Charting the Path towards Effective Knowledge Visualisations

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ABSTRACT

Knowledge visualisation is enjoying increasing attention from researchers and organisations, due to its potential for expediting knowledge transfer. Despite the availability of many information visualisation guidelines, those who are tasked to produce knowledge visualisations currently do so without any formal guidance. These unguided efforts do not reliably deliver efficacious visualisations.

The research reported in this paper sought first to delineate the *essence* of knowledge visualisation. We captured this essence in the form of a comprehensive definition as well as a list of essential criteria exhibited by effective knowledge visualisations. Using these, we moved on to address the lack of guidance by producing a set of knowledge visualisation guidelines. We report on how we derived and evaluated these guidelines.

The guidelines, despite the rigorous derivation process, did not help the evaluators to produce effective visualisations. We reflect on the reasons for this and report on a number of lessons learned during the process. We conclude by suggesting a direction for future research.

CCS CONCEPTS

• **Human-centered computing → Visualization theory, concepts and paradigms**; **Visualization design and evaluation methods**; *Empirical studies in visualization*;

KEYWORDS

Knowledge Visualisation; Visualisation Characteristics; Visualisation Criteria; Visualisation Guideline Evaluation

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1 INTRODUCTION

It is no longer possible to read all new publications in a particular area, due to the sheer number of research papers appearing daily [62]. This makes it increasingly challenging for subject experts to keep up with the knowledge development in any given area [35].

Researchers suggest that knowledge can be transferred more effectively, and efficiently, if the author includes well-crafted visualisations to condense the knowledge into an easily processed unit: a *knowledge visualisation* [1, 5, 25]. The inclusion of a knowledge visualisation makes it possible for a subject expert quickly to gain a sense of the paper, and thus stay apprised of the latest developments.

It is non-trivial to craft effective knowledge visualisations [50], so those wishing to craft visualisations would benefit from a widely-applicable set of guidelines to guide their development.

Visualisation, as a scientific field, is a mature scientific discipline [11]. It has accumulated a resource base of approved methods and rigorous processes. This includes guidelines to inform the development of *data* and *information* visualisations [13, 20, 36, 67]. Knowledge visualisation is much less mature field [12]. Hence no widely-applicable set of knowledge visualisation guidelines has yet emerged [48], a deficiency that we seek to address to reduce the incidence of ineffective visualisations [40].

This research investigated knowledge visualisation, with the aim of supporting knowledge visualisation designers. The first step, therefore was to explore the **essence** of knowledge visualisation (Section 3), and then, secondly, formulate a set of knowledge visualisation **guidelines** to inform designers (Section 4). Finally, in Section 5, we explain how we evaluated these guidelines. We reflect on our findings and report on some lessons learned in Section 6. We suggest a way forward before concluding in Section 7.

2 RESEARCH DESIGN

The research design comprised three stages. This included two systematic literature reviews and an empirical evaluation of the guidelines, as depicted in Figure 1:

Stage 1: Delineating the Essence

(1) We carried out a review of the literature to find papers that provided definitions of *'knowledge'* and of *'knowledge visualisation'*. Papers published in academic journals were collected from electronic databases, including ACM, IEEE Explore, Scopus, Springer and Web of Science. The keywords used for the searches were ('knowledge visualisation' or 'knowledge visualization') and 'definition'. The search was restricted to papers published between 2004 and 2016 in English, excluding blogs, patents and book chapters. We commenced searching in 2004 because that is when the Eppler [21] published the seminal paper on knowledge visualisation.
(2) We synthesised all the definitions and derived an initial set of criteria for knowledge visualisations,

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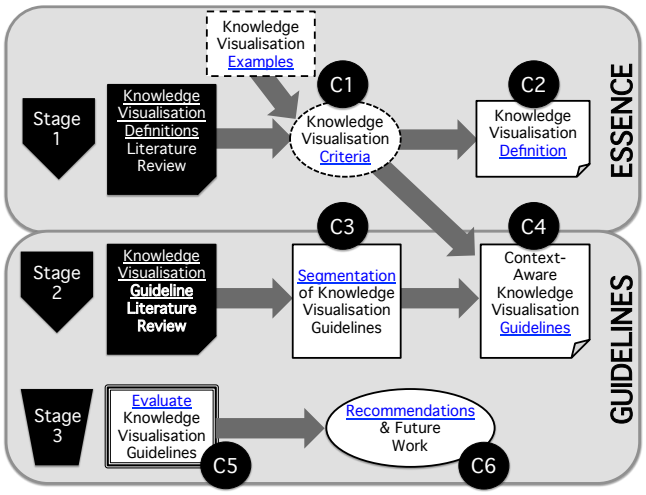

Figure 1: Research Process

(3) We searched for existing knowledge visualisations to confirm the validity of these criteria, searching for those labelled both 'good' and 'bad'.
(4) **Quality Measure: (C_1)** Based on the insights gained from this process, we refined the criteria, and
(5) **Definition: (C_2)** We derived a comprehensive definition of knowledge visualisation.

Stage 2: Deriving Knowledge Visualisation Guidelines

(1) We carried out a review of the literature to find papers that provided knowledge visualisation guidelines. Papers published in academic journals were collected from electronic databases, including ACM, IEEE Explore, Scopus, Springer and Web of Science. The keywords used for the searches were ('knowledge visualisation' or 'knowledge visualization') and 'guidelines'. The search was restricted to papers published between 2010 and 2016 in English, excluding blogs, patents and chapters.
(2) **Segmentation: (C_3)** We then synthesised all the definitions and segmented the guidelines on two dimensions: (1) context and (2) specificity.
(3) **Guidelines: (C_4)** Having identified the level of specificity and context awareness that should be addressed, we derived a comprehensive set of knowledge visualisation guidelines based on the criteria derived in Stage 1.

Stage 3: Evaluation of Guidelines:

(1) **Evaluation: (C_5)** We carried out an evaluation of the guidelines;
(2) **Reflection: (C_6)** We reflected on the results and conclude with recommendations for future work.

Contribution

In summary, the contributions of this paper (C_{1-6}) are:

Delineating Knowledge Visualisation Essence:
The Cambridge dictionary defines essence as *"the basic or most important idea or quality of something"*. To capture the concept of quality, we have to identify a set of criteria demonstrated by a 'high quality' knowledge visualisation. A comprehensive definition then incorporates the sense of these criteria.

