Understanding Concept Maps: A Closer Look at How People Organise Ideas

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ABSTRACT
Research into creating visualisations that organise ideas into concise concept maps often focuses on implicit mathematical and statistical theories which are built around algorithmic efficacy or visual complexity. Although there are multiple techniques which attempt to mathematically optimise this multi-dimensional problem, it is still unknown how to create concept maps that are immediately understandable to people. In this paper, we present an in-depth qualitative study observing the behaviour and discussing the strategy used by non-expert participants to create, interact, update and communicate a concept map that represents a collection of research ideas. Our results show non-expert individuals create concept maps differently to visualisation algorithms. We found that our participants prioritised narrative, landmarks, abstraction, clarity, and simplicity. Finally, we derive design recommendations from our results which we hope will inspire future algorithms that automatically create more usable and compelling concept maps better suited to the natural behaviours and needs of users.

Author Keywords
Design; Interfaces; Information; Visualisation; Data; Interaction; Concept Maps; Knowledge; Organisation.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces: User-cantered Design.

INTRODUCTION
The organisation and representation of knowledge is an important area of visualisations. These serve as a common medium to explore, explain, and communicate information produced in medicine, the sciences, engineering, humanities, and between individuals as described by Bigelow et al. [6] and Heer et al. [28]. A few example applications of these type of visualisations which organise and represent knowledge are concept maps [22], mind maps [20], and scientific overviews [47, 51]. Information in these maps usually consists of various abstract ideas (Figure 1) that link together to represent a high level multi-dimensional concept, topic, or query [13, 29, 36, 54].

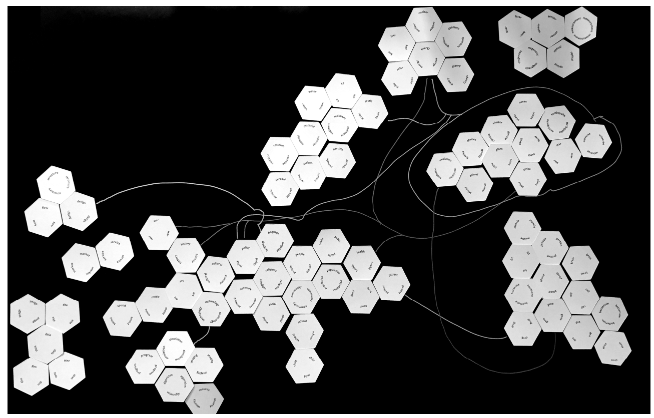

Figure 1. Example of ideas organised by one of our pilot participants {Pp}.

Concept maps have no simple or optimal solution to represent and structure their information either by conventional theory, mathematical algorithms, or evaluation methods [50, 63] due to their complex multi-dimensional nature [61]. Individuals, however, can come up with a satisfactory solution quickly and effortlessly. As a result, we believe this is an interesting problem to observe and explore from a non-expert perspective as it will help us inspire designers and create novel algorithm of concept maps that are immediately understandable to people.

Early research focused on building these maps either using simple visual theories (such as the Gestalt Laws) or by using mathematical rules to define and organise the ideas into a Euclidean space [65, 66]. These earlier visualisations were also evaluated using traditional usability metrics such as efficiency, effectiveness, and satisfaction as described by O'Connell [50]. Recent research, however, has begun to observe novice users and expert designers create visualisations either with physical objects, or on a screen [6, 26, 55]. Furthermore, there has been a drive to explore how humans interact with visualisations using various novel techniques including physicalisation [30, 33].

In this paper we present an in-depth study that examines how non-experts create physical concept maps, and their

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experience of doing so, by conducting extensive semi-structured interviews afterwards. Our main aim is to understand how people organise ideas in concept maps.

In particular, we focus on the four main aspects found in visualisations: how people *create* visualisations to map information, how they *interact* with them once created, how they would *update* their visualisations with new information, and how they *communicate* the concepts within their maps to others [66].

Our primary contributions from our study are that we:

- document how people create, interact, update, communicate, and feel about how successfully their concept maps convey the information contained within;
- analyse how people create concept maps using content and thematic analysis to formulate design considerations; and
- discuss new general design approaches that can be applied to concept maps and suggest opportunities for future research and creation of algorithms and tools.

RELATED WORK AND DESIGN CHALLENGES

In this section, we review the related work of the three main areas of research which informed the design of our study.

Information mapping

The process for information visualisation has been previously modelled as a sequence of steps starting with data and finishing with interactions. The main model has been described by Card et al [7] where they explain how visualisations are created in four steps (data, tables, structures and views) and how the user interprets and interacts with the visualisations. Card's model was extended by Chi et al. [9] to allow for multiple pipelines and later it was further refined [8] and extended again by Jansen et al. [33]. For our study, we are focusing on the *visual mappings* and *structures* required to create *views* (Figure 2 highlights these sections).

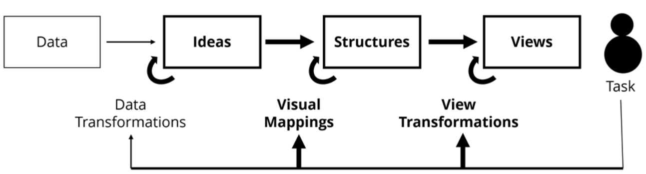


Figure 2. Visual reference model by Card et al. [7]. We have slightly modified the model to highlight sections of our study.

While several aspects of the models have been researched in depth, including interactions of views and analytical processes [2, 24, 37, 58, 70], relatively few studies show how visualisations are created from the point of view of those who are actually going to use them [6, 14, 29, 55, 69]. In addition, understanding how users map and communicate multi-dimensional information remains quite limited [3].

This paper, therefore, aims to shed some light on these less researched areas and find out how non-experts would organise and visualise information if given the chance.

