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NON-LINEAR FORMS OF KNOWLEDGE REPRESENTATION IN TEACHING AND THEIR EVALUATION ACCORDING TO MOODY'S PRINCIPLES OF GRAPHICAL DIMENSIONS

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ABSTRACT

At present, there are many methods how to evaluate the structure quality of concept maps; however, there is no tool which would evaluate the cognitive effectiveness of graphic notations in concept maps. One of the possibilities how to evaluate concept maps is to use the principles of graphic notation design. These principles, which were developed by Daniel Moody, are based on experience from various fields of study, such as cognitive psychology, human-computer interaction, semiotics, communication etc. This article presents the use of Moody's principles for the evaluation of the effectiveness of graphic notation in concept maps.

KEYWORDS

concept map, visual notation, cognitive effectiveness, visual representation, principles of graphic notation.

1 CONCEPT MAPPING AS A REPRESENTATION OF NON-LINEAR FORMS OF KNOWLEDGE INTERPRETATION

Concept maps are graphical structures which are becoming more and more popular in teaching. They are used for the improvement of remembering and understanding of new education content, as well as for revision or evaluation in teaching.

Concept mapping is based on the fundamentals of cognitive psychology. One of the key ideas is the Assimilation Theory by D. Ausubel (1963), who based his theory on the structuring and organisation of individual's mental field. Concept maps are well-known thanks to J. D. Novak and D. B. Gowin (Novak, Gowin, 1984), who dealt with the structuring of education content in the 1980s.

According to Novak (Novak, 2010), a concept map can be defined as a hierarchical structure of concepts and relations between them. Each concept is in relation to one or several concepts, where individual concepts can interconnect in various hierarchies. Such a connection is called vertical, or a vertical relation. In concept maps, there are also concepts in the same hierarchy and they form horizontal relations. Therefore, concept maps are generally called hierarchical. There are also other types of concept maps, such as spider maps, chronological maps, or cyclic maps. Nonetheless, more details about these maps and their structure are beyond the scope of this article.

Concept mapping is based on the underlying assumption that students learn new concepts by searching for relations to concepts already learnt which are tightly integrated in the concept net in their brains. It is necessary for students to be able to evaluate the importance of a new concept in their minds, and then to possibly rebuild their net based on new knowledge (Keprtová, 2011).

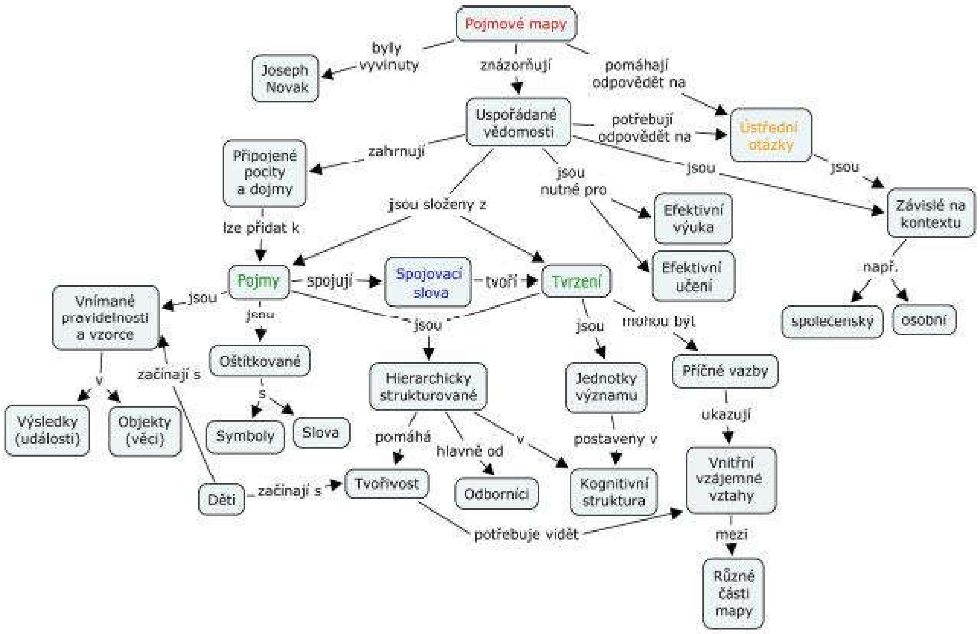

Figure 2 Hierarchical concept map (source: Keprtová, 2011)

Concept maps are a constructive tool for expressing individual thought processes, a tool for collective dealing with problems and primarily for the structuring of knowledge and concepts, which is then elaborated further.