C_1: A list of the **criteria** for effective knowledge visualisations;
C_2: A comprehensive **definition** of "knowledge visualisation";

Deriving & Evaluating Knowledge Visualisation Guidelines:
Having encapsulated the essence within a list of desirable criteria and a comprehensive definition, we derived guidelines to help knowledge visualisers. This stage included the following activities:

C_3: A **segmentation** of the extant literature related to knowledge visualisation guidelines, on two dimensions;
C_4: A set of **context-aware knowledge visualisation guidelines**;
C_5: An **evaluation** of the guidelines;
C_6: A **reflection** on the essence of guidelines and a suggestion for future development of knowledge visualisation guidelines.

3 STAGE 1: ESSENCE

Knowledge can be tacit, explicit or codified [61]. *Tacit* knowledge refers to the knowledge held in practitioners' heads [46]. Some researchers refer to this as *implicit* knowledge [59]. Tacit knowledge is not always articulated but, when it is, it is referred to as *explicit* knowledge. When explicit knowledge is documented, perhaps by producing a visualisation, it becomes *codified*.

McInerny [46] argues for the need to understand the essence and dynamic nature of knowledge, before any attempt to manage such knowledge is attempted. We thus proceed to explore the nature of knowledge in the following section.

3.1 Knowledge

Knowledge is always constructed with a purpose in mind [33]. Knowledge results from human cognition [33], from someone forging new connections [43], identifying concepts or finding evidence of the existence of something previously uncovered [57]. Knowledge is inherently contextual [56], a particularly important feature, and a theme we will return to in our final reflection.

When someone carries out research to discover new knowledge, or has experiences that result in new knowledge, they effectively *internalise* their new understanding. The knowledge is tacit or implicit. This knowledge then has to be communicated to an interested audience: it has to be *externalised* i.e. made explicit.

Externalising knowledge is challenging: it is surprisingly difficult to articulate and share some kinds of knowledge, especially using the written word [16, 18]. Eppler [21] explains that knowledge communication includes the know-how, know-why, know-what, know-where and know-who of knowledge. A failure to convey any of these adequately renders the communication process ineffectual.

In summary, knowledge is complex, multi-connected, the result of reasoning and begets more knowledge. This makes the codification, effective communication and transfer of knowledge non-trivial. Visualisations can maximise the effectiveness and efficiency

of knowledge communication, and we explore their nature in the next section.

3.2 Knowledge Visualisation

Knowledge visualisation is a relatively new field that focuses on the use of visualisation to facilitate effective and speedy knowledge transfer [8, 12, 22, 33, 53] with the sole aim of transferring knowledge from visualisation author to viewer [19]. Effective visualisation of knowledge is non-trivial [33] but, if done well, can exploit key strengths of the human cognitive processing system to enhance communication [37].

3.2.1 *Definition.*

A very simple definition of knowledge visualisation would be "*Visual Representations of Knowledge*". While accurate, this definition does not really capture the essence, nature and capabilities of knowledge visualisation. It is thus helpful to derive a more comprehensive definition. To do this, we conducted a systematic literature review as described in the research design section under Stage 1.

We identified the following publications: [7, 8, 14, 26, 28, 29, 47, 66, 71–73]. We grouped the delineating concepts in these definitions into the categories shown in Table 1.

Table 1: Knowledge Visualisation Definitions

PURPOSE — **THE WHY**
transfer and creation of knowledge [7, 8, 21]
instrument for knowledge processing [26]
INTENDED AUDIENCE — **FOR WHOM**
augmenting knowledge-intensive communication between *individuals* [47, 66]
at least two persons [28]
THE WHAT & THE HOW
visual representations [14, 21, 66, 71, 74]
represent experiences, insights, instructions, and assumptions [28]
construct and convey complex insights [66]
giving [people] a richer means of expressing what they know [66]
promotes the conveyance of experiential knowledge [29]

Eppler and Burkhard's original definition is: *"the use of visual representations to improve the creation and transfer of knowledge between at least two persons"* ([21] p. 551).

Using the extensions and clarifications presented in the other publications, we can extend this as follows:

> ***Knowledge Visualisation*** *is the use of graphical means to communicate experiences, insights and potentially complex knowledge. Such means should be flexible enough to accommodate changing insights, and facilitate conversations. Such representations facilitate and expedite the creation and transfer of knowledge between people by improving and promoting knowledge processing and comprehension.*

Eppler [23] offers some criteria for a graphical depiction to be considered a knowledge visualisation. We map each criteria to our definition in Table 2.

Table 2: Mapping Eppler's [23] Criteria to Definition

EPPLER'S CRITERIA	OUR DEFINITION
Essence: it captures and depicts knowledge	*"...potentially complex knowledge"* (**The What**)
Connections: it contains insights and relates ideas	"*experiences, insights*" (**The What**)
Visual: it must be visual	"*use of graphical means*" (**The How**)
Satisfy Audience Need: it should facilitate conversations	"*facilitate conversations*" (**For Whom**)
Flexible: it should be flexible enough to integrate changing insights	"*flexible enough to accommodate changing insights*" (**The How**)
Knowledge Transfer: it's primary *raison dêtre* is to support knowledge communication	"*transfer of knowledge between people*" (**The Why**)
Simplicity: it has to be useful to viewers	"*promoting knowledge processing and comprehension*" (**The How**)

3.2.2 *Knowledge Visualisation Examples.*

In order to test the comprehensiveness and applicability of our list of our criteria we sought out examples of 'good' and 'bad' knowledge visualisations. The former were of high quality and the latter of low quality, in terms of effectiveness. We classified them in terms of how well they communicated the 'who', 'what', 'where', 'why', 'when' and 'how' of the underlying knowledge [31], as judged by the two authors (neither of whom are subject experts in the knowledge being depicted). This exercise helped us to identify additional quality criteria that should augment our visualisation criteria. Due to space limitations we provide only a small sample to demonstrate particular qualities.

All visualisations in this section depict knowledge visually, aim to facilitate useful conversations and support knowledge communication.

Effective Visualisations.

One of the most effective and famous uses of knowledge visualisation is the Coxcomb diagram invented by Florence Nightingale (Figure 2). She wanted the army generals to understand what was really killing the soldiers. Nightingale's graph makes it clear that the Russians were killing far fewer soldiers than cholera, typhus, and dysentery. It is unlikely that the generals would have gained the same insight from descriptive texts, nor felt compelled to take action to establish field hospitals, without the understanding fostered by this diagram.