Visual mapping

Various studies have been produced in the area of human vision exploring how our visual system organises elements into groups [4, 5, 27, 53]. In psychology, the pioneering Gestalt theory enlightens our understanding in terms of organisational principles for visualisations [4, 38, 66, 68].

There are 8 commonly defined Gestalt laws [4, 68]. Two are outside the scope of this study as they are concern with motion perception which we are not planning to investigate at this stage. The remaining 6 laws can be summarised as:

- *Proximity*: things closer together are perceptually grouped together.
- *Similarity*: similar elements tend to be grouped together.
- *Connectedness*: expressing relationship between objects by entities (e.g. lines).
- *Continuity*: well aligned contours are perceived as to be grouped.
- *Closure*: closed contours are to be grouped.
- *Symmetry*: symmetrically arranged pairs of elements are perceived as a group.

Some research has explored the use of these theories for human interaction [25, 39, 42, 64]. Our motivation and challenge, however, is to understand if participants use vision fundamentals and Gestalt laws to map information and how the results of our study can influence the development of design recommendations.

Human perspective

Novak et al introduced the theoretical foundations and psychology advantages behind concept maps [49], while Ruiz-Primo studied concept maps when looking at student assessment [57]. Markham et al also studied concept maps in the domain of research and evaluation tools [43] while Sims-Knight et al explored them in the design domain [59]. While these studies present glimmers of insight into the creation of concept maps by participants, they have not explored the process itself with the aim of discovering the insights into the aspects of visualisation, usability and communication of concept maps.

The process of organising ideas into groups has been researched extensively using methods like card sorting, which has been used in a wide variety of ways, from organising web sites [48] to clinical application design [60], both locally or using remote card sorting tools [10, 44]. While card sorting resembles the process, however, it does not work well for concept maps as ideas in groups do not overlap, there are no links, and they do not provide concise concepts.

Finally, constructive visualisations are an innovative paradigm that can aid the creation of flexible and dynamic visualisations. They rely on elementary building blocks to allow non-experts to create simple, expressive and dynamic visualisations as described by Huron et al. [31]. This new trend has a few advantages over digital representations: it enhances cognition, communication, learning, problem solving, and decision making [26, 41, 33, 61] while avoiding the creation of complex interfaces with possible confounding factors. As a result, we decided to exploit the advantages of physical elements to allows us to comprehensively study the key behaviours of how our participants organise and represent knowledge using concept maps without adding any complexity from visual interfaces.

STUDY METHOD

The aim of this study is to observe the behaviour and discuss the strategy used by non-expert participants to create, interact, update, and communicate a concept map that represents a collection of ideas. We designed our study to consider the organisation of specific ideas, as described in the next sub-sections, as this is performed almost daily in companies, research organisations, and at the individual level for various tasks.

Dataset

For our study, we chose research information as the main data source for the ideas. Previous studies have tried to organise and evaluate visualisations of this information using mathematical models [47, 52], but to our knowledge none of these studies involved feedback from individuals. Furthermore, visualising this type of information has been identified as a major challenge by various national research organisations, as they believe there are important gains in inter-disciplinary collaboration and research to be had. Just three of the research organisations concerned with this challenge are the NIH/NSF [34], RCUK [17] and Europe H2020 [19].

The raw data for our study was acquired from a national research organisation [56] and it consisted of a portfolio of accepted research grant ideas from all research areas at the national level. These data were suited for our study as it is possible to extract ideas that can be encapsulated into *units*, are *comprehensible* without further need to explain them, occupy a *multi-dimensional* space, have known *links* between ideas, and can be *abstracted* into an overview, or visualisation.

Our raw data consisted of 42,861 descriptions of research grants with an estimated value of over £3.0 billion GBP (approximately $4.5 billion USD at time of writing). We used topic modelling to encapsulate the grant descriptions into 100 unit ideas using a similar process to that described by Padilla et al. in their work to map the HCI area [51]; specifically, we used Latent Dirichlet Allocation as defined by McCallum [35]. We set our model parameters (beta = 0.01) to benefit from the natural structure of the data, and to allow the necessary coverage and overlap in the portfolio.

The output from the topic model was 100 individual topics, each of which consisted of a distribution of terms. To further encapsulate these ideas, we used just the most important term for each topic. Finally, we removed repeated and meaningless terms. Our final set of unit ideas consisted of 79 words representing the whole research portfolio as shown in Table 1.

aerosol	design	ice	patient	simulation
africa	dna	image	people	site
algorithm	drug	imaging	plant	social
animal	earth	language	policy	solar
arctic	earthquake	laser	population	sound
art	energy	magnetic	program	species
bacterium	evolution	market	protein	star
blood	fat	material	public	structure
brain	film	measurement	quantum	technology
carbon	flow	muscle	reaction	text
cell	food	music	religious	theory
child	fuel	network	school	universe
climate	gene	nuclear	security	virus
community	health	ocean	sediment	war
cultural	history	optical	sensor	water
data	hormone	particle	service	

Table 1. List of ideas used in the study.

By using the techniques previously described, we processed our dataset into ideas that do not only fit the design challenges for our study, but also have the advantage of representing a real problem rather than a synthetic one. This was to allow us to observe how non-experts react to and solve some of the problems found in real, complex, and often contradictory information datasets.

Data representation

Each idea was represented as a unit on white card inspired by the work from Huron et al. [31] and described in the previous section. Care was taken to print the label of each idea onto the cards so it could be read in any orientation to avoid any possible orientation biases. As a result, the word was printed three times, following the circumference of a circle inside the hexagonal card shape.

