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Graphical Knowledge Representation Tools for High Quality Learning

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Abstract

The common aim of graphical knowledge representation techniques in education is to facilitate a deep approach to learning. There is empirical evidence that the use of graphical knowledge representation tools enhances learning and improves knowledge: when people are able to represent a complex set of relationships as a diagram, they are more likely to understand and remember them. There are however differences in the conception and use of these tools. The article describes mind mapping and concept mapping methods and shows the process of their creation in an educational context. The authors also briefly introduce research methods that can be used to analyse the resulting maps, and present the benefits of applying these techniques; they also mention the application of these maps as research instruments to gather information on certain phenomena. In education, this supports reflection on a study theme from different perspectives; as such, graphical knowledge representation tools are relevant for high quality learning particularly in higher education.

Keywords

mind maps; deep approach to learning; graphical representation; meta-learning

Abstrakt

Grafické nástroje pro znázornění informací mají ve vzdělávání podporovat hluboký přístup k učení. Existují empirické důkazy, že používání těchto nástrojů zlepšuje učení a rozvíjí znalosti - pokud jsou lidé schopni si představit složité vztahy v podobě diagramu, je pravděpodobnější, že jim porozumí a zapamatují si je. Existují však rozdíly v koncepci a použití těchto nástrojů. Článek popisuje různé metody myšlenkového a konceptuálního mapování, a ukazuje způsoby, jak je vytvářet, například ve vzdělání. Autoři také stručně představují metody výzkumu, které mohou být použity k analýze výsledných map, ukazují výhody jejich použití; zmiňují také použití těchto map jako výzkumných nástrojů pro získání informací o určitých jevech. Při studiu to pomáhá reflektovat studovaná témata z různých perspektiv; díky tomu jsou grafické nástroje pro znázornění informací důležité pro kvalitní proces učení, zejména na úrovni vysokoškolského vzdělávání.

Klíčová slova

myšlenkové mapy; hluboký přístup k učení; grafické znázornění informací; meta-rovina učení

Introduction

The common aim of graphical knowledge representation techniques in education is to promote a deep approach to learning.

There is empirical evidence that the use of graphical knowledge representation tools enhances learning and improves knowledge – when people are able to represent a complex set of relationships as a diagram, they are more likely to understand and remember them (Heinze-Fry and Novak 1990, Farrand et al. 2002).

The principle of dual coding (Paivio 1986) underlies the functioning of most graphical knowledge representation tools – in a mind maps, for instance, information is coded in visual as well as propositional form.

Although the objectives of all graphical knowledge representation techniques are similar, there are differences in their conception and use.

Mind mapping (Buzan 1976, 1993) allows people to imagine and explore associations between concepts or ideas.

Concept mapping (Novak, Gowin 1984, Wheeldon, Åhlberg 2012) allows people to understand the relationships between concepts and hence understand these concepts.

A mind map consists in a network of connected and related concepts (for examples, see appendix 1). Spontaneous thinking is required when drawing a mind map and the aim of mind mapping is to develop creative associations between ideas.

Concept mapping is often confused with Mind mapping. It is however more structured and less pictorial. The aim of concept mapping is not to develop spontaneous associations between ideas but to outline the relationships between these ideas. Thus, concept mapping is a relational tool (for an example, see appendix 2).

The main components of mind maps are images and topics, those of concept maps are concepts and relations.

Knowledge Representation Tools and Levels of Abstraction

Borrowing from Computer Science (Abelson et al. 1996), one can distinguish three levels of abstraction in our knowledge about the objects of the real world:

a) The conceptual level

This is the highest level of abstraction. At the conceptual level, objects are considered from an external point of view. They are abstracted as concepts. Relationships between objects translate into associations between concepts. Information is summarized through a conceptual model.

b) The organizational level

At this level, objects are abstracted as systems of simple concepts. Their internal structure is the focus of interest. Information is summarized through a relational model.

c) The logical level

At this level, objects are abstracted as pieces of information. The relational model disappears and relationships are understood as logical objects in their own right. Information can be summarized through tables.

We propose that different mapping tools correspond to different levels of abstraction:

Mind maps correspond to the conceptual level.

Concept maps correspond to the organizational level.

