Rethinking Map Legends with Visualization

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Fig. 1. *The Map is the Legend – Map Becomes Legend (Becomes Map...)*. Relationships between map and legend are explored in *Prototype 1* with animated transitions between three ordered layouts: *legend* (1D categorical, *left*), *map* (2D geospatial, *center*) and *mapped legend* (2D geospatial, *right*). ©*Crown Copyright/database right 2010. An Ordnance Survey/EDINA supplied service.*

Abstract—This design paper presents new guidance for creating map legends in a dynamic environment. Our contribution is a set of *guidelines* for legend design in a visualization context and a series of illustrative *themes* through which they may be expressed. These are demonstrated in an applications context through interactive software prototypes. The guidelines are derived from cartographic literature and in liaison with EDINA who provide digital mapping services for UK tertiary education. They enhance approaches to legend design that have evolved for static media with visualization by considering: *selection*, *layout*, *symbols*, *position*, *dynamism* and *design and process*. Broad visualization legend themes include: *The Ground Truth Legend*, *The Legend as Statistical Graphic* and *The Map is the Legend*. Together, these concepts enable us to augment legends with dynamic properties that address specific needs, rethink their nature and role and contribute to a wider re-evaluation of maps as artifacts of usage rather than statements of fact. EDINA has acquired funding to enhance their clients with visualization legends that use these concepts as a consequence of this work. The guidance applies to the design of a wide range of legends and keys used in cartography and information visualization.

Index Terms—Cartography, design, Digimap service, legend, online web mapping, visualization.

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1 INTRODUCTION

Information visualization is concerned with spatial mappings of data that are not "*inherently spatial*" [29]. These should be "*cognitively useful*" when applied to well-defined tasks in combination with dynamic and interactive techniques that support a process of data exploration [29]. Yet the degree to which data, or the spatial mappings derived from them to amplify cognition, are "*inherently spatial*" is far from unequivocal. We explore this uncertainty to enhance map legends specifically and spatial information visualization more generally.

All cartographic projections transform data about positions on the Earth's surface to a plane, resulting in the loss of important characteristics of space [54]. Some emphasize the aspatial aspects of data at the expense of geospatial properties for good reason [16, 56]. Equally, geospatial orderings in 1D (e.g. distance) and 2D can be usefully added to established mappings of aspatial data [11, 62]. The degree to which space is fundamental to information also varies across the map in its broadest sense. Wood and Fels [61] draw attention to the *paramap* – "*the production surrounding a map*" [34]. This consists of *perimap* – including titles, photographs, illustrations and credits and the *epimap*

– accompanying articles, advertisements, marketing copy, letters and details on how the map was produced. This information has a powerful role in conveying authority and affirming the status of the map as an objective reference object [61]. Certain elements of the *paramap* have geographic characteristics that may be reflected through spatial mappings (cartography). In some cases spatial layout can be used to show aspatial relationships (information visualization), whilst other elements do not seem inherently spatial or would not benefit from spatial representation. Here we focus on an important component of the *perimap*: the legend – a mapping of data that uses space and so benefits from methods from information visualization and cartography in which layout represents information or geospatial structure. We do so for four related reasons:

1. the legend is an influential component of the *paramap* [61];
2. an effective legend seems key to a *cognitively useful* map;
3. there is scope for using dynamism to achieve this;
4. cartography texts provide little guidance on the *paramap* [61].

Our work is undertaken in response to a request by EDINA to "*reimagine*" the legend in the context of visualization. 50,000 active users from 150 UK tertiary education institutions access 1TB of geospatial data through EDINA's Digimap service [55]. Eighteen web mapping clients combine and present national data sets of varying theme, content, scale and format (including products from Great Britain's mapping agency, Ordnance Survey) in user-defined maps. Six of these clients contain legends, which fulfill multiple roles in terms of map comprehension, customisation and exploration. They can be bulky

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and difficult to navigate when comprehensive.

Our objective is to explore possibilities for enhancing legends with visualization – to see whether cartography and information visualization can be effectively applied to generate novel and cognitively plausible mappings of the spatial elements of the *perimap*. We do so in the Digimap context by exploring visualization design opportunities for Digimap data sets and establishing affect. This is achieved through a phased study based upon a *formalised informal* approach to multimedia cartography praxis and evaluation [35, 36] in which participatory approaches are used to characterize the problem domain and determine *goals*, *formative evaluation* is undertaken and *impact* established.

Phase 1 – Imagination Exercise: to *characterize the problem domain* by establishing context, exchanging ideas and data and identifying broad requirements; to develop broadly applicable *guidance* from existing practice, *themes* that inform design and *digital prototypes* to demonstrate possibilities with data.

Phase 2 – Focussed Development: to *evaluate* themes and their implementation in digital prototypes, establish more specific requirements and generate more focussed and functional digital prototypes with selected Digimap data sets.

Phase 3 – Impact: to *evaluate* views of the Digimap team and potential for incorporating visualization legends into their services.

2 PROBLEM DOMAIN CHARACTERIZATION

Harrower contends that "*Digital and Web cartography fails when we try to reproduce paper maps on-screen*" [24] and calls for a creative approach to design. Keates [33] bemoans the tragedy of cartographers to failing to think beyond existing norms. We required creative thinking on visualization and legends and promoted this through a structured *imagination exercise*. The problem domain was explored in a dedicated workshop at EDINA. A loosely structured opening session allowed for lengthy discussion to ensure comprehensive common understanding of the data, the user base and outstanding issues. EDINA GeoSpatial Services and User Support ("*EDINA*") described current approaches to legends and introduced data sets and user needs. Digimap clients, paper and digital prototypes that provide access to the comprehensive Historic, Geology and Ordnance Survey collections were presented and their characteristics and usage discussed. Existing Digimap legends have a dual role in supporting the visual interpretation of maps through lookup and as a means of map customisation by enabling the selection of data types for display. Discussions were manually transcribed in parallel by participants, collated and approved as an accurate and comprehensive record.

The creative activity began with a refresher session in which information visualization examples were presented to prompt discussion. The intention was to stimulate broad and creative thinking by distancing the group from existing Digimap legends and ideas, whilst demonstrating the scope of visual solutions. Data collection followed with three participatory exercises to establish views on Digimap legends.

2.1 Current Problems and Successes

Existing services were the initial focus with the seven participants recording problems and successes associated with the current clients on sticky notes. Participants were asked to highlight the most significant of their responses and report this characteristic to the group, drawing attention to the scope of issues, common ideas and ensuring buy-in from all members. The twenty-five responses were retained with closely related issues subsequently grouped into ten response sets. Each was allocated an indicative name, such as "*Information doesn't fit on screen*", which contains 7 items (Fig. 2) including "*You can't see all the information – doesn't fit on screen and is difficult to locate / remember*".

