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ASSESSING STUDENTS' INTERDISCIPLINARY APPROACH WITH CONCEPT MAPPING

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Abstract: it is common for several curricula to teach subjects in separated disciplines. Some of the researches have pointed out, that disciplinary learning is not constantly effective due to students' weak ability to create connections between different concepts or topics and because they often do not see the value in what they have learnt. To prevent this from happening, interdisciplinary learning is becoming more and more popular. Interdisciplinary means here that two or more academic disciplines are combined by projects, researchers special subjects etc.. In many countries the topics of natural science (biology, chemistry, physics and geography) subjects are taught separately. Often different teachers teach these subjects. One of the teachers' aims is to develop students' scientific literacy skills on knowledge and understanding of scientific concepts and processes required for personal decision-making, interest for science etc. Researchers have understood that flexible assessing instruments are needed for examining interdisciplinarity. This study focuses on: how to measure students' interdisciplinary approach with concept mapping; what are the measures of concept maps that are important in assessing students' interdisciplinary approach; and how can students create interdisciplinary concept maps? This research focuses on 343 students who combined a focus question based concept map with 30 given concepts. Concepts of the concept maps were separated into four categories: biology, chemistry, physics and everyday life. Analysis pointed out that students created most propositions between concepts from everyday life and within one discipline. It means, students created on average three times more connections between concepts from the same category, than between different categories. Based on the definition of scientific literacy it could be said that the level of scientific literacy is not high for those students, because they are not able to use subject based concepts in different conditions and connect concepts from different categories with one another.
Keywords: interdisciplinary learning, concept mapping, meaningful learning, scientific literacy

1 Introduction

When researching the traditional curricula of different countries, one could notice, that often disciplines are separated from one another and taught by different teachers. It is said that such learning lessens students' learning motivation and entire understanding of the specific topic. As a result, students are not interested in the discipline in the future and do not choose their profession from the unpleasant field. To avoid such outcome, interdisciplinary learning should be used more at schools (in lessons, special projects etc.). Interdisciplinary learning helps to eliminate the fragmentation of isolated skills. It gives students the opportunity to understand a particular theme from different angles and to reach higher scientific literacy skills. It is demonstrated that interdisciplinary teaching can increase students' motivation towards learning as well as raise their level of active engagement. (Ivanitskaya et al 2002; Dillon 2008)

This study introduces the results of a research, where interdisciplinarity was assessed using concept mapping method. The results pointed out that students are not able to associate concepts from different disciplines properly. Research questions were as follows: How to measure students' interdisciplinary approach with concept mapping? What are the measures of concept maps that are important in assessing students' interdisciplinary approach? How can students create interdisciplinary concept maps?

2 Theoretical background

2.1 Cognitive skills

How and when learning appears is the principle question of teaching and learning. According to cognitive psychology, understanding is a mental process of perceiving and knowing. Some compounds of cognitive learning are: reasoning, abstract thinking, decision-making and problem solving. In cognitive learning process, the individual learns by listening, watching, reading or experiencing some stimuli. This input is processed by the brain and noted later. Students, who have learnt cognitively, are able to integrate new information, can explain new knowledge in their own words and know how the studied material fits into other things that they already know (Klassen, 2006). Novak (2010) writes that cognitive learning is the acquisition of knowledge. Cognitive learning establishes some kind of meaning of the concept. Meaning is not an absolute term, but relative. Wong (2012) generalized, that meaning comes from the combination of knowledge learned, feelings felt and actions taken during learning process. That is why meaning is different for every individual. Interplay between new and prior knowledge creates meaning.

2.2 *Meaningful learning*

Meaningful learning is said to be an important educational purpose. It occurs when students create their knowledge. Cognitive processes are needed for successful problem solving. (Mayer, 2002) Meaningful learning leads to the changes in learners' cognitive structure, so they think more about the idea behind the expressions rather than definition. Interrelated ideas form several networks. (Wong, 2012) According to the Ausubel assimilation theory, three conditions are needed for meaningful learning: 1) students should have relevant prior knowledge; 2) learning materials should be meaningful; 3) learners should want to learn meaningfully. (Novak, 2010; Emenike et al., 2011). In theory, meaningful learning should occur, when above discussed conditions are met. Usually meaningful learning does not appear in every phase of learning, but it gives the opportunity to understand daily surrounding processes and to reach higher scientific literacy skills.