Knowledge Representation Tools and Information Gathering

Due to the emergence of the global Knowledge Society, educational systems are increasingly open to the media (OECD, http://www.oecd.org/fr/sites/educeri/spotlights-trends-shaping-education.htm). Several initiatives accompany this trend by developing and promoting new teaching concepts and methodologies.

Pupils are increasingly gathering valuable information from a variety of sources like the internet, television, magazines and movies, but also through interactions with professionals whom they visit, or who visit their schools.

In such a dynamic information-laden context, tools are needed to assimilate and organize information on the go.

Concept maps and mind maps, for instance, can be such tools. They allow pupils to integrate information gradually and visualize the progress of their own learning and understanding.

Concept maps or mind maps can be drawn all along a learning path, testifying to the growing knowledge of a pupil, or of a group of pupils if they are created collaboratively.

New concepts and links or branches appear gradually in the map, others may disappear. The dynamic graphical representation thus parallels the dynamic learning process of the pupils.

Modern graphical knowledge representation software allows this dynamical aspect to be taken into account – a tool like cMap (https://cmap.ihmc.us) allows one to record short movies showing the evolution of a concept map through time.

Mind maps

What is a mind map?

The human brain does not work as a computer but in a natural, organic way (Buzan 1976, 1993).

Mind maps are a visual mental tool reflecting the natural organization of the brain. They allow one to think laterally (bi-dimensional thinking) instead of thinking linearly (one-dimensional thinking) (Buzan 1976, 1993).

They can be applied to all the functions of the brain, in particular to memory, innovation and learning. They were introduced by Tony Buzan in the 1970s. Ideally, a mind map is structured in the following way:

At the center of the mind map, an image summarizes the main subject of the map. Branches are then drawn starting from the central image: The first branches represent the

main themes associated with the main subject. Secondary branches correspond to secondary themes. An image and/or a keyword appear on each branch.

The more beautiful a mind map is to the user, the more efficient it is. The more creative the mind mapping process, the more successful the mind map is.

Five steps to mind mapping

There are five steps that can be followed to create a mind map (Buzan 1976, 1993, Hemmerich et al. 1994).

1. Create a central idea

The central idea is the starting point of the mind map and represents the topic one is going to explore. It usually includes an image that represents the mind map's topic.

2. Add branches

The next step is to add branches. The main branches which flow from the central image are the key themes. One can explore each key theme in greater depth by adding secondary branches, and so on.

3. Add Keywords

Each new branch of the mind map must correspond to an idea or concept. An important principle of mind mapping is using one word per branch.

4. Color code the branches

Color coding links the visual with the logical and helps the brain to create mental shortcuts. The color code allows categorizing, highlighting, and analyzing information.

5. Include Images

Images have the power to convey much more information than a word or sentence. They are processed instantly by the brain and are a universal language which can overcome any language barrier.

Why do mind maps work?

The most important reason for the increased use of mind maps is that they enhance people's learning (Novak, Gowin 1984, Heinze-Fry, Novak 1990, Brinkman 2003). But why do mind maps work? Several reasons have been advanced to explain this, including the following propositions:

a. Mind maps support meaningful learning

This means that, thanks to mind maps, new perspectives are integrated into people's knowledge.

b. Mind maps build on existing knowledge

This is due to the fact that mind maps complement existing information with new elements.

c. Mind maps make new information more usable

Drawing, studying or manipulating mind maps develops people's skills more than less usable information representational techniques.

d. Mind maps augment the brain's ability to understand and process information

This is due to the fact that diagrams are more easily stored in memory than other kind of representational devices.

e. Mind maps promote active engagement

They enable people to develop their own learning path and check their own understanding.

Collaborative mind mapping

Mind mapping is often considered as a personal endeavor – drawing a graphical representation of one's own ideas about a main topic. However, mind maps can, and have been, created and used in a collaborative way.

Here, the emphasis is on interpersonal understanding and common knowledge building.

Collaborative mind mapping can involve a facilitator (a teacher, in an educational setting) and several participants (pupils, in an educational setting). The creation of collaborative mind maps involves four steps:

a. The brainstorming step

Ideas about the main topic are put forward by each participant and laid down on paper or on board by the facilitator.

b. The organizing step

Ideas are classified; common concepts are identified and gradually laid down on a separate paper or a separate part of the board.

c. The relational step

Concepts are circled and links between concepts are identified and drawn.

