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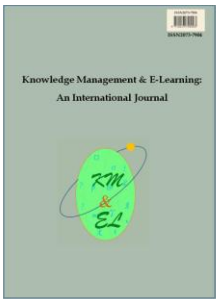

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Justifying the usage of concept mapping as a tool for the formative assessment of the structural knowledge of engineering students

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Abstract: Even though there is a lot of research both on formative assessment and structural knowledge, the formative assessment of structural knowledge is an absent element in the study process. One tool which could be used successfully by teachers for the mentioned purpose is concept mapping. However, its application for formative assessment is rarely based on a well-planned approach. This paper presents results indicating that concept mapping is a suitable tool for the formative assessment of structural knowledge. It is the first step of the development of an approach for the use of concept mapping in the formative assessment of structural knowledge. This paper is based on a) extensive analysis of available information sources on formative assessment and concept mapping and b) reflection of the author's personal experience of implementation of formative assessment activities using concept mapping. The goal of the paper is not only to justify usage of concept mapping as a tool for the formative assessment of structural knowledge, but also to encourage teachers to use concept mapping in their practice for formative assessment purposes. This paper briefly describes elements of concept maps, defines the concept of structural knowledge and discusses the process of formative assessment. Suitability of concept mapping for the formative assessment of structural knowledge is considered in the light of three questions: Do concept maps allow seeing clearly differences between experts' and novices' structural knowledge? Does concept mapping support the main aspects of formative assessment? Is it possible to minimise the cost of formative assessment based on concept mapping?

Keywords: Concept mapping; Formative assessment; Structural knowledge

Biographical notes: Alla Anohina-Naumeca is an associate professor at Riga Technical University, Latvia, and simultaneously a PhD student of the study programme 'Pedagogy' at the University of Latvia, Latvia. She received a Dr.sc.ing. from Riga Technical University in 2007. At the moment she is developing her PhD thesis on the concept map-based formative assessment of the structural knowledge of students of engineering study programmes. Her research interests include assessment practice, instructional methods, intelligent tutoring systems, and computer-assisted assessment systems. She has participated in more than 20 research projects related to the development of educational software and improvement of curricula. More details can be found at http://stpk.cs.rtu.lv/dalibnieks/alleila.

1. Introduction

Nowadays there exists an urgent demand for engineers all around the world, but educational institutions are not able to satisfy it fully (Department of Labour, 2008; Design Engineering staff, 2011; Dupre, 2014; Harrison, 2012). In such circumstances it is important that students who have graduated from higher educational institutions are capable of adapting quickly in a working environment and to begin professional activity in an efficient manner. This could be done by implementing an integrated set of problem-based and project-based learning activities, aligning curricula with industry demands, supporting students' mobility, etc. One such activity is to equip students with well-developed structural knowledge at least partly matching (as far as it is possible in the study process) experts' structural knowledge. This requires applying in the study process tools for assessment and further development of students' structural knowledge on a regular basis. A form of assessment which is aimed at the development and further improvement of learning and its aspects is formative assessment. Despite the volume of research on formative assessment, many authors lament the fact that formative assessment is seldom put into practice or not applied at all. For example, Moss and Brookhart (2009) claim that high-quality formative assessment is rarely an integral part of class culture, but Irons (2008) and Boud (2000) pay attention to the dominating position of summative assessment. A similar situation is found in relation to the assessment of structural knowledge. There is a paucity of publications on the practice of this type of assessment in higher educational institutions. Thus, we conclude that the formative assessment of structural knowledge is generally an absent element in the study process. However, this type of assessment is very important for engineering students because engineers are specialists who develop complex technical systems having great impact on people's lives and, therefore, to make these systems reliable and safe, students/engineers should possess well-developed structural knowledge and understanding of main laws and patterns of the knowledge domain. One tool which could be used successfully by teachers for the assessment of structural knowledge is concept mapping, particularly suited to engineering programmes, as these students typically have experience working with different graphical tools and diagrammatic representations. Therefore, it will be relatively easy for teachers to introduce concept mapping in the study process.

This paper presents findings indicating that concept mapping is a suitable tool for the formative assessment of structural knowledge. It is the first step of the development of an approach for the use of concept mapping in the formative assessment of structural knowledge. This paper is based on a) analysis of available information sources on formative assessment and concept mapping and b) reflection of the author's personal experience of implementation of formative assessment activities using concept mapping. The author of this paper is a member of the research group of Riga Technical University (Latvia), which has been developing a concept map-based Intelligent Knowledge Assessment System (IKAS) since the year 2005 (Anohina-Naumeca, Grundspenkis, & Strautmane, 2011). Therefore, the personal experience includes not only the development of the system itself, but also its use for the formative assessment of students' structural knowledge in different engineering study courses over the past 10 years. The author has also used paper-based concept maps actively in her instructional practice.

