The Use of Conceptual Maps for Competencies Mapping and Knowledge Formalization in a Virtual Lab

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Abstract In this work we address the need to formalize knowledge in a systematic way in order to productively explore it. We present a methodology on how to capture and archive information and then transform this plain information into valuable knowledge. In a specific case study, the competencies of each node/organization of a networked Virtual Laboratory have been identified. Conceptual maps aiming to host the identified competencies are structured based on specific rules; the population of the conceptual maps and the mapping of the competencies give a user-friendly overview of the Virtual Lab's overall knowledge and expertise, considering both internal and cross-organizational aspects. The benefits of this work are described and guidelines for the implementation and introduction of the proposed work to multi-stakeholders environments are provided. The results of this work are expected to be of value to both industrial and academic audience with interests on topics such as knowledge mapping, knowledge formalization, competencies mapping, conceptual maps, tacit knowledge, and ontologies.

Keywords: Knowledge formalization; Conceptual map; Competencies mapping; Virtual Laboratory

1 Introduction

The strength of knowledge formalization comes from its impact and integration with individual experience and expertise. The results of knowledge formalization are not evaluated by how well they meet some ideal definitions and expectations, but by how effectively the achievements permit and support the use of existing organizational knowledge to generate, retain or expand research activities. Sometimes, this can be also referred as the conversion of plain information to valuable knowledge.

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The concept of the Virtual Laboratory is, that instead of having individuals and teams working (perhaps without knowing it) in parallel with each other, or what is worse – at cross purposes, organizations that effectively practice good knowledge management will have everyone working in a careful alignment towards the objectives, without reinventing any wheels or overlooking any opportunities, and being certain to reuse and reapply as much of the past information and work as possible.

2 The Use of Conceptual Maps to Formalize Knowledge

2.1 Defining the Conceptual Map

Conceptual Maps are simple and practical knowledge representation tools that allow conveying complex conceptual messages in a clear, understandable way. Concept maps are graphical tools for organizing and representing knowledge. [1] They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts. Sometimes more than two concepts can be directly or − more frequently − indirectly related. Concept is defined as a perceived regularity in events or objects, or records of events or objects, designated by a label. The label for most concepts is a word, although sometimes symbols such as + or % are used, and sometimes more than one word is used. Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected using linking words or phrases to form a meaningful statement. Sometimes these are called semantic units, or units of meaning. Figure 1 shows an example of a concept map that describes the structure of concept maps and illustrates the above characteristics. [1]

Another characteristic of conceptual maps is that the concepts are represented in a hierarchical fashion with the most inclusive, most general concepts at the top of the map and the more specific, less general concepts arranged hierarchically below. The hierarchical structure for a particular domain of knowledge also depends on the context in which that knowledge is being applied or considered. Therefore, it is best to construct conceptual maps with reference to some particular question we seek to answer, which is called a focus question. The concept map may pertain to some situation or event that we are trying to understand through the organization of knowledge in the form of a concept map, thus providing the context for the concept map. [1]

Another important characteristic of conceptual maps is the inclusion of cross-links. These are relationships or links between concepts in different segments or domains of the conceptual map. Cross-links help us see how a concept in one domain of knowledge represented on the map is related to a concept in another

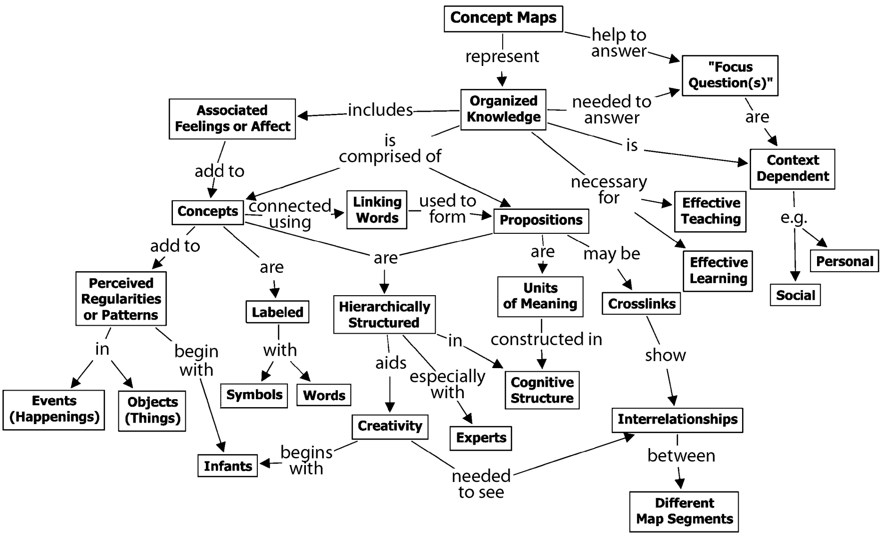

Fig. 1 A conceptual map showing the key features of conceptual maps. Conceptual maps tend to be read progressing from the top downward [1]