2.3 *Scientific literacy*

It has been ascertained that individuals have some level of scientific literacy skills. There are several different definitions for scientific literacy. According to the *National Science Education Standards* (NSES), the student, who has scientific literacy skills, is able to:

1) ask, find, or determine answers to questions derived from curiosity about everyday experiences;
2) describe, explain, and predict natural phenomena;
3) read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions;
4) identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed;
5) evaluate the quality of scientific information;
6) pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.

The definition for scientific literacy by Holbrook & Rannikmäe (2009) is: developing an ability to creatively utilize appropriate evidence-based scientific knowledge and skills, particularly with relevance for everyday life and a career, in solving personally challenging yet meaningful scientific problems as well as making responsible decisions. Evaluating and developing scientific literacy needs flexible assessing and studying instruments and interdisciplinary teaching which considers students' cognitive skills. There are different levels of scientific literacy like nominal, functional, conceptual, procedural or structural and multidimensional, that assess students' ability to understand and use discipline based terms, principles and theories in everyday life and create connections between different disciplines. (Bybee 1997; Biological Sciences Curriculum Study (BSCS), 1993)

2.4 *Interdisciplinary teaching approach*

Dillon (2008) wrote (p. 256): "Disciplines have been defined as bodies of knowledge that have been structured culturally and which can be acquired, practised, and advanced through the act of creating" (Li & Gardner, 1993).

Interdisciplinary teaching means teaching a unit across different curricular disciplines. In 1997, Nicolescu defines interdisciplinarity as the transfer of methods from one discipline to another. Interdisciplinarity points out the overflow of disciplinary boundaries but their goals remain limited to the framework of disciplinary research (Dillon, 2008). There are several different models for describing interdisciplinarity. Moran (2002) has pointed out, that interdisciplinary learning includes a valuable degree of flexibility, meaning any form of dialogue between two or more disciplines, but expecting it to be transformative, producing new forms of knowledge (Dillon, 2008). Several authors have described learning outcomes of the interdisciplinary approach. Ivanitskaya and her research team (2002) made a summary of the main statements. Outcomes of interdisciplinary learning are: extending the development or enhancement of cognitive skills; motivating students for deep learning (higher-order thinking); developing critical thinking; knowing when and how to use different learning strategies; knowing how to plan, monitor, and control learning; knowing how to transfer learning skills acquired in the classroom to other contexts and enabling students to expand the range and meaning of their existing knowledge.

Both- scientific literacy and interdisciplinary learning- emphasise, that learning should be meaningful and students should be able to use the knowledge learnt in everyday life and in differently separated disciplines. There are difficulties in examining interdisciplinary knowledge with ordinary assessing methods. Schaal et al (2010, p 341) made a conclusion based on several researches: „When assessing learning in complex interdisciplinary knowledge domains, traditional tests often fail, especially when specific proficiencies require a foundation of advanced knowledge". For evaluating interdisciplinary learning we need a flexible assessing instrument that considers students' cognitive skills. Borrego with his research team (2009) made a conclusion (p. 5): "To address the gap in assessment tools for interdisciplinary learning and collaboration, we argue that concept maps are an appropriate method of assessing the integration of content knowledge from various disciplines into a coherent picture." Therefore it could be concluded that interdisciplinary learning should develop students' meaningful learning and scientific literacy skills and could be assessed with concept mapping method.