A well known example of a good knowledge visualisation emerging from an initial poor one is the London subway map. The map shown in Figure 3 was the first of its kind. This was an accurate depiction but it was also unhelpful to commuters. What was not initially understood was that different stakeholders had different needs. The maintenance and management teams did indeed need this kind of visualisation but the commuter wanted to interrogate the map

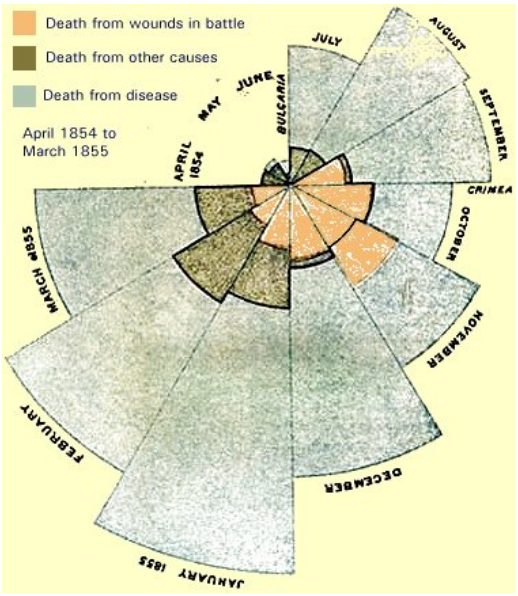

Figure 2: Modified image of the first of the two Coxcomb Charts provided by Florence Nightingale in 1858 [52] (described by [41]). Obtained from [42]

for a different purpose: to find out how to get from one point to another. The current visualisation is a model of economy (Figure 4). All extraneous details that would interfere with the commuter's need to navigate London are omitted; only necessary details are retained. This is a superb knowledge visualisation, crafted specifically to support knowledge transfer from the creator to the viewer.

Ineffective Visualisations.

Darrell Huff published a seminal book in 1954 [32], demonstrating some very poor knowledge visualisations, many of which seem designed to mislead.

At the top of Figure 5, Huff provides a map published by Newsweek to show that the United States federal government is taking the incomes of the majority of states. The same data can be depicted as shown in the map at the bottom, but this visualisation is less compelling so did not serve the alarmist purposes of those who published the top map.

3.2.3 *Augmenting the Criteria.*

The importance of a number of Eppler's criteria was confirmed by these visualisations:

- They are all **visual** and purport to exist in order to **transfer knowledge**.
- **Meet Audience Need:** The main problem with the map at the top of Figure 4 is that it was produced for the subway planners, and included information that was important to them in terms of rail maintenance. The later map, at the bottom of Figure 4, presents the information to support the commuter's task, and does so admirably.

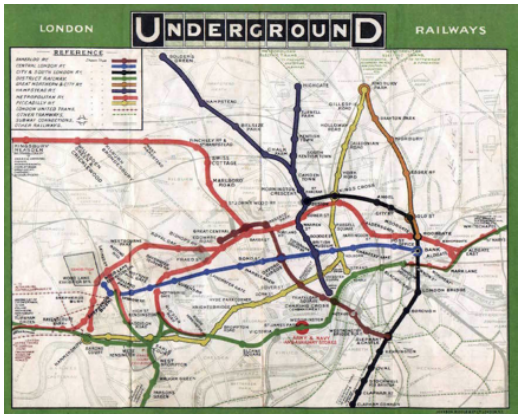

Figure 3: Initial Map (1908) Obtained from [70]

Figure 4: Snippet of Current Commuter Map (Pioneered by Harry Beck) Obtained from Obtained from [70]

- **Essence:** Figure 4 does not present the lay of the land, the depths of the tunnels or accurate depictions of journey lengths. That is not essential to support the commuter's task. Such details are extraneous and thus omitted.
- **Simplicity:** It could have been tempting to use images of soldiers in Figure 2, as is done in http://rhystat.blogspot.com/. It might well have been more appealing emotionally, but Florence Nightingale wisely produced a very simple visualisation.

Some new criteria emerged:

- **Context:** It is interesting to note that the author of Figure 5 provides a geographical context. This confirms the arguments of [24] with respect to the importance of context.
- **Exploit Familiarity:** Figure 2 adapted the well-known pie chart. The generals would have been familiar with that kind of diagram so the enhancements Florence Nightingale made would have improved the diagram, and not overwhelmed them by using a completely different kind of diagram that they would first have had to try to comprehend. Figure 5 exploits the familiarity of the map of the USA to convey the knowledge.
- **Integrity:** Figure 5 constitutes a warning in terms of how **not** to craft a knowledge visualisation. The aim is to transfer knowledge honestly, not to use visualisations to promote personal agendas.

The criteria to be satisfied are depicted in Figure 6.

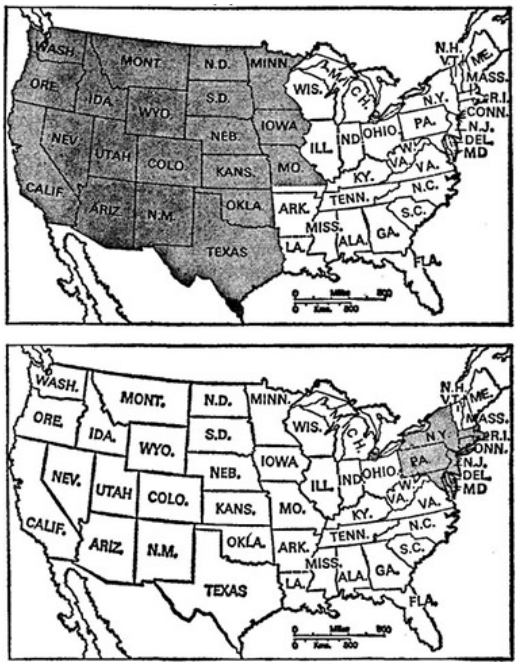

Figure 5: Two ways of portaying the amount of national income taken by the federal government from page 103 of [32] (a) [top] (b) [bottom]

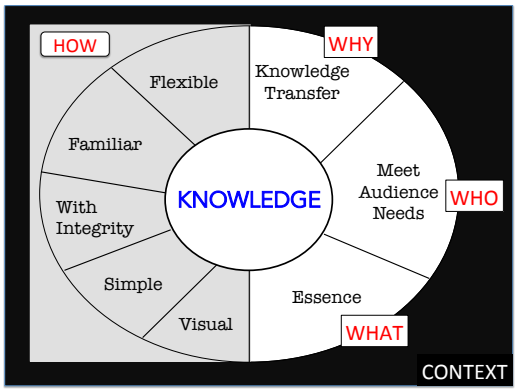

Figure 6: Knowledge Visualization Criteria

3.2.4 Final Definition.
We now further refine our definition to produce the following comprehensive definition of knowledge visualisation:

> ***Knowledge Visualisation*** *is the use of graphical means to communicate experiences, insights and potentially complex knowledge* **in context**, *and to do so* **with integrity**. *Such means should be flexible enough to accommodate changing insights, and facilitate conversations. Such representations facilitate and expedite the creation and transfer of knowledge between people by improving and promoting knowledge processing and comprehension,* **using familiar concepts where possible**.