domain shown on the map. In the creation of new knowledge, cross-links often represent creative leaps on the part of the knowledge producer. There are two features of concept maps that are important in the facilitation of creative thinking: the hierarchical structure that is represented in a good map and the ability to search for and characterize new cross-links. [1]

A final feature that may be added to concept maps is specific examples of events or objects that help to clarify the meaning of a given concept. Normally these are not included in ovals or boxes, since they are specific events or objects and do not represent concepts. [1]

Concept maps were developed in 1972 in the course of Novak's research program at Cornell where he sought to follow and understand changes in children's knowledge of science [2]. During the course of this study the researchers interviewed many children, and they found it difficult to identify specific changes in the children's understanding of science concepts by examination of interview transcripts. This program was based on the learning psychology of David Ausubel [9, 10, 11]. The fundamental idea in Ausubel's cognitive psychology is that learning takes place by the assimilation of new concepts and propositions into existing concept and propositional frameworks held by the learner. This knowledge structure as held by a learner is also referred to as the individual's cognitive structure. Out of the necessity to find a better way to represent children's conceptual understanding emerged the idea of representing children's knowledge in the form of a concept map. Thus was born a new tool not only for use in research, but also for many other uses. [1]

2.2 Capturing and Archiving Expert Knowledge

One of the fast growing uses of conceptual maps is their use for capturing the "tacit" knowledge of experts. Experts know many things that they often cannot articulate well to others. This tacit knowledge is acquired over years of experience and derives in part from activities of the expert that involve thinking, feeling and acting. Often experts speak of a need to "get a feeling for what you're working on". [1]

Prior to the use of conceptual maps, most of the knowledge capturing methods consisted of various forms of interviews and analyses with experts. Such methods are still in use and in some cases very popular, but in many cases they allow gaps in the representation of knowledge. Furthermore, they are usually not flexible in updates regarding how the knowledge of the experts is changing over time.

While it is expected that interviews, case study analyses, "critical incident" analyses and similar techniques have value in extracting and representing expert knowledge, it is likely that the results of these studies might still be best represented in the form of concept maps. [1]

In order to identify the competencies of a virtual laboratory and accordingly the expertise fields of the organizations, appropriate questionnaires were prepared and distributed. The feedback was afterwards analyzed in order to identify the main competencies that would eventually be integrated to the conceptual map. [4]

3 Mapping the Competencies of a Virtual Laboratory

The virtual lab of our case consists of several European universities, laboratories, institutes and research organizations that joined in a network of excellence in order to create a Knowledge Community in Production, which will aim to integrate the particular cultures in the development of new products, systems and services and to build a knowledge sharing culture.

One of the major issues identified even from the beginning of this Virtual Lab, was the need for creating a Knowledge Map, which will depict the competencies of all the participating members. These competencies in the research and scientific fields would represent the knowledge accumulated by each one of the network members. Additionally, knowledge mapping is a first and mandatory step in ontology definition [5].

One problem that had to be faced was how to distinguish the individual from the organizational knowledge. *Individual knowledge* is owned by individual researchers and resides in their minds, whereas organizational knowledge exists in the organization and is created through organizational learning and evolution. *Organizational knowledge* can be in a tangible form like patents and licenses or in an even more important intangible form like technical know-how, product design, marketing presentation, understanding industrial needs, personal creativity and innovation. It can also be seen as organization's intellectual assets. An approach to reorganizing knowledge as a corporate asset is new to organizations. They are starting to understand that they have manage and invest into knowledge with the same care as paid to getting value from other more tangible assets [3, 8].

Another problem was the format to be followed in the creation of the Knowledge Map, in order to follow a common, understandable, easy to search and trace format. After having examined several methods and approaches, it was decided to create a conceptual map for each one of the three main research fields so as to collect:

- Competencies on manufacturing processes
- Competencies on design and virtual prototyping (presented as example in this chapter)
- Competencies on simulation

The formalization and structuring of the available information, within the context of the conceptual map, was implemented by utilising a commercial tool for the construction of conceptual maps. The specific tool was selected as it provides a number of features that assist the user towards this effort. One of the main reasons is that this application provides a user-friendly interface in order to generate a hierarchical structure of information, just as the objective of this task suggests.

