Creative Thinking through Concept Mapping

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Abstract

The aim of this project is to promote creative thinking through the learning activity of concept mapping. A specific design is required so that a learning environment can support this aim. Serendipity, modular development, and reflective activities are three key elements, in which our design is based. In this paper, we describe a framework for the development of such a learning environment, a use case scenario and the specific methods that were implemented. These methods exploit findings from the field of computational linguistics as well as algorithms from the area of network theory.

1. Introduction

A young child acquires meaningful knowledge about its surrounding environment not so much by accumulating new information, i.e. by adding new to existing information, but mainly by organizing information in new ways [1]. One way to achieve this organization is through a concept mapping activity. There are a variety of software tools that provide a graphical user interface to help a learner to design a concept map. Traditionally, these tools have limited, or no, computational creativity capabilities. The lack of these capabilities restricts the caliber of this type of software in supporting more advanced learning outcomes.

Creativity is not an optional or peripheral learning outcome. According to Ken Robinson [2], creativity is as important in education as literacy and should be treated with the same status.

Although there is no consensus about the definition of creativity, at least two characteristics [3] are essential in order for an idea or a product to be creative: a) novelty and b) value. Other researchers [4,5] add the characteristic of surprise. This is also essential when we would like to evaluate ideas and products in a more dynamic and internal way, adding the space and time dimensions. The distinction between novelty and surprise is that a product or an idea is new as a whole, while it produces surprise based on its internal qualities.

In a complementary line of thought, the clarification of an initially vague and ill-defined problem is also a criterion used by Newell, Shaw and Simon [6]. The main issue in such problems is how to conduct effective searches. Searching is difficult because the space is enormous without visible cues. However, the process is not completely blind. There are methods and appropriately designed environments that promote creative thinking.

In this paper, we present a software tool for the learning activity of concept mapping. This tool is equipped with computational methods especially designed to support creativity. In order to achieve this aim, we adopt research findings from the area of creative environments design and we elaborate on the requirements of the previous characteristics.

In the next sections, we present some theoretical aspects regarding the concept of creativity and a computational framework that could facilitate it. The specific methods and the logic behind the proposed framework and the ways that the learner interacts with the software are also presented. Finally we conclude with some initial evaluation findings.

2. A computational creativity framework

Creating a concept map means creating a structure. On a higher level, this structure consists of substructures. On a lower level it consists of linked nodes which form propositions. Every node is a concept which could be similarly analyzed into structures displaying an iterative manner and delving more and more into a deeper level like the exploration of a fractal.

This means that a structure, like a concept, is determined semantically by a name. The name of the structure does not necessary coincide with one of the names of the concepts that it contains. Normally, in order for a learner to accurately conceive a structure as a whole compact entity, the provision of a name is required.

A first challenge for a computational creative tool is to determine the meaning of each concept. This meaning is expressed by a name which normally consists of one or more words, images, or other symbols. This unstructured information can be comprehended by the tool, quite sufficiently, using

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computational linguistics or other techniques. We exploited the findings from the research area of computational linguistics in order to overcome some obstacles regarding the meaning of a concept.

2.1. Analyzing a concept map

Topologically, a structure is determined by its nodes and propositions but usually not in a rigid and unique way. A structure is a versatile entity with vague borders. The borders of a structure are dependent on the level of analysis as well as on the different points of view that we take. However, on each level of analysis, well-structuredness has to be preserved. Well-structuredness [7] is a property dependent on internal qualities of the structure as well as on the broader context, i.e. on other structures that are connected with it. An analysis of well-structuredness can reveal problems like unbalanced development, structures that are not smoothly integrated with the rest of the map and other structural deficiencies or problems. All these characteristics can be expressed quite sufficiently using suitable mathematical methods as we present in the next sections. To a large extent, the characteristics of a structure are indicative of the competence of the learner. As research has shown [8], a novice learner usually creates star, chain, or tree type structures while an expert more frequently creates networks. Beyond these general types, a further analysis could provide useful information. Number of substructures, nodes and propositions, as well as density, diameter, cyclic patterns, etc., are some of the parameters carrying pedagogical value.