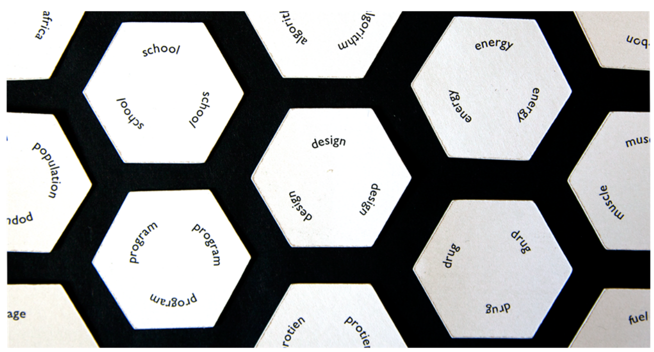


Figure 3. Ideas were represented as hexagonal cards to allow connections, easy handling, placement, and to maximise the possible area for each idea. The cards were machine cut, white, 4.5 cm in width and 300 GMS in weight.

The white cards were hexagonal (see Figure 3) in shape to allow for naturally accessible *structure* and *connections* between ideas which is commonly used in concept maps [49]. Also, hexagons are the most optimal shape to minimise wasted space between items while maximising the area inside it. Thanks to these advantages, hexagons are fairly common in nature, further enhancing the *aesthetic quality*, *familiarity*, and *acceptance* from our participants as described by Emmer [16]. Finally, hexagons allow some immediate perceptual affordances, in particular their *symmetry* and *tiling* properties that would benefit our context and task without over-restricting it or over-complicating it.

The physical space was restricted to a board of 76.0 cm by 47.0 cm (30.0 in by 18.5 in), denoted by a black card background to further highlight the ideas and task. The specific dimensions were calculated to allow 3 times more empty space than the total area the cards would occupy. A Golden ratio was used to maintain a familiar and also natural appearance. This is a well know ratio common in nature and devices like monitors and portable devices [16].

Figure 4. A lab member demonstrating the study. The experimental setup includes the hexagonal ideas, markers, board and video recorder.

Task

Our task was inspired by evaluation patterns [15], reflections on scenarios [40], and methods [63] for visualisations. In our study we used a similar technique to the *Once Upon A Time* method, where we provided a fictional scenario for our participants to solve [15]. Participants were asked to imagine they were new employees at the organisation in charge of research in their country, and their supervisor had asked them to *create an overview* of funded research ideas using only 75 ideas (keeping 4 ideas). In addition, participants were asked to:

- make the overview simple, clear, and easy to understand by the general public,
- ensure the overview gave a complete view of all the ideas funded by the organisation,
- design the overview so it could be reproduced on paper, and
- fit the overview within the designated black card area.

At a later stage participants were asked to think about how they would update their visualisation if they had to add the 4 remaining ideas [40, 63]. Users were also able to annotate their visualisations with three colour markers, either by drawing on the card, or by using extra blank cards if desired. By defining the task in this manner, it allowed us to probe the thoughts and reactions of participants when they were *creating*, *interacting*, *updating*, and *communicating* their visualisations.

Procedure

The study was carried out in a controlled environment. The set up consisted of a table with a sheet of black card in front of the participant. In addition, a box containing 75 of the hexagonal cards (in random order), a box with three markers of different colours, and a box with blank tiles were placed above and outside the black card, but within the view of the participants. The missing 4 cards (75 + 4 = 79) were hidden from the participant until they were asked to think about how they would update their visualisation with these new ideas.

A video camera was used to record the actions of the participants when they were creating their visualisations as shown in Figure 4. Care was taken to only record the experiment area to maintain as much anonymity as possible. Participants were allowed two hours to complete the experiment and they were given a voucher worth £20 GBP (approximately $30 USD) for their time.

Semi-Structured Interview	**Creation**	Gestalt Structures Links Abstractions Strategies Annotations
	Interaction	Possibilities Physicality Engagement
	Update	Strategies Reorganisation
	Communication	Confidence Problems Memory

Table 2. Example aspects covered in the semi-structured interviews.

We conducted semi-structured interviews after a participant had finished creating their visualisation to investigate the thought processes and decisions they underwent while they were creating, and later, explaining their visualisations. We decided to use semi-structured interviews as our main data collection method, instead of other methods like recording participants thinking out loud, as the former allowed us to investigate more complex issues and strategies. Furthermore, the interviews were conducted shortly after the creation process allowing us to capture the participants' immediate recollections and avoid biases due to fatigue and self-awareness issues. These concerns are highlighted in Ericsson and Simon's work [18]. Moreover, in our pilot we observed that participants did not find it natural to talk out loud during the creation task. We believe the main reason was that the task is an automated and rapid process that hinders out loud reporting from participants.

The semi-structured interviews were organised based on the four aspects of visualisations (*creation*, *interaction*, *update* and *communication*). In addition, these aspects were extended as shown in Table 2 to get a deeper understanding into the participants' thoughts and actions in the semi-structured interviews. These are based on insights from

Ware [66] and the research literature as described in the previous sections.

A senior researcher running the study was present in the room throughout the duration of the experiment to aid and answer any questions from the participants about the procedure. Finally, the interview was carried out after the visualisation was completed. The same video camera which recorded the construction of the visualisation was also used to record the participants' answers during the semi-structured interview, which consisted of both audio of their answers and video of the gestures towards their creation.

RESULTS

In total, 14 subjects {P1 – P14} agreed to participate in our study (including 1 pilot participant {Pp}), Figure 6 presents photographs of all the visualisations (high res versions available here: dx.doi.org/10.6084/m9.figshare.c.3658130). Our participants were recruited across departments in our institution and from external companies. We recruited a varied group of participants comprising of 9 male and 5 female participants with an age range of 20-40 years. Professions included creative to mathematical sectors. All participants declared they had no professional experience with concept maps, apart from creating the occasional Excel or Matlab chart in their daily work. Ethical approval was granted from our institution before proceeding with the study. All participants stated that they would allow themselves to be recorded, and have their post-study interview recorded and transcribed for this study, as long as their results were anonymised.