The application demonstrates a number of helping features to further enhance the usability of the categorised information and the conception of valuable conclusions. The ability to attach files, add notes or other material in any node of the map was also a very important feature since the conceptual map can in this way be integrated to cover all the analysis for a specific field of expertise: From the capital competence area downwards to the last but very important level of an attached related publication. Furthermore, the filtration of the available information according to multiple criteria is a feature which proves very useful since it can support the easy handling of vast information. [6]

3.1 Constructing the Conceptual Map

The procedure that was followed in order to implement the conceptual map is schematically presented in the next figure. As shown, this procedure can in general terms, be summarized in the following four main steps:

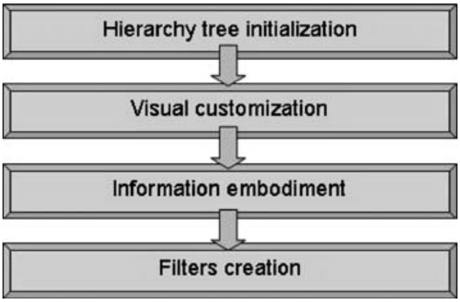

Fig. 2 Basic steps towards the implementation of the conceptual map

The first node of the map was named "NoE Competencies Map" and it was then gradually expanded. The two main areas of competencies were presented next as shown in the figure below. These two main topics were further expanded to competence areas, fields of expertise in each area, methods and tools used and so on.

