Use of Concept Maps to Aid Early Engineering Design

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This paper reports on the use of concept maps as a tool to facilitate innovation and aid in the communication of ideas during the initial stages of engineering design. The authors propose that engineering design, especially in the early stages, is a learning exercise. In exploring the different characteristics, requirements, and constraints of a design problem, a design team can better understand the limitations of their design, as well as encourage more innovative thinking that works within these limitations. For engineering purposes, the organization of different ideas with concept maps may provide insight into the kinds of subsystems the design may require as well as the interconnectivity between these subsystems as represented by the links between various nodes and the evolution of concept maps may help understand the collaborative design processes used by the designers who created the maps.

1.0 Introduction

Concept maps are a specific type of web diagram that facilitates the exploration, gathering and sharing of ideas. Using a medium like concept maps is a powerful method to portray a large amount of complex information, making it easier to understand and see the interactions between concepts. Novak [7] describes concept maps as a visual roadmap to show pathway that connect concepts. This makes the communication of that information easier since it is now in an organized manner that can be easily assimilated. With this organized knowledge it is possible to answer focused questions about the context of the map.

Concept maps have been predominantly used in education as a tool to aid learning as well as assess understanding of what is being taught. Concept maps allow students to organize their current knowledge in a way that they can understand. This also makes it easier for them to see possible relationships between different pieces of knowledge, thus further advancing their understanding. Once new knowledge is learned, the student can go back to his/her current map of knowledge and see how the new knowledge can be integrated into the existing body.

The early stages of engineering design can be seen as a learning process in that each member of a design team has to become familiar with each other's capacity as well as understand the problem that is set before them, so an educational tool may provide insight into the design process. Successful capture and sharing of each member's expertise depends on their ability to explain their knowledge and then represent it in such a way that it supports effective examination by other members [1]. But learning a piece of knowledge cannot be

accomplished through reading alone, it requires dialogue, exchange, sharing and most often compromise. It is this back and forth sharing of ideas and feedback that makes concept maps a viable tool for engineering design. With concept maps a team can firmly establish the different aspect of their design problem and visually layout the constraints within which their design will fall. Once those limitations have been established, each member can contribute their expertise on the problem and thus build the map in such a way that every member of the team clearly understands how the project is developing.

2.0 Concept Maps

Concept maps consist of *nodes* connected by *links*. A node is a geometric shape (usually a rectangle) containing a text fragment that represents a concept, idea, item, or question. A link connects two or more concepts together, and represents a relationship between the concepts. Links are labeled with a text annotation describing the nature of the relationship. The links can be unidirectional or bi-directional, depending on the nature of the relationship.

To achieve a higher level of organization, users can change the graphical properties of these elements. For nodes, the style can be altered to group common concepts by colour or shape or font of the node's text. For links, the style can also be altered to reflect various types of relationships between nodes, including line thickness, arrowhead style, colour, and style (e.g. dashed versus solid lines). Concept maps make no specific commitments to what such style variations mean. Instead, one expects the user to establish conventions regarding style that are meaningful to the expected "readers" of the map.

In a design setting this means that each user community can establish their own norms, thus increasing flexibility while allowing the groups to develop their own semantics for the maps, and thus improving the capacity of the maps to convey knowledge. One useful tool that CmapTools [3], a concept mapping software tool, provides is the ability to make custom styles for nodes. As mentioned earlier, the graphical elements of a node can be changed to provide added information to the map. Should the user wish to group a number of different concept nodes by using a certain style pattern, he/she may do so by creating a custom style. Once the desired combination of style elements have been selected they can be saved as a 'New Style' on the Cmap. Now instead of going to each individual node and configuring it to the one style, the user can just select all the desired nodes and then select the custom style so that all of those nodes are now visually linked. This flexibility can also be added to maps that are loaded onto a server. This gives a collaborative team the ability to use these custom styles from multiple locations as the style is now linked to that specific map.

CmapTools also provides a server capability that allows multiple users to view and edit maps from a central location synchronously or asynchronously. Synchronous collaboration allows two or more users to be logged into the server and edit the same concept map. This provides a more robust tool for collaboration as the designers can now work together, sharing their knowledge and organizing their thoughts in real time, which greatly increases the speed at which the project progresses. The added benefit of a real time chat facility to allows users to discuss the map and potential changes all within the same medium. For asynchronous collaboration, authorized users have the opportunity to view the map and make their own editions and suggestions thus further expanding the knowledge that is captured in the map. This gives design teams that are not co-located the opportunity to collaborate on a project without having to spend large resources to bring everyone into a conference room.