The main advantages of concept mapping are definitely a hierarchical structuring of concepts and visualisation. Supposing that a student cannot remember education content linearly but structurally, concept mapping, as a non-linear tool for knowledge representation, is ideal. Some authors say (Vaňková, 2014) that a creation of a concept map is a creative activity and it significantly enhances thinking about a given problem. It is also important to mention that concept mapping creates connections between new pieces of knowledge and it also develops abstract learning.

Nevertheless, this kind of representation is not always an advantage. The main precondition for the effective use of concept maps is a student who prefers a visual type of learning and has creative abilities. There are also other limiting factors, such as a bad applicability of concept maps for very gifted students, for young learners, or student and teacher's inexperience with concept mapping. Lastly, it is necessary to realise that this method does not answer the basic questions such as: Why? Where? How? Under what conditions?

Concept mapping or concept maps actively increase the amount of understood and remembered knowledge. It is reported that the increase in remembered knowledge is in tens of percent, also in students who are considered as weak or mediocre (Janík, 2005). There is a provable relation between the brain, where new information is stored, and the method for increasing the capacity of remembered knowledge, i. e. concept mapping. Remembering and storage of new knowledge is managed by a cell in the brain - a neuron. A neuron consists of a cell body and a number of axons, which have the ability to create physical connections with other axons from different neurons. To put it simply, these physical connections create the basis for remembering knowledge and information in the human brain. All information is thus stored in the form of neural connections, which form a neural network. The human brain has difficulties to remember information presented in a usual way, i. e. in the form of definitions, propositions, a sequence of words, or a linear text. In the human brain, there is a more effective way to store information - through concepts and relations between them (Janík, 2005). This will only work if mutual semantic connections between the concepts are respected. Student's brain thus has to transform the sequence of words (a linear text) into a hierarchical structure *concept* $\rightarrow$ *relation* $\rightarrow$ *concept*, i.e. a proposition of a text[1]. These propositions form a deepened propositional net through associations with already existing propositions (Eysenck, Keane, 2008). Given that students form this hierarchical structure by themselves, often without knowing individual relations between concepts or other concepts related to the given education content, remembering of knowledge is ineffective and created mental schemata can be wrong. A question is whether this process can be enhanced. It is possible to think that this structure should resemble neural networks in the human brain. Therefore, the concept map should respect and support the ability of the brain to store and understand concepts and relations between them (Janík, 2005).

2 AIM OF THE RESEARCH

The main aim of the research is to find out how to write education content into a concept map so that the graphic notation is in accordance with cognitive mental processes which take place in students' brains during learning.

For this purpose, Moody's evaluation principles of physical notation of visual programming were used and adapted for the evaluation of the cognitive effectiveness of graphic notation in concept maps.

3 MOODY'S PRINCIPLES – A POSSIBLE WAY HOW TO DEFINE PRINCIPLES FOR CONCEPT MAPPING?

One way how to evaluate concept maps is an analysis of their physical dimensions. Physical dimensions, developed by Daniel Moody, are commonly used for the evaluation of graphic notation of visual programming.

How can we create better concept maps from the graphic notation point of view? A possible solution can be to determine rules (criteria) for a physical notation of concept maps, which would respect the hierarchical structure, relations between concepts and other factors for the creation of concept maps. Opponents of this solution could argue that the uniformity and bounds (of rules) hinder creativity of an individual. However, it is important to realise that we are not dealing with the development of creativity, but we want to increase the effectiveness of a method, which should help students remember concepts and understand relations between them better.