This paper is structured as follows. Section 2 considers the concept of structural knowledge. Section 3 defines formative assessment. A short description of concept mapping is given in Section 4, paying particular attention to modifications we have introduced into concept maps as a result of our own experiences. Section 5 describes related work on the usage of concept mapping for purposes of formative assessment.

Section 6 presents the main results of the research justifying the suitability of concept mapping for the formative assessment of structural knowledge. Conclusions and the direction of future work are given at the end of the paper.

2. Structural knowledge

The concept of structural knowledge (or knowledge structure) is not defined in a unified way. Actually, there exist two different viewpoints. On one side, structural knowledge is regarded as a separate knowledge type (Day, Arthur, & Gettman, 2001; Jonassen, Beissner, & Yacci, 1993; Kinchin & Cabot, 2010; Meyer, 2008). In this case it is defined as an intermediate knowledge type between declarative (knowledge about facts) and procedural (knowledge about how to do something) knowledge and it allows for the transformation of declarative knowledge into procedural knowledge and facilitates application of procedural knowledge. As a result, this type of knowledge is defined as 'knowing why' (Jonassen, Beissner, & Yacci, 1993; Jonassen, 2000). On another side, structural knowledge is considered to be a feature of other knowledge types. In this case it is defined as a combination of knowledge type and its quality (De Jong & Ferguson-Hessler, 1996; Shavelson, Ruiz-Primo, & Wiley, 2005).

However, we agree with Jonassen, Beissner, and Yacci (1993) that all definitions only point out semantic distinction, which does not affect recognition of structural knowledge as an entity. Therefore, in our research we define structural knowledge as awareness of organisation of declarative knowledge in human semantic memory or, more specifically, understanding of relations between concepts within some knowledge domain. Well-developed structural knowledge is very important because it allows for fluency in cognitive activity (Clariana, 2009) and high-level expert performance in the problem-solving process (Davis, Curtis, & Tschetter, 2003). Therefore, according to Davis, Curtis, and Tschetter (2003), 'evaluating structural knowledge may be equally if not more important than evaluating declarative knowledge when conducting an assessment of learning outcomes'. Clariana (2009) points out that 'it seems important to assess students' structural knowledge as a part of and complement to regular classroom assessment and evaluation'.

It is necessary to note that there have been developed a number of models of expertise and have been defined characteristics significant to expertise but all of them include a component related to domain-specific knowledge, saying that this knowledge is organised differently in comparison with less experienced professionals (Feltovich, Prietula, & Ericsson, 2006; Mayer, 2003; Yielder, 2009). Usually these differences are manifested as a greater number of relations between knowledge elements, more relevant knowledge, inclusion of knowledge application aspects, etc.

3. Formative assessment

Formative assessment or assessment for learning is not a new phenomenon and there exist a lot of definitions of this concept. However, on the basis of summarisation of available explanations and definitions given by Bell and Cowie (2002), Black and Wiliam (1998, 2009), Chappuis (2009), Cizek (2010), Greenstein (2010), Irons (2008), Keeley (2008), McMillan (2010), Moss and Brookhart (2009), Ruiz-Primo, Furtak, Ayala, Yin, and Shavelson (2010), and Shavelson (2006), formative assessment in this paper is defined as a process which can be described by the following attributes:

- Purposes: a) to increase students' achievement levels, b) to improve students' learning, and c) to increase the quality of the teacher's work;
- Time span: during the ongoing study process;
- Participants: student, student group, teacher;
- Implementation forms: any (observations, questions, discussions, projects, homework, etc.);
- Integral parts: feedback both to the teacher and to students; precisely defined study goals, learning outcomes, and assessment criteria; adjustment of the study process through the teacher's and students' actions according to feedback;
- Essential characteristics: systematic and grade-free.