A structure or a concept is connected to another structure or a concept forming a proposition.

Semantically, a connection is characterized by the words that exist or are implied on the linking lines. Two broad categories of connections can be distinguished: standard linking, like "is a", "part of", etc., and arbitrary linking where the implied linking words could be any words. A computational creative tool has to distinguish between these two categories because each type of linking has certain implications on the level of creativity. Standard linking corresponds to zero novelty in the sense that these connections already exist. On the other hand, arbitrary linking, upon the condition of acceptance, reveals more or less novelty.

Topologically, a connection is characterized by the position of the two nodes. These nodes could be directly or indirectly connected (a concept map is a compact entity). In either case, we could attribute a semantic distance between the nodes based, for example, on an ontology. For an arbitrary type of linking, the distance is a measure of novelty. For a certain distance, the fewer the steps between the two nodes on the concept map, the bigger the surprise which is attributed to the connection.

Let's suppose that the learner connects, directly or indirectly, the concepts “lion” and “chrysanthemum”, which are far apart in a typical ontology. This is a novel connection. The distance is an index to measure the novelty. For example, in the poem “The Monkey Puzzle” the sentence “The lion's ferocious chrysanthemum head” contains a connection between a lion's head and a chrysanthemum. This is a successful connection and because of the long distance that separates the two words, it reveals creative thought. The presence of the two words in the same proposition corresponds to maximum surprise. The surprise would be less or zero, if the two words were considered connected in a broader section like e.g. a paragraph. Similarly, in a concept map, the surprise is less when between two concepts there are one or more words.

The design of the learning environment is based on the dimensions of topology and semantics as is described in the following section.

2.2. Designing the environment

During the development of a concept map, a learner has in front of her a concept and she tries to think of some other concepts relevant to it. It has been proven [9] that a creative individual is able to produce a flat sequence of concepts, while a less creative a more steep one. A flat sequence represents many concepts, which on average display less obvious and therefore weak relations with the given concept. It is also flat in the sense that the learner does not perceive the dominant concepts, within the list the list of relevant concepts, to have a high degree of relevance to the given concept or, in other words, does not exaggerate about the degree of relevance to that concept. On the contrary, steep means less concepts that display strong relationships. The less creative person is able to think and come up with concepts that are semantically close to the given concept, but in a very short period of time the process is stopped. A more creative person typically spends more time and thinks of more concepts, some of which, of course, are not as close to the given one.

One main idea that guides the design of a creative environment is to bring the required associative concepts as close as possible. In other words, to improve the coherence of the space, in order for the learner to have the opportunity to find an appropriate concept. This condition will increase the probability for a learner to reach a creative solution or simply to think in a creative way. It could be considered as a different type of scaffolding. There are various ways to improve the coherence of a space. Some of them like a) the serendipity and b) the modular development have been proved to lead to more creative environments than others.

Drawing on research results from the field of Associative theory [9], a very powerful way to

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achieve the above is to design an environment that promotes serendipity. Serendipity means a pleasant surprise. For example, unexpected appearances of a useful concept during the creation of a concept map. The goal is to design an environment where the learner will have the opportunity to think about something that is out of the mental path that is intentionally followed. The challenge for learners is to be in such a mental state that they recognize and exploit these opportunities. Literally, serendipity is accidental but in order for it to be effective as a learning process, an adjustable relevance to the current situation needs to exist.

A learner has to create a concept map that is novel and valuable. Valuable could mean many things but in the case of a structure, there are certain general qualities that can be mentioned: extendibility, adaptability and resilience are three main qualities that could be used to determine a structure as valuable. These desirable characteristics have as a requirement a specific way of development. When the structure is fairly large, the modular way of development is a necessity. A computational creative tool has to provide feedback guiding the learner to proceed in a modular way of development.