Content and thematic analysis was used to discover and conceptualise the structures, patterns, insights, recommendations and interests from the interview data. We followed standard guidelines to code our themes, as described by Wengraf [67] and Corbin and Strauss [11]. In our analysis we found saturation for our themes, therefore, we believe the sample size in our study was appropriate. Finally, the visuals of their videos were coded and analysed to gather further insight into the creation process.

As show in the time column of Table 3, participants took between 11 and 64 minutes to complete the experiment, with the interviews afterwards taking, on average, 30 minutes. Participants were allowed as much time as they felt necessary to familiarise themselves with the task instructions, and to then create their visualisations. In total, more than 20 hours of video was recorded and analysed. Analysis and coding of the results data took approximately 100 researcher-hours in total, and more than 2,500 coding instances were compiled. In addition, we are making the transcribed interviews and analysed data open for future research (dx.doi.org/10.6084/m9.figshare.c.3658130).

Resulting concept maps

First we present some simple metrics collected from the concept maps created by our participants (Table 3 and Figure 6). We can conclude from these collected statistics that:

- On average, participants took 36 minutes to *create* their concept maps from the 75 supplied ideas.
- These ranged from having a *single connected* group, to 20 *distinct groups*.
- Participants used *grouping* (a collection of ideas), *narrative* (connecting ideas using a story), or *both* to communicate their visualisation to others.
- Participants that created a single connected group {P5, P13} did not feel *confidence* communicating it.
- Only half of the participants felt the need to *annotate* their concept map.
- In addition, *annotations* did not improve {P5}'s confidence to communicate their concept map.
- 12 out of 14 participants used groupings as their main *strategy* to create and communicate their maps.
- Finally, participants struggle the most with *singletons* (groups with only one idea).

	Time (hh:mm:ss)	Number of groups	Annotations	Singletons	Communication Confidence	Style of communication	
P1	0:16:21	9	No	0	Yes	Groups	
P2	0:44:05	17	Yes	1	Yes	Groups	
P3	0:33:59	10	No	0	Yes	Both	
P4	0:57:44	9	No	10	Yes	Both	
P5	0:51:10	1	Yes	0	No	None	
P6	0:26:55	6	Yes	1	No	Both	
P7	0:27:01	13	Yes	10	Yes	Both	
P8	0:27:56	20	No	0	Yes	Groups	
P9	0:38:17	10	No	0	Yes	Both	
P10	0:20:09	9	Yes	0	Yes	Both	
P11	0:53:07	10	No	0	Yes	Both	
P12	0:39:31	5	Yes	0	Yes	Both	*
P13	0:10:56	1	No	0	No	Narrative	
Pp	1:04:05	10	Yes	0	Yes	Groups	

Table 3. General statistics of all participants' visualisations. N.B. The starred participant created a single island, but elucidated separate groups in the post-study interview.

In the next section we discuss the data from the post-creation semi-structured interviews and our design recommendations derived from our study.

DISCUSSION AND DESIGN RECOMMENDATIONS

Insights were discovered after analysing the information from our semi-structured interviews. In total 28 sub-themes reoccurred in the interviews, these were organised into 4 over-arching themes as previously discussed:

1. ***Creation***: the *strategies* of how non-experts created their concept maps and the *structures* used during creation (Gestalt laws).
2. ***Interaction***: how they *interacted* with the physical elements provided, and their enjoyment of the process.
3. ***Update***: strategies used when *adding* new ideas.

4. ***Communication***: how *confident* they would be communicating the visualisation and the strategies they would use to do so.

For each theme we will discuss the design implications including the sub-themes, the frequency of the sub-themes (Tables 4 to 7), and discuss various design recommendations in the form of questions and answers highlighted by borders in the text.

Creation

First, we will discuss what techniques and common *strategies* our participants used in order to build their visualisations from the basic elements. Second, we will discuss the use of *structures* and Gestalt laws by our participants.

Creation strategy

Participants started creating their visualisations by either reading all the ideas first, or by taking the ideas one by one from the box of ideas. In either case, the next step for 12 of our participants was to create groups which contained ideas of a similar nature. e.g. *"...I have just tried to group them into like groups which kind of relate to some general theme"* {P1}. The remaining 2 participants just connected ideas together to create either a narrative only visualisation {P13} or an aesthetically packed mass of linked ideas {P5} (see Figure 6 Participant 5). E.g. *"...I sort of started connecting… things [ideas] that related, that depended on each other… And then connect to the next [idea] to the next to the next to next…"* {P12}.

From the 12 participants that created groups, all of them abstracted their groups by adding a notion of a *core idea* or unique abstracting concept for each group. Participants reported that having this 'core' allowed them to remember and communicate their groups more easily, e.g. *"P11: I tried to relate the research ideas so that the audience can easily understand [them]. So, what I did here. I wanted to group the related ideas together so that if someone reads these they could easy grasp the idea. Interviewer: So each group had a main core idea? P11: Yes, the universe here, public, and service, and here policy, here …"* {P11}.

What strategies do people use to create their concept maps?

In our study it was discovered that participants were using *groups defined by a core idea, narrative*, or *both* to simplify the ideas into a more memorable number of abstract concepts (1-20). The best strategy was to use both narrative and core concepts to aid the communication of the visualisation. The participant that created a visualisation using only narrative {P13} commented that they thought they would be the only one who could understand their visualisation, while the participant with all the ideas in a single, contiguous island, rather than as separate groups, {P5} commented that they would not be confident if asked to explain or remember his visualisation. As a result, we believe narrative by itself is not enough, while abstraction into core concepts is always needed to create successful visualisations of this type.