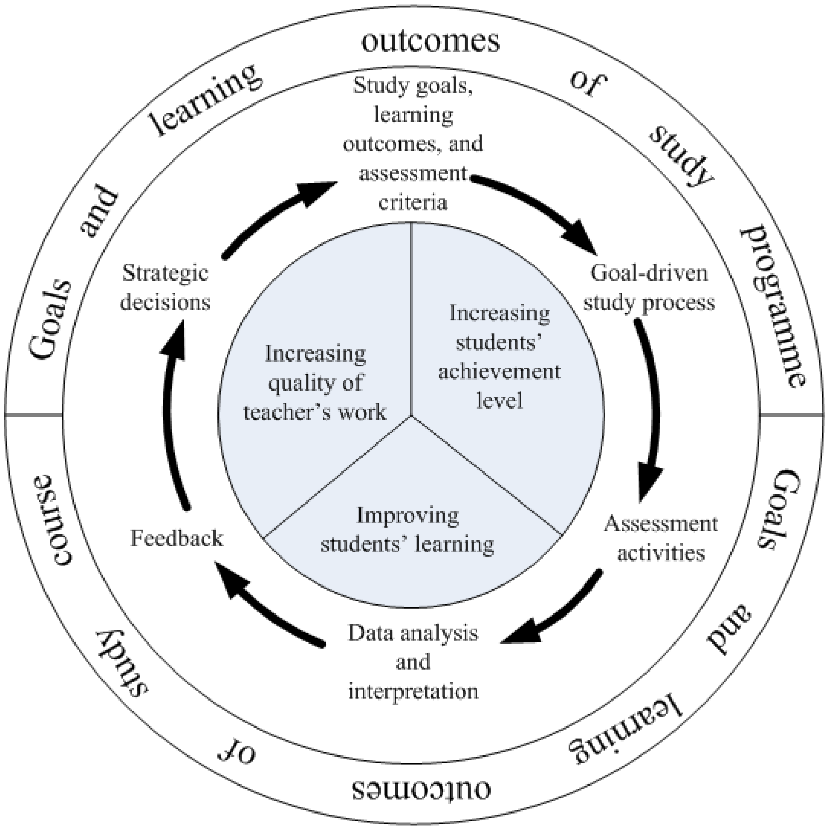

Fig. 1. The process of formative assessment

Fig. 1 displays a summarised view of the formative assessment process. Taking into account the three main purposes mentioned above, formative assessment is implemented as a cyclic process which includes the following main activities: a) defining study goals, learning outcomes, and assessment criteria, b) implementation of the study process, taking into account the previously defined goals, c) implementation of assessment activities with the aim to acquiring information about students' learning and teaching effectiveness, d) analysis and interpretation of data acquired during assessment activities, e) development and delivery of feedback to students, f) making strategic decisions in relation to actions which should be performed in the next steps of the study process, and g) returning to the definition of study goals, learning outcomes, and assessment criteria, taking into account the decisions made considering remediation of the study process. The defined activities should be implemented, taking into account both goals and learning outcomes of the study course and the study programme.

One of the main aspects in the defined process of formative assessment is the teacher's strategic decision-making in relation to the selection of remediation actions. These actions can be quite different; for example, according to Greenstein (2010), they can include changing a particular lesson plan in the unit, selecting different or additional resources, using different instructional strategies, identifying specific students in need of remediation, customising rubrics to personalise the weight of the mastery of selected standards, grouping students homogeneously for differentiation or in heterogeneous groups for collaborative learning, and changing the planned summative assessments.

4. Concept mapping

Concept mapping is a tool for the elicitation, representation, organisation, analysis, and conveying of knowledge. During a concept mapping activity, a concept map is manipulated (created, changed, extended, etc.). A concept map displays knowledge using labelled nodes which correspond to concepts in a knowledge domain and arcs displaying relations between pairs of concepts. The main elements of Novakian-style concept maps are (Cañas, 2003; Novak & Cañas, 2008; Novak & Gowin, 1984):

- Concepts: a concept is a perceived regularity in events or objects, or records of events or objects, designated by a label. Concepts are displayed using some geometric shape with a label inside it.
- Concept examples: an example of a concept is a specific example of events or objects that helps to clarify the meaning of the given concept. Concept examples are not included in a geometric shape but they are added as text which is connected with a concept by a connecting line.
- Relations: a relation displays a connection between two concepts and is characterised by a linking phrase explaining the essence of the relation. Relations are displayed as a connecting line, an arrowhead (for non-hierarchical relations), and a linking phrase.
- Propositions: a proposition is a statement about some object or event in the universe. It consists of two or more concepts connected by relations.
- Cross-links: a cross-link is a sub-type of relations. It displays non-hierarchical relations between concepts located in different segments of a concept map and shows how these segments are related. Cross-links are displayed by a connecting line with an arrowhead.
- Focus question: this is a question which clearly specifies an issue the concept map is devoted to.