At the end of these three steps, the graphical representation which is obtained can be a basis for a mind map or a concept map.

d. The graphical step

A mind map or a concept map based on the output of the relational step is drawn by the facilitator interactively with the participants.

Concept maps

What is a concept map?

Concept maps are a graphical tool for organizing and representing knowledge (Novak, Gowin 1984, Wheeldon, Åhlberg 2012). They include unique concepts, usually enclosed in circles or boxes. Lines and linking words between concepts suggest hierarchical relationships.

They were originally designed to assist people in visualizing the way they organized and structured their thoughts.

They allow one to form meaningful propositions about the map's theme and are very often used in quantitative social research (Wheeldon, Åhlberg 2012).

The Origins of concept mapping

According to Åhlberg (in *Varieties of concept mapping*, Proceedings of the First International Conference on concept mapping, Spain 2004): "It is commonly known that concept mapping was developed at Cornell University. Stewart, Van Kirk, and Rowell (1979) claim, in *The American Biology Teacher*, that they developed concept maps. However, in their concept maps, the links were not named and no propositions were formed from concepts. In that same journal, Novak (1979, 1980) later published two articles in which he referred to Stewart, Van Kirk, and Rowell (1979). He also presented examples of concept maps, but the links were still unnamed. However, in Novak (1981) the links were named, and meaningful propositions were created out of concepts. This is the form of Novakian concept maps that has been spread globally. In fact, Novak and Gowin (1984) were very influential in spreading it all over the world".

Five Steps to concept mapping

How does one construct a concept map? Here are five steps to do so (Novak, Cañas 2008).

a. The brainstorming Step

One writes down the major terms or concepts one knows about a given topic on a piece of paper. Then, one writes each concept or term on a post-it.

b. The organizing Step

One sorts through the post-its, putting terms one does not understand aside. Also one puts aside those that are not related to any other term or concept. The post-its left over are the ones that will be used to construct the concept map.

c. The layout Step

One sticks the post-it's on a piece of paper so that related terms are close to each other. One tries to group them so as to emphasize hierarchies. One identifies terms that represent higher categories, one writes them on post-it, then one adds them. One is free to rearrange thing at any time during this phase. The most important concepts or terms should be at the center or at the top.

d. The linking Step

One draws lines with arrows between the terms one thinks are related. Then, one writes on each line a word or a short sentence describing the relationships between the terms or concepts. Many arrows can originate or terminate on particularly important concepts.

e. The finalizing Step

If one puts any post-it aside in Step b, one has to go back and see if some of them will fit into the concept map just constructed. If they do, one adds the lines and relationships corresponding to the new items. Then, one converts the concept map into a permanent form by drawing it on a piece of paper or on the computer. One has to be creative through the use of colors, fonts, shades, border thickness, and so on. Finally, a title can be assigned to the concept map.

Analyzing and Synthesizing mind maps

Normative mind map Analysis

The normative analysis of a mind map consists in comparing it as a whole or branch by branch to a reference map.

For example, in the case of the French synthetic Opeduca (https://www.opeduca.eu) mind maps (see Appendix), one could compare the Solutions branches appearing in the different maps to a reference Solutions branch created by the Analyst or by an Expert.

This reference branch could, for example, span the following sub-branches: Short-term, Middle-term, Long-term, with Education appearing as a sub-branch of Solutions – Long-term.

This normative analysis can help suggest to the creator or creators of the mind map new associations and ideas about the topic. It can also be used in an assessment process.

Comparative mind map Analysis

How can mind maps be compared?

Mind maps provide a graphical representation of the concepts evoked by a topic in someone's mind or in the minds of a group of people if they are created collaboratively.

They are always drawn by an individual: a learner (a pupil, in an educational setting), a facilitator (a teacher) if they are created collaboratively, or an analyst (in synthetic mind mapping – see section 5.3.).

Let us note that two kinds of comparisons can be made:

a. Comparison of mind maps about the same topic

Here, the analyst starts by comparing the key themes of the mind maps, identifying the key themes which are shared by the different mind maps and the ones which differ.