Design Recommendation*: Use groups and narrative to simplify abstraction and enhance the communication of your concept maps.*

Several participants (5) gave more prominence to certain hexagons, using them as *landmarks*, to aid the understanding and communication of their visualisation, e.g. *"So what I was thinking was… what people are most going to be interested in are themselves. So I put people at the centre, and then we branch off into things people are concerned about"* {P4}, *"the main purpose is the 'people' which is why I put it in the middle"* {P7}, and "*child is basically where all ideas centre around*" {P13}.

From all the participants, half of them (7) *annotated* their visualisations using the provided pens. The annotations were used to enhance their visualisation e.g. *"This (annotation) was just to make it a little bit more exciting"* {P12}, and to strengthen the groups and their core idea, e.g. *"You'll notice I've labelled them. So this is 'technology island', 'material island', 'earth island', this is 'health and patient island', that's 'art island' …"* {P6}. Contrary to popular visualisation techniques (e.g.. spider diagrams, network diagrams, or concept maps) participants did not use annotations to link ideas, however, three participants {P2, P6, and Pp} did use annotations to create links between groups of ideas instead.

How can I enhance the main ideas in my visualisations?

We observed two techniques commonly used by our participants to enhance their maps. *Landmarks* and/or *annotations* aid the understanding of the core narrative, and groupings in their visualisations. This result confirms what has also been found by Gansner [21]. We believe these two techniques are currently under used and if investigated further could lead to more understandable mapping of information in concept maps.

Design Recommendation*: Use landmarks and annotations, if possible, in your visualisations to strengthen core ideas to help people remember and communicate it at a later date.*

Most of our participants were aware that ideas next to each other were conceptually linked together. If an idea did not match their neighbours they relocated it to a different section of the group, "*the connections were much more if the tile should be touching other tiles*" {P5}. Only one participant {P7} matched all of the ideas to the core of the group, similar to card sorting, effectively creating piles of ideas represented by the one on top, their aim to simplify the communication task, "*the purpose was … because people don't spend much time looking at things … one concept, that would kind of summarise (the group)*" {P7}.

Only two participants {P5 and P13} thought of links between ideas expanding further than their immediate neighbours "*maybe, like... two-levels I guess*" {P5}. The rest of the participants only linked the ideas to their immediate neighbours and to the essence of the group. However, participants did discuss an implicit, transitive relationship between ideas in groups e.g. "*Yes they are related because this one [1st idea] here is related to this one [2nd idea] - what I thought is this one [3rd idea next to 2nd idea] is related to this one [1st idea]*" {P11}. Furthermore, no participant used distance to quantify connection, "*it is just the same group, being far off it, no [it makes no difference]*" {P9}.

How aware are non-experts of long distance interactions between ideas in their visualisations?
The similarities and connections from non-neighbouring ideas were mostly transitive and, as a result, the long distance relationships were mostly between the core concepts and not between individual ideas. In addition, our participants stated that the similarity of items beyond neighbours was non-linear. For example, none of our participants through that an item being twice as far from another item made it twice as dissimilar. We therefore suggest that non-experts might not have a notion of long-distance information or similarity. As a result, we believe that the distance similarity data created by dimensionality reductions algorithms, such as Multi-Dimensional Scaling, might be overlooked by users.

Design Recommendation: *Use local similarity information in preference to long-distance similarity when designing or creating algorithms for visualisations.*

Less than half of the participants (6) were aware of the need to or did actually pack and optimise their space. Mostly the packing was concerned with joining groups together into bigger groups (11), e.g. *"Yes, I think I joined two groups together. I think this one was two groups. The first one was... the social service, for example, and then I combined it with the school."* {P3}, or *"That is what I do and at the beginning I had many groups… I did tried to join some of the groups to minimise the category or classification"* {P11}. Even though some participants were aware of packing, almost all of the participants (12) agreed with the notion of needing empty spaces to differentiate groups, e.g. "*there was a kind of general concept of the islands being all related to each other … But then... I think there is a need to separate this island off [with a space], because having these two connected is making it too confused*" {P5}, "*I wanted spaces so it was not a complete mass*" {P12}.

Do we need to optimise space and efficiency in our visualisations?
Most of our participants (12) expressed a preference for having blank spaces between groups of items and did not feel the need to pack these groups efficiently, nor keep them on the grid implied by the ideas being presented as hexagons. Most visualisation algorithms, however, are optimised to reduce spaces and use the available space efficiently. We believe new algorithms in visualisations could incorporate blank spaces as a metric.

Design Recommendation: *Allow blank spaces between groups to signify breaks and groups don't necessarily need to be aligned on an underlying grid.*

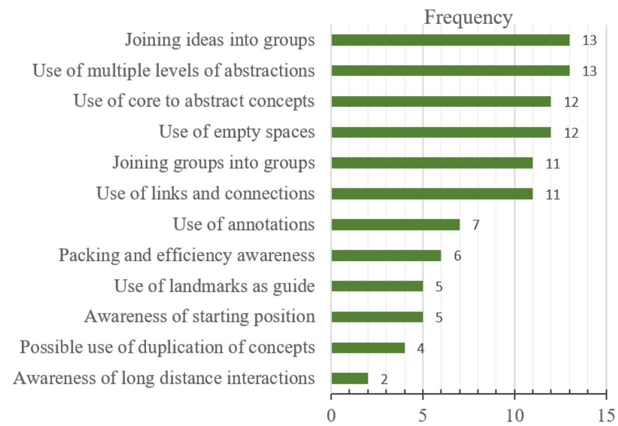


Table 4. Creation strategy sub-themes from our interviews.

Creation Structures

The creation structures results are linked to the 6 Gestalt laws (proximity, similarity, connectedness, continuity, closure, and symmetry) explained in the previous section.