However, in our practice we have introduced some modifications to Novakian-style concept maps to eliminate ambiguity, students' mistakes due to inattention, and sometimes also overburdening of a concept map. In comparison to Novakian-style concept maps, which do not have restrictions on the usage of linking phrases, we use five standard linking phrases ('is a' – a relation between a class and its sub-class, 'part of' – a relation between a part and a whole, 'example' – a relation between a general concept and its example, 'attribute' – a relation between a concept and its attribute, and 'value' – a relation between an attribute and its value) and linguistic phrases for types of relations which are not specified above. On one side, student-generated linking phrases provide greater insight into students' knowledge and understanding. On another side, usage of standard linking phrases habituates students to think in the main categories of human thinking and facilitates the evaluation of students' concept maps, reducing the teacher's load. In Novakian-style concept maps, arrowheads are not used until relations between concepts are hierarchical. In our practice we always use arrowheads to show precisely in which direction a proposition should be read. We include all concepts in a geometric shape, while in Novakian-style concept maps, concept examples are added as text. We use weighted relations to show the relative importance of relations in the whole knowledge structure. Weights of relations are displayed by the different thicknesses of connecting lines. Usually we have two types of relations: important relations showing important knowledge in the study course and less important relations specifying desirable knowledge.

5. Concept mapping and formative assessment

It is important to note that regardless of the fact that concept mapping has been studied already for more than 40 years, until now researchers have paid little attention to the usage of concept mapping for the purposes of formative assessment. Therefore, we agree with Trumpower and Sarwar (2010) that 'the use of concept maps for formative assessment has been particularly sparse' because in reality there are only few research works in this direction and they present mostly some experiments rather than analysis of regular practice based on a well-planned approach. Some authors, for example, Trumpower and Sarwar (2010) and Hung, Hwang, and Hung (2010), point out that concept maps do have good potential to be effectively used in formative assessment. Wehry, Monroe-Ossi, Cobb, and Fountain (2012) used concept maps both for formative assessment and summative assessment and they conclude that concept mapping can be used successfully for both types of assessment.

In the study of Buldu and Buldu (2010), concept mapping was used as a formative assessment technique in teacher education programmes for one semester and several significant conclusions concerning the improvement of learning, reducing learning barriers, provision of information for instructors, stimulation of reflective thinking, etc., are made about features of concept maps as a tool of formative assessment. Results of the longitudinal study performed by Walker and King (2002) indicated that concept mapping is a valuable technique for formative assessment because it provides substantial benefits to students in terms of motivation and critical thinking skills, while demanding a minimal cost from the instructor in terms of time and materials. The most prominent is a research work of Trumpower and Sarwar (2010), in which the authors offer a computer-based formative assessment system which uses concept maps as a basis for assessment activities.

Using IKAS in our formative assessment practice, we always ask students to evaluate their experience with concept mapping. Results of this evaluation are described in a number of publications, for example, (Anohina & Grundspenkis, 2006; Anohina-Naumeca, Grundspenkis, & Strautmane, 2011; Grundspenkis & Anohina, 2009). Typically students point out that they like using concept maps because they help to systematise their knowledge and to develop structural knowledge, as well as promote logical thinking. However, usually concept mapping tasks are difficult for students, as they demand active thinking and form a high cognitive load in comparison with other standard tasks like tests and essays.

6. Suitability of concept mapping for the formative assessment of structural knowledge

Considering the possibility of using concept mapping for the formative assessment of structural knowledge, attention should be paid to the following questions:

- Do concept maps allow for seeing clearly differences between experts' and novices' structural knowledge?
- Does concept mapping support the main aspects of formative assessment (see Section 3)?
- Is it possible to minimise the cost of formative assessment based on concept mapping?

6.1. Displaying differences between experts' and novices' structural knowledge

There are a number of research works indicating that concept maps allow clear differences to be seen between experts' and novices' knowledge. The study of Koponen and Pehkonen (2008) showed that experts' (physics instructors) maps had conceptual coherence and hierarchies while novices' (students) concept maps were characterised by partial coherence and a severely fractured organising hierarchy; in some cases there was no structure at all. Walker and King (2002) have found that the concept maps of professors were denser while students' concept maps contained fewer connections (quantitative difference), and professors' concept maps displayed not only domain knowledge but also included core competencies or the application of domain knowledge, while students' concept maps rarely contained them (qualitative difference). Differences between novice and expert history teachers described in the research work of Simon and Levin (2012) are mainly related to the fact that experts had more consolidated arrangements of concepts and a higher degree of integration within and between components of the map. Kinchin (2000) has summarised key characteristics observed in experts' and novices' concept maps, paying attention to differences in the degree of integration of the structure, quality and diversity of linking phrases, nature of concepts added, and dynamism of knowledge.