This definition includes all the essential features of a knowledge visualisation's key characteristics but it does not explain how to craft visualisations that display these.

4 STAGE 2: GUIDELINES

We firstly sought guidance for what should be included in our knowledge visualisation guidelines. Craft and Cairns [15] explain that visualisation guidelines should encapsulate the following: (1) suggest a number of useful techniques; (2) be measurably valid; (3) be developed with the target user in mind; (4) provide a step-by-step approach; and (5) be useful for both novices and experts.

These are feasible as a long-term vision rather than constituting a helpful set of guidelines. We thus realised the need first to interrogate the literature on published knowledge visualisation guidelines.

4.1 Guideline Publications

We conducted a systematic literature review as described under the research design section in Stage 2. The guideline-related literature we gathered included: [4, 6, 9, 17, 34, 38, 39, 44, 45, 49, 55, 58, 60, 63, 66].

Classifying Guidelines.
The first important aspect that emerged from our perusal of these papers is the importance of context [3, 64]. Jonasson argues that contextualisation is essential if recipients are to be able to make sense of the knowledge being depicted [34]. Moreover, this confirms the importance of context, as captured in our definition of knowledge visualisation.

The other aspect is the fact that some guidelines were overarching and non-specific [6, 8] whereas others focused on minutiae and specifics of visualisation aspects [9, 10, 15, 25, 49, 58, 63]

We segmented the guideline-related publications in terms of these two dimensions. The first considers whether they are *contextual* or *context-neutral*. The other dimension is related to whether the publications offer *over-arching principles* to direct visualisations, or whether they attempted to be more *specific* in their directives. The final segmentation is depicted in Table 3.

4.2 Choosing a Quadrant

The first step was to decide which quadrant in Table 3 to focus on. The more abstract the guidelines, the less helpful they can be to someone learning how to produce knowledge visualisations. On the other hand, the more context-specific guidelines are, the less generalisable they might be to different contexts. Hence the upper two quadrants might not be generic enough to be applicable in multiple contexts.

The bottom left quadrant is context neutral and, because knowledge itself is context-rich, this quadrant did not serve our purposes.

The context-aware quadrant is conspicuously empty. It is this quadrant that we wish to focus on. We aim to craft a set of guidelines that will be tailorable to the context of the applicable knowledge domain. On the other hand, the guidelines should be equally applicable to a wide range of different contexts.

Table 3: A Segmented Overview of Knowledge Visualization Guidelines on Two Dimensions: Context and Specificity

	Context-Neutral	Contextual
Specific	Strategy: [10]	Healthcare [44]
	Visual Notations [49]	Business Intelligence [60]
	Perceptual Principles [58]	Learning [38, 45, 65]
	Diagram Understandability [63]	Inspection of Knowledge Bases [4]
		Company Strategy [5]
		Medical [39]
		Node-Link Mapping [17]
		Problems [34]
		Personal Learning [55]
		CONTEXT-SPECIFIC
Over-Arching	Risks [6]	
	Framework [8]	
	Visual Languages [25]	
		CONTEXT-AWARE

4.3 Deriving Context-Aware Guidelines

We wanted the guidelines to be context-aware, but not context-specific, so we provided two sub-components.

The first component supports delineation of context [3]. Here the focus is on the visualisation audience, the kind of knowledge to be visualised and the function of the visualisation. Here, too, the visualiser is required to make a broad decision related to the type of diagram to be used.

The second component focuses on specificity of the visualisation, informed by the previous step that established the overarching context. There is also some advice about including a legend and the use of textual labels.

4.3.1 *Guideline Contents:*

We extracted advice and guidelines from the research publications discussed in the previous section. We were also mindful of the criteria depicted in Figure 6. We first checked to see how many of the criteria were mentioned by the guideline publications. They were sparsely covered. Two mentioned three of the criteria [9, 55], two mentioned two [5, 44]. Most of the rest mentioned only one (usually the fact that it was visual) with only two mentioning none. This emphasised the need for a comprehensive set of guidelines.

We allocated guidelines gathered from the publications to two categories: (1) those that were related to context, and (2) those related to actual visualisation techniques. The former were included in the first component (Establishing Context) and the latter in the second component (Visualisation Techniques).

This pair of components encapsulates the criteria reflected in the definition of knowledge visualisation proposed in Section 3.2.3 and the insights of the knowledge visualisation publications we reviewed.

To support a step-by-step approach in following these guidelines we provided two accompanying checklists so that designers could chart their progress in working through the components [27].

4.3.2 *Component 1: Establishing Context.*

The need to establish context is related to the nature of knowledge as explained in Section 3. We provided guidance to help the designer delineate the context of the visualisation.

The final categories are shown in Table 4, with mappings to the criteria identified in Figure 6.

Table 4: Component 1: Establishing Context

QUESTION	CRITERION
What is the function of the visualisation? [10, 25]	Knowledge Transfer (**Why**)
What type of knowledge are you visualising? [8, 15, 25]	Essence (**What**)
For whom? [10, 25]	Meet Audience Need (**Whom**)
Visualisation format [10, 25] (Visual examples were provided of a Sketch, Visual Metaphor, Diagram, Pictorial Story and Knowledge Map)	Visual (**How**)

This aims to focus the designer's attention on the target of the visualisation [15]. We wanted them to ask themselves *why* they were producing the visualisation, *what type* of knowledge was being visualised, *who* the target viewer was, and *how* the knowledge ought to be presented. Visual examples were provided of a visual metaphor [8, 54], a diagram [8], a pictorial story [2] and a knowledge map [30].

4.3.3 *Component 2: Visualisation Techniques.*

This component gives advice about various features of symbols that could be used in the visualisation. Table 5 shows mappings to the criteria identified in Figure 6. In the actual guidelines a visual example was provided of something that demonstrated the quality. So, for example, next to "semantic transparency" we explained that a Skull and Crossbones (Figure 8) was widely understood but other symbols, such as the Eye of Horus (Figure 7), would not demonstrate semantic transparency.

Figure 7: Eye of Horus (obscure) [68]

Figure 8: Skull & Crossbones (familiar) [69]

The advice is based on well-known perceptual principles and insights gained by those who have investigated knowledge visualisations. Following it can maximise knowledge transfer efficacy.