Then, the analyst singles out the common key themes for which the secondary branches differ most.

The difference between the secondary branches reveals a difference in meaning of the key theme in the different mind maps. This reveals in turn that different associations with the main topic are designated by the same label (key theme) in the different mind maps.

To sum it up, the comparison of several mind maps about the same topic can proceed in the following way:

- One lists the key themes which are common to the different mind maps and the ones which differ.
- For the common key themes, one lists those who differ in their interpretation based on the secondary branches, and provides this interpretation.

b. Comparison of mind maps about different topics

Here, the analyst starts by identifying the concepts which are common to all the minds map and, for each of these concepts, looks at the branch in which they appear and the branches which originate in them.

For example, in the French Opeduca (https://www.opeduca.eu) synthetic mind maps about Food, Energy, and Water (see Appendix), one can see that the concept of Costs is shared by the three mind maps. However:

- For Food, it appears in the branch: Distribution
- For Energy, it appears in the branch: Society
- For Water, it appears in the branch: Marketing

The sub-branches of Costs are:

- For Food: Retail, Transportation, and Politics
- For Energy: Checks, Regulations, Strategies, Consumption, Conception, Policies, and Control
- For Water: Network, Collectivity, Bills, Service, and Cleansing

This reveals a different understanding of the concept of Costs for the three topics. For Food, it is a distribution cost, for Energy, it is a societal cost, and for Water, it is a production cost.

Note that this approach can also be used for mind maps about the same topic. However, in this case, the common concepts are likely to be more numerous. So, in order to apply this method, the analyst has to single out one or two concepts on other grounds.

Synthetic mind mapping

How can one synthesize several mind maps on the same topic?

Such a question may arise in an educational setting when mind maps about the same topic are created by different classes or groups of pupils.

That was for example the case in the "Flight for Knowledge" phase of the Opeduca project in France. Four topics were proposed to the pupils: Food, Energy, Water, and Eco-

Design. On each of these topics, mind maps were created by different groups of pupils in a collaborative way.

The task of analyzing these mind maps was entrusted to the University of Southern Brittany (http://www.univ-ubs.fr). It immediately appeared that, besides comparative and normative analyzes of the different mind maps, a synthesis of these maps would be helpful in visualizing the collective knowledge of the pupils about the topics. It could also be submitted back to the pupils as a basis for discussion. This could enhance their knowledge about the topics with concepts originating from other pupils.

The four synthetic mind maps constructed at the University of Southern Brittany appear in the Appendix.

A rigorous procedure has to be followed to derive synthetic mind maps:

First, a decision about the depth of the synthetic mind map has to be made. Here, the depth is understood as the maximum number of sub-branches along a branch. In the case of the former mind maps, this level was often three, extending to four for some particular branches. Let us denote this depth by D.

Then:

1. One gathers all the mind maps that deal with the same central topic and put them in a stack.

2. One puts the central topic at the center of the synthetic mind map.

3. One adds all the key themes from the first mind map to the synthetic map.

4. On the second mind map, one crosses out all the synthetic map's key themes. Then, one adds all the remaining key themes to the synthetic map.

5. One proceeds in the same way with the third mind map, and so on, until one reaches the end of the stack.

During this process, for each new mind map from the stack, all the key themes from the synthetic map are crossed out and the remaining themes are added to the synthetic map.

At the end of this procedure, all the key themes of the synthetic mind map are identified.

1. One proceeds in the same way for each key theme: one starts by identifying the mind maps where the key theme is present; puts them in a stack; adds the secondary branches of the key theme from the first mind map as secondary branches of the key theme in the synthetic map; crosses them out on the second mind map and adds the remaining secondary branches to the synthetic map, and so on.

2. At the end of this process, all the secondary branches of the key theme in the synthetic mind map are identified.

3. One iterates this process for all the synthetic map's key themes.

4. One applies the same procedure for each secondary theme, and so on.

A draft of the final synthetic mind map is obtained when all the concepts with depth lower or equal to D have been crossed out on all the original mind maps.

Finally, one edits this draft to obtain the final synthetic mind map, following the general principles of mind mapping.