Our own experience is consistent with the results of other researchers; that is, students' concept maps usually differ from the teacher's concept map in the total number of relations and such aspects as missing standard linking phrases, correctness of linguistic linking phrases, uncovered relations, superfluous relations, and uncovered important relations.

Therefore, concept maps allow for seeing differences between experts' and novices' structural knowledge in quantitative (like number of relations and concepts) and qualitative (like quality of linking phrases, uncovered relations, etc.) aspects of concept maps. This allows one not only to elicit students' concept maps and to analyse them in relation to experts' structural knowledge, but also to identify common mistakes and patterns in students' concept maps and to elaborate not only individual feedback but also feedback relevant for the group of students. This also gives good information for teachers to make necessary improvements in the study course and content to bring engineering students' structural knowledge closer to experts' knowledge.

6.2. Satisfying purposes of formative assessment

As it was described in Section 3, formative assessment has three main purposes and concept mapping is able to satisfy all of them through feedback and completion of concept mapping activities. In the case of a student, feedback which can be acquired from concept maps after their evaluation provides information about his/her knowledge gaps and misconceptions, and this information, supplemented with the student's own motivation, can be used for improving structural knowledge, achievement level, and learning skills. In the case of a teacher, feedback gives valuable information about the knowledge state of students and, supplemented with the teacher's own motivation, can be used for making changes in the study course. Examples of feedback are described in Sub-section 6.4.

A student completing concept mapping tasks needs to work hard with his/her structural knowledge and to re-construct/re-combine it to answer such questions as Which concepts are interrelated? What kinds of relations exist between concepts? Which propositions display important knowledge in the study course? Therefore, concept mapping activates students' cognitive processes. It also allows them to develop skills of meta-cognitive reasoning; for example, if the student has some concepts which he/she cannot relate with other available concepts, the student can ask him/herself what he/she does not know. Concept mapping helps students, on the one hand, to externalise their structural knowledge and, on the other hand, to re-conceptualise their understanding of the knowledge domain and elaborate their structural knowledge by adding new propositions (Jonassen, 2000; Ryssel, Sommer, Fürstenau, & Kunath, 2008). Concept maps improve the usability of information (Davies, 2011) and, therefore, increase students' mental capacities to understand this information, process it in meaningful way, and retain and retrieve it from memory when this information is needed (Davies, 2011; Jonassen, 2000; Wang, 2003), so concept maps support the operation of cognitive processes. The teacher not only prepares his/her own concept map (an activity which is quite similar to the completion of concept mapping tasks by students) and so develops the same skills as students do but also trains his/her skills in analysis and evaluation of students' concept maps. This is a contribution to his/her professional development.

In relation to the increase of students' achievement levels, there exists a lot of research in different knowledge domains, for example (Cheema & Mirza, 2013; Chiou, 2008; Chularut & DeBacker, 2004), comparing results on post-tests between an experimental group which completed concept mapping activities and a control group which used another instructional method, and concluding that the experimental group had a significantly higher achievement level than the control group. These results are not surprising, taking into account that concept maps are visual aids whose effectiveness is wide-known due to raising information usability and demanding active involvement of students.

Considering the improvement of students' learning, concept mapping allows students to develop a number of skills which can help them in future learning. These skills include information organisation and processing in meaningful way, meta-cognitive reasoning, and self-reflection. If concept maps are used on a regular basis, students' thinking will be always activated and, together with students' experience, which grows with each concept mapping activity, students will start to view new content of the study course as a concept map. Our own experience shows that in working with concept maps, students train their minds to think in main categories of human thinking and to see which knowledge is important and which is not so important.

Concept maps can be used effectively for improving a teacher's work quality. This is possible mainly because concept maps give the teacher rich information about the current knowledge state of students. This information can be used for making improvements in the study course; that is, instructional methods, course content, and plan. For example, in our practice we usually use information provided by the IKAS system on differences between teachers' and students' concept maps. As a result, each year the same study course is presented differently (some topics are omitted/added, some topics are restructured to show more clearly interrelations between concepts, etc.) to students depending on the quality of their structural knowledge. If it is clear from students' concept maps that some concept is not well-understood by students, this concept is considered once again at the beginning of the next instructional unit. Common misconceptions are discussed together with students. Usually some topics are re-considered to show more clearly relations between concepts. This makes the study course more available and transparent for students.