Fig. 3 Main areas of the map

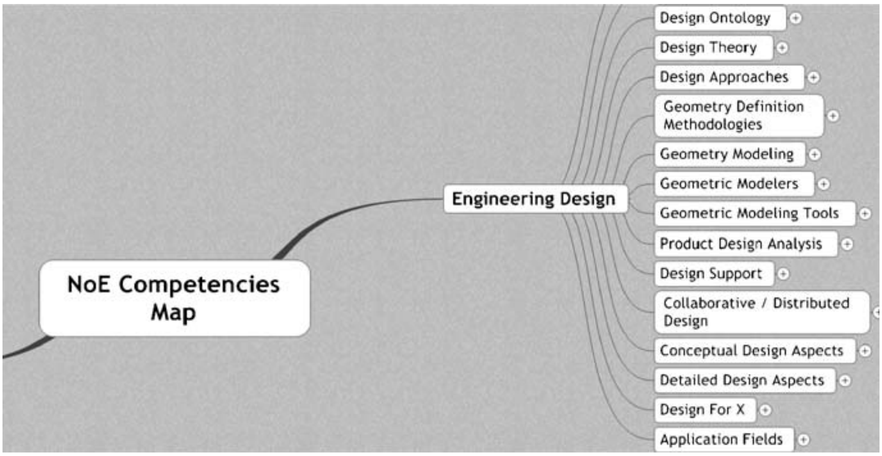

Fig. 4 Initial expansion of the main areas

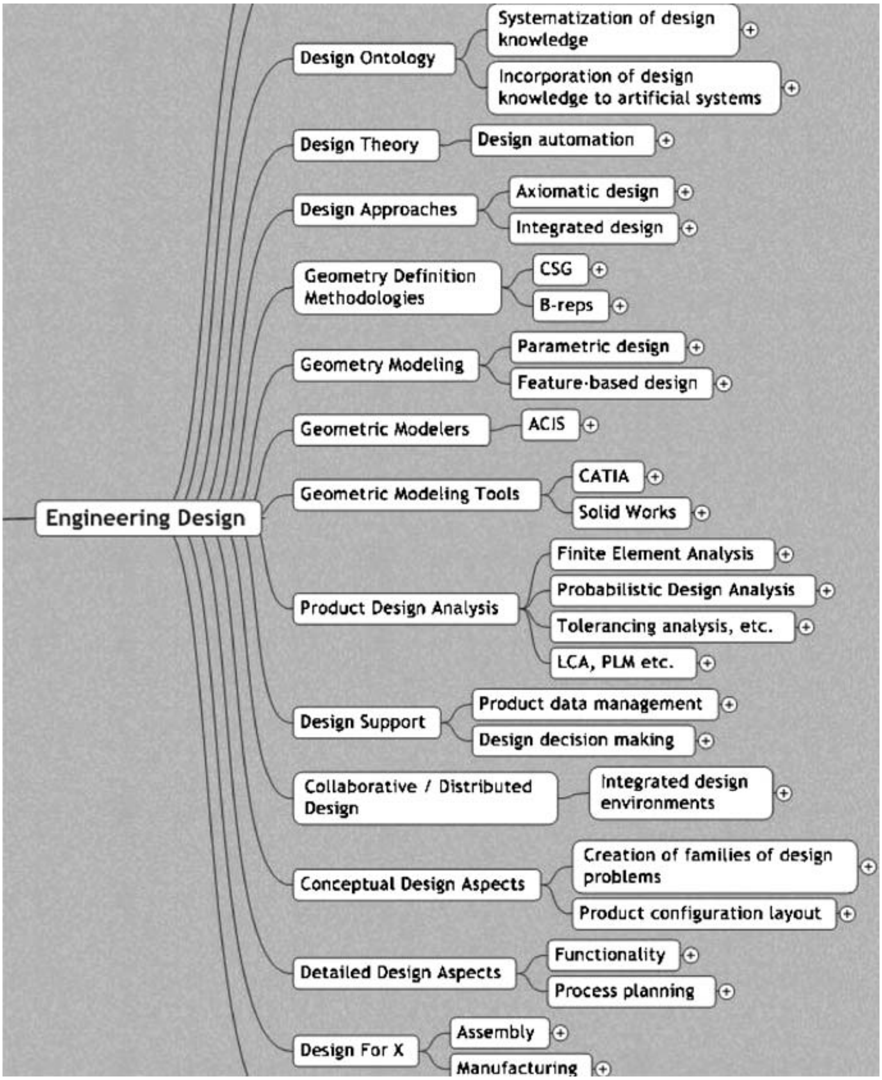

Fig. 5 Gradual expansion to further levels of detail

The integration of the Conceptual Map includes the mapping of each partner to a specific field of expertise. Hence, a new tree of all organisations should be created and then each organisation should be linked to a specific field of expertise.

The “organizations” tree, additionally customised for visual optimization, can be found in Fig. 6. In every field of expertise, the organizations that claimed competencies are linked to it. This tree can continuously be updated in order to finally include all the members of the Virtual Lab with specific expertise in the “Design” and “Virtual Prototyping” areas.

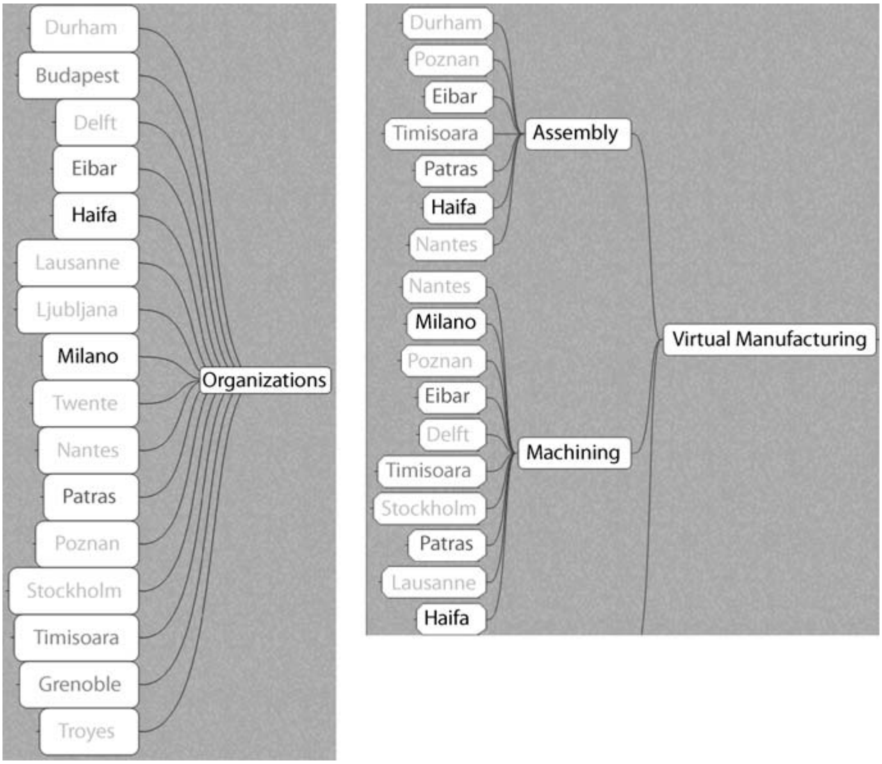

Fig. 6 Organizations tree and claimed competencies

The Conceptual Map was implemented and enhanced with advanced features in order to improve its usability and to further assist the cooperation between the NoE partners.