The Collaborative Use of Synthetic mind maps in The Classroom

Teachers are professionals; they have their teaching skills. They have learning objectives for their pupils. But the pupils may know something that the teacher does not know. Everybody is a learner, including the teacher.

In any case, teachers should have a bigger picture about the topic under study. Their greater experience of life makes this more likely. Their duty is to facilitate the learning process of their pupils. Presenting synthetic mind maps to the pupils, derived from their own mind maps by the teacher, can be a tool for such an endeavor. They can be a basis for discussion, raise questions, and contribute to the building of a new common knowledge. Finally, they can help promote good interactions between the pupils, with the teacher, and with other people.

Conclusion: High Quality Learning and Graphical Knowledge Representation Tools

Mind maps and concept maps can be used to promote meaningful high quality learning and teaching. They show externally and explicitly, hidden and implicit conceptual and propositional structures. This promotes shared understanding, learning, thinking and acting and hence contributes to high quality learning (Åhlberg 2013).

Mind maps and concept maps can also facilitate meta-learning. Meta-learning (metacognitive learning) is learning about one's own learning, thinking and acting. Learning about one's own most effective learning styles and learning to be a more self-directed learner are two important aspects of meta-learning. Both contribute to high quality learning and are promoted by mind maps and concept maps (Novak, Gowin 1984). Thus, Knowledge Representation Tools are keys to fruitful thinking and discussion, for and about learning. They are very appropriate learning tools for a high-quality open education.