Our analysis showed that almost all of our participants used proximity and similarity while creating their visualisations. Only participant {P13}, who created their visualisation based only on narrative and storytelling, did not used these two Gestalt laws, however, they were still aware of similarity by means of connection, e.g. *"It's a bunch of ideas connected"* {P13}.

Connectedness was expressed in terms of annotations, and links between ideas and groups as previously described in the creation strategies subsection. Connectedness was also expressed by participants {P6 and P12} by connecting groups using ideas that were of a higher level of abstraction or of ambiguous nature (for example *'site'*, *'technology'* or *'Africa'*). *"You could then just connect it [an idea] to anything [the rest of the group], really"* {P6}.

A few participants use continuity (5), closure (3), and symmetry (3). Most participants did not focus on these three laws, but instead concentrated on the connections and similarities of the groups, e.g. "*…the shape is dependent on the criteria we considered when grouping.*" {P11}. Even so, almost all participants (13) expressed that symmetry would probably have improved their map, e.g. "*That would be nicer. I haven't got it symmetrical at all. But yeah, I'd prefer it to be more symmetrical, that's why I'm not happy with the shape. ... some work would have to be done with the jigsaw puzzle because there were some things that could fit different ways… made it a bit more symmetrical ..., or more the shape of something particular.*" {P12}

Should we care about Gestalt?
The laws of *proximity (13)*, *similarity (13),* and *connectedness* (12) were observed in the majority of our

participants' visualisations. To a lesser extent *continuity* (5), *closure* (3), *and symmetry* (3) were used by participants. Most participants thought these laws would enhance their visualisations but most of them (11) did not actually use or were unaware of them whilst creating their own visualisations.

Design Recommendation: *Use proximity, similarity, and connectedness in your visualisation. In addition, use continuity, closure, and symmetry only to improve the aesthetic nature of the visualisation.*

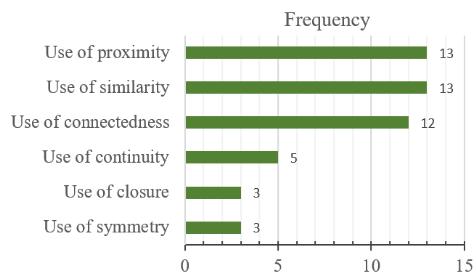


Table 5. Creation structures sub-themes from our interviews.

Interaction

Participants expressed various possible interactions that could be applied to the visualisations. These include the ability to colour the core idea of a group, or colouring individual groups in different colours, e.g. "*What might have been an interesting idea is if certain ones could have been color-coded*" {P4}.

An interesting interaction from participant {P1} was to perfectly tessellate ideas with strong relationships while more loosely arranging ideas when there was not a strong link. "*All these words are quite strongly related. I was able to kind of make it [the groups] quite nicely...*" {P1}. We believe this interaction can be replicated in digital interfaces using positioning or some kind of subtle wobbling animation to indicate uncertainty.

Almost all participants enjoyed the physicality of the study. They could easy organise, pile, and think about the task in hand, e.g. "*It's easier for me to think if I can build... so what I did at the start, was I took them all out and went 'right, let's first of all just throw them into piles*" {P6}. Some participants, however, mentioned a few advantages a digital study could allow, compared to the physical study. These included easier reorganization {P4}, zoom capabilities {P2}, and cleaner placement of ideas {P8}.

Did people enjoy the physical side of the study?

Almost all the participants enjoyed the physicality of the task. They asserted that having the ideas as physical items allowed them to reflect longer on them, handle the ideas in ways not possible on computer screens (e.g. piling), and concentrate more on the task in hand. We believe this physicality could allow for interesting research in the areas of communication, collaborations, and the networking of people using physical and digital visualisations. These avenues of research are already being explored in some human computer interaction workshops [1]. In addition, our results and observations can also be applied to other areas, including information communication using interactive walls [12], interactive networking tools [45], and table top collaboration [62].

In addition, we believe that by freeing our participants from the various aspects of interfaces (like menus, commands, buttons or instructions), we can investigate more in-depth the natural behaviours from our participants when creating their concept maps. Furthermore, we can later apply our finding to digital interfaces.

Design Recommendation: *Paper prototype your design using simple materials and discover the possible advantages to it. You can also use colours, groups, tessellations, positioning and tightness to enhance interaction in your digital designs.*

The biggest annoyance identified by all participants (14) was that some ideas were too ambiguous or at a different level of abstraction (for example *'site'* and *'technology'*) and these were difficult to place. Some participants just separated these ideas into singletons {P6} while others used these ideas as links between groups {P12}. Participant {P10} suggested an interesting solution to this ambiguity problem by adding descriptions of the idea to the back of the hexagon to disambiguate singletons: "*... there were a few that I thought they were quite general and it was not quite clear to me ... maybe if I had the whole description [on the back – the participant points]*" {P10}.

What got in the way of creating the visualisations?

While participants abstracted the ideas into groups we noticed that all participants found it difficult to group the ideas that they saw as ambiguous. We believe the main reason for their difficulties was that the ambiguous ideas were at *different levels of abstraction* from the other ideas in a group. For example, *health* is a more general concept than *brain*, *cell*, *DNA*, *fat,* or *gene*, making it difficult to link the general and more specific ideas into a single group. We believe abstraction levels can solve these problems, similar to Scheiderman's recommendations [58].

Design Recommendation: *If possible, ensure that the ideas or concepts represented in your visualisation are at the same level of abstraction.*

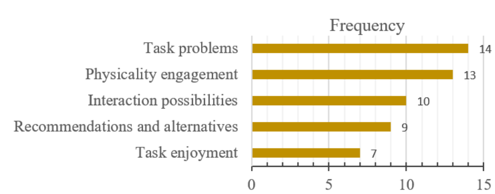


Table 6. Interaction sub-themes from our interviews.