Table 5: Component 2: Focusing on Symbol Choice in Visualisations (The How)

FEATURE	CRITERION
Clarity (symbol meaning should be clear)[6, 9, 49, 58]	Simplicity
Consistency (one symbol = one concept) [6, 8]	Simplicity
Semantic Transparency (exploit symbol familarity) [9, 49, 63]	Familiarity
Complexity Management (Everything Should Be Made as Simple as Possible, But Not Simpler) [6, 8, 9, 49]	Simplicity
Reduce Information Overload (Consider separate overview and detail diagrams) [9, 22]	Simplicity
Dual Coding (use text and visuals) [6, 22, 49]	Knowledge Transfer
Legend and Textual Description must be provided [33, 51]	Knowledge Transfer

5 STAGE 3: EVALUATION

Twenty three teams of designers (two or three per team) were asked to find a way to use the smart city concept to solve a big city's problems. They were given a *faux* map of the city in question to work with. We thus gave them the context by instructing them to superimpose their solution over a map of the centre of the city.

Firstly they had to identify the problems of the given city, and then come up with a way that ubiquitously-sensed information could be used to solve the problem. Using the 'establishing context' table (Table 4) with the accompanying checklist, we expected them to narrow down the context as follows:

The Why: a problem communicating *new insights*,

The What: communicate *what the solution delivers, how it achieves this & where it is positioned in terms of the map (context).*

For Whom: This was tightly specified it was to be communicated to an *expert* (the course instructor).

The How: superimpose their visualisation over the provided map. Hence they could feasibly use a *sketch, diagram or story.*

They were free to choose particular symbols to represent concepts on the map, as explained by the 'visualisation detail' table (Table 5) and recorded in the accompanying checklist.

5.1 The Produced Visualisations

We assessed the visualisations in terms of how well they conveyed the essence of the solution, how simple yet understandable the diagram was, and how well it served the purpose of knowledge transfer. The visualisations were generally poorly done. One or two were very good but these were a minority. An example of one of the best is shown in Figure 9. This visualisation was **simple** enough to **depict the knowledge**, with admirable economy of symbol usage. They included text only where it served a purpose in communicating the **essence**. **Context** is supplied by superimposing the solution onto a **familiar** map. In terms of satisfying **audience needs** it is particularly good: a mere glance tells me what my options are with respect to traversing the city using different kinds of public transport, and helps me to prioritise them according to my personal values. Knowledge is transferred successfully.

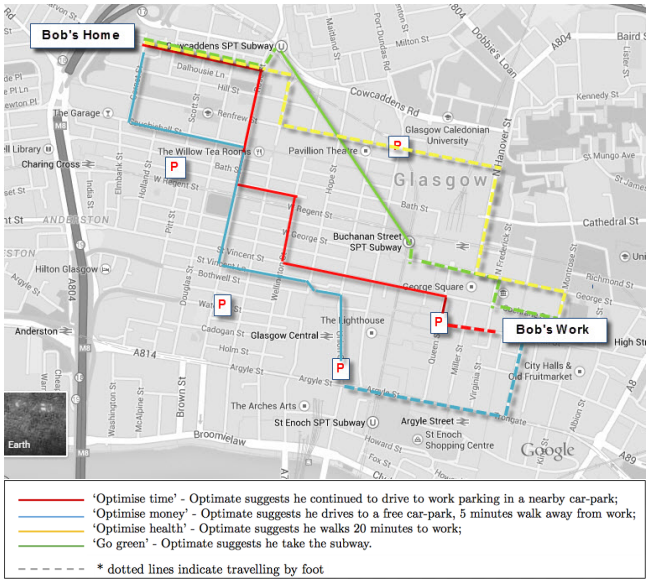

Figure 9: Excellent Visualisation, drawn by Frances Cooper and Adeel Amin, of an App that shows people their options in terms of getting to their destination (included with their permission)

Others failed to meet the criteria for knowledge visualisations for a number of reasons.

Insufficient Essence: Many did not communicate the essence of their solution, focusing instead on the software solution depicting their mechanism for solving the problem. Some teams produced UML diagrams or flowcharts depicting their system design. Some depicted the flow of the software solution, showing how data would flow from one software component to the next. Some provided screen shots of mocked-up Smartphone Apps. They focused on *what*, but did not provide *how* or *where*.

Many who did provide context by superimposing their solution over a map of the city sometimes simply provided a map with some lines drawn on it, without any explanations, so that the essence was not communicated effectively. These solutions communicated the *where* but not the *what* or *how*.

Focus on Aesthetics: Some teams thought the visualisations were for aesthetic purposes, and provided images of people using their solution. Some produced an aesthetically pleasing visualisation which gave the illusion of depicting the solution but, when examined, left many details of the actual solution unspecified. These solutions missed the point, and failed to communicate any of *what, how* or *why*.

No Knowledge Transfer: Some put symbols onto the map but did not explain how these were connected (lack of clarity). Some provided a map depicting the problem e.g. at-risk health zones, but these omitted the solution from the map (poor essence). These

solutions also failed to communicate any of *what, how* or *where* with any level of efficacy.

One team simply included a map screenshot obtained from Google with no attempt at superimposing their solution onto it (context without solution). Very few included a legend or caption despite the fact that the guidelines specifically advised this. This is a failure to communicate the *what*.

5.2 Questionnaire

We asked the designers to give us feedback about the visualisations and their helpfulness. 22 designers (about a third) responded. They unanimously rated the guidelines as unhelpful. The only part of the guidelines that they approved of was the instruction about avoiding information overload and some of them appreciated being told to include a legend and textual labels. They were fairly scathing in their responses: "*I didn't find them applicable*"; "*These guidelines provided little clarity for our team*"; "*The guidelines would have been more useful if it included examples of good practice, exemplar visualisations, etc.*"

6 REFLECTION

Based on the evaluation of our guidelines we concluded that they fell far short of meeting the needs of our evaluators: novice knowledge visualisation designers. We now consider why this was so.

Choice of Quadrant.
The first consideration was to re-examine our quadrant focus choice. In terms of strategy, targeting the upper right quadrant of Figure 3 does not seem to be a wise alternative course of action. Knowledge is complex, diverse and unpredictably interconnected, and this approach would lead to a multitude of very specific guidelines with no possible emergence of "good practice" to inform the field of knowledge visualisation. This would leave us without any guidance for novice designers crafting a visualisation of a previously-uncharted knowledge domain.

The left-hand quadrants are also infeasible because knowledge is inherently contextual and visualisation thereof *must* be informed by this reality.

Hence our focus on the right-hand bottom quadrant still seems wise, but we have to find a better way of intertwining context with specific guidance to inform and assist knowledge visualisers. What we need to do is to find the line between context *awareness* and context *specificity*. We are fully cognisant of the difficulty of achieving this, and we suggest a way forward later in this section.