A modular structure brings the associative concepts as close as possible, which is according to the main idea that we posed previously. Of course, a structure like a concept map may have small distances between its nodes, but only if it is dense. Unnecessary density means redundancy and poor - non-creative - design. Otherwise, in order to have small distances between its nodes, it should be modular. In such a design, the nodes within every distinct structure of the concept map communicate well together, but the same is true between the nodes which belong to different structures since they communicate easily through the main nodes of each section. A design compatible in format with the features above consists of considerably fewer high degree nodes than other nodes. Similarly, in terms of links: there are fewer long distance links (structure-range links) but many local (node-range links) links. In terms of network theory, this is referred to as small world phenomenon.

Serendipity and modular development are complementary techniques in the sense that the first refers to the development phase before the selection of a concept and the distance between concepts as calculated out of the concept map, while the second to the phase after the selection of every concept and the relevant distances as calculated based on the concept map structure.

Creativity is not only a matter of intelligence combined with domain knowledge, but also a matter of personality. Time expenditure is necessary. The culture of fast thinking hinders the creativity of people. So, a second idea that guides the design of a creative environment is the addition of a reflection process. This is also supported by research findings from the field of psychology [10]. In the following section, we refer to this issue.

3. The computational creative tool: a use case scenario

This section discusses a typical use case scenario regarding the operations that the computational creative tool provides. In this scenario, the focus is on the services which are not provided within the scope of conventional concept mapping software.

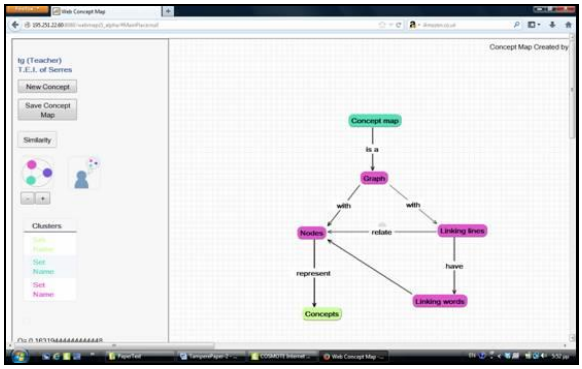

Figure 1. A concept map divided into modules

Some of these services are fully implemented and some others are currently implemented as separate components (not yet integrated with the rest of the software) as they are currently in an experimentation stage and being tested with real data.

3.1. An initial creation stage

The student initially logs into the system and selects either to create a new or to edit an existing concept map "see figure 1" just as she would do in a traditional environment. Both creating and editing a concept map constitute the construction stage and include actions related to concepts and linking phrases: addition, deletion, renaming, moving nodes and linking phrases.

Depending on the specific type of learning activity, the teacher could provide some initial concepts or, the learner could create the map without concepts or other restrictions. The more the restrictions, the less the potential for the learner to be creative. After the conventional creation stage, the learner could a) exploit fertile grounds for insight that the tool provides and b) improve the structure of the map in the next stage.

3.2. The reflection stage

At any point during the construction of the concept map the learner may reflect "see figure 2" on the concept map created thus far. The reflection activity is currently related to a) the judgment about

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the appropriateness of unexpected concepts that are provided by the tool as well as b) the identification of conceptually important substructures of the concept map and their naming.

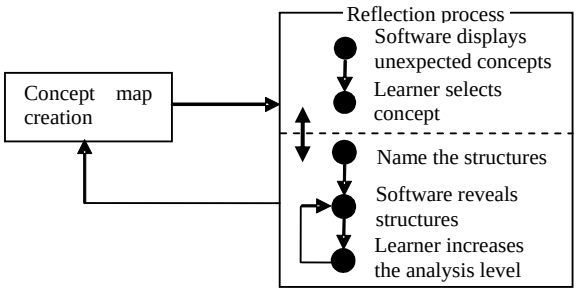

Figure 2. The reflection process

Let's display the first case using a classical insightful puzzle. The concept maps, which are produced by puzzles are very small. The very small size allows us to study only the concepts of the map as the structure is trivial and because of this is practically irrelevant.