2.5 Concept mapping

Joseph Novak and his research team developed the concept mapping method in the 1970s. This method bases on the meaningful learning theory of Ausubel (1968). Concept mapping suggests that connections could be created between the prior learning and new learning. These connections could be expressed by means of a graphical structure, usually called a concept map. A concept map links new concepts, with prior concepts with lines, labelled as proposition (Novak, 2010; Kinchin 2011). Concept map is a collection of propositions (one proposition consists of 2 concepts and we could "read" them as a sentence) and it declares personal understanding. In this research a special computer program called IHMCmap Tools was used for creating concept maps. The main purpose of concept mapping is to facilitate and assess meaningful learning.

2.5.1 Assessing with concept mapping

Concept maps can be used in school learning process and as an assessment tool, giving a better overview of the student's mental processes and the structure of their knowledge than any other assessment tools. A well-designed concept map test should be able to distinguish between knowledge that has been learned by rote memorization and knowledge that is integrated with related conceptions. (Novak, 2010) There are several different possibilities to assess concept maps. This study focuses on quantitative and qualitative assessment. Quantitative assessment means that numerical scores for a concept map are calculated. These measures should reflect students' understanding of a particular domain. (Keppens, 2007) That information gives the opportunity to analyse the structure of the concept map. A special analysing program CmapAnalysis (Cańas et al 2010) is developed for analysing different parameters in concept maps made with IHMCmap Tools program. These measures are also analysable in MS Excel. This research is looking for the values of:

a) proposition count (the number of propositions ("sentences") in the concept map);
b) branch point count (the total number of concepts and linking phrases that have at least one incoming connection and more than one outgoing connection);
c) orphan count (the number of concepts in the map that have no connections);
d) intra-cluster proposition count ("sentence", that is created from concepts from the same cluster (discipline));
e) inter-cluster proposition count ("sentence", that is created from concepts between different clusters (disciplines)).

Kinchin, Hay, and Adams (2000) developed qualitative schemes for assessing concept maps fast and easy. These schemes do not assesse the correctness of a map, instead of that they observe the level of complexity by describing cards shapes. They pointed out three categories of maps: spokes (one hierarchy level- shows little complexity and overview); chains (consist of many levels but these are often unclear; links between different levels are missing) and networks (several recognisable levels; this type is the indicator for meaningful learning sequence). (Kinchin, 2011). Schaal et al (2010, p 349) wrote: „However, most important is the innovative possibility to get insights into structural aspects of knowledge and the linkage of concepts. Nevertheless, concept map assessment still is not a common tool in the science education community and more experience is needed." Klassen (2006) made the same conclusion in his research. In this study new possibilities on how to assess interdisciplinary approach with concept mapping are looked for.

3 Methodology

This study focused on students (N=343) aged sixteen to seventeen, from 46 different Estonian high schools, who were examined with focus question biased and given concept mapping method. Each of them had to create a certain focus question (instant cold pack- is it only a chemistry?) based concept map with 30 given concepts. Given concepts were from different fields: instant cold pack, first aid, exothermic reaction, energy transfer, pain, bloodstream, cure, friction, edema, risk, nerve impulse, dislocation, water, solvation, endothermic reaction, salt, equilibrium of chemical reaction, tumour, absorption, ethics, health, capillary, freezing temperature, the law of conservation of energy, safety, melting, speed of chemical reaction, lymphatic, pressure, pH, mole. The aim of the study was to examine the interdisciplinary approach of students. The design of the study is illustrated in Figure 1.