6.3. Usage in the study process: time, participants, and forms

Concept maps can be used at any stage of the study process. At the beginning of instruction, concept maps allow the teacher to check what knowledge students already possess (diagnostic assessment) and to establish a baseline for future formative assessment activities. During instruction, concept maps can be used for the evaluation of changes in students' structural knowledge and the altering of instruction accordingly (formative assessment). At the end of instruction, concept maps can be useful for the evaluation of the final knowledge structure the students have already acquired. This is summative assessment, evaluating efforts of formative assessment activities. The line 'diagnostic assessment-formative assessment-summative assessment' can be applied both to the whole study course and to any of its elements (module or unit).

Moreover, the usage of concept maps during instruction can take different forms, starting from a task for students to provide linking phrases for already given propositions and finishing with a carefully planned set of concept mapping activities. A large spectrum of concept mapping tasks is described in by Anohina-Naumeca and Graudina (2012). The selection of tasks depends not only on assessment purposes, but also on the familiarity of students with concept mapping. For example, if concept mapping is a totally new activity for students, some simple tasks can be given to them as training tasks like provision of linking phrases for already given propositions. However, if students are well familiar with concept mapping, the teacher can start with concept map construction from scratch.

On the basis of our experience, we have developed the following scenario (Fig. 2) for the use of concept mapping in study courses. First of all, students need to be presented with explanatory material about the essence of concept mapping. This step can be omitted if students have enough experience working with concept maps. After that diagnostic assessment is performed, the teacher offers students a task in which they should create a concept map using a set of concepts which serves as a basis for the current study course. After a comparison of students' concept maps with the teacher's one, the teacher needs to alter the study course to satisfy students' needs. The study course itself should be divided into several assessment stages when formative assessments will be performed. A stage can be any logically completed part of the course; for example, a unit. For each stage, the teacher needs to prepare a concept map by specifying relevant concepts and relations among them. From our experience, we advise to include in each concept map no more than 15-20 concepts and three to five of them must be concepts from previous assessment stages. Concepts from previous stages will activate students' thinking and will allow easier integration of new concepts into the existent knowledge structure. During the formative assessment, a concept mapping task corresponding to the assessment stage should be given to students. After that, the teacher's and students' concept maps should be compared and feedback should be generated. The teacher needs to discuss results with students and to alter the study course accordingly. At the end of the course, a summative assessment should be performed by giving students a task to create a concept map using a set of the core concepts of the study course.