Positive legend characteristics were recorded, shared and aggregated through a similar process. Eighteen notes were allocated to seven response sets (Fig. 2). The most popular of these contained 7 responses including "*The maps have legends! They are clear, comprehensive and visible concurrently alongside the map*". This set was labelled "*clear, comprehensive, concurrent*" (Fig. 2).
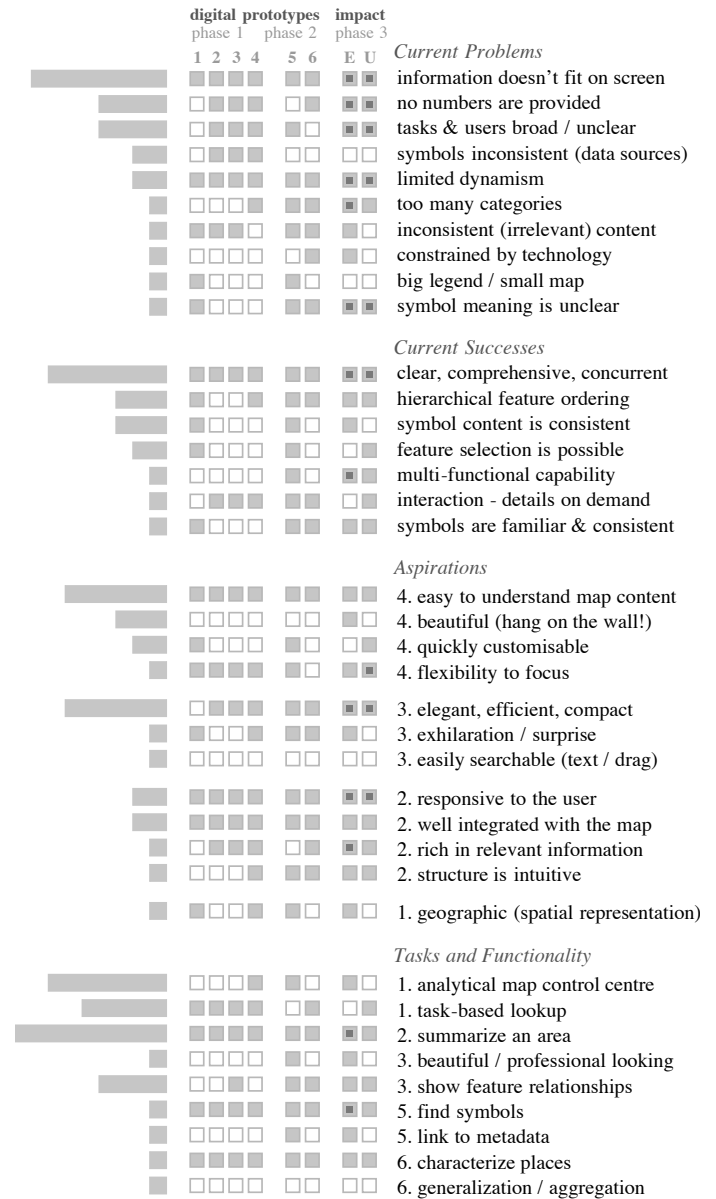

Fig. 2. *The Problem Domain – Responses, Emphases and Impacts.* Aggregated sets of responses established during the problem domain characterization workshop are mapped to stages of the process. Rows relate to response sets with indicative names (*right*) and bars (*left*) showing numbers of responses. Square symbols in three groups of columns relate to *phase 1* prototypes, *phase 2* prototypes and reported *impacts* on the EDINA '*E*' team and Digimap users '*U*' established in *phase 3* (as reported in *section 7*). Gray squares show associations, with dark dots representing strong *phase 3* impacts.

2.2 Aspirations

Workshop participants were then asked to express aspirational characteristics associated with an excellent legend in short phrases. Thirty of these were suggested and then prioritised by the group in a four stage hierarchical process. Characteristics were subsequently aggregated into twelve categories containing between 1 and 6 responses (Fig. 2). The highest level of the decision hierarchy reached by any member of the response set was recorded – 4 being the final stage achieved by the four highest priority aspirations. Response sets are represented by an indicative response and ordered by the stage of the hierarchical process that they reached in Fig. 2. Once again, bar length represents the number of responses in each set.

2.3 Tasks and Functionality

Finally we asked participants to identify up to four important tasks that Digimap legends should support or functionality that they should exhibit. Participants were then allocated to one of two discussion groups. Responses were presented to the group and aggregated into categories according to broad themes that emerged through discussion. Thirty characteristics were suggested and aggregated into twelve categories (six for each group). These were named and prioritised by group members as detailed in Fig. 2. The results for both groups are combined in Fig. 2 where bar length shows how often a theme was identified and the numbers show the highest priority amongst groups.

3 LEGEND DESIGN

Established guidance on legend design is very general, with occasional examples [53] and alternatives [13], but few principles – perhaps because it is difficult to generalize between use cases and experimental contexts. As in cartography more generally, legend design seems to rely on a subjective evaluation of design options informed by experience, preference and knowledge in the context of particular use cases: "*cartographers must rely on their best judgments*" [15].

The focus is predominantly on static cartography but Lobben and Patton include a short section on legend design in their "*Design Guidelines for Digital Atlases*" [40]. The suggestions are surprisingly conservative, recommending replication of static legends or the use of symbols that reveal text when interrogated. The former of these seems to contradict their earlier advice on ensuring graphic simplicity for maps that are designed for computer screens and is challenged by Harrower [24] who draws particular attention to the need to minimise the degree to which users divide their attention between map and legend.

A review of 47 cartographic texts, papers and digital resources leads us to propose broad guidelines relating to six high-level characteristics for consideration in visualization legend design.

3.1 Selection – What to Include?

Only show relevant information – include just what is required.
Our domain characterization emphasized the cartographic tendency for comprehensive legends. However, effective selection of content will minimise cognitively expensive look-up tasks and reduce the extent to which attention is divided between map and legend. It can be achieved by limiting to "*all unknown or unique symbols used*" [15], those that are "*not self-explanatory*" [53] or items "*critical to reading the map in question*" [48]. Relevance changes over time, and according to task and user – thus requiring careful consideration. Visual methods may be useful to highlight selected and de-emphasize non-selected items through binary or continuous symbolism. Updates may be appropriate where legends are dynamic and visual de-emphasis may maintain legend stability where selection changes. Input from the user and system use may be effective in determining what is required. Evidence suggests that legends are not necessary amongst some users for some map tasks and a situation with no look-up and no legend may sometimes be a viable and effective objective [2].