Puzzle: A man, in the middle of a desert, sees another man who is dead. The dead man has a pack on his back and a big ring on his finger. There are no trails and no strange cues. What has happened?

The concept map of the puzzle is like the map in Figure 3.

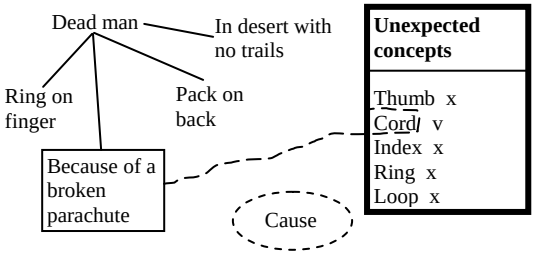

Figure 3. Unexpected concepts

The role of unexpected events as triggers for insightful thinking is well documented from historical quotes, research papers and many other sources.

The unexpected event was the presentation of the first five concepts: thumb, cord, index, ring, and loop. These were produced by the processing of big data, made available by the tool, when the word finger was given as the seed. Four of them proved not to be helpful, but the second one could trigger the learner's creative insight.

A characteristic and striking part of the image of a parachute is the suspension lines which is made by the parachute cord. The challenge for the learner is to have the required domain knowledge as well as to have such intellectual readiness in order to make the connection between parachute and paracord. The tool could produce new additional concepts, even the most indicative word parachute among many others, using the word 'pack' as the seed.

For every concept and every structure of a map, the learner could ask for unexpected concepts, in the sense of semi-random concepts, if she believes that they could trigger insight to complete the map creatively.

The second part of the reflection process is referring to the structures. However, the whole reflection process is not sequential but iterative. The learner could indicate the substructures of the concept map that she considers to be conceptually essential by using the buttons "new", "select" and "add to existing": when the learner wants to define a new conceptually important substructure of the concept map, she presses the button "new"; when the learner wants to declare that a concept belongs to a defined substructure, first she selects the substructure, then she clicks on the concept and then presses the button "add to selected". Apart from defining the structures of the concept map on a level of analysis that the learner believes to be the most appropriate, the tool can also divide the map into structures based on its own criteria. These are twofold criteria:

a. The tool guides the learner to create a well-structured concept map. The process is the following: After an initial completion of the map, the learner can ask the tool to reveal the structures that are formed upon the condition of modularity. In other words, the tool supposes that the map is developed by the learner according to the principle of modularity and reveals structures based on this supposition. The learner can compare the two groups of structures. If the two groups coincide or there are minor differences, then the map is a well-structured map. By pressing "see figure 1" the button "+" or "-", the learner can further increase or decrease the level of analysis. In this way, the tool provides views on multiple levels. Reflection is an iterative process. The learner can modify the map again and again based on the feedback from the tool or can maintain certain options when less modularity is imposed due to the nature of the problem.

b. Similarly as with the first case, the tool supports the learner to analyze the map into structures. The process is the same as in the previous case but now the criterion is determined by the semantics of the concepts and not by their topology. Therefore, an external entity is required so that the semantic distance between each pair of concepts in the map can be measured. The external entity is the ontology of WordNet [11]. The tool "supposes" that the map is developed according to the principle that concepts belong to same structure when they are semantically close and to different structures when the opposite exists. This is a valid supposition upon the condition that the focus is on the appropriate level of analysis. Again the learner could compare and reflect on this group of structures. However, the

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role of this operation is different: When there is a deviation between this and the previous group, it is a clear indication that the concept map contains a good portion of creative thinking. This is justified by the fact that the substructures in the second case are created based on the typical relationships that are found in the ontology, while in the first case express the thinking of the learner.

3.3. Evaluation phase

Regarding the creativity embodied within a particular concept map, the tool gives the learner information regarding the semantic distance between concepts as calculated based on the WordNet ontology. This information corresponds to estimation of the novelty as well as of the surprise that is embodied within the concept map. The evaluation applies to the level of propositions and reaches the level of the concept map at whole.