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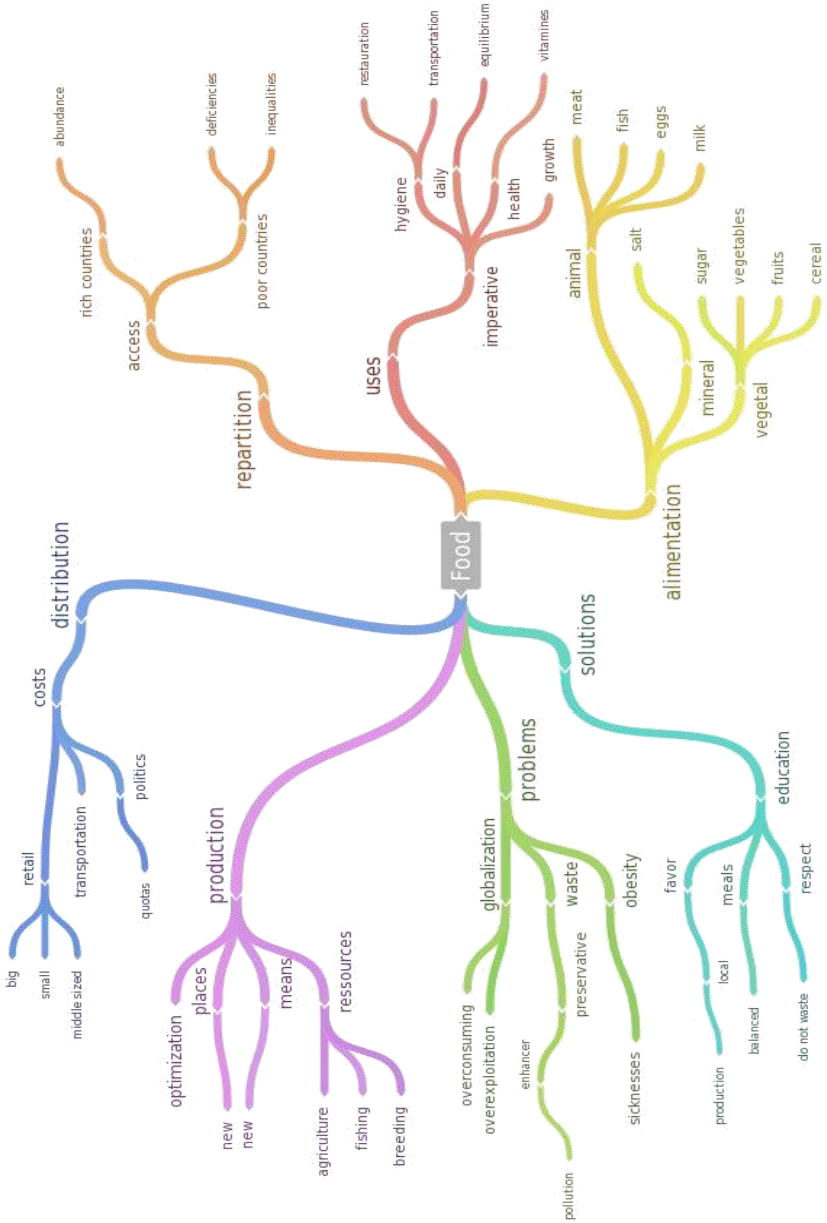
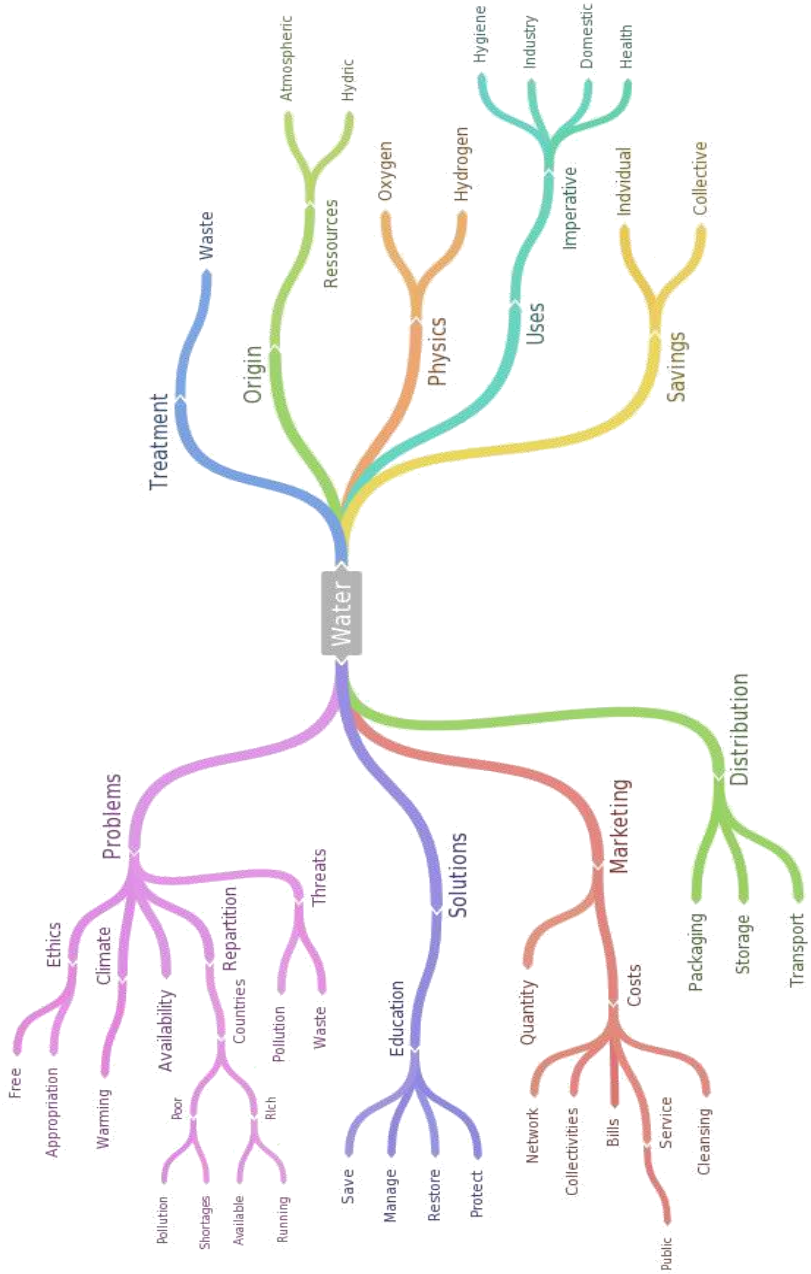
Appendix 1: Opeduca mind maps for France

Each of the following mind maps synthesize several mind maps about Food, Energy, Eco-Design, and Water, drawn by pupils from Lycée Lesage secondary school (Vannes, France) with the help of their teachers. They were made using the Coggle software (https://coggle.it/).


