a rare disease, so the advisors are configurable and can be turned off under user control. Some advice is given passively by highlighting areas in the presentations that warrant attention, with pop-ups to explain why attention is needed.

A monitor alert function compares map area populations and densities (populations/area), and distribution statistics (standard deviation, skew, kurtosis) to alert the user when any of these values exceeds a preset threshold. The figure or map area is highlighted to warn the user. A pop-up containing the threshold value appears when the user’s mouse is placed over the figure/area. The alert reminds the user about properties of the underlying data distribution and thus contributes to closing the rationale gap. As the validity of distribution depends on the nature of the dataset, the alert function is configurable, so the rules can be edited to deal with general health (normal datasets) or rare events (disease epidemiology: non-normal datasets).

\[(b) \text{Visualization advisor}\]

Design of the visualization advisor was motivated by the requirement to display more than one variable on a map. Visual coding requires psychological knowledge; however, the knowledge can be formalized, so the expert advisor module automatically codes the range categories on the maps and graphs.
Complex research questions may involve two to three variables, e.g. ‘What is the distribution of type II diabetes and obesity for different levels of socio-economic deprivation in different areas of the northwest health region?’ This association–location question implies visualization of the average density of diabetes patients and overweight people in each health district. Assuming range-category subdivisions by quintiles, the visual coding has to represent $5 \times 3$ coding combinations in any one area.

HCI knowledge from the visualization literature (Tufte 1997; Ware 2000; Spence 2007) was applied to specification of an automated visualization coding function. Shape and size was ruled out because this attribute was constrained by the map areas, e.g. different line sizes are not reliably discriminated and common area boundaries made this solution unworkable. Three-dimensional encoding (e.g. histogram bars on map areas) was avoided because of the occlusion problem, leaving colour and texture. Advice on colour coding favoured a single colour saturation scale rather than rainbow spectrum codes (Ware 2000). Guidance on texture coding was not so specific, so we decided to use single-texture density gradients (e.g. dot stipples, bar density) rather than several different textures, to avoid imposing a learning burden on users (Shenas & Interrante 2005). Two variables could be represented on one area, one by colour and the other by texture (see figure 5). Although these representations were effective in usability testing, further evaluation is advisable to check acceptability for users with colour blindness.

The visualization expert automatically selects the codings, favouring colour if only one variable is displayed. When small map areas are present, a warning is given that discrimination of categories in small areas may not be reliable, since the texture gradients will not be easy to discriminate.

The system was implemented in C# using Microsoft SILVERLIGHT for graphics and animating map displays for trend questions so that successive displays gradually morph into each other to enable users to see the trend change over...
time within different map areas. A distributed architecture was adopted and developed as a set of Web services, with major class packages in the following functional areas.

— **Dataset access**: loads datasets from remote servers.

— **Map displays**: loads shape files from the UK Land Registry server and displays maps using Microsoft Charting libraries. Map displays can be overlaid, so point data (e.g. location of health clinics, sports facilities, etc.) can be displayed at appropriate locations.

— **Charts and statistics displays**: runs basic statistical analysis scripts (R script calls), then displays range split histograms, box-and-whisker plots, etc., using Microsoft Charting.

— **Dialogue management**: handles the query interface, interactive query-by-pointing and sliders.

— **Expert advisors**: classes which implement the statistics and visualization experts, with dataset monitors to trigger advice.

Map shape files, databases, query handling and statistical analysis components were remote services; other components were client resident. However, performance problems did lead to (hopefully temporary) compromises with the distributed architecture; consequently, some services were reconfigured to be client resident.

However, it is worth noting that several functions did not get implemented, in particular, a set of configuration editors that would have made the ADVISES system into a portable, flexible toolset which could be configured for different domains to support other scientific data-driven research requiring visualization, e.g. population dynamics research.

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7. Evaluation and reflections on user engagement

The prototype was subject to two cycles of evaluation after the requirements exploration–design phase, illustrated in Table 1. Round 1 was formative for usability debugging and design improvement, whereas the second round was more summative in nature and captured users’ attitudes and satisfaction ratings for the prototype. In both rounds, users completed a representative set of tasks which enabled assessment of system performance.

During each round of 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.

After working through the set of tasks, users were asked about their experiences with the system. The majority felt that their experiences 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, and further mixed reaction to the redesign has led to additional design changes to be tested in the final round of evaluation currently in progress. Thus, each round of the evaluation directly influenced the next iteration of design and development. Although evaluation with more users is always desirable, the sample of 21 users is within the accepted norms of usability evaluation recommendations (Monk et al. 1993).

The current state of ADVISES is that the map component (Obesity Atlas) is being developed for implementation in PCTs in a programme sponsored by a consortium of the users’ organizations, the local Manchester PCTs. Roll-out of the full ADVISES application is planned in the near future in a programme managed by e-Health North West, an NHS-financed body to promote collaboration between the University of Manchester and NHS trusts in the northwest of England. These initiatives provide evidence that our approach to user engagement is appropriate, because our users are prepared to sponsor the final development of the prototype; this involves re-engineering some of the code to increase robustness and reliability as well as implementing the code in the users’ software environment.

Of the requirements techniques we employed, the combination of storyboards, scenarios and prototypes integrated in a UCD cycle, was the key to user engagement. Visualization of realistic design enables users to critique and contribute ideas in their own terms without having to understand software
Table 1. Summary of participants’ responses. Interviews were transcribed and the participants’ answers coded as positive, negative or neutral.