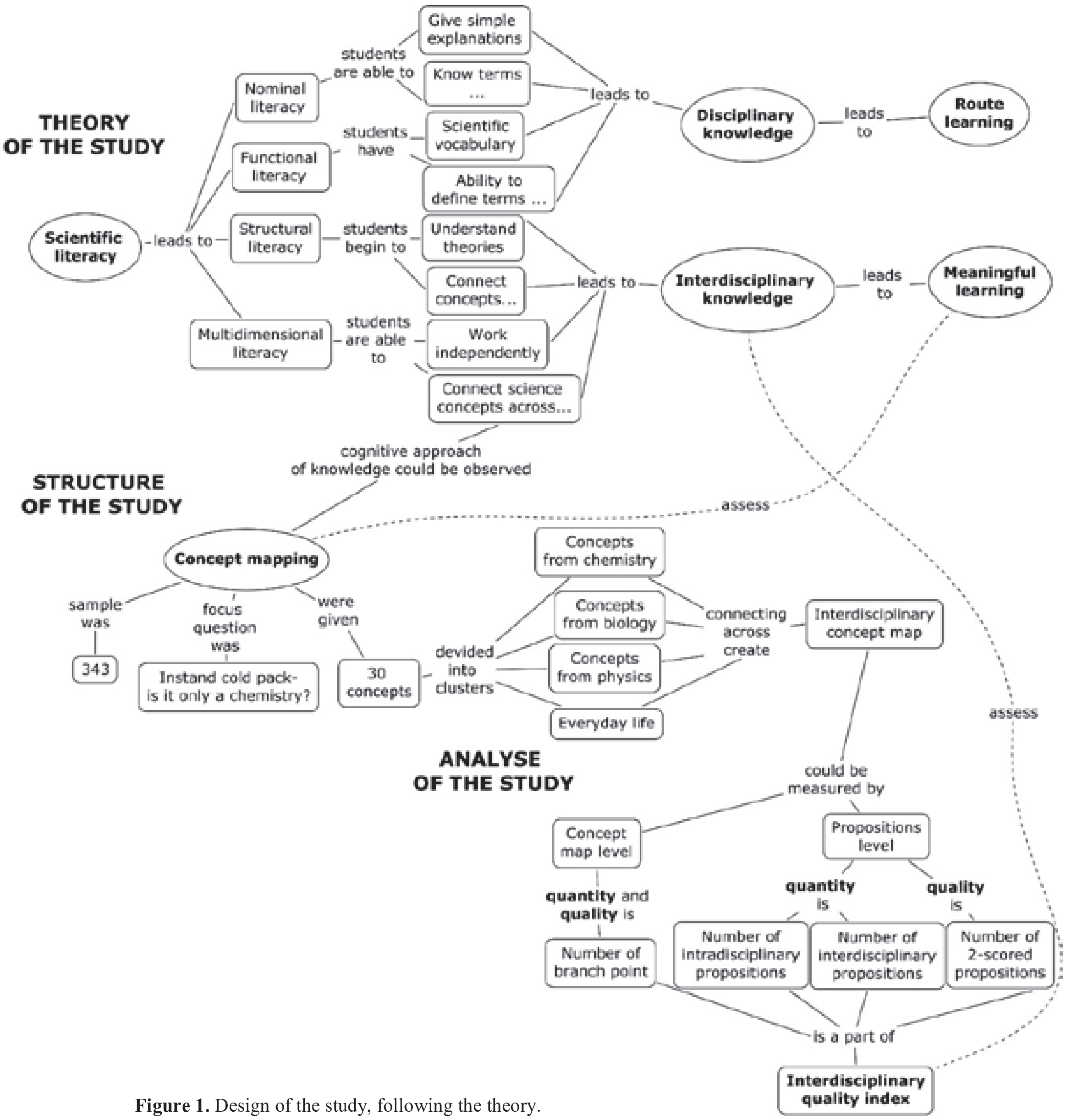

Figure 1. Design of the study, following the theory.

3.1 Data analysis and the results of the study

Data analyses consisted of several different stages. The three stages of the analysis are described below using figure 2.

Firstly, two experts assessed the quality of propositions manually using MS Excel. Marks were given from 2 to 0 (2- very good subject based proposition; 1- correct ordinary daily used proposition or subject based proposition with some questionability; 0-wrong or grabbled proposition).

Secondly, 85 experts, whom were teachers from grammar school (N=14), students from Tallinn University (N=9) and students from grammar school (N=62), distributed the concepts into clusters. It was interesting to note that concepts were distributed by experts mainly by the disciplines, where they are taught and not by the content of the concept. For example dissolution is a concept that describes physical process, but it is taught in chemistry lessons and 94,5% of the experts noted that it is a concept of chemistry.