3.2 Layout – How to Use Legend Space?

Reflect meaningful geospatial or attribute structure by arranging legend symbols in a relational manner.
Legend layout "*is worthy of careful attention*" [48] and should exhibit "*visual logic*" [13] and "*visual balance*" [48] so that symbols are unambiguous, harmonious with the map and clear [15]. This may be achieved through 1D ordering of legend items [48] or more sophisticated use of the space. 2D layouts that represent information structure have been shown to be effective in some circumstances [2, 14], suggesting that improvements in performance may result where the dimensionality of a legend concurs with the dimensionality in the data. MacEachren [41] explains in terms of *schemata* – elements of long-term memory used to organise knowledge and frame future understanding. For example, the abstract notion that closer in space means closer in kind is a spatial schema used advantageously in cartography and information visualization [50, 51]. Any visual description of information, such as a map or legend, will rely upon both the graphic

itself and the schemata used to view it – particularly in terms of their appropriateness and completeness. Interpretations of legends are considered as specific map schemata: "*For cartographers and readers to share interpretants for specific signs requires a common understanding of how sign-set variation is matched to data set variation and/or an explicit definition for a sign relationship*" [41].

Legends that reflect the nature of relationships in the data are thus likely to be most effective [41]. Aspects of layout may do this effectively through image schemata, which include center-periphery and containment: "*While legends typically employ linguistic codes to provide a link to propositional knowledge representations, presentational codes can also be used to link with analogical knowledge representations and image schemata*" [41].

Ordering legend items consistently with lower values at the bottom and high at the top [48], natural legends [14], and 2D legends [2, 3] may meet these criteria. Considering the planar dimensions as mappable space into which information that contains 1 and 2D orders, hierarchical relationships and categorical differences may be productive – for example to represent category, age and regional variation in a geology map legend [22]. Doing so may also lead to new ideas for improved legends that are based upon image schemata. The container schema is not used frequently in legend design, but as an embodied image schema that is considered by some to have inherent meaning [38, 41] it may be effective when used in legend layout.

In short we recommend the legend be considered as a spatial representation of information and thus the relative positions of elements should be of primary concern as they are when developing a map or less inherently spatial graphic. Recent cartographic literature makes useful recommendations about visual groupings, meaningful metaphors and effective use of text [4, 53].

3.3 Symbols – How to Represent Features?

Symbols in the legend must relate directly to those used on the map.
Legends should be consistent with the maps they support. Symbols should relate: directly to the map with identical characteristics [48, 53]; to each other (see section 3.2 above); to the mapped phenomenon of interest; to social and cultural expectation. Some evidence suggests that where quantitative estimation tasks are important, displaying a range of values may be effective in overcoming the non-linear nature of perception [12]. In such cases the zero lookup or empty legend objective may not apply and advice on representation is available [30]. Emerging technologies and contributed geo-referenced data sources provide scope for innovation in terms of using ground truth to relate maps and legends to mapped phenomena [8].

3.4 Position – Where or When to Show Legends?

Ensure that when, where or how a legend is encountered, is task appropriate and matches expectation.
The position or availability of the legend may vary according to prior knowledge, task and cultural expectation or norm but should be a key element of design. In the case of bivariate legends or unfamiliar symbolism it has been argued that the legend should be seen before the map [48]. When legends are expected to be used less frequently and as map use continues, this primacy may become less necessary.

3.5 Dynamism – Which Interactions and Animations?

Supplement information and vary legend characteristics in informative and relevant ways.
Dynamism can overcome some issues associated with alternative design decisions and change. In dynamic environments *selection*, *layout*, *symbols* and *position* can be varied to emphasize relationships and suit situation, task and user. For example:

- varying *selection* – by geography, attribute, choice or experience: *symbol transparency* [49] may be used effectively here;
- varying *layout* – to reflect different orders of and relationships between symbols: if layout changes then it must be clear why the change has occurred and what it represents;
- varying *symbols* – to reflect different (transient) design priorities.

Concepts and approaches useful in implementing these guidelines include *the active legend* [46, 49], *bi-directional highlighting* [49], *smart legends* acting as a *central control unit* for the map [49], *animated transitions* [28] and the application of *styles* [10, 31, 32, 43].

3.6 Design and Process – How to Proceed?

Design the legend as you would a map or data graphic – consider the legend as (spatial) information visualization.
Overall legend design is an informed trade-off that should be undertaken in close association with map design using appropriate design principles. The cartographic literature lists various characteristics that are indicative of good legend design that might be considered as aesthetic and relational qualities. Aesthetic qualities include *harmony*, *visual balance*, *clarity*, and legends that are *in keeping with the map*. Relational qualities include *visual logic*, *logical groupings* and *unambiguous encoding*. We might add functional qualities, which are related and the subject of various experiments (e.g. [2, 12, 14, 20]).

These guidelines emphasize the informed and effective use of layout in legend design. As such, approaches used in information visualization and cartography are applicable. The seven controls on the map design process may be a helpful starting point for spatial legends: *purpose*; *reality* (and mapped reality); *available data* (and its selection or omission in the map); (map) *scale*; *audience*; *conditions of use*; *technical limits* (and opportunities?) [48]. The information visualization literature also contains a wealth of relevant knowledge with recent indications that interactive legends have positive effects in certain circumstances [47]. Ultimately, design relies on a cartographer's judgments in the light of experience and consideration of use. A creative and open approach is important throughout the process [7, 24, 33, 42]. Continual reflection, discussion, task-based evaluation and redesign should be applied [35] as the designer "*edits vigorously*" [4].

4 LEGEND THEMES

Our characterization of the problem domain and development of design guidelines provided impetus for a creative exercise in which broad visualization legend themes were developed to frame ideas and guide software development. Each describes a novel perspective on the legend that can be used with the guidelines to address the problem domain. Themes are neither comprehensive nor mutually exclusive and may be used individually or in combination to inspire visualizations.

4.1 The Map is the Legend

The roles of map (spatial representation of geographic setting) and legend (spatial representation of map content and symbols) are blurred in this theme that emphasizes spatial layouts.

- **No Legend** – Must a map always have a legend? If symbols are known or map tasks do not require precise identification or accurate estimation then expensive map-to-legend references may be removed by omitting the legend – the map sufficing as an indicator of content. The omission of many known symbols from existing legends (see [60]) could be extended to zero selection if all symbols were known or "*self-explanatory*" [53]. In a dynamic environment details on demand [40] may suffice and limit the risks associated with *no legend*. They may also limit the interruptions associated with look-up assumed by the literature on (static) cartography. Transient legends are used in a number of Digimap clients and offer possibilities.

- **Map Section** – Legends with 2D spatial ordering. *Natural legends* of topography, annotated and stylized indicative map sections relating symbol and referent, have significant positive effects for some tasks [14]. This approach is used to an extent by the Ordnance Survey in their paper map legends [44] (Fig. 3) and by Digimap with marine data sets. In both cases the features used tend to occur in broadly linear arrangements. A stylized labeled 2D map section is a viable and effective alternative [14].