In 2009, Moody came up with a new approach to the evaluation of the cognitive effectiveness of graphic notations in a theory called the Physics of Notations (Moody, 2009). The model of human perception and processing of graphical information is divided into two parts: perceptual processing (vision, perception) and cognitive processing (comprehension). Perceptual processes are automatic, very quick, and parallel in many cases, whereas cognitive processes occur during a conscious control of attention and are relatively slow, taxing and occur in parts.

[1]Proposition is a representation of knowledge in the long-term memory, which does not have a linguistic form of a sentence, but which represents a relation, connection between concepts (Hartl, Hartlová, 2000).

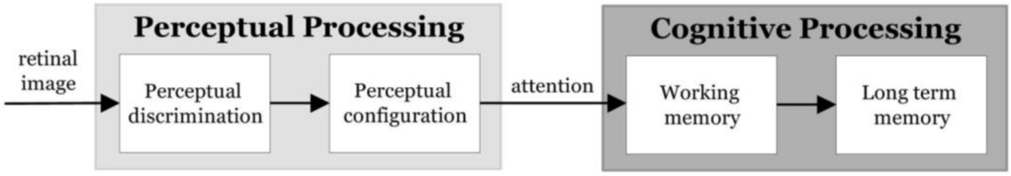

Figure 2 Maximizing cognitive effectiveness means optimizing notations for processing by the human mind (source: Moody, 2009).

This theory consists of a system of principles, which have to be followed in order to create a cognitively effective notation, see Table 1. These physical dimensions are commonly used for the evaluation of graphic notation of visual programming. The principles (nine at present) are organised in such a way that the central Principle of Semiotic Clarity is the fundamental and initial principle for further evaluation according to neighbouring principles (Figure 3). They are listed in the diagram in form of a 'honeycomb' consisting of nine hexagons. This structure was designed for an easy removal or addition of principles with regard to modifiability and expansion of principles in the future.

Table 1 The Physics of Notations theory: Principles for the design of cognitively effective visual notations (Moody, 2009).

	Název v angličtině	**Název v češtině**
1	Principle of Semiotic Clarity	Princip sémiotické čištoty
2	Principle of Perceptual Discriminability	Princip fyzické rozlišitelnosti
3	Principle of Semantic Transparency	Princip sémantické jednoznačnosti
4	Principle of Complexity Management	Princip řízení složitosti
5	Principle of Cognitive Integration	Princip kognitivní integrace
6	Principle of Visual Expressiveness	Princip visuální expressivity
7	Principle of Dual Coding	Princip duálního kódování
8	Principle of Graphic Economy	Princip ekonomie grafiky
9	Principle of Cognitive Fit	Princip kognitivní vhodnosti

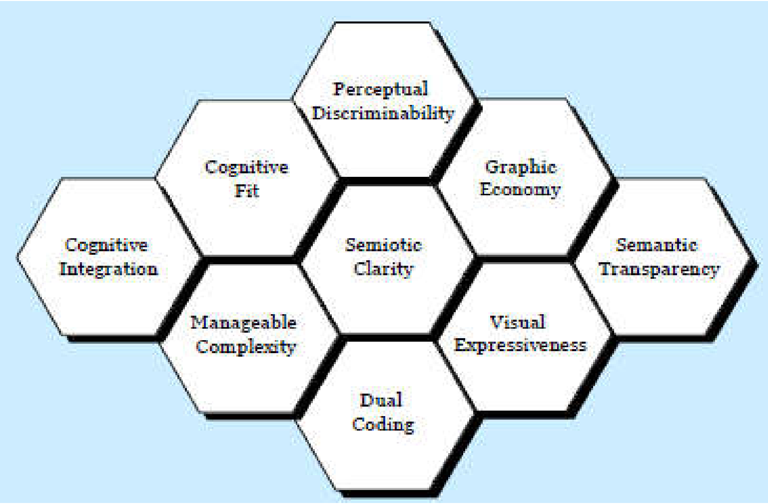

Figure 3 Principles of evaluation of graphic notations according to Moody (Moody, 2009)