Complexity & Context.
To acknowledge the importance of context (context-awareness), but also to refrain from making the guidelines too context-specific, we produced a two-component guideline, the first to inform context delineation, the second focused on the specifics of the visualisation. The pair of guidelines themselves aimed to be both context-aware and overarching.

Such an approach might well be unrealistic. We thought we could ensure the prominence of context with our first component. The fact that so many of our knowledge visualisation producers failed to understand the importance of context shows that our approach, in this respect, was less than optimal.

The use of two seemingly disjointed guideline components is likely to have added too much complexity to the guidelines. If we continue with two components we should provide a mapping, to help the designers to understand the connections between them. We need to make the impact of the context clear and unambiguous, rather than nuanced. Context must be an integral part of the guidelines rather than being an add-on.

Essence of Knowledge Visualisation.
It became clear, during the re-evaluation of our guidelines, that knowledge visualisations are profoundly different from information visualisations. The latter are used *during* the course of research in order to interrogate, explore and spot interesting trends and patterns in large amounts of information. Knowledge visualisations are created once the research has been completed, and the resulting knowledge needs to be made explicit and codified, i.e. communicated.

This difference implies that whereas one over-arching set of *information visualisation* guidelines is indeed feasible and helpful, this might not be the case for knowledge visualisation guidelines. If we reconsider Table 3 it might be that we need a hybrid set of guidelines, neither context-aware nor context-specific, but rather *context-aligned*.

It might be necessary to have a suite of guidelines, with some inbuilt notion of context to support choice of the appropriate set to inform visualisation a particular kind of knowledge.

The Evaluation.
The evaluation of the guidelines was, in retrospect, unrealistic. We asked the teams to produce the knowledge *and* to visualise it. There were thus two tasks, with the success of the second being wholly dependent on the first. In future evaluations it would be better to give the required knowledge to the evaluators and then to ask them to use guidelines to visualise it.

Summary & Lessons Learned.
Our ***first*** insight was that it might be unrealistic to expect one set of knowledge guidelines to guide the development of all possible knowledge visualisations.

The ***second*** insight is that context is not merely important but the foundation upon which knowledge visualisations are constructed. Knowledge visualisation guidelines must make the central role of context prominent, salient and compelling.

The ***third*** insight is that the guidelines themselves ought to demonstrate the same simplicity that should characterise the visualisations themselves.

In retrospect, we conclude that it might make more sense to move away from a linear set of guidelines to a set of knowledge visualisation *patterns*. This mechanism is particularly suitable in terms of making context prominent and ensuring that the solution aligns with the context in the visualisation solution. The positioning of such patterns is depicted in Figure 10. Developing such a set of patterns is the focus of a future research project, and out of scope for this paper, but one that we intend pursuing in the near future.

7 CONCLUSION AND FUTURE WORK

Our main aim was to help knowledge workers to communicate their knowledge more efficiently using visualisations. We produced a

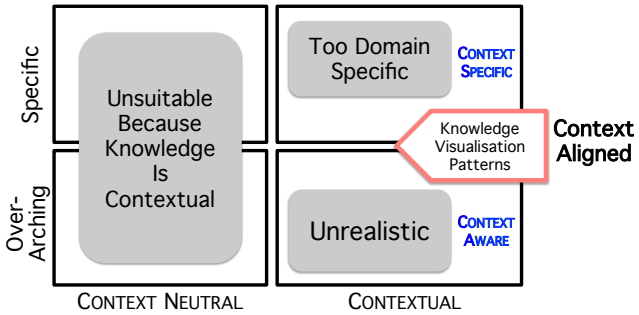

Figure 10: Knowledge Visualisation Patterns

definition of knowledge visualisation, enumerated the criteria of an effective visualisation and derived guidelines from the literature. Yet our guidelines did not serve their intended purpose. The experience was not without value, however, because it delivered a confirmation, an epiphany and an admonition.

The ***confirmation*** was that most people cannot intuitively produce a "good" visualisation.

The ***epiphany*** was that the structure of the guidance, and the extent to which it supports context, is critical. Guidance must provide far more than a table saying what criteria the visualisation ought to satisfy; it needs to be far more prescriptive and provide more detailed instructions.

To provide such meaningful guidance we might have to structure the guidelines as individual patterns, which lend themselves particularly well to context alignment. Such solutions are chosen according to context, giving context the primary role that it ought to have in the visualisation crafting process.

Finally, the ***admonition*** is that guideline evaluations ought to evaluate the impact of guidelines on knowledge visualisation production only. The participant task should not require knowledge production in addition to knowledge visualisation.

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REFERENCES

[1] Maryam Alavi and Dorothy E Leidner. 2001. Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS quarterly* 25, 1 (2001), 107–136.

[2] Naser Asl Aminabadi, Ali Vafaei, Leila Erfanparast, Sina Ghertasi Oskouei, and Zahra Jamali. 2011. Impact of pictorial story on pain perception, situational anxiety and behavior in children: a cognitive-behavioral schema. (2011), 127–132 pages.

[3] Xiaoyan Bai, David White, and David Sundaram. 2012. Contextual adaptive knowledge visualization environments. *Electronic Journal of Knowledge Management* 10, 1 (2012), 1–14.

[4] Joachim Baumeister and Martina Freiberg. 2011. Knowledge visualization for evaluation tasks. *Knowledge and Information Systems* 29, 2 (2011), 349–378.

[5] Sabrina Bresciani, Martin Eppler, Asha Kaul, and Riina Ylinen. 2011. The effectiveness of knowledge visualization for organizational communication in Europe and India. In *Information Visualisation (IV), 2011 15th International Conference on*. IEEE, London, UK, 365–370.

[6] Sabrina Bresciani and Martin J Eppler. 2009. The risks of visualization. *Identität und Vielfalt der Kommunikations-wissenschaft* (2009), 165–178.

[7] Sabrina Bresciani and Martin J Eppler. 2013. Knowledge Visualization for Social Entrepreneurs. In *Information Visualisation (IV), 2013 17th International Conference*. IEEE, London, UK, 319–324.

[8] Remo Burkhard. 2005. Towards a framework and a model for knowledge visualization: Synergies between information and knowledge visualization. In *Knowledge and information visualization*. Springer, 238–255.

[9] Remo A Burkhard. 2005. *Knowledge Visualization: The Use of Complementary Visual Representations for the Transfer of Knowledge: a Model, a Framework, and Four New Approaches*. Ph.D. Dissertation. Swiss Federal Institute for Environmental Science and Technology.