- **Map Becomes Legend (Becomes Map...)** – A dynamic map that transforms from map to legend and vice versa may help relate
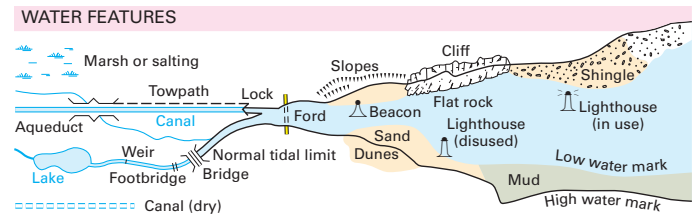

Fig. 3. *The Map is the Legend – Map Section.*
An extract of the OS Landranger 1:50,000 map symbols sheet [44] containing a natural legend. Features are arranged in a linear fashion to show indicative but fictitious geography. ©*Crown Copyright 2002.*

symbol and location effectively and reduce lookup activity by removing the need to separate the representation of map and legend. Smooth animated transitions [28] may be beneficial. Animating symbol locations between positions that are geospatial, spatially indicative and those that relate to aspatial feature characteristics such as order and hierarchy addresses this theme in an innovative way (Figs. 1 and 9).

4.2 The Legend as Statistical Graphic

A graphical statistical summary of current map content and a dynamic query filter for map exploration.
Layout and dynamism can be combined effectively to develop *active legends* [46] whereby graphical statistics summarise current map content and act as a query filter or *control center* [49]. Map exploration is supported by linking views with *bi-directional interactions* [49]. This theme provides scope for a variety of 1 and 2D uni and bivariate statistical graphics [19, 37] and draws upon a rich tradition of combining alternative views of data for exploration through dynamic linking (e.g. [1, 17, 26, 27]). Interface elements containing graphically encoded information may be appropriate [59]. Requirements for exploratory data analysis software [57] should be considered to support typical queries discussed at our workshops such as: *Are there more A or B-roads on this map? Where are the museums? What type of landcover do windmills occur on? Does this vary in different places?*

4.3 A Legend of Legends

Alternative styles are displayed and related using layout.
The emergence of alternative symbolism schemes for maps through expert systems [31] or crowd sourcing [10] poses an additional issue: how do we produce a legend of legends? Furthermore, in the context of the advice proffered here, how do we spatially arrange, or *map*, these legends? Maps of symbolism styles arrange alternatives spatially so that users can relate and navigate between alternative symbolism sets (Fig. 4) according to relevance determined by preference [10], usage, scale or geography [32].

4.4 The Relevant Legend

Selection includes only what is required, varying as this changes.
Relevance is a key concept in considering *selection* and *layout*. This changes over time, according to data and with use and user. The *Relevant Legend* shows only what is required. A geospatially *Relevant Legend* shows only what is on the map and addresses a common user concern raised directly during our workshops: "*I don't want a legend that is showing things that are not on the map*". A dynamic implementation updates continually.

For example the content of a geological legend may be adjusted to show particular aspects of the stratigraphy (Fig. 5) or to emphasize the bedrock in a selected locality. This may involve limiting selection (and thus changing layout), or specific emphasis with highlight or lowlight (maintaining consistent layout). The latter is advisable in the geological case as the entire stratigraphic sequence is important in map interpretation. This theme is easily combined with others and is likely to draw upon the *active legend* concept. Examples include:
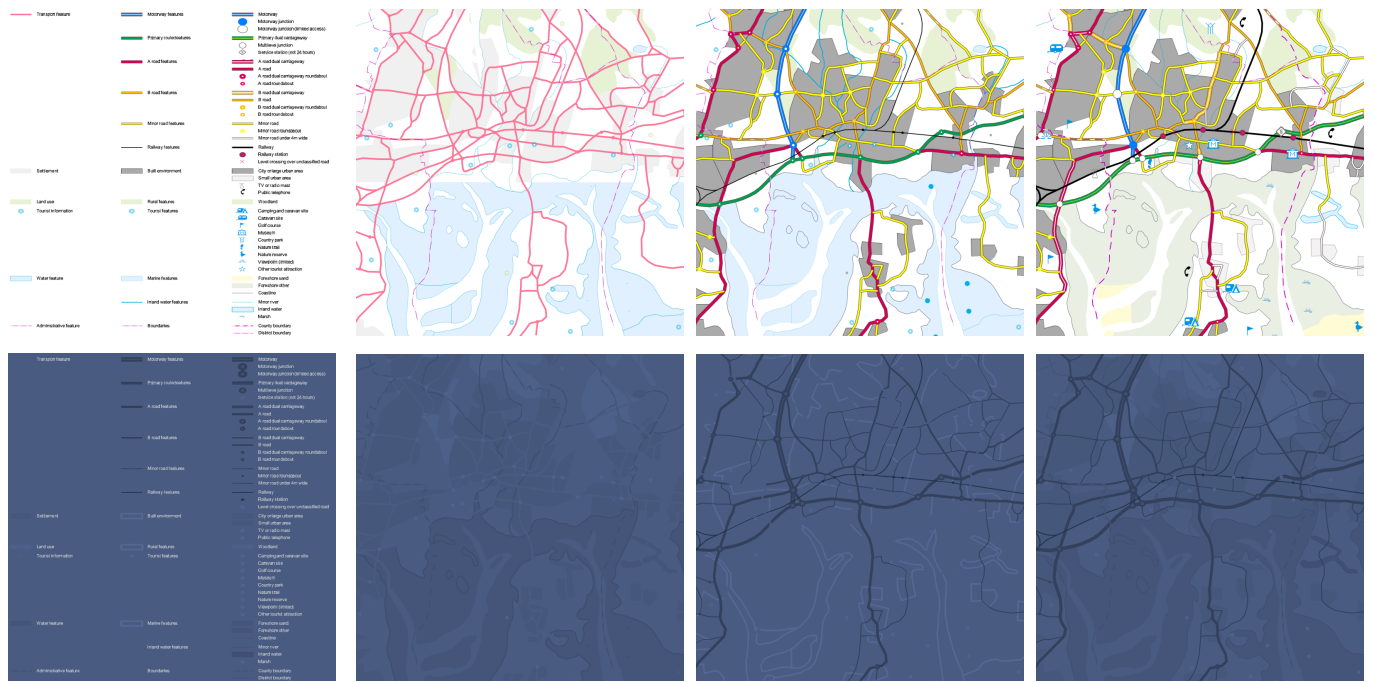
Fig. 4. *The Legend of Legends*. Legends for three levels of feature classification (*left*) and associated sets of maps (*right*) are shown for two contrasting styles (*top* and *bottom*) in *Prototype 5*. Either of the legend triplets *left* can be considered a *Legend of Legends* and could be used for selecting levels of aggregation. Any vertical pair of maps (*right*) can be considered a *Legend of Maps*. These or the vertical pair of *Legend of Legends* could be used to select styles. ©*Crown Copyright/database right 2010. An Ordnance Survey/EDINA supplied service.*
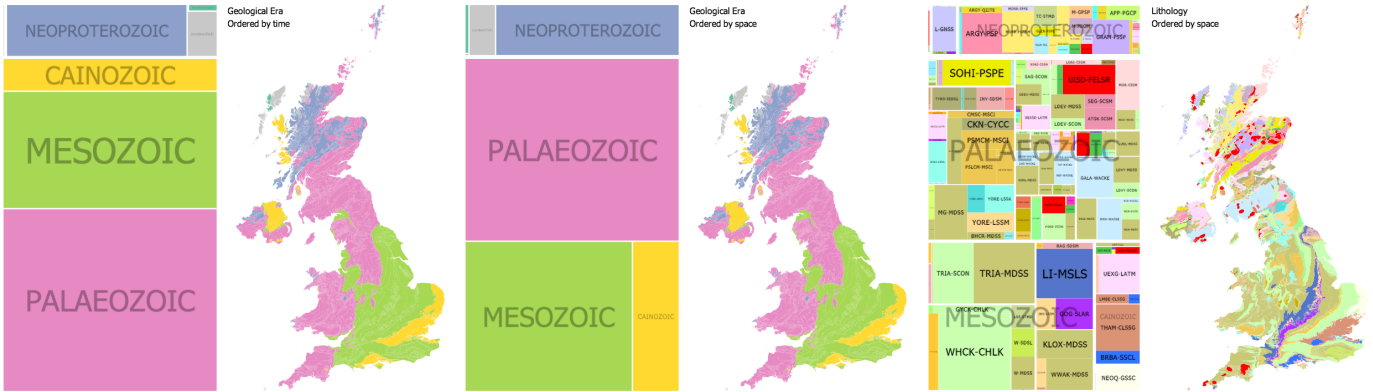