Food
repartition
access
rich countries
abundance
poor countries
deficiencies
inequalities
uses
imperative
hygiene
restauration
daily
transportation
health
equilibrium
growth
vitamines
alimentation
animal
meat
fish
eggs
milk
mineral
salt
sugar
vegetal
vegetables
fruits
cereal
distribution
costs
retail
big
small
middle sized
transportation
politics
quotas
production
places
optimization
new
new
means
ressources
agriculture
fishing
breeding
problems
globalization
overconsuming
overexploitation
waste
preservative
enhancer
pollution
obesity
sicknesses
solutions
education
favor
production
meals
local
balanced
respect
do not waste


Water
Treatment
Waste
Origin
Ressources
Atmospheric
Hydric
Physics
Oxygen
Hydrogen
Uses
Imperative
Hygiene
Industry
Domestic
Health
Savings
Individual
Collective
Problems
Ethics
Free
Appropriation
Climate
Warming
Availability
Poor
Pollution
Shortages
Repartition
Countries
Rich
Available
Threats
Pollution
Waste
Running
Solutions
Education
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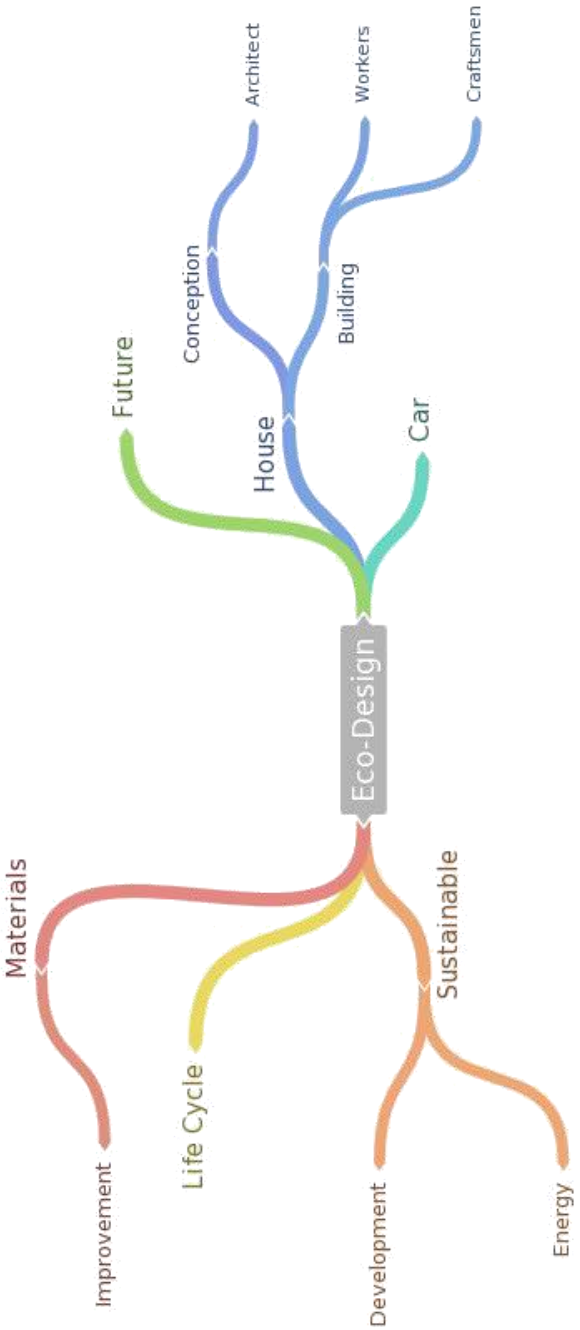