[10] Remo A Burkhard. 2005. Strategy visualization: A new research focus in knowledge visualization and a case study. In *Proceedings of I-KNOW*, Vol. 5. Graz.

[11] Remo A Burkhard. 2006. Is it Now Time to Establish Visualization Science as a Scientific Discipline?. In *Information Visualization, 2006. IV 2006. Tenth International Conference on*. IEEE, London, UK, 189–194.

[12] Alberto J Cañas, Roger Carff, Greg Hill, Marco Carvalho, Marco Arguedas, Thomas C Eskridge, James Lott, and Rodrigo Carvajal. 2005. Concept maps: Integrating knowledge and information visualization. In *Knowledge and information visualization*. Springer, Berlin, 205–219.

[13] David A Carr. 1999. Guidelines for designing information visualization applications. *Proceedings of ECUE* 99 (1999), 1–3.

[14] Alice Comi and Martin J Eppler. 2011. Visual representations as carriers and symbols of organizational knowledge. In *Proceedings of the 11th International Conference on Knowledge Management and Knowledge Technologies*. ACM, Graz, 8.

[15] Brock Craft and Paul Cairns. 2005. Beyond guidelines: what can we learn from the visual information seeking mantra?. In *Information Visualisation, 2005. Proceedings. Ninth International Conference on*. IEEE, 110–118.

[16] Bill Crowley. 2001. Tacit knowledge, tacit ignorance, and the future of academic librarianship. *College & Research Libraries* 62, 6 (2001), 565–584.

[17] Donald F Dansereau. 2005. Node-link mapping principles for visualizing knowledge and information. In *Knowledge and information visualization*. Springer, 61–81.

[18] Thomas H Davenport and Laurence Prusak. 1998. *Working knowledge: How organizations manage what they know*. Harvard Business Press, Boston, MA.

[19] David J Duke, Ken W Brodlie, David A Duce, and Ivan Herman. 2005. Do you see what I mean? *Computer Graphics and Applications, IEEE* 25, 3 (2005), 6–9.

[20] Niklas Elmqvist and Jean-Daniel Fekete. 2010. Hierarchical aggregation for information visualization: Overview, techniques, and design guidelines. *Visualization and Computer Graphics, IEEE Transactions on* 16, 3 (2010), 439–454.

[21] Martin J Eppler. 2004. *Knowledge communication problems between experts and managers*. Technical Report. Università della Svizzera italiana.

[22] Martin J Eppler. 2013. What is an effective knowledge visualization? Insights from a review of seminal concepts. In *Knowledge Visualization Currents*. Springer, 3–12.

[23] Martin J. Eppler. 2013. What Is an Effective Knowledge Visualization? Insights from a Review of Seminal Concepts. In *Knowledge visualization currents: From text to art to culture*, Francis T. Marchese and Ebad Banissi Editors (Eds.). Springer, 1–12.

[24] Martin J Eppler and Remo A Burkhard. 2006. Knowledge visualization. In *Encyclopedia of knowledge management*. IGI Global, 551–560.

[25] Martin J Eppler and Remo A Burkhard. 2007. Visual representations in knowledge management: framework and cases. *Journal of Knowledge Management* 11, 4 (2007), 112–122.

[26] Tatiana Gavrilova, Artem Alsufyev, and Margarita Gladkova. 2015. Perceptual factors in knowledge map visual design. In *Proceedings of the 15th International Conference on Knowledge Technologies and Data-driven Business*. ACM, 39.

[27] Atul Gawande and John Bedford Lloyd. 2010. *The checklist manifesto: how to get things right*. Vol. 200. Metropolitan Books New York, London.

[28] Andreas Hall and Kirsi Virrantaus. 2016. Visualizing the workings of agent-based models: Diagrams as a tool for communication and knowledge acquisition. *Computers, Environment and Urban Systems* 58 (2016), 1–11.

[29] Timothy Hanratty, Robert J Hammell, John Yen, Michael McNeese, Sooyoung Oh, Hyun-Woo Kim, Dev Minotra, Laura Strater, Haydee Cuevas, and Dan Colombo. 2009. Knowledge visualization to enhance human-agent situation awareness within a computational recognition-primed decision system. In *MILCOM 2009-2009 IEEE Military Communications Conference*. IEEE, 1–7.

[30] Manel Heredero. undated. Creating a Knowledge Map: The Basics. (undated). https://www.mindmeister.com/blog/build-knowledge-map/.

[31] Yongwen Huang, Zuhua Jiang, Lijun Liu, Bo Song, and Lijie Han. 2015. Building a knowledge map model situated in product design. *International Journal of Information Technology and Management* 14, 1 (2015), 76–94.

[32] Darrell Huff. 1954. *How to lie with statistics*. WW Norton & Company.

[33] Dong Hyun Jeong. 2010. *Knowledge visualization: From theory to practice*. Ph.D. Dissertation. Computer Science.

[34] David H Jonassen. 2005. Tools for representing problems and the knowledge required to solve them. In *Knowledge and information visualization*. Springer, 82–94.

[35] Benjamin F Jones. 2009. The burden of knowledge and the "death of the renaissance man": Is innovation getting harder? *The Review of Economic Studies* 76, 1 (2009), 283–317.

[36] Christa Kelleher and Thorsten Wagener. 2011. Ten guidelines for effective data visualization in scientific publications. *Environmental Modelling & Software* 26, 6 (2011), 822–827.

[37] Tanja Keller and Sigmar-Olaf Tergan. 2005. Visualizing knowledge and information: An introduction. In *Knowledge and information visualization*. Springer, 1–23.

[38] Joris Klerkx, Katrien Verbert, and Erik Duval. 2014. Enhancing learning with visualization techniques. In *Handbook of research on educational communications and technology*. Springer, 791–807.

[39] Jean-Baptiste Lamy, Catherine Duclos, Vincent Rialle, and Alain Venot. 2005. Which Graphical Approaches should be Used to Represent Medical Knowledge? *Studies in health technology and informatics* 116 (2005), 719.

[40] Joel R Levin and Alan M Lesgold. 1978. On pictures in prose. *ECTJ* 26, 3 (1978), 233–243.

[41] John H. Lienhard. undated. NIGHTINGALE'S GRAPH. (undated). http://www.uh.edu/engines/epi1712.htm.

[42] John H. Lienhard. undated. Nightingale's Graph. (undated). http://www.uh.edu/engines/epi1712.htm on 2 August 2017.

[43] John Locke. 1689. Of Knowledge and Probability. In *An Essay Concerning Human Understanding*. unknown, Chapter Book IV. http://enlightenment.supersaturated.com/johnlocke/BOOKIVChapterI.html.