4. Methods

In this section, we present the main methods we used.

4.1. Distance between concepts

In order to estimate the semantic distance (similarity) between two concepts, we used WordNet.

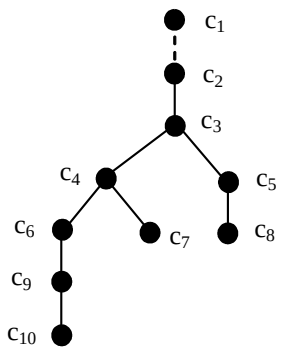

Figure 4. Ontology tree

The similarity index is calculated based on "see figure 4" as, for example:

$$sim(c_6, c_7) = \frac{2d_3}{2d_3 + d_1 + d_2}$$

d1 are the steps from c6 to common concept (c4), d2 are the steps from c7 to common concept (c4), and d3 are the steps from the common concept (c4) to the selected root (c2).

The logic of the index is the following: There is a selected root which corresponds to the domain of knowledge that the concept map belongs to. We begin with each of the two concepts and ascend the hierarchy until the first common concept is found. The further away from the common concept the two concepts are, the smaller the index is, while the further from the common concept the selected root is, the bigger the index is because the differences do not refer to general and broad concepts but to specific and narrow ones.

4.2. Revealing structures

Two connected concepts may belong to the same or to different structures. When belonging to the same structure, the linking line between them connects concept loads. Despite the fact that there may be more than one line between structures, when belonging to different structures the linking line connects structure loads. For this reason, determining where the load is maximized, is a very reliable way to find where the borders of structures are.

The algorithm we have implemented in our system is based on [7].

The Newman-Girvan algorithm is the following:

1. Find the shortest paths between all pairs of concepts
2. Calculate the number of shortest paths that pass through each edge.
3. Find the edge with the greatest number of paths and delete them from the network.
4. Repeat step 1.

Every time that an adequate number of edges are deleted from the map, a new structure is revealed.

This method gives the learner the opportunity to reflect on the concept map, to reveal poorly connected or strongly connected structures, to judge the balance of the overall map, to distinguish organic parts of the whole from others which are simply informational or complimentary elements, etc.

4.3. Presenting partially relevant concepts

The idea behind this method is that we can improve the creativity of the learner through the design of an environment where some relevant, in a broad sense, concepts pop up in order to puzzle and trigger the thinking of the learner. This situation is usually referred to as serendipity and is considered as the fertile soil that will help in cultivating creativity. The concepts, which pop up, have to have the potential to connect with the concept that the learner asked for, but not through trivial connections. As trivial, we define connections found in a typical ontology, i.e. connections not produced by the imagination of the creator but connections which exist in an obvious manner in the real world.

Despite the fact that this design reminds us of the type of concept mapping learning activity, where the teacher simply provides some additional concepts in order to puzzle the learner, this is a radically different activity: In this case, the learner is placed in a vast space, the existence of which is the main characteristic of every creative problem. Limited

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predefined search space and creativity are incompatible.

The software can propose relevant concepts through the exploitation of a huge corpus. Big data are necessary so as for non-standard relationships between concepts to emerge. Drawn from research in the computational linguistics field, we have designed a method based on the frequency that two words appear in the same sentence. The method is the following:

1. Get the word that is given by the learner
2. Find the words which exist most of the time together with the word which is given by the learner
3. For each word of step 2, create an index dividing the frequency with the degree (times that the word is generally displayed) of that word. The division derives from the fact that frequent words do not express creativity
4. Sort the words according to the index
5. Present a subset of these words to the learner.

5. A preliminary evaluation

We conducted a preliminary evaluation of the tool in the form of a case study involving a small group of learners. The aim of the preliminary evaluation was to establish the operational state and the usability of the system as well as to validate the reflection process. A short presentation of the concept map and the software was given to the learners. Then the learners were asked to develop a concept map and they were encouraged to think aloud. A member of the research team was present when the users were developing their concept map using the tool and took notes of their conversations.