4 EVALUATION OF CONCEPT MAPS USING MOODY'S PRINCIPLES

A concept map, which is dependent on so-called components, is evaluated by an evaluation mechanism. At present, two basic tools are used: structural and relational. The structural method, which emerged in the 1970s and whose author is J. D. Novak, is based on the examination of the organisation of a concept map and focuses on individual parts of the map structure. A usual structural evaluation measures the number of concepts, relations, hierarchical levels, examples and crossed relations. Authors state that this method is popular thanks to its mathematical popularity and objectivity. However, it is important to mention that it does not deal with the quality of a component as such. The evaluation of concept maps (and not only them), i. e. the use of evaluation principles according to Moody, seems to be promising. The following analysis will clarify a possible application of Moody's principles for the evaluation of graphic notation in the field of concept mapping.

Principle of Semiotic Clarity

The requirements of character systems force available language expressions to maximise their accuracy and expressiveness, which are required aims of notation designs in software engineering. The Principle of Semiotic Clarity evaluates the correspondence between a semantic element and graphic symbol of syntax at the ratio of one to one. If there is no correspondence between elements, one of the four following errors may occur in the graphic notation:

- Redundancy symbol – occurs when one element can be expressed by several graphic symbols of syntax.
- Overload symbol – occurs when several elements can be expressed by one graphic symbol of syntax.
- Excess symbol – occurs when there is no element for a graphic symbol.
- Deficit symbol – occurs when an element is not represented by any graphic symbol.

Application of this principle is better visible in concept maps in Figure 4 and Figure 5, where we can see 'overload' and 'redundancy' error.

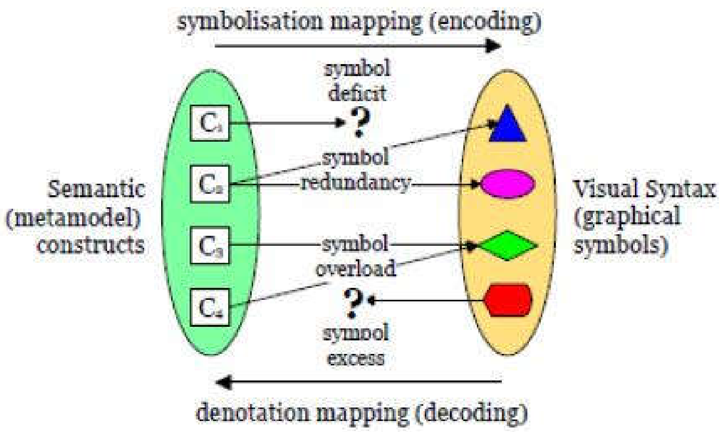

Figure 4 Principle of Semiotic Clarity (Moody, 2009)

Figure 5 ‘Overload’ and ‘redundancy’ error in a concept map (source: http://1url.cz/9tNkK, modified by authors)

Principle of Perceptual Discriminability

Physical (perceptual) discriminability expresses ease and precision with which individual graphic symbols can be distinguished. This principle is related to the first phase of human perception and graphic information processing. The difference between symbols is primarily determined by a visual distance. This is measured using a number of visual variables which distinguish the symbols and also the difference between them. The bigger the visual distance between symbols, the faster and more accurate their recognition. Among the visual variables, a shape plays an interesting role in the discrimination of symbols. We also distinguish objects according to a shape in real life. The shape should be used as a primary visual variable for distinguishing between various semantic elements. Several visual variables can be used for the extension of the visual distance between symbols. For instance, a colour (apart from shape) is used to accentuate differences in ER diagrams. This method is called redundant coding. In some graphic notations, a text is used for the differentiation between symbols. They use various typographic characteristics (bold, italics, underline) to distinguish various kinds of elements (e.g. relations). This method is common but ineffective, in terms of an excessive complexity of a notation or diagrams.