3.0 Auto21 Design Case

An initiative called The Automobile of the 21st Century (<http://auto21.ca>) was undertaken within the Canadian Network of Centres of Excellence and provides funding for a number of research projects in all aspects of automobile design among which is an interest in collaborative design methods and tools for design teams. One such project brings together a number of universities to study the design methodologies in the North American automobile

industry and investigate collaborative tools that may aid in these design strategies. Among these tools is *concept mapping*, which is used to help organize thoughts and foster innovative ideas in the early stages of an engineering project. This project provides the opportunity to observe and analyze the use of concept maps generated by members from each university to see how effective the maps are in facilitating the overall project. In order to do this, part of the team will explore the design of a small environmentally friendly urban vehicle while others will observe the design process and analyze the collaboration between the different schools. The current authors are part of the latter team.

3.1 Concept Map Iteration

The initial stages of the design process in the project were very slow since all the members of the design team were getting familiar with the concept mapping software, so they were not able to use it to its full potential for collaborative work. From their first maps it can be seen that everyone was creating their own map, but they all provided the same basic information about the project. While this is a good example to evaluate how each member understands the goals of the project, it does little to provide progress as no new concepts are being generated, thus no new knowledge is being shared.

Figure 1: Initial Concept Map

Further into the project team members were developing maps with new concepts and new knowledge based on older concept maps. While this showed definite progress in the project, there resulted a number of maps that were redundant or obsolete. For collaboration, it would be more useful for team members to add concepts to one map and allow it to grow as new information is added thus allowing each member to contribute their expertise to the project and see how that knowledge fits in the "big picture."

This evolution can be seen starting with Figure 1, which shows one of the initial concept maps that was created after the first meetings of the Auto21 project. Most of the nodes in this map represent general concepts requiring further

Figure 2: Project Concept Map

definition, so there is very little detail shown, but the basic information of the project could easily be created at a time when the team members were just learning about concept maps, so the depth of knowledge represented was very low. Still, there is a clear distinction between the two project streams: vehicle design, and research.

Looking now to a map created a couple of months later, Figure 2, we can see there has been substantial development of various subsystems as well as addition of new concepts that were found to be relevant to the project. The two areas of interest that were seen in the first map are more clearly defined. Under 'vehicle design' one can see all aspects of the vehicle that the designers have to take into consideration including the design characteristics and then further down, the constraints that they must work within.

In the second stream there is a break down of the various areas of research that the team will look into based on the expertise of the schools contributing to the project.

3.2 Concept Map Layout

Layout can have a significant impact on how information is captured. Novak writes that concept maps should have vague and general concepts higher up on the map and more specific concepts below, generally allowing it to flow downwards, to the left or right, but never up.

Figure 3: Layout Configuration 1

He also discusses how the same set of concepts can be configured to any map pattern depending on the context of the map which plays an important role in determining which concept will be the focus of the map. As can be seen in Figures 3 and 4, each map consists of the same nodes, but in the first map the importance is given to "living thing" and what that concept entails, while in the second map the emphasis is placed on the "molecule" [7].

This is very useful for engineering design as it gives the team flexibility in situations where the focus of the design shifts from one requirement or constraint to another. The designers can reconfigure the map without having to start from the beginning.

Figure 4: Layout Configuration 2

A study of concept maps in design done by the University of Massachusetts shows that they follow four major patterns: linear, web, branched and cat's cradle. Linear patterns represent a step-by-step relationship from one concept to another, but showed no interrelationship between a number of concepts or a need to iterate the map to include new concepts. While the cat's cradle, branched and web patterns all showed more diverse connections between concepts, cat's cradle contained many additional links that lead to misconceptions about the concepts being discussed [5]. Looking back to Figure 2, even though it has evolved to show more information, the layout of the map does little to allow for faster assimilation of the knowledge that it represents. By following the links to each concept, there is a definite hierarchical pattern between the two streams, thus leading to the iteration of the map to Figure 5. Here there is a clear distinction, in terms of layout, of the two major concepts as they are spaced out and have their subsystems clearly organized under them. The 'vehicle/mechanism to facilitate research' is noticeably seen as the link between two concepts.