Update

On further inspection of the video recordings, along with analysis of the interviews, only three participants {P1, P3 and P13} reorganised a group when adding new ideas to their visualisations. It was apparent that once the groups and/or narrative was defined the participants were unwilling to change the fundamental structure of it by changing the number of groups.

Almost all participants just attached the new ideas to existing groups, or narrative chains, e.g. "*In general yes [I would attach them]. When they became too many or clearly they are completely different then I would create the new [group]*" {P10}, "*I'd have preferred to put them into the design I already [have]*" {P4}.

What can we learn from non-experts updating their concept maps?

As mentioned before participants were reluctant to update their main group structures. We assume the cognitive effort to re-abstract, re-organise and re-learn new group structures constrained participants. Instead the simplest strategy for them was to simply attach ideas to their previous groups.

Design Recommendation: *When updating the main structures or groups think of the cognitive effort from users to understand, memorise and abstract your new structures.*

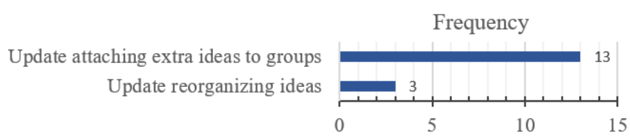


Table 7. Update sub-themes from our interviews.

Communication

From our participants, 11 of them reported feeling confident enough to communicate their visualisations in terms of a general overview of core ideas, or the narrative they'd created, but not the individual ideas, e.g. "*Yes, I think I could give them an overview of the general things in [it]*" {P12}, "*yeah I think so, maybe, I don't know if I would remember these small things [ideas]. But as a general idea I think so*" {P10}.

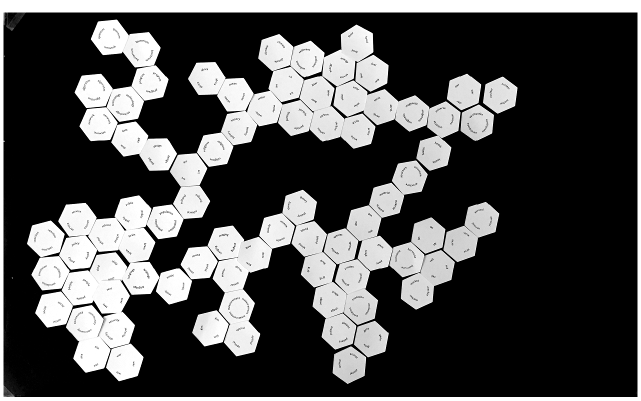


Figure 5. Participant 13 {P13} created their concept map only using narrative. They later expressed their concern about communicating their concept map.

Participant {P6} expressed concerns about how the many permutations of the visualisation could affect their ability to communicate it, however, they were quite pleased that their visualisation reflected their personal opinion, *"My brain was arguing with me that there were other ways of doing it... and there are very different ways of grouping these together. These ones reflect 'me'... so I'm happy in that respect, I'm happy that this reflects my opinion of them, and how they relate to each other."* {P6}.

Participant {P5} argued they could not communicate it at all, "*I doubt it'd be very clear to the public*" {P5} while participant {P13} also expressed concern about other people understanding their visualisation, "*No, because the words are too limited to explain my ideas*" {P13}. We argue that the blocking factor for both participants is that neither of them abstracted the ideas into different groups, each containing a core idea. In the case of {P5} there is no distinction of core groups, instead they relied on a single contiguous island containing all the ideas, while in the case of {P13} they decided to create their visualisation using only narrative, therefore missing the abstraction provided by separating the ideas into thematic groups.

How do people think about and communicate their visualisations after they've finished creating them?

It is important to note that most participants could remember the abstractions of their groups easily, but struggled with the individual ideas. We believe *memory* plays a crucial role as people can only keep a limited amount of things in their working memory [46]. As a result, participants found it natural to abstract the 75 ideas into a smaller number of memorable concepts. We believe visualisations can benefit from this by allowing users to abstract the visualisation at different levels. For example, Google Maps [23] allows users to start from one simple concept, the Earth, and then zoom in to a more detailed level, continents, then zoom in again to another level, countries, and so on.

Design Recommendation: *Allow users to customise the complexity of the visualisation, so they can see a simple overview of the ideas, memorise the main structures, and navigate into the detail if they want to.*

Table 7. Communication sub-themes from our interviews.

CONCLUSIONS AND FUTURE WORK

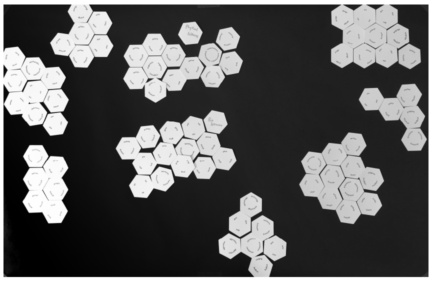
In this paper we presented a comprehensive study designed to help understand how non-experts create, interact, update, and communicate information using concept maps. We asked 14 participants to organise 79 ideas into a single visual overview. Insights into the thoughts of the participants were collected by recording their actions and by analysing post-study, semi-structured interviews.

By analysing their actions and responses, we deconstructed the process into 28 sub-themes, to understand how they organised separate ideas into cohesive concept maps. These sub-themes are explained in detailed in our *Results* and *Discussion* section. In addition, we defined 9 design recommendations distilled from our results, which we hope will inspire future algorithms that automatically create usable concept maps better suited to the natural behaviours and needs of users.