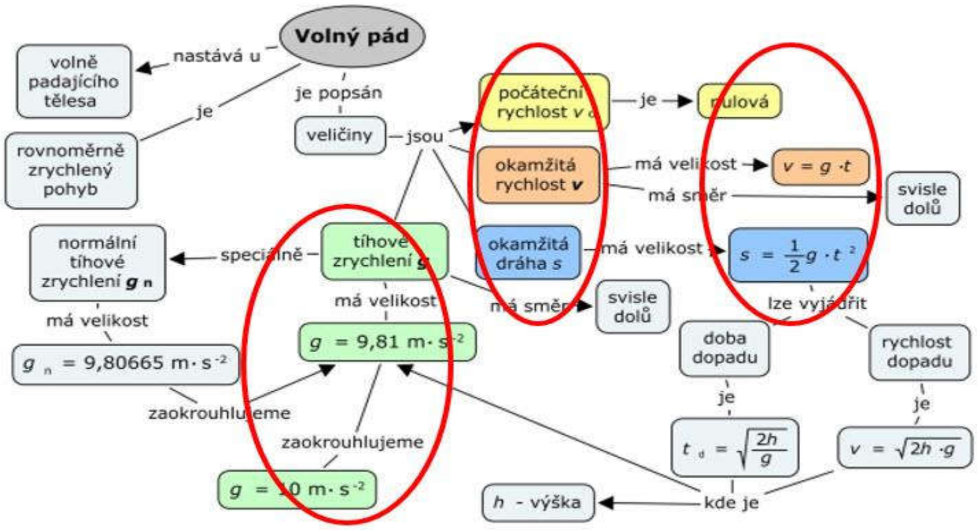

Figure 6 Error of perceptual discriminability. (source: Keprtová, 2011, modified by authors)

Principle of Semantic Transparency

While perceptual discriminability distinguishes only individual symbols, this principle evaluates whether the symbol provides evidence and signs for the derivation of its meaning. The semantic derivation is defined as an extent to which the meaning of a graphic symbol can be derived from its appearance. This principle does not only apply to graphic symbols of individual semantic elements but also to bonds and relations which exist between them.

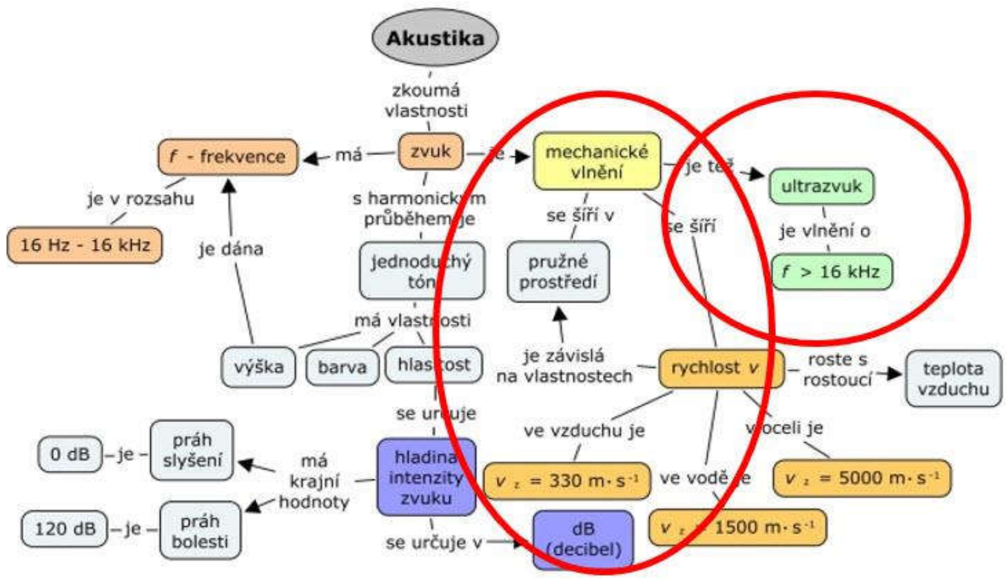

Figure 7 Errors of semantic transparency (source: Keprtová, 2011, modified by authors)

The illustration above aptly demonstrates incomprehension of this principle. Probably in good faith to point out all possible relations between them, concepts are closed cyclically and students cannot guess even intuitively where the beginning and end of a relation between concepts are. The connecting lines between relations sometimes end in an arrow and sometimes not, which can mislead the student.