<table>
<thead>
<tr>
<th></th>
<th>round 1 responses</th>
<th>round 2 responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>first impressions of the system?</td>
<td>5 positive, 3 negative</td>
<td>6 positive, 2 negative</td>
</tr>
<tr>
<td>system easy to understand?</td>
<td>7 positive, 1 negative</td>
<td>7 positive, 1 negative</td>
</tr>
<tr>
<td>enjoy using the system?</td>
<td>8 positive, 0 negative</td>
<td>8 positive, 0 negative</td>
</tr>
<tr>
<td>would use the system in your job?</td>
<td>7 positive, 1 negative</td>
<td>5 positive, 2 possible, 1 negative</td>
</tr>
</tbody>
</table>

engineering notations. Our experience has been that even simple notation such as use cases presents a barrier to understanding; furthermore, abstract models are less meaningful for users. The second reflection is the importance of conversation and dialogue, especially when it is anchored in the users’ domain and language. Talking through and demonstrating working practices are important motivators for end users. In workshops, conversations have the added advantage that users outnumber software professionals and hence own the dialogue and can direct it towards their own goals.

The mix of designer-led initiative in the use of HCI patterns and UCD that responded to user requirements worked well. The basic design paradigm of multiple displays and dynamically coupled queries and displays introduced research-inspired designs into health informatics tools. These design concepts stimulated interest and hence engagement among the users. The expert advisor modules, which were a designer initiative in response to problems discovered during the requirements analysis, were not seen as an imposition by the users, as they might have been; for instance, the statistics advisor might be viewed as criticizing users’ judgement. We attribute user acceptance of these ideas to the process of engagement where the problems and proposed solutions were discussed openly with the users and illustrated in storyboards and prototypes so that the design implications were explicit. Of course, application to a wider user base depends on the generalization of these results from our sample of PCT analysts, who, we believe, were faithful representatives of that NHS role. On the user-led requirements side, several aspects of the design arose directly from users’ suggestions; for example, the two maps comparative displays, and functions for subdividing continuous distributions into range categories. Design, or more realistically emergence of transformation of working practices, evolved throughout the process as users responded to presentations of the tools. Users accepted workflow transformation by osmosis as tools and tasks co-evolved during the project. We believe this was a positive contribution to user engagement rather than top-down design of new working practices and then fitting tools to a designed socio-technical system.

8. Discussion

The contributions of this paper have been to demonstrate how the application of sound UCD methods can produce productive user engagement. However, we have also advocated a design-led approach and shown how user engagement can integrate design visions with appropriate responses to user feedback and needs.
The success of ADVISES in migrating towards a product, sponsored by the PCT users themselves, demonstrates the effectiveness of our approach. ADVISES shared many design features with the *Pennsylvania Cancer Atlas*: both systems have map displays, temporal animations and multiple graphical displays, although only ADVISES implemented sliders for dynamic ‘what-if?’ queries, and expert advisors are a testament to its HCI design heritage. However, the *Cancer Atlas* did have a population pyramid graph for epidemiology analysis which appears to be an omission from ADVISES. Bhowmick *et al.* (2008) report a set of design guidelines from their experience including interactive queries and multiple displays. The convergence of the two systems may have been the consequence of a similar UCD process. The *Pennsylvania Cancer Atlas* team carried out three rounds of prototyping and evaluation although they did not report using storyboards or scenarios.

Previous methods and approaches to integrating UCD into the software development process have focused on reorienting the development process to emphasize user goals, iterative development, scenarios and prototyping (Potts & Anton 1998; Beck 1999; Potts 1999). Our approach shares goal orientation and use of scenarios. Our use of workshops contrasts with that of Letondal & Mackay (2004), who used workshops for participative programming, although the activities they describe appear to be closer to our scenario–storyboarding sessions. The participatory role framework they report of computer scientists, bioinformaticians and biologists maps to our experience, in that we had computer scientist developers; bioinformaticians as epidemiology researchers who also developed the statistical analyses as R routines; and biologist end users, represented by our PCT analysts and a few of our researcher epidemiologists. Our experience agrees with their finding that role and responsibility allocation is difficult. In ADVISES, design influence originated in all three roles: the computer scientists supplied the HCI patterns and software engineering, the bioinformaticians motivated the statistics advisor as well as developing the statistical routines, while many requirements emanated from the PCT analyst users. One reflection is that multiple-stakeholder engagement was successful because all the roles had a stake in the design, realized in a transparent process. In contrast to top-down approaches to workflow transformation (Herrmann *et al.* 2004), we found that transformation was an emergent property from the user-centred process.

The success we experienced was built upon a long-term collaboration between academic researchers and PCT practitioners in the Northwest Institute for Bio-Health Informatics. This collaboration facilitated cooperation and, more importantly, access to our users. However, the ADVISES experience also shows the limitations of user engagement within a more general technology research programme with objectives to produce general solutions to scientific problems. Users are inevitably engaged with their own specific domain and respond positively to specific solutions, whereas general design concerns are seen as a distraction and a barrier to effective use. Hence, the more general requirements of the UK e-Science programme which we attempted to follow in ADVISES tended to militate against successful user engagement in the domain of epidemiology and public health. A possible solution is to adopt a phased approach to user engagement in the small (and with a specific domain), followed by user (community) engagement in the large with more customizable solutions. In the
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future, we will extend the architecture and scope of ADVISES with configuration editors, so the software can be customized to different research domains and analysis tasks. Contextual evaluations in users’ workplaces will assess how successful the research questions and multi-view displays are in bridging the world-view and rationale gaps, as well as exploring the fit of the ADVISES architecture with the working practices of diverse stakeholders to deliver effective support for health informatics.

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