Fig. 5. *The Legend as Statistical Graphic – Hierarchy*. Three legend / map pairs show bedrock geology for the United Kingdom in *Prototype 4*. Areas on the legend relate to areas on the map for era (*left, center*) and lithology (*right*). The legend can be interactively reordered to show chronological (*left*), geospatial (*center, right*) or attribute orders at and for each level of the attribute hierarchy.
Based upon 1:625K DiGMapGB with the permission of the British Geological Survey.

Pop Legend – *Legend items are selected and arranged according to user community usage or needs.* A legend in which *selection* and *layout* (order) depend upon symbol usage (by recency or particular users and groups) may be useful. Mapping Digimap usage would allow frequently selected, included or interrogated symbols to be explored and may help identify those that are relevant: *What do people map or look-up?*
Spatial selection by popularity might be effective in some circumstances [21]: *Where do people download or map?*

My Legend, My Map – *Content, layout and order are controlled and saved by individuals or groups as required according to task, knowledge, location or symbolism.* Users vary a range of map and legend characteristics to address the issues of relevance and knowledge associated with effective legend design. These include selection of features, feature classes (with possible aggregation or disaggregation - see Fig. 5, *center, right*), geographic

location, legend structure or layout (see Fig. 5, *left, center*), legend position and symbolism or style (see Fig. 4).

The Paint-Box Legend – *Symbols are dragged from a comprehensive legend on to the map.* This approach may be beneficial in the learning and teaching context. A *Paint-Box Legend* might be used to find areas containing features, or groups of features relating to symbols or groups of symbols. Symbol combinations could be used to identify areas where features co-occur: e.g. *Where do windmills and lighthouses occur?*

The Shopping Basket Legend – *Symbols are dragged from the map into a legend area when needed [49].* A teacher could use a *Shopping Basket Legend* to create a subset of items from which students could create maps with a *Paint-Box Legend*.

A *Legend of Legends* could use this widely applicable theme with layout ordered according to individual or group activity.

4.5 The Source Independent Legend

Data are integrated from multiple sources with conflicts resolved. Sources are identifiable but items grouped by other characteristics.

Legends frequently integrate data from multiple sources, the Digimap *Carto* and *ROAM* clients are examples with scales varying across the Ordnance Survey collection. Feature classes, definitions and levels of uncertainty may differ between sources in a single 'mashed-up' map. The *Source Independent Legend* address such conflicts in a seamless and elegant manner, perhaps through hierarchical ordering. Origin should be evident in the legend but symbols should be distinguishable and grouped according other characteristics – such as feature class, task, users' knowledge, popularity of use, or others. Varying imposed (false) hierarchies can help explore structure in a data set [52] and this approach may be relevant here.

4.6 The Ground Truth Legend

Symbols are augmented or replaced with (local, community contributed) imagery. The user community could determine relevance.

In traditional legends the relational link is between symbol and map. Various online communities provide access to geo-referenced imagery that could be used to augment the links between location and reality afforded by traditional symbolism. A number of sophisticated and spatial designs use imagery in this way [8, 18, 23]. The theme could be enhanced by community contributions – with images tagged according to the degree to which they are representative of particular features or places. Queries that might be answered include:

Is there a photograph of this [feature]?
What does this [feature] look like?
Do all the [features] around here look the same?
Where is the nearest photograph of this [feature]?
Where are the most typical [features]?

Requests could also be combined:

Where do typical cases of [feature1] occur
 ***near to** typical cases of [feature2]?*

Most of these questions could be usefully asked and answered both locally and globally to encourage consideration of spatial variations.

5 DIGITAL PROTOTYPES: IMAGINATION EXERCISE

The themes were used to design visualization legends for core Digimap data sets identified in characterizing the problem domain. Four initial prototypes (numbered 1-4) were presented to EDINA along with the guidelines and themes to demonstrate possibilities, communicate ideas and elicit further feedback in ways that are only feasible with tangible artifacts containing real geospatial data [39]. Each prototype is dominated by a particular theme, and named accordingly, but influenced by others (Fig. 6). Variations on a theme are differentiated by graphic type. Characteristics of the problem domain addressed by each prototype are tabulated in Fig. 2. The accompanying movie details the dynamic functionality of each prototype and should be consulted in conjunction with these static figures.

5.1 The Map is the Legend

We use this theme to explore the relationships between geospatial and aspatial graphics of geographic information with three alternative combinations of layout and selection for legend items (Fig. 1). The idea is to create a legend that is as familiar as possible to users and yet to take advantage of alternative layouts that are available in a dynamic medium. *Prototype 1* uses the *1:50,000 Scale Colour Raster Landranger* for a 20km^2 tile with a broad range of inland and coastal features (*SU60*). Vectors were acquired from the *OS Meridian 2* product. Feature locations within the selected area were manually digitized from Landranger to relate locations with symbols and symbol categories supplied by EDINA.

The *legend* view consists of a 1D ordered layout with a single case of each feature (Fig. 1, *left*). This transforms into a *map* – a 2D geospatial layout of all features (Fig. 1, *center*). A third layout, the *mapped legend* is a 2D geospatial ordering with a single case of each feature at an indicative location (Fig. 1, *right*). These are randomly selected in our prototype, but our emphasis on the importance of layout

Fig. 6. *Themes and Data Sets Used in Developing Prototypes.* The matrix shows associations (*influenced by / demonstrates*) between theme and prototype (*top*). Gray squares show associations, dots dominance. Data sets used in each prototype are also recorded (*bottom*).

suggests that locations should be selected in more meaningful ways. Smooth transitions animate between each view to relate locations in geographic and attribute space. Selection updates as geospatial extent is varied through zoom and pan.