Semantic transparency can be enhanced using an appropriate alignment of the diagram. However, the spatial arrangement of the diagram depends solely on its author and is very subjective (Šimoník, 2014). The author can indicate the logical hierarchical structure of the map to the student by using an appropriate alignment. The illustration above implies certain hierarchy; nonetheless, we can ask a question how it will be perceived by students with worse spatial and visual imagination.

Principle of Complexity Management

Complexity is one of the problems which is difficult to resolve when designing graphic notations. This principle deals with the complexity of a diagram and it is given by a number of elements in the diagram. Complexity influences effectiveness in an important way because the amount of information which can be presented effectively using one diagram is limited by people's perceptual and cognitive abilities. Effective management of a diagram is particularly important for people inexperienced in software engineering, who do not have sufficient knowledge for the comprehension of diagram complexity. Excessive complexity is one of the main obstacles which end users have to overcome to comprehend diagrams (Šimoník, 2014).

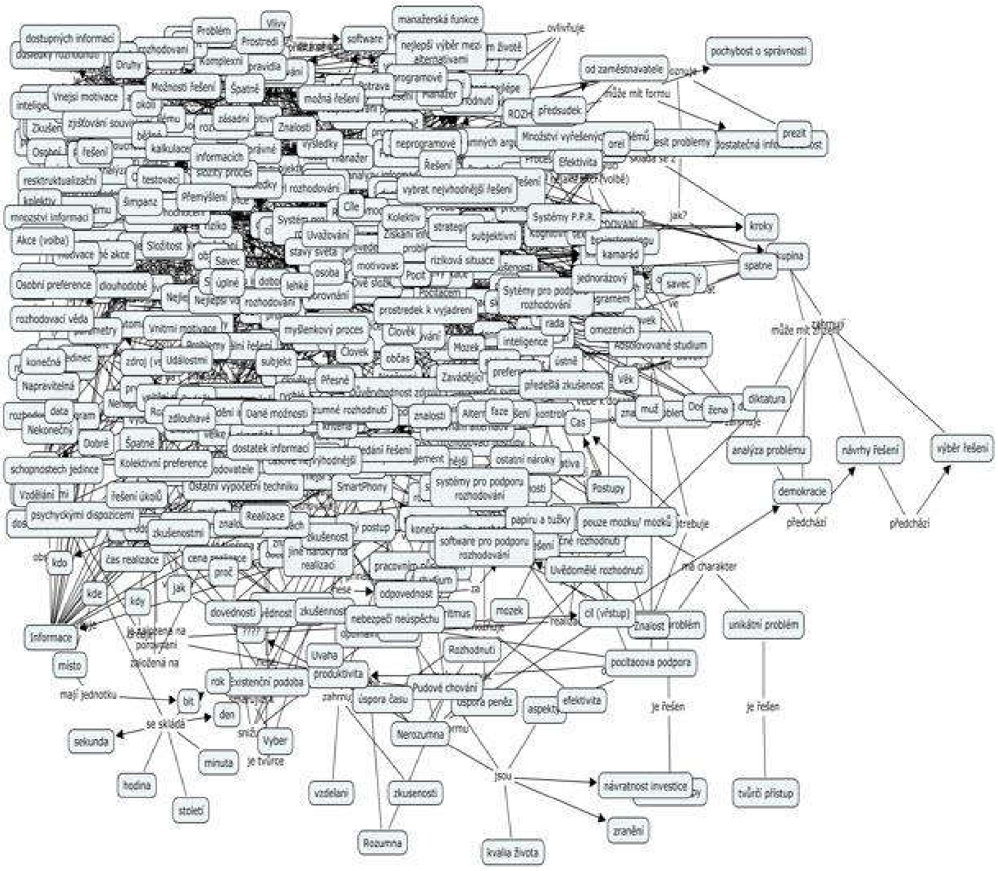

Figure 8 Error of complexity – a real concept map (source: http://1url.cz/9tNkK)

Principle of Cognitive Integration

This principle is used when several diagrams represent a system of diagrams. A representation using a system of diagrams is more frequent in software engineering than a representation using one diagram. We distinguish two types of diagram integration: homogenous (diagrams of the same type) and heterogeneous (diagrams of different types). The principle evaluates the involvement of explicit mechanisms which support and help integrate a diagram into a system of several diagrams. We believe that this principle is irrelevant when dealing with the problem of concept mapping.