Finally, it is of value to mention that the Conceptual Map that was implemented can be easily customized according to each organisation's specific needs. The customization could include new visual sorting techniques, new filtering mechanisms and much more. A variety of other complementary features like hyper-linking or additions of notes in any node are also available to be used. Furthermore, a number of these features will be used for the implementation that will take place under the context of the next paragraph for populating the Conceptual Map.

3.2 Populating the Conceptual Map

In order to have a holistic view on the background of the competencies of the NoE partners, the Conceptual Map was populated with useful information. Indicatively, references to related scientific literature produced by the members of the Virtual

Lab have been included in this version of the conceptual map. Additionally, a short summary of the state-of-the-art in respective key competence fields was also included in specific nodes of the hierarchy tree. The text included in these summaries provides an overview of the related references.

The integrated information also includes references from international organizations and not only from the Virtual Lab members. The references have been linked to each member responsible and then to the related field of expertise. The aforementioned implementations are introduced in the following figure.

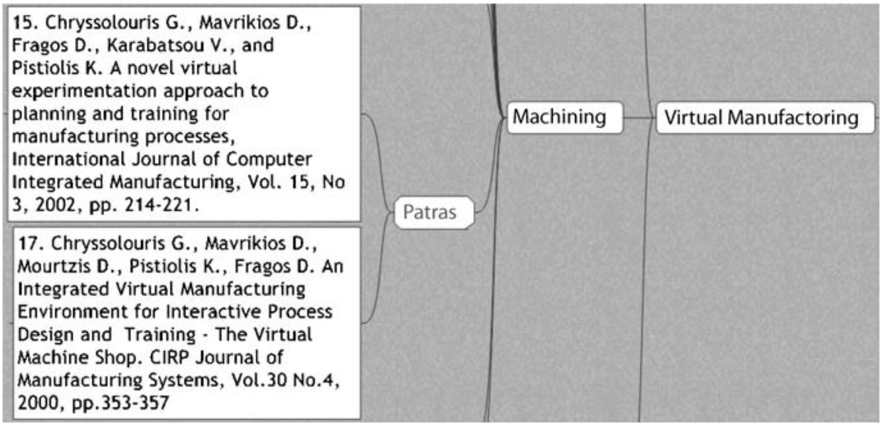

Fig. 7 Example of references' linkage to a member of the Virtual Lab

4 Unification of the Conceptual Maps

As it was previously mentioned, three conceptual maps were created in order to collect the competencies of the members in the three main research fields:

- manufacturing processes
- design and virtual prototyping
- simulation

The three maps should now be merged into a common, integrated conceptual map so as to cover the competencies of the member in all three research fields.

In spite that the three maps were created with the same software tool, when the time for merging them into one had reached, a number of differences appeared. These differences occurred due to the different approaches followed by the developers of each map, and a homogenization process should start in advance to the unification.

4.1 Methodological Approach

A decision on the detailed format for the final unified conceptual map was required for securing a straightforward unification of the conceptual maps. The three maps had to be examined in detail so as to identify the important points of difference in their concept and construction, and then decide on a qualified approach for the unification process. Their differences and similarities should be identified. Moreover, the interesting features presented by each implementation will be recorded for adoption and future use in the unified conceptual map.

The general aim was not to decide which was the best of the three approaches, but to select the most commonly used mapping aspects enhanced by the best-identified practices. This way, two main objectives could be accomplished [4]:

- The unified conceptual map should be more consistent to its features, scalability, visual representation, tree information structure and general format.
- All the identified interesting features should be integrated to the unified conceptual map.

Starting from the visual representation, the visual format of the conceptual maps should be examined and the more user-friendly representation scheme should be indicated. The visual representation of the several knowledge branches would assist the user to easily locate the information of interest. A hierarchy tree structure was also examined in relation to the visual representation scheme of the unified conceptual map.

The identification of best practices and the most interesting developed features took place, so as to be incorporated to the unified conceptual map. These practices included features and mechanisms for visual differentiation of the expertise fields, or mechanisms that easily define groups and respective sub-groups of experts.