6. Discussion and future improvements

The traditional activity of concept mapping is a very simple process. The learner writes concepts and connect them. Similarly, the role of technology is limited to editing and displaying.

An enhanced way of developing a concept map, from a pedagogical as well as from a technological point of view, is the proposed framework. The additional activities guide the learner to rethink the concept map structurally as well as conceptually and also to self-evaluate her current effort in order to improve it. Increased time expenditure is intentionally inserted because it is a constituent element of creativity. The increased time is needed for the learner to search the big space that characterizes nearly every problem which requires creative thinking.

Searching is supported by a semi-random presentation of concepts, which have a linking potential with the current concepts of the map. Here, the core issue is the ability of the learner to judge, to select, to drive the search, etc.

Topologically, the proposed framework introduces the level of structure. Essentially, concept and structure are equivalents but now, the learner has more space to elaborate on her thinking and hence to increase her analytical and synthetic abilities.

From a technological point of view, the framework introduces various methods. Some of them are based mainly on an ontology and others on big data. In this context, many issues arisen such as the following:

What ontology has to be used? WordNet is a typical choice, but it is not an ontology created for this purpose. Trying to specify the distance between two words, what is a truly appropriate way to handle the density, the hierarchy depth of the ontology, or similar issues?

Every learner has his own individual needs. The applied method take into account the frequency of the words that are displayed in the same sentence. The criterion of sentence is an obvious choice, but the direct sequence of the words or the scope of a paragraph could also be used as a criterion in order for the results to improve the learning potential. In any case, a model that could represent basic features of the learner and appropriately handle them with relation to flexible search methods in a vast big data corpus have to be developed.

7. Conclusions

Through this research work we have stated that concept mapping learning activities could essentially be enhanced in order for advanced outcomes like creativity to be addressed. The required technologies are not as immature as one would expect. The next step is to combine findings from somewhat different and distant fields like artificial intelligence, computational linguistics, ontologies, big data, etc.

At the same time, we observed a severe lack in pedagogical theories regarding creativity. For example, we needed to explore the field of psychology in order to validate our initial intuition regarding the value of the reflection process in creative thinking. This lack is quite plausible because at present, creativity is not a sufficiently clear concept based on which a new learning theory could be developed. But, the main reason is that education does not focus on creativity.

The path we need to follow is to focus on the concept of creativity and the combination of various technologies as well as the invention of relevant theories and tools.

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9. References

[1] Minsky, M., *Society of mind*. Simon and Schuster, 1988.

[2] Robinson, K., "Ken Robinson says schools kill creativity." *Talk.[Online]. TED-Talks. Retrieved on Apr* 21 (2006): 2011.

[3] Villalba, E., "On creativity: Towards an understanding of creativity and its measurements." *JRC Scientific and Technical Reports* 23561 (2008).

[4] Maher, M. L., and Fisher, D.H., "Using AI to evaluate creative designs." *2nd International Conference on Design Creativity, Glasgow, UK*. 2012.

[5] Baldi, P., "A computational theory of surprise." *Information, Coding and Mathematics*. Springer US, 2002. 1-25.

[6] Newell, A., Shaw, J.C., and Simon, H.A., *The processes of creative thinking*. Santa Monica, CA: Rand Corporation, 1959.

[7] Newman, M., *Networks: an introduction*. Oxford University Press, 2010.

[8] McPhan, G., "A developmental framework for assessing concept maps." *Proceedings of the 3rd International Conference on Concept Mapping*. Vol. 2. 2008.

[9] Mednick, Sarnoff. "The associative basis of the creative process." *Psychological review* 69.3 (1962): 220.

[10] Verhaeghen, P., Joorman, J., and Khan, R., "Why we sing the blues: the relation between self-reflective rumination, mood, and creativity." *Emotion* 5.2 (2005): 226.

[11] Miller, G., "WordNet: a lexical database for English." *Communications of the ACM* 38.11 (1995): 39-41.

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