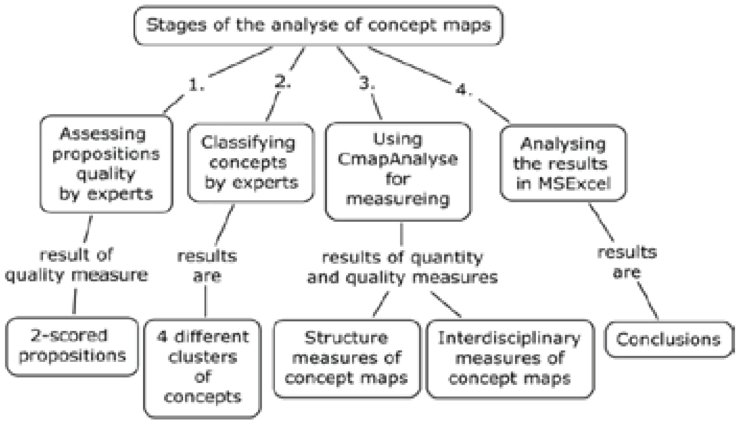

Figure 2. Stages of data analyse of the study

We calculated the possibility to create inter-cluster and intra-cluster propositions. Intra-clusters propositions creating ability is calculated by formula: $C_n^m = \frac{n!}{m!(n-m)!}$; inter-clusters propositions creating ability is calculated as multiply of clusters concepts count.

Thirdly, after using the program CmapAnalysis, several numerical data was received. The aim was to calculate in which cluster (one discipline based or different disciplines based) students created the most propositions from possible proposition ratio. It occurred that students created the highest number of propositions in clusters of one discipline and preferred to compose propositions between everyday used concepts (15,5% of possible propositions). The lowest number of propositions was in the cluster, where concepts from physics and everyday life were presented together (0,5% from possible propositions). It became obvious that students preferred to create one discipline centred propositions for two disciplines or one discipline and everyday used concepts centred propositions.

Next, based on the results, the number of interdisciplinary propositions students had made per concept maps was under study. The authors supposed that interdisciplinarity could have been measured by counting interdisciplinary propositions. The analysis pointed out that only a few students (1,7%) created over 20 interdisciplinary propositions per concept map; 20,5% created 0-5 interdisciplinary propositions; the highest percentage of students (36,7%) created 6-10 interdisciplinary concepts per concept map. While looking at the designs of concept maps, we discovered that although the number of interdisciplinary propositions was high, the concept maps actually did not show students' ability to connect concepts meaningfully from different disciplines so that a highly structured concept map had been created. Many of the concept maps marked as highly interdisciplinary were actually structured as a "star" (or spoke) as there was only one centred concept (as illustrated in Figure 3). Some of the highly scored concept maps were chain type and also did not point out the multidimensional literacy or meaningful learning ability. Some of the concept maps marked as averagely interdisciplinary pointed out that students had connected concepts as groups from different disciplines (as illustrated in Figure 5) or had created really poor concept maps. The number of interdisciplinary proposition count did not point out interdisciplinary concept maps with scientific literacy and meaningful learning ability approach. It was concluded that such measure does not reveal the best interdisciplinary concept maps. Supposedly the reason is that neither the branching of the concept maps nor the quality of propositions was taken in account. The interdisciplinary proposition count: quantity of interdisciplinary concept maps pointed out maps, where many interdisciplinary propositions had been made, but concept map itself was not always highly valued. One of the aims was to find out what components give the best information about the most interdisciplinary concept map structure.

The concept map in figure 3 is "star" shaped, there are a few meaningful connections between concepts; no branch points neither orphans. Interdisciplinary propositions are pointed out with dotted lines. That concept map reflects that student is able to create propositions from concepts of different clusters, but there are no connections of them and this concept map does not express high interdisciplinary nor multidimensional literacy approach. Structure of the concept map is not network and so it does not reflect meaningfully learnt knowledge.