5.2 The Legend as Statistical Graphic – Bar Chart

Areal features and associated descriptive groups are the focus of *Prototype 2*, which uses a subset of the *OS MasterMap Topographic Layer*. This high-resolution vector mapping product partitions Great Britain into just under half a billion tessellating polygons corresponding to buildings, fields and the geometry of roads and paths. Dynamic legend symbols summarise features in the current map view through a *Bar Chart* (Fig. 7). The planar coordinates of the legend show all feature classes displayed in the map with a magnitude (*horizontal axis*) relating to some statistical attribute of the class (e.g. number [37], area, perimeter). Bars are ordered by an appropriate characteristic (*verti-*
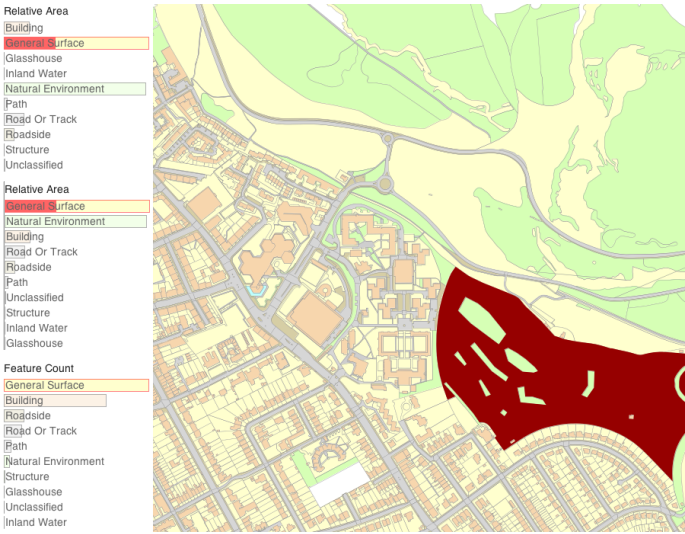

Fig. 7. *The Legend as Statistical Graphic – Bar Charts.* Bar charts (*left*) in *Prototype 2* show characteristics of an area selected with zoom and pan (*right*). Feature areas (*top, center*) and counts (*bottom*) are shown, with vertical ordering by alphabet (*top*) and magnitude (*center, bottom*). Bi-directional highlighting allows symbols or features to be selected on demand with linked views. ©*Crown Copyright/database right 2010. An Ordnance Survey/EDINA supplied service.*

cal axis). Map and statistical graphic exhibit consistent bi-directional interactions for selection and highlighting. Bar orders and lengths update during navigation. The concurrent use of feature class label and statistical graphic could be considered a '*scented legend*' after the 'scented widgets' of Willett *et al.* [59].

5.3 The Legend as Statistical Graphic – Matrix

We compare features of different geometry from different sources in *Prototype 3* where geology and road data are combined in an interactive statistical graphic (Fig. 8). The BGS Rock Lexicon recorded in *DiGMapGB* [6] is used to classify the geology. This 1:625k data set contains onshore bedrock polygons with information about rock age and type. Road features are from *OS Strategi*, a vector version of the *1:250k Scale Colour Raster* that contains feature type, point and line geometry and a rich set of attributes for roads, rivers and points of interest (see section 6).

A dynamic 2D visualization legend shows a feature class from one of the sources in each dimension (Fig. 8, *left*). These are ordered by an appropriate characteristic: age in the case of bedrock (*vertical*) and capacity for roads (*horizontal*) and shaded to show co-occurrence. Secondary visual variables are used to show quantity in a heat map [58] – in this case the degree to which legend elements co-occur geographically in the current map. Interactions relate visualization legend and map with mouseover-invoked details on demand supporting lookup tasks. This example shows 'line in area' relationships as requested in our workshops, but for data sets with limited likely association in this case. The approach is applicable to other data sets and relationships including: point in area, point within distance of line, and point within distance of point. Different configurations of layout and symbolism in the legend could transform the matrix into a mosaic plot or fluctuation diagram. Dynamic functionality such as feature class re-ordering and aggregation could be applied within this theme.

5.4 The Legend as Statistical Graphic – Hierarchy

Prototype 4 consists of a dynamic, spatial legend in which the geographic and hierarchical nature of the national bedrock geology classification (see *section 5.3*) is depicted through a 2D spatial treemap [62]. We built a 6-level classification hierarchy from the four hierarchical geological timescale units of *Eon*, *Era*, *Period* and *Epoch*, followed by the BGS Rock Classification Scheme (RCS) and the BGS Rock Lexicon entry (LEX). Established color schemes were used for the latter two levels [5]. We allocated ColorBrewer [25] *Set1*, *Set2* and *Set3* schemes to *Eon*, *Era* and *Period* and random colors to the 30 *Epoch*
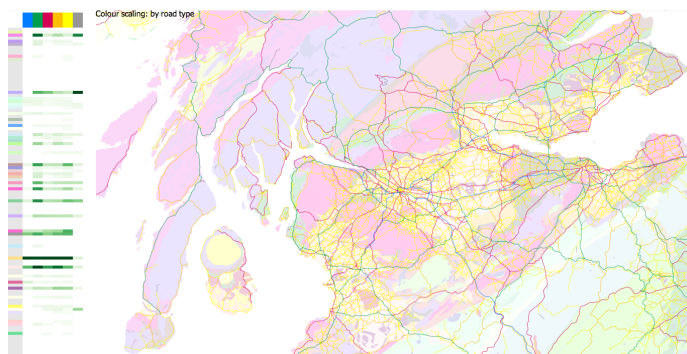

Fig. 8. *The Legend as Statistical Graphic – Matrix.*
A matrix legend allows co-occurring features to be explored in *Prototype 3*. Here the matrix shows bedrock (*vertical*) vs. roads (*horizontal*) with colors indicating relative co-occurrence for each road type (*column*). Alternative scalings by bedrock (*row*) or global values (*area*) are available. The matrix values update as the map is navigated with zoom and pan. Bi-directional highlighting relates map and legend with textual details provided on demand. ©*Crown Copyright/database right 2010. An Ordnance Survey/EDINA supplied service. Based upon 1:625K DiGMapGB with the permission of the British Geological Survey.*

categories. In Fig. 5 the treemaps are at the level of *Era* (*left, center*) and *rock lexicon* (*right*). Chronological (*left*) and geospatial (*center, right*) layouts of legend categories are shown hierarchically. The legend can also be ordered by *area*. Other 1 or 2D orders could be added – relevance ordering would address the *Relevant Legend* theme. Smooth animations are used to transition between layouts. Bi-directional interactions relate map and legend with details on demand supporting lookup tasks – any category being selectable in map or legend.