Principle of Visual Expressiveness

Visual expressiveness is defined as a number of visual variables which are used in graphic notation. While visual distances, a part of perceptual discriminability, evaluate differences between two symbols, visual expressiveness evaluates differences among all symbols of graphic notation. Visual expressiveness distinguishes two groups of visual variables: variables carrying information and free variables (not containing information). The majority of graphic notations in software engineering are one-dimensional notations, which use only one visual variable to communicate information. This variable is most often a shape, which is one of the weakest visual variables in this respect and can be only used for nominal data.

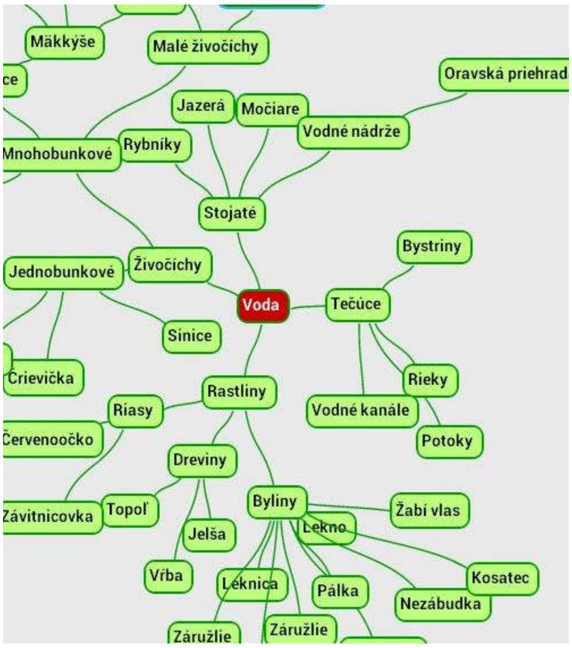

Figure 9 Error of visual expressiveness (source: http://1url.cz/ntNku)

This concept map contains one visual variable (one-dimensional graphic notation). Other visual variables were not used (shape, size). When noticing two symbols differing in size, the human mind perceives a difference between them, which then represents a difference in their importance or hierarchical position (Šimoník, 2014).

Principle of Dual Coding

The combination of a text and graphics is more effective in conveying information than when they are used separately. If the information is interpreted verbally as well as visually, these pieces of information are processed separately by the human mind, which enhances the connection between them. It is this principle that supports and evaluates dual coding, which recommends combining graphic symbols with text. Symbols which consist of a graphical and textual part are called hybrid symbols. Dual coding does not influence discriminability, and the addition of a text does not influence a visual distance either (Šimoník, 2014).