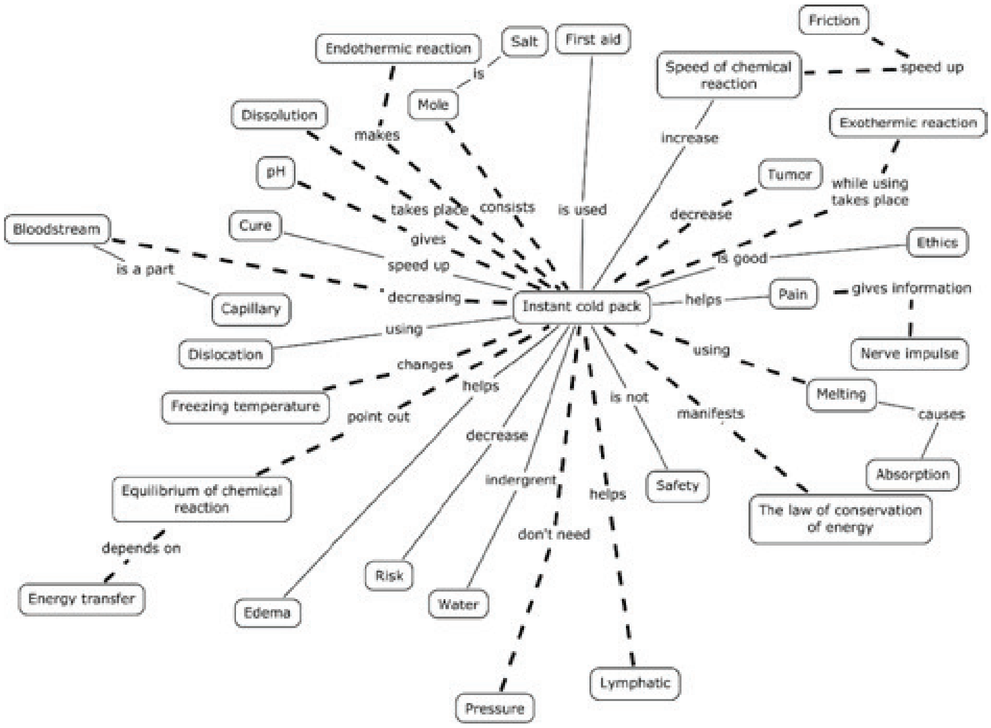

Figure 3. A concept map with high interdisciplinary proposition count (15).

Finally, inter-cluster proposition count was divided with intra-cluster proposition count for eliminating "stars" with high interdisciplinary proposition count. However, this step also did not bring out the most interdisciplinary concept map. Thereafter the quality of interdisciplinary concept map was calculated. At first, the correlation between interdisciplinary proposition count and other quantitative and qualitative measures of concept maps was studied. Correlations occurred between branch points of concept maps (r= 0,67), orphan count (r=-0,65) and experts marked 2-scored propositions (r= 0,61)- these measures correlated the most. The most interdisciplinary concept map was found, when the results of measures of concept map (branch point count- it is quantity and quality of concept maps; 2-scored proposition count- describes the quality of propositions) were added. The equation, that describes the quality and quantity of interdisciplinary concept map, is given in Figure 4. One could compare these measures, because they are countable and we optimized each of them to one by the highest result of the sample. There are two examples (Figure 5 and Figure 6) of concept maps and the interdisciplinary index of them.

$$interdiciplinarity\ index = \frac{\frac{\sum interdiscipl.propositions}{\sum intradiscipl.propositions}}{Max_{\frac{interdiscipl.propositions}{intradiscipl.propositions}}} + \frac{\sum branch\ points}{Max\ branch\ points} + \frac{\sum 2\text{-}scored\ propositions}{Max_{2-scored\ propositions}}$$

Figure 4. Formula for calculating interdisciplinarity index.