6 DIGITAL PROTOTYPES: FOCUSSED DEVELOPMENT

A *Possibilities Report* containing the legend guidelines and themes, along with the four initial prototypes demonstrating how these could be applied imaginatively to Digimap products, formed the basis of a second round of more focussed discussion. The objectives of the *imagination exercise* involved collectively exploring and communicating possibilities and generating more specific requirements for further development. Responses were positive. Discussion about the ideas and their applicability to the various data holdings and utility to user groups was broad initially, but constructive and animated – the prototypes stimulated plenty of ideas. EDINA suggested various ways of applying the themes in a variety of use cases with a range of additional data sets, demonstrating their utility in communicating possibilities. These included a wireframe of *The Ground Truth Legend* with community contributed styles and locally relevant photographs. EDINA took time to evaluate the possibilities before establishing priorities for more constrained and functional prototypes. These included:

- a focus on the *Strategi* data set [45];
- applying 2D layouts to the rich *Strategi* feature class hierarchy;
- enhancing prototypes with styles, layout options and more features for bi-directional interaction.

OS Strategi feature descriptions are very specific (e.g. *Motorway, under construction*) and we used EDINA's existing interpretation of the three-level Ordnance Survey hierarchy [45] to group features with 8, 46 and 210 categories at each level. Two of the digital prototypes were enhanced accordingly in line with the design guidelines. *Prototypes 5 and 6* resulted and are illustrated in Figs. 9 and 10 and through the accompanying movies.

6.1 The Map is The Legend – Strategi

We applied *The Map is the Legend* to *Strategi* and further spatialized the legend view with 2D ordered layouts containing a single case of each feature structured according to feature class. Navigation through the legend hierarchy in *Prototype 5* is supported through interactive controls to select levels. The richer feature set required a number of design issues to be considered. The traditional legend no longer fitted on screen if viewed with a large (familiar) font and a number of features selected. Interactive controls over item size and spacing were added to provide a continuum between 'visible' and 'not visible' depending on the importance of the legend view at any time. To reinforce the continuum between map and legend views, togglable feature class selection and highlighting was added in all views to allow features to be selected geospatially or thematically (see Fig. 9). Multiple legend orderings reinforce the notion that the traditional legend is simply one of many possible views of the data. Three orderings are available: by theme, alphabet (for finding a symbol of known named type) and drawing order (related to the *Strategi* feature code order). Other orders are possible, for example to address *The Relevant Legend* theme.

Allowing selection and display of features in any layout reinforces the way in which we disassociate the data being shown from the mode of display in this theme. An alternative approach is to apply different symbolization styles to the same data. Two example styles were implemented in *Prototype 5* (see Fig. 4). The default *Strategi* style matches the standard *1:250k Scale Colour Raster* map (Fig. 4, *top*). An alternative gray-blue style derived from a contribution to CloudMade [10] can be applied to all views of the data (Fig. 4, *bottom*).
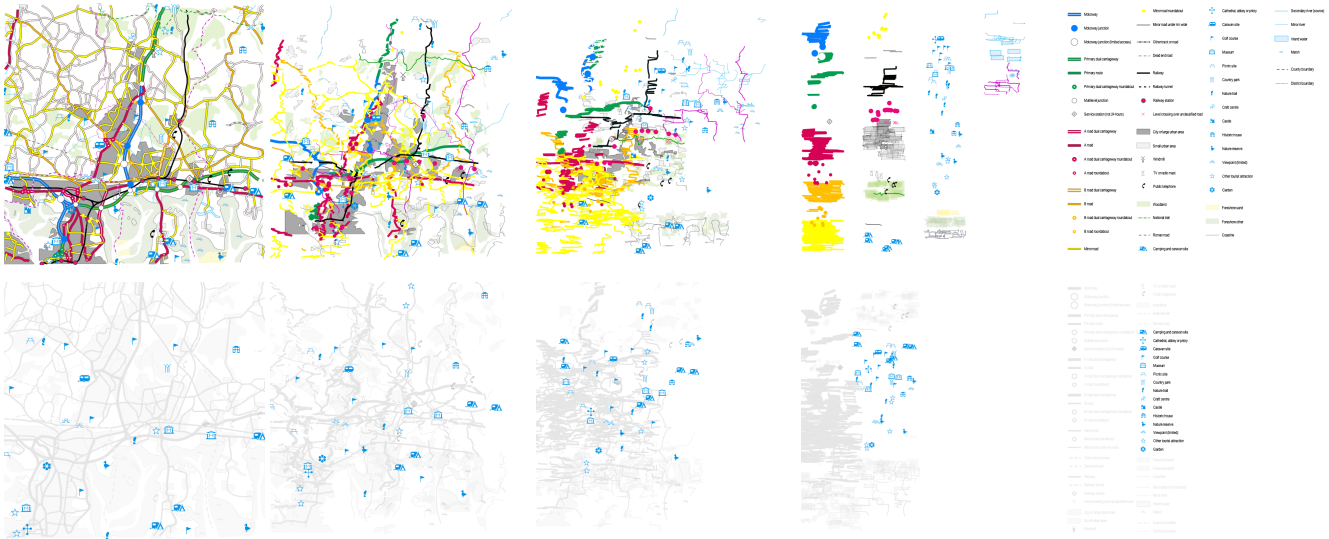
Fig. 9. *The Map is the Legend – Strategi*. Symbols move between geospatial and thematic layout in *Prototype 5*. The map-to-legend transition is shown for the all features (*top*) and a selection (*bottom*). ©*Crown Copyright/database right 2010. An Ordnance Survey/EDINA supplied service.*

Fig. 10. *The Legend as Statistical Graphic – Strategi*.
In *Prototype 6*, containment reflects the hierarchy of point, line and area features in *Strategi*. Legend symbols show relative occurrences for each geometry type through size (national) and color (local). The area south of Berwick (*top*) is characterised by level crossings, minor roads and rivers and foreshore features in comparison to the Barmouth area (*bottom*) where coastline and railway stations feature more than at national level. Camping sites are expected in coastal regions with low proportions of urban area but the predominance of picnic sites and trails in one location versus museums and golf courses in the other suggests different functions and recreational possibilities. Raster maps are generalized in *Prototype 6* to ensure rapid response. © *Crown Copyright/database right 2010. An Ordnance Survey/EDINA supplied service.*

6.2 The Legend as Statistical Graphic – Strategi

In *Prototype 6* the treemap legend acts as a 2D statistical graphic showing *Strategi* feature occurrence for three feature geometries at two geospatial extents: *national* occurrence with areas relating to counts, total length and total area for point, line and area features respectively; and *local* occurrence through color schemes showing relative frequencies for each geometry in the current view (Fig. 10). 2D ordering in the legend emphasizes different characteristics of the global data set or the local selection including: geography, occurrence, relevance. Point count, line length and area are not directly comparable characteristics of features with varying geometry – the same area is thus allocated to each geometric type in the default treemaps. Features in the treemaps can alternatively be sized equally, as in conventional legends, or according to local occurrence. These different orderings and emphases may draw attention to particular characteristics of the area summarized by the legend and address or inspire particular research questions [52]. Animated transitions morph between views whenever layout changes. Map and legend are closely linked and highly interactive with the legend updated according to geospatial selection through zoom and pan.