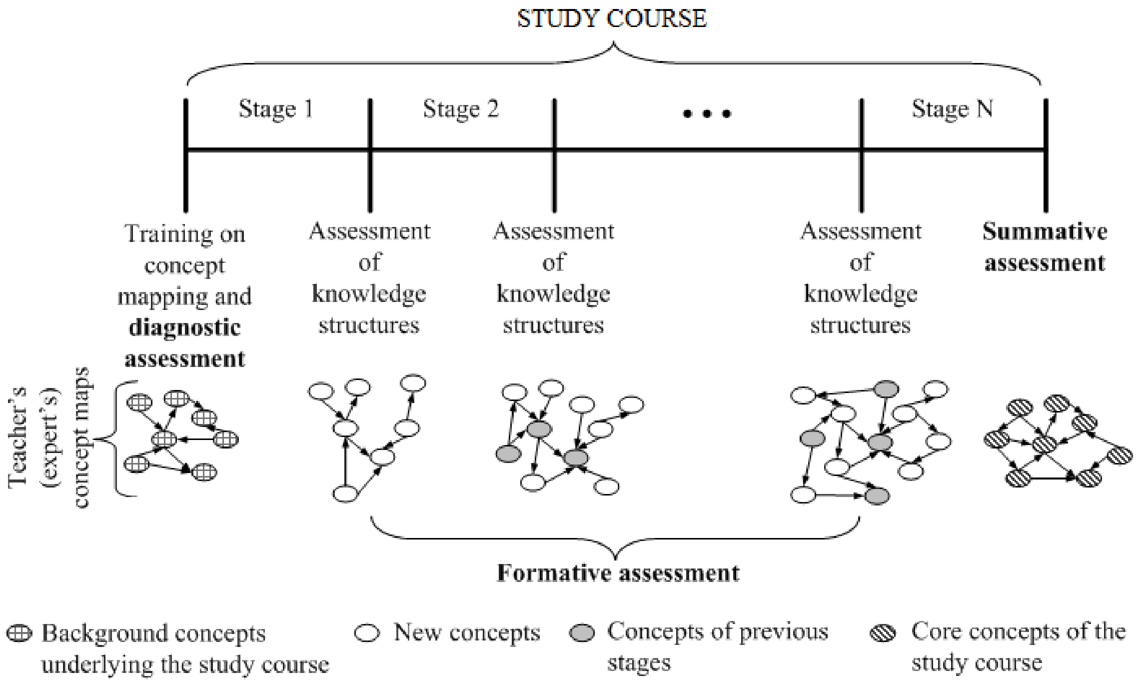

Fig. 2. Scenario of usage of concept mapping in a study course

Concept mapping activities need involvement between each student and teacher. This involvement mainly is related to activities performed by each part (students' activities are to complete a task, to analyse feedback, and to make improvements; the teacher's activities are to create concept maps, to plan and administer assessment activities, to evaluate concept maps, to generate feedback, and to make improvements). At the same time, concept mapping can support cooperative work in the class as concept maps are objects which can be easily shared and discussed (Hay & Kinchin, 2006; Reese, 2004).

6.4. Feedback

Analysis of students' concept maps can provide rich information about students' knowledge states. Regardless that this information can have both a quantitative nature and a qualitative nature, the main value coming from the latter is proved by a number of research works. Gouli, Gogoulou, and Grigoriadou (2003) mention that concept maps allow for the identification of unknown concepts (concepts missing in students' concept maps), incomplete understanding (relations between two or more concepts which do not correctly/fully address the relation of these concepts in the context of the subject matter), and false beliefs (a clearly false proposition, inclusion of invalid concepts, or a proposition which is not false, but is characterised as false due to the omission of other relevant propositions).

Novak (2002) refers to misconceptions in students' concept maps as coming from limited or inappropriate propositional hierarchies. According to Cicuto and Correia (2012), these hierarchies can be considered by the teacher to intentionally plan and revise upcoming learning activities. Hay (2007) points out that concept maps allow for the revealing of deep-, surface-, and non-learning. So they are useful in following and distinguishing meaningful and non-meaningful changes in the course of the learning.

Our IKAS system provides several types of feedback both to students and to the teacher. In the labelled students' concept maps, relations are coloured in different tones according to their correctness. A student can acquire detailed information about each relation such as its weight, the total number of points received for a particular relation, and contribution to the correctness of a relation of all constituent parts (like presence of a relation, correct linking phrase, correct direction of the arc, correct weight, etc.). The most important quantitative data are difficulty degree, score received, time spent, description of the score calculation process, and average results of other students who completed the same task at other degrees of difficulty. Qualitative descriptions include concept mastering degrees (poorly known, unknown, and well-known concepts), calculated by a special formula and an individual study plan. The individual study plan advises kindly to revise learning materials regarding poorly known concepts and insists on studying hard, unknown concepts. In checking a proposition, a student points out his/her created proposition, and the system shows contributions of each constituent part to the correctness of the proposition. In the case of incorrectness, the system provides tutoring, presenting explanations of both concepts involved in the proposition. The teacher's concept map is shown to students after tasks of all assessment stages are completed. Differences between students' and the teacher's concept maps focus on relations: a) typically, those created by students, but missing in the teacher's concept map, b) existing in the teacher's concept map, but usually remaining unrevealed by students, and c) defined as important in the teacher's concept map, but presented as less important in students' concept maps.

When we use paper-based concept maps, feedback includes summarisation of common mistakes and their descriptions together with illustrative examples. Further feedback is discussed in class and specific mistakes are discussed with individual students. Usually, common mistakes are related to missing standard linking phrases.

6.5. Definition of study goals, learning outcomes, and assessment criteria

The definition of study goals, learning outcomes, and assessment criteria depends not as much on concept mapping itself as on the teacher because the teacher should understand clearly why he/she makes assessments of students' structural knowledge and how he/she is planning to do that. The overall objective of the formative assessment of the structural knowledge of engineering students is to bring them closer to the expert's structural knowledge. Students must be informed about that and also about the fact of which concept map (the teacher's concept map, an agreed map of a group of teachers, an industry expert's map, etc.) will serve as the expert's map in the study course. Moreover, the teacher should clearly define task statements and assessment criteria. All this information should be communicated to students and then the teacher should check if students understand it well. If not, then discussion should be organised in class.

Our experience shows that one of the most important aspects in the usage of concept mapping is educating students about concept maps. We have prepared some training materials on this subject. Materials must be as simple as possible. Sometimes (it depends on the student group) further discussion on concept mapping should be organised in class. As the result of the concept mapping activity is a map which does not contain superfluous relations and in which standard linking phrases are correctly used and important relations are clearly distinguished from less important ones, we consider all these aspects in the training materials and give demonstrative examples. We have found 'the Golden Rule' allowing students to easily understand if their propositions are right: if reading a proposition in the direction of the arrowhead makes sense, then leave this proposition. Moreover, our training materials contain information about assessment criteria and an example of applying them.