The main implications from our study is that non-experts appreciate narrative, landmarks, abstraction, blank space, and groups of items related to a core concept, instead of algorithmic optimisation and space efficiency. Furthermore, we think our study can be extended by future work which explores wider issues including communication confidence metrics, scale, training, strategies, and additional applications of our recommendations. Finally, we believe that understanding and researching the needs and behaviours of non-experts will improve the way we design and implement visualisations like concept maps.

ADDITIONAL MATERIALS

Data, including high resolution images, animations, transcriptions and interview coding available here: dx.doi.org/10.6084/m9.figshare.c.3658130.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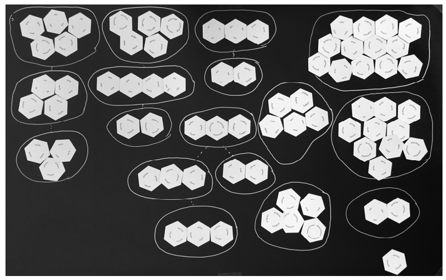
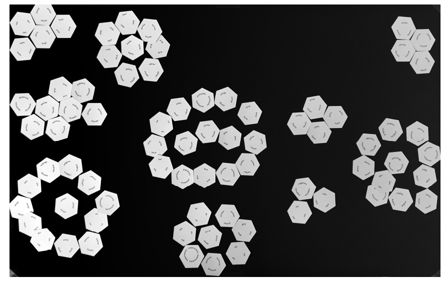
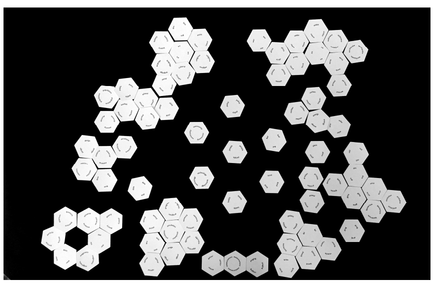
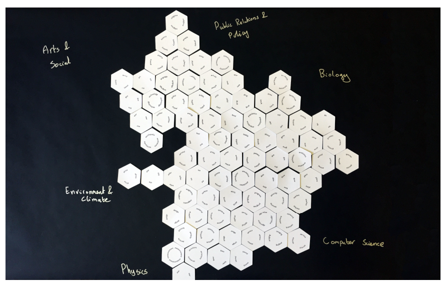
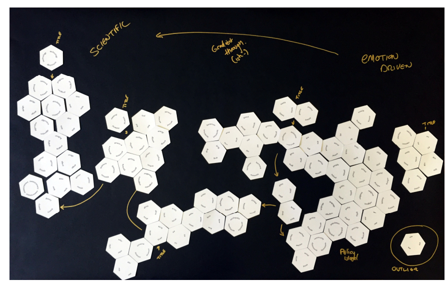

Participant 2


Participant 3

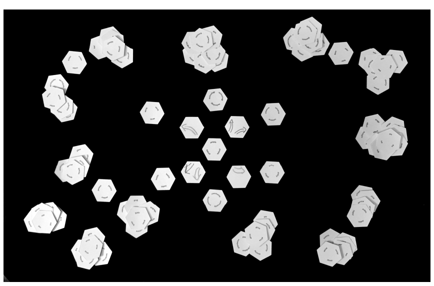

Participant 4

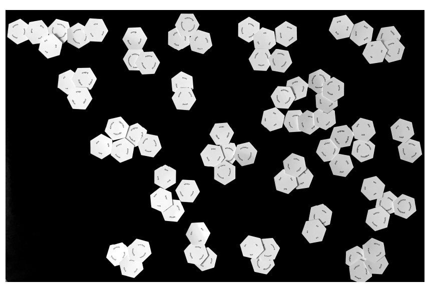


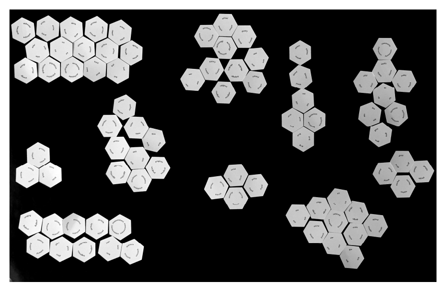
Participant 5

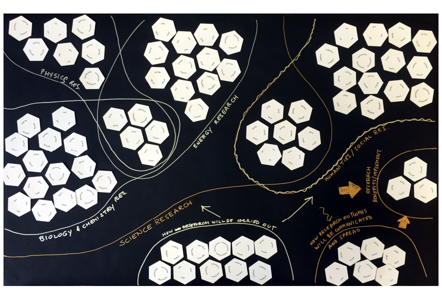


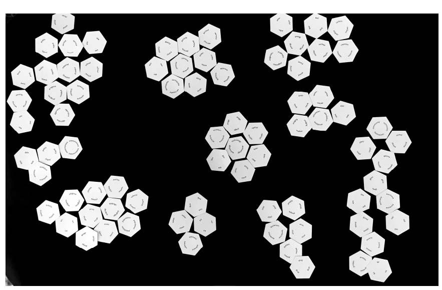
Participant 6

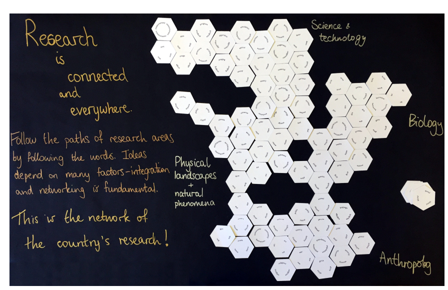

Participant 7


Participant 8


Participant 9


Participant 10


Participant 11



Participant 12

Figure 6. The visualisations created by our participants for the study. Participant 13 and pilot results are shown in figure 1 and 5 respectively. High resolution images and animated GIFs available from our public research repository (dx.doi.org/10.6084/m9.figshare.c.3658130).

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