[44] Wei Luo, Marcus Gallagher, Di O'Kane, Jason Connor, Mark Dooris, Col Roberts, Lachlan Mortimer, and Janet Wiles. 2010. Visualising a state-wide patient data collection: a case study to expand the audience for healthcare data. In *Proceedings of the Fourth Australasian Workshop on Health Informatics and Knowledge Management-Volume 108*. Australian Computer Society, Inc., 45–52.

[45] Roberto Martínez, Anthony Collins, Judy Kay, and Kalina Yacef. 2011. Who did what? Who said that?: Collaid: an environment for capturing traces of collaborative learning at the tabletop. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*. ACM, 172–181.

[46] C McInerney. 2002. Knowledge management and the dynamic nature of knowledge. *Journal of the American Society for Information Science and Technology* 53, 12 (2002), 1009–1018.

[47] Tunc Medeni, Serbülent Ünsal, Meryem Ayas, and İhsan Tolga Medeni. 2011. Tacit knowledge extraction for software requirement specification (SRS): a proposal of research methodology design and execution for knowledge visualization. In *Proceedings of the 55th Annual Meeting of the ISSS-2011, Hull, UK*, Vol. 55.

[48] Robert Meyer. 2010. Knowledge Visualization. *Trends in Information Visualization* 23 (2010).

[49] Daniel L Moody. 2009. The "physics" of notations: toward a scientific basis for constructing visual notations in software engineering. *Software Engineering, IEEE Transactions on* 35, 6 (2009), 756–779.

[50] Christophe Mues, Johan Huysmans, Jan Vanthienen, and Bart Baesens. 2006. Comprehensible credit-scoring knowledge visualization using decision tables and diagrams. In *Enterprise Information Systems VI*. Springer, 109–115.

[51] Thomas L Naps, Guido Rößling, Vicki Almstrum, Wanda Dann, Rudolf Fleischer, Chris Hundhausen, Ari Korhonen, Lauri Malmi, Myles McNally, Susan Rodger, et al. 2002. Exploring the role of visualization and engagement in computer science education. *ACM SIGCSE Bulletin* 35, 2 (2002), 131–152.

[52] Florence Nightingale. 1858. Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army. (1858).

[53] Janika Niskanen. 2012. *Can You Picture It? The use of knowledge visualisation in knowledge transfer*. Master's thesis. Department of Communication. Masters Dissertation.

[54] Richard Nordquist. 2017. Visual Metaphor. (2017). https://www.thoughtco.com/visual-metaphor-1692595.

[55] Jasminko Novak and Michael Wurst. 2005. Collaborative knowledge visualization for cross-community learning. In *Knowledge and Information Visualization*. Springer, 95–116.

[56] William Pike and Mark Gahegan. 2007. Beyond ontologies: Toward situated representations of scientific knowledge. *International Journal of Human-Computer Studies* 65, 7 (2007), 674–688.

[57] Michael Polanyi. 2012. *Personal knowledge: Towards a post-critical philosophy*. University of Chicago Press.

[58] Penny Rheingans and Chris Landreth. 1995. Perceptual principles for effective visualizations. In *Perceptual Issues in Visualization*. Springer, 59–73.

[59] Bertil Rolf. 2004. Two theories of tacit and implicit knowledge. *Blekinge Institute of Technology. Ronneby, Sweden* (2004).

[60] Martin Smuts, Brenda Scholtz, and Andre Calitz. 2015. Design Guidelines for Business Intelligence Tools for Novice Users. In *Proceedings of the 2015 Annual Research Conference on South African Institute of Computer Scientists and Information Technologists*.

[61] Mark Stover. 2004. Making tacit knowledge explicit: The ready reference database as codified knowledge. *Reference Services Review* 32, 2 (2004), 164–173.

[62] Jean Tague, Jamshid Beheshti, and Lorana Rees-Potter. 1981. The law of exponential growth: evidence, implications and forecasts. *Library Trends* 30, 1 (1981), 125–149.

[63] Niek Tax. 2012. Towards Understanding the Understandability of Diagrams. In *Proceedings of the 16th Twente Student Conference on IT*.

[64] Martijn Van Welie, Gerrit C Van Der Veer, and Anton Eliëns. 2001. Patterns as tools for user interface design. In *Tools for Working with Guidelines*. Springer, 313–324.

[65] Minhong Wang, Jun Peng, Bo Cheng, Hance Zhou, and Jie Liu. 2011. Knowledge visualization for self-regulated learning. *Educational Technology & Society* 14, 3 (2011), 28–42.

[66] Xiao-Yue Wang and Yan Mu. 2009. Visualization based on concept maps: An efficient way to knowledge sharing and knowledge discovery in e-science environment. In *Fuzzy Systems and Knowledge Discovery, 2009. FSKD'09. Sixth International Conference on*, Vol. 2. IEEE, 144–147.

[67] Matthew O Ward, Georges Grinstein, and Daniel Keim. 2010. *Interactive data visualization: foundations, techniques, and applications*. CRC Press.

[68] Wiki. [n. d.]. Eye of Horus. ([n. d.]). https://en.wikipedia.org/wiki/Eye_of_Horus.

[69] Wiki. [n. d.]. National Poison Prevention Week. ([n. d.]). https://en.wikipedia.org/wiki/National_Poison_Prevention_Week.

[70] Wiki. undated. Tube map. (undated). https://en.wikipedia.org/wiki/Tube_map 2 August 2017.

[71] Suraya Ya'acob, Nazlena Mohamad Ali, and Norshita Mat Nayan. 2013. Understanding Big Picture and Its Challenges: Experts and Decision Makers Perspectives. In *International Visual Informatics Conference*. Springer, 311–322.

[72] Mohamad Yusrizal Mohamed Yusoff, Jafreezal Jaafar, and Ahmad Kamil Mahmood. 2011. KM practice in Community College: Knowledge visualization in KM framework. In *National Postgraduate Conference (NPC), 2011*. IEEE, 1–5.

[73] Zarwina Yusoff and Halina Mohamed Dahlan. 2013. Mobile based learning: An integrated framework to support learning engagement through Augmented Reality environment. In *2013 International Conference on Research and Innovation in Information Systems (ICRIIS)*. IEEE, 251–256.

[74] Zarwina Yusoff, Siti Aminah Katmon, Mohammad Nazir Ahmad, and Siti Hidayah Mohd Miswan. 2013. Visual Representation: Enhancing Students' Learning Engagement through Knowledge Visualization. In *Informatics and Creative Multimedia (ICICM), 2013 International Conference on*. IEEE, 242–247.