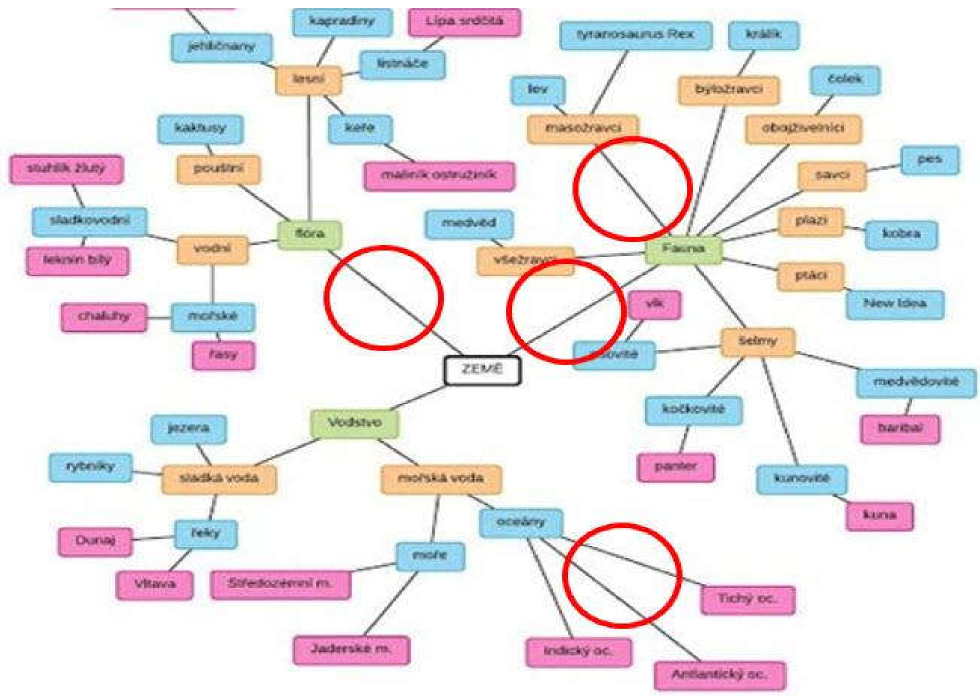

Figure 3 Error of dual coding (source: authors)

This map contains a number of above-mentioned errors. From the dual coding point of view, it is necessary to point out that graphic symbols contain textual information. In this case, the error of dual coding is considered to be the absence of a description of relations between concepts on individual connecting lines.

Principle of Graphic Economy

This principle states that the number of various graphic symbols should be cognitively 'manageable'. It determines the number of symbols in graphic notation, i.e. the size of its visual vocabulary. The more symbols a notation uses, the more complex the resulting diagrams, and they then influence users in their interpretation, especially those with less experience in the field. A human mind is able to distinguish around six perceptually different categories (Miller, 1956). This sets the upper limit for graphic complexity. Nonetheless, many graphic notations exceed the upper limit for graphic complexity. For instance, graphic notation of UML diagrams contains up to 40 different graphic symbols and is therefore very complex. On the other hand, two most frequently used graphic notations (DFD and ERD) respect this limit, and it is probably one of the reasons why these two graphic notations are used so often (Moody, 2009). We believe that this principle is not usually used in concept mapping. In most cases, one or two symbols (different categories) are used.

Principle of Cognitive Fit

The theory of cognitive fit is widely accepted in the field of information systems and has been tested in a wide range of tasks - from decision-making processes to software maintenance. This theory determines whether the method in which information is presented fits given tasks and a given group of users. The ability to solve problems, in this case finding and interpretation of information, is dependent on the way in which the information is represented, the nature and difficulty of tasks and user's skills for solving this problem. Moody recommends using more visual dialects, where each of them is suitable for different types of tasks and different users according to a current situation (Moody, 2009).

It is also necessary to mention negative features of concept mapping:

- They use declarative knowledge.
- Maps cannot be used universally.

- Maps are not beneficial for those who lack previous knowledge, those who prefer a visual type of learning, who are text-oriented, or without creative thinking.
- Maps do not support declension and conjugation when using the Czech language (Vaňková, 2014).

5 CONCLUSION

As for graphic notation, nowadays the majority of authors create their concept maps rather intuitively, without set rules or suitable methodology. In publications, there are many methodologies for the evaluation of the structure quality of concept maps; nonetheless, there is no tool which would evaluate the cognitive effectiveness of their graphic notation. Principles of graphic notation developed by Daniel Moody are commonly used for the evaluation of graphic notation of visual programming. On the basis of Moody's physical dimensions, authors demonstrated how to use these principles for the evaluation of cognitive effectiveness in concept maps.

We suppose that a methodology for the creation of effective concept maps from the point of view of cognitive effectiveness will be made on the basis of Moody's principles.

The article will attempt to show some basic aspects of graphic notation:

- The association method is beneficial in learning, but only under certain conditions.
- In large measure, concept maps are often created intuitively, without clear rules.
- According to authors, Moody's theory of graphic notation is an ideal theory for the creation of a specific methodology for creating concept maps.
- Authors and their assumptions and hypotheses will be tested in practice.

The authors tried to show that it is possible to use partially modified Moody's theory for concept mapping.

The connection of Moody's theory and concept mapping is undoubtedly a new approach in this area.

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