6.6. Adjustment of the study process through the teacher's and students' actions

As described above, concept maps give rich information about students' current knowledge, but motivation is needed both from the teacher's side and the students' side to use this information for taking action aimed to improve the study process. The teacher can take action in relation to a) a specific student (for example, to discuss main misconceptions and give advice about aspects which must be studied more carefully), b) a group of students, and c) course plan, content, and instructional methods. Examples of the teacher's actions are described in Section 3. A student can re-consider his/her approach to learning, pay attention to poorly known concepts, and also make changes in the depiction of his/her knowledge structure.

6.7. Essential characteristics of formative assessment

The process of formative assessment should obligatory be systematic to satisfy its purposes and to bring the structural knowledge of engineering students closer to the expert's structural knowledge. The teacher can decide how often the process will be implemented. Our developed scenario which is displayed in Fig. 2 allows for the use of concept mapping in a systematic way.

Formative assessment activities should be grade-free in order to promote the improvement of learning and not create stress for students. There are a number of evaluation schemas and rubrics for calculating the score of concept maps. However, these scores usually do not provide meaningful information for students and the teacher. Therefore, attention should be paid to qualitative evaluation.

6.8. Minimisation of cost

Paper-based concept mapping activities, on one hand, require only paper as a main resource, but, on the other hand, they demand a lot of the teacher's time for evaluation of students' concept maps and generation of feedback. Therefore, their use in big classes can be very time-consuming and in practice is usually unrealistic. However, these costs can be minimised using available concept mapping software.

A number of commercial and non-commercial graphical software packages and tools displaying relations between pieces of information already exist, for example VUE (http://vue.tufts.edu/), AXON Idea Processor (http://web.singnet.com.sg/~axon2000/), and Inspiration (www.inspiration.com). They provide such functions as concept map construction, navigation, and sharing, and can be used as a useful learning tool. However, these products do not assess or compare created concept maps. This task can be solved by such tools as IHMC CmapTools (http://cmap.ihmc.us/) or our developed IKAS system.

The IHMC CmapTools programme allows users to construct, navigate, share, print, and decorate concept maps. One of the most valuable functions is the possibility to compare two concept maps (using any or all of these options: propositions, connections, linking phrases, and/or concepts) and receive a detailed analysis of the comparison. The IHMC CmapTools client is free for use by anybody and it is possible to download and install it in as many computers as desired, not only in educational institutions but also at home. Moreover, the tool is available in 17 different languages and is common in concept mapping community.

The IKAS system fully implements the scenario displayed in Fig. 2. It also allows for the comparison of two concept maps, usually a student's and a teacher's concept maps, and the generation of extensive feedback. Moreover, it supports the changing of task difficulty degree by students. The system is available only in English and is free for use.

7. Conclusion and future work

On the basis of extensive literature study and the author's personal instructional experience, this paper presents facts proving that concept mapping is an excellent tool for the formative assessment of students' structural knowledge. Therefore, concept maps allow for seeing clearly differences between experts' and novices' structural knowledge; they are able to satisfy purposes and characteristics of formative assessment, and it is even possible to minimise the cost of formative assessment activities using specially developed concept mapping software. Teachers should introduce concept mapping activities in their instructional practice on a regular basis to bring structural knowledge of engineering students closer to experts' knowledge and to prepare students for their professional performance in the best way. However, it is worth to mention that implementation of concept mapping presents the teacher with several serious challenges (aside from high costs related to evaluation of students' concepts maps and generation of feedback). Some of these challenges are a) a great number of criteria (inter alia an assessment purpose, ways of use of assessment data, number of students, student's familiarity with concept mapping, regularity of assessment, etc.) influencing the selection of concept mapping tasks, b) a need for effective strategies for students' training on concept mapping, c) dealing with students who have different achievement levels and attitudes towards concept mapping. Therefore, the usage of concept mapping for the formative assessment of structural knowledge demands a well-planned scenario or an approach which would include all necessary elements: an effective strategy for training of students on concept mapping, guidelines for the selection of concept mapping tasks, a diagnostic assessment for revealing students' knowledge states before instruction, formative assessment activities with an incremental increase of task difficulty degree, and a summative assessment for the evaluation of final knowledge structures constructed by students. Moreover, the approach should be adaptive to support students' diversity in achievement levels, familiarity with and attitudes towards concept mapping. As a result, the continuation of this research is the development of an approach for the formative assessment of structural knowledge using concept mapping and its experimental evaluation in courses of study.

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