In addition to the layout, different colors were added to the map to further distinguish the two areas of interest, thus allowing the viewer to immediately see all the concepts relating to the vehicle design and all the ones relating to research.

Figure 5: Project Concept Map with Layout Editions

3.3 Concept Map Linking

As more knowledge is added to a map they inevitably become very expansive and require extensive scrolling by the user to see all the information that the map contains. This retards the effectiveness of the map since there is now too much information in the one map to be gleaned at first glance. A NASA/IHMC collaborative study [1] showed that a map has to be able to fit in one screen and contain up to 30 concepts only to retain its usefulness. To add more information, major concepts in the main map should link to minor maps that contain more details about the subject of the major concept. This allows for the main map to be a guide to the information while the minor maps can go into more detail about each topic.

As the Auto21 project progressed one of the major maps, see Figure 6, shows all of the requirements and constraints that the principal investigators had placed on the design. Upon closer inspection of this map there was a lot of information here that had been repeated from the previous map showing the evolution of the project (Figure 5). This information is now redundant and does nothing to show new knowledge in the project. To solve this problem, Figure 5 was iterated so that the concept node 'Performance Specification' now contained a link to the map with all the design limitations, Figure 7. This makes the 'project' map more conducive to quick knowledge capture as it reduces the number of concepts in it, but it also links two maps together which shows a greater understanding of how the knowledge is interconnected.

Figure 6: Constraint Map

Figure 7: Iterated Project Map with Linking

3.4 Cyclic Map Pattern

Layout is not limited to hierarchical patterns; there are situations where the flow isn't necessarily up to down.

Figure 8: Overall Systems, cyclic pattern

Figure 7 shows a cyclical nature which is necessary to showing how each of the major subsystems are related to the chassis subsystem. A hierarchical pattern in this situation would have spread the map over a number of screens making it lose some of its ability to relay information quickly. Patterns like this are going to be necessary for designers to see how their particular subsystem relates to all the other systems (Figure 8). This can also give an idea as to what magnitude each system is interconnected, providing a sense of priority that would relate to future design trade off decisions.

Figure 9: Subsystem interfaces, cyclic pattern

4.0 Conclusion

From the many concept maps that have been shown in this report, there is a clear progression in the amount of information that each map holds. As the Auto21 project has developed the quality of the maps have improved, showing greater consideration to layout and style allowing the viewers of the maps the ability to better glean information. Each time a map is changed or more information is added represents iteration in one aspect of the design showing that traditional design methodologies can be seen in concept maps.

In using concept maps designers working on a common project are better able to organize their ideas and help inspire innovative concepts that push the norm of design. By using the online capabilities of concept maps a design team is not restricted to face-to-face meetings that may be few and far between and a drain on resources, to make any progress on the project. With concept maps a member can provide valuable input from half way

around the world either synchronously or asynchronously.

5.0 References

- [1] Briggs, Geoffrey et al. Concept Maps Applied to Mars Exploration Public Outreach. 1st CMC. Pamplona. 2004
- [2] Dumestre, Jeanie. Using CmapTools Software to Assist in Performing Job Task Analysis. 1st CMC. Pamplona. 2004
- [3] IHMC CmapTools. Synchronous Collaboration Using CmapTools.[URL: http://65.212.118.148/servlet/SBReadResourceServlet?rid=1064009710027_2127618864_27105&partName=htmltext] Last Viewed May 29, 2006.
- [4] King, P.H. and Walker, J.M.T. Concept Mapping Applied To Design. 2nd Joint EMBS/BMES Conference. Houston, Tx. 2002
- [5] Knight, Judith et al. Using Concept Maps to Assess Design Knowledge. 34th ASEE/IEEE Frontiers in Education Conference FIG-10. Savannah, GA. 2004
- [6] Moon, Brian. Concept Maps and Wagon Wheels: Merging Methods to Improve the Understanding of Team Dynamics. 1st CMC Conference. Pamplona. 2004
- [7] Novak, Joseph and Gowin, Bob. Learning How to Learn. Cambridge University Press. New York. 1984.

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