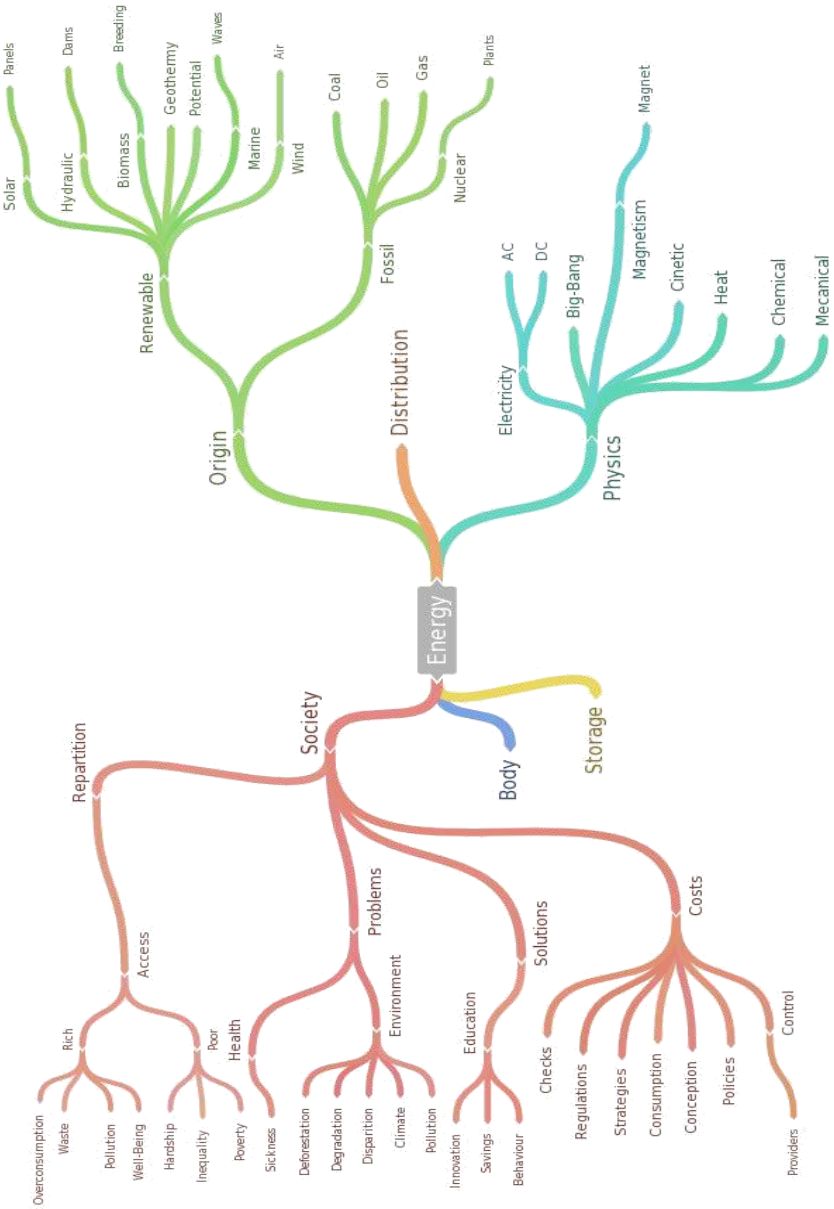
Quantity
Network
Collectivities
Costs
Bills
Service
Public
Cleansing
Distribution
Packaging
Storage
Transport


Eco-Design
House
Conception
Architect
Building
Workers
Craftsmen
Future
Car
Materials
Improvement
Life Cycle
Sustainable
Development
Energy


Energy
Origin
Renewable
Solar
Panels
Hydraulic
Dams
Biomass
Breeding
Geothermy
Potential
Waves
Marine
Air
Wind
Fossil
Coal
Oil
Gas
Nuclear
Plants
Distribution
Physics
Electricity
AC
DC
Big-Bang
Magnetism
Magnet
Cinetic
Heat
Chemical
Mecanical
Society
Repartition
Access
Rich
Overconsumption
Waste
Poor
Pollution
Well-Being
Health
Handship
Inequality
Poverty
Problems
Environment
Sickness
Deforestation
Degradation
Disparition
Climate
Pollution
Solutions
Education
Innovation
Savings
Behaviour
Costs
Checks
Regulations
Strategies
Consumption
Conception
Policies
Control
Providers
Body
Storage

Appendix 2: A Concept map presenting RCE Brittany

The following concept map presents RCE Brittany (https://rcebretagne.org) and its activities. It was made using the cMap Tools software (https://cmap.ihmc.us).