7 IMPACT

This study involved ongoing communication between the designers and EDINA. Feedback was regular and largely informal. Reactions at a third workshop to *Prototypes 5 and 6* were very positive and sometimes effusive: "*Even my Mum would understand that!*"

In line with the *formalized informal* approach to cartographic praxis [35, 36] we solicited views on the degree to which the Digimap visualization legends had achieved impact in EDINA. A lightweight evaluation structured responses around the issues identified in domain characterization (Fig. 2). Two key contacts at EDINA were asked to consider whether the two-phase process of *Imagination Exercise* and *Focussed Development* had or were likely to have a *valuable impact* on:

- *them as individuals* – through their thinking about legends
- *the service* – through plans to deploy any knowledge acquired

Responses are summarized below and in Fig. 2 where designers' intentions for each of the six prototypes are listed against reported impacts.

7.1 Current Problems and Successes

Responses indicate that many of the problems identified were addressed and many of the successes built upon both in terms of the individuals' viewpoints and potential for use by Digimap subscribers. Design intentions were achieved in most cases with an emphasis on

the high ranking successes and problems, indicating that the exercise enhanced the way in which clear, comprehensive and logically structured legends are applied to Digimap data in limited screen real estate. The case of too much space being given over to legend at the expense of map is the only issue in which the prototypes were designed to have an impact, but none was recorded – an ongoing priority.

7.2 Aspirations

A valuable impact on achieving aspirations was reported, with particular emphasis on *elegance*, *flexibility*, *richness* and *responsiveness* (Fig. 2) – key characteristics of the information visualization approach emphasized in our designs. The issue of text-related search was not addressed. Whilst not originally identified as a high priority, our themes and guidelines provide scope for additional designs through which search could be supported. Aesthetic is important in cartography and has been shown to have a measurable effect on usability in information visualization [9]. Perhaps our most challenging aspiration was to produce a solution "*so beautiful [that] the user prints the legend and puts it on their wall!*" Positive feedback on this was encouraging.

7.3 Tasks and Functionality

Responses to the impact evaluation emphasize the way that visualization legends summarize and characterize an area effectively in ways that static legends do not, show relationships between features and can help users find and relate symbols (Fig. 2) – key tasks associated with map use. The evaluators also indicated that visualization legends can make digital maps look more professional – an important role of the *paramap* to which visualization can contribute. EDINA respondents did not report a valuable impact on their thinking about legends in terms of *providing support for communicating symbol meaning across a range of tasks* (*task-based lookup* response set in Fig. 2). They did however acknowledge a likely impact upon users of the service in lookup tasks through the planned adoption of the ideas.

7.4 Other Reactions

Views expressed in free text indicated that the exercise helped EDINA investigate alternate approaches to visualization and consider how these might be applied in the various clients. The work was regarded as "*inspirational*" by one respondent who indicated that "*Exciting times lie ahead*". The most significant achievements were deemed to be:

- the opportunity to think about legends in new ways and incorporate these ideas in the new generation of mapping clients;
- demonstration that legends can be more information rich and functional by providing more than an explanation of symbol meaning and through higher levels of user interaction that support a number of tasks involved in understanding data;
- raising awareness of possibilities for improving the presentation of other sorts of *[aspatial]* digital content delivered by EDINA.

The responses link closely to our objectives and the issues raised in establishing the problem domain. They can be considered as evidence of success. The first achievement is particularly important as EDINA has secured financial support for this activity on the basis of the value of the work undertaken – the Joint Information Systems Committee (JISC) is funding a 12-month service enhancement project to develop *Active Bi-directional Legends* in Digimap clients. This will include a new *Geology Mapper* and a plan for active legend functionality in other clients. EDINA regard this as "*a major step forward for Digimap in approaching how we tackle legend visualization*" and describe the visualization legend work as "*making us realise that we had an exciting opportunity to do something innovative and beneficial both for the service and the user's experience*". A satisfying outcome beyond the original scope of our rethinking exercise is the suggestion that upgrades to non-GeoSpatial EDINA services may result – supporting our contention that the work is of broad relevance.

Reported *disappointments* included operating within the technological constraints associated with national service delivery, the realisation that legend visualisation in existing clients was lacking and the time that will be needed to realize the ideas. Happily, the funding secured on the basis of the successes will help with some of these issues. Neither the inconsistency of symbolism between products and data of different scales, nor possibilities for aggregation / generalization functionality were addressed (Fig. 2) – but neither were all themes utilised (Fig. 6). The same is true of issues relating to paper legends, which are important in a large number of Digimap use cases. These remain open issues requiring creative solutions.

8 Conclusion

The *paramap* makes a significant contribution to geospatial visualization and other para-information is important in information visualization. We have argued here that the principles and guidance governing good map design should also direct good *paramap* design and we extend this argument to keys, legends and meta-information associated with other data graphics that are less "*inherently spatial*". This contention is explored here with respect to map legends for a national digital data provider through a series of priorities and ideas that emerged from users and an assessment of good practice described in the cartographic literature. The high-level principles and broad themes developed have shaped design decisions and enable us to use principles and guidance for map design in legend design. We explored the themes and principles through data prototypes and suggest that this approach may be widely beneficial in information visualization where understanding data is intrinsically linked with understanding data representation.

The various impacts and omissions reported in *section 7* indicate that there is scope for further work to apply, enhance and evaluate the various concepts and to extend and enhance the application of visualization legends. The general nature of the themes and guidelines leaves ample room for interpretation and refinement. We need to explore the design space partially described by the concepts presented here and address many of the open questions raised regarding use of legend space as we react to this re-thinking of legends. This work may include: designing and evaluating interactions and controls that support the kinds of dynamism presented here; evaluating legend designs to build on reports of positive effects under certain conditions [47]; understanding, predicting and accounting for the effects of legend instability (in for example the *Relevant Legend*); establishing meaningful locations for the *mapped legend*; the possibility of a *Legend Legend* as legend designs use layout and colour in more sophisticated ways.

Working with a large data provider serving mapping data that have traditionally been considered static and often paper-based has provided some interesting challenges. We found conducting the *imagination exercises* highly valuable in this context where opportunities offered by information visualization can allow radically different approaches to legend construction and use. Our prototypes that implemented these approaches have with favourable responses from the data provider and have resulted in new funded activity to implement novel forms of legend for end users. This should allow more task-based evaluation and the approach to be applied, enhanced and evaluated in a wider range of data visualization contexts and activities.

Ultimately, design in both cartography and information visualization involves informed human decision-making, as does effective usage of the artifacts each discipline produces. We draw attention to the need to design spatially, whatever the degree of spatiality in a particular data set, or view of it. We hope that a focus on legend design will result in more cognitively useful and explicitly spatial maps, graphics and associated para-information to support those using visualization.

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