Similarly, integrated search methods were identified and incorporated into the unified conceptual map. Concurrently with the search methods, "data filtering" mechanisms were also defined so as to enable the user to focus only on the most interesting features.

Furthermore, the different approaches concerning the standardization of the included knowledge data were identified. The most suitable approaches for the standardization were selected so as to promote the information consistency and to assist on the formalization of the information. Standardized information plays an integral role in ensuring the success of any information quality initiative. To correctly analyze, report and eventually utilize information, each conceptual map information branch should meet the established quality requirements.

The following figure presents the most important aspects that had to be examined for the three conceptual maps [7].

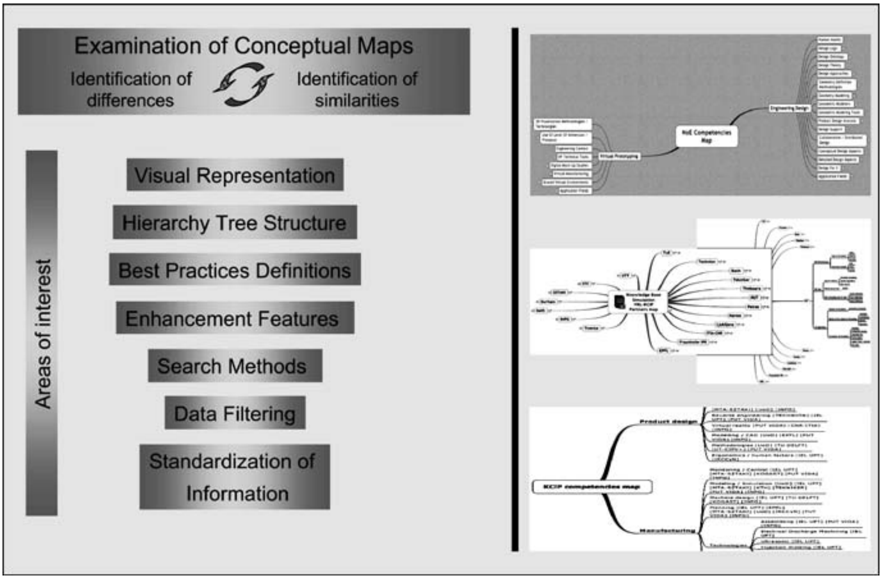

Fig. 8 Conceptual map unification approach

4.2 The Unification Process

The unification process should be done within the context of the methodological approach as described before. The procedure should be executed with respect to the updated developments. The unification process should start from the visual representation and then should gradually extend to the more detailed aspects.

After the visual representation, which is in close connection with the hierarchy tree structure, the supplementary features should be included in all the related points. Especially the search methods should be employed together with the smart data filtering so as to establish a straightforward approach for every user that interacts with the unified conceptual map.

Moreover, it must be noted that the unification process should take place with respect to the intended integration of the knowledge. The unification at all times should be considered as a step towards an integrated knowledge map.

The following implementation phases were considered in order to finally achieve the unified conceptual map.

1. A responsible team for the unification process was organized.
2. The examination of the various aspects of the currently developed conceptual maps took place afterwards.
3. A decision was made for the final picture of the unified conceptual map in terms of visual representation, contents and enabling features.

4. The conceptual maps were assembled and a unified conceptual map was deployed.
5. The responsible for the unification team ensured that map consistency is expanded to all the elements of the unified conceptual map.
6. Interesting features such as search capabilities, information filtering and supplementary tools were included.
7. A test phase took place for ensuring the correct operation.
8. Members of the Virtual Lab verified the quality of the included information. Comments were provided concerning the optimization of the developed features and enhancements were implemented where needed.
9. Documentation and Tutorials for the unified conceptual map and its usage were also provided.

5 Conclusions

Within the context of this work we explore the benefits of competencies mapping and knowledge formalization when achieved through the development of appropriate conceptual maps. However, the purpose/focus of this work goes a step further by presenting the procedure and guidelines for the successful implementation and introduction of the proposed conceptual maps to real practice. Accordingly, the significant benefits expected from this work have been identified. It is expected that the findings will be of value to both industrial and academic audience with interests on topics such as knowledge mapping, knowledge formalization, competencies mapping, conceptual maps, tacit knowledge, ontologies and even more, by also considering internal and cross-organizational aspects. Finally, we conclude by expressing our belief that this work will assist towards an important objective, the conversion of plain information to valuable knowledge.

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