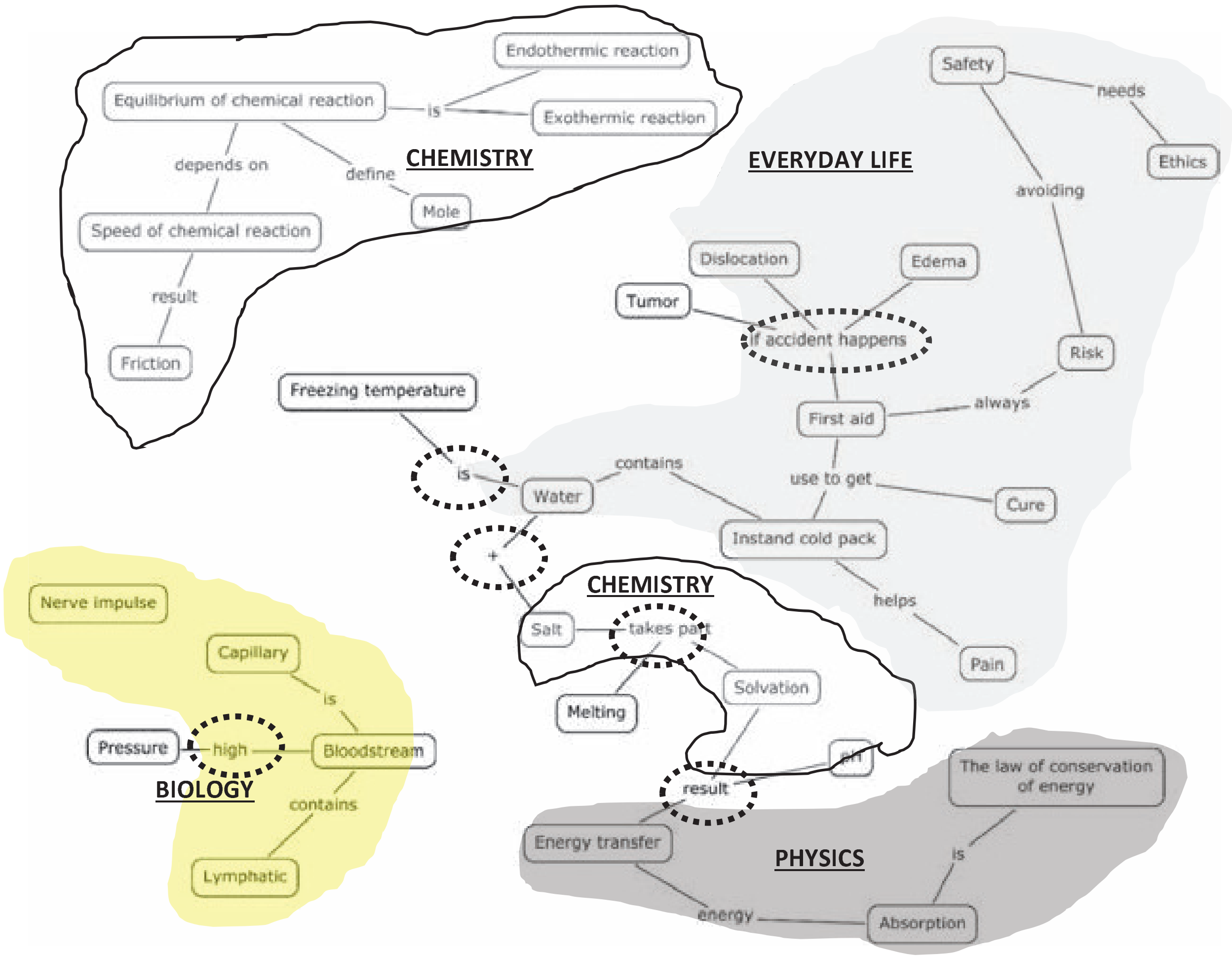

Figure 5. An example of a concept map.

On figure 5, the concept map has 7 interdisciplinary propositions (linking phrases are surrounded with dotted circles) from 26 propositions. The general structure and hierarchy of the concept map are not high. There are discipline based "islands" (surrounded with different coloured shapes). The shape of the concept map is not network, rather consists of several spokes and chains. There are some branch points and one 2-scored proposition. Interdisciplinarity index for that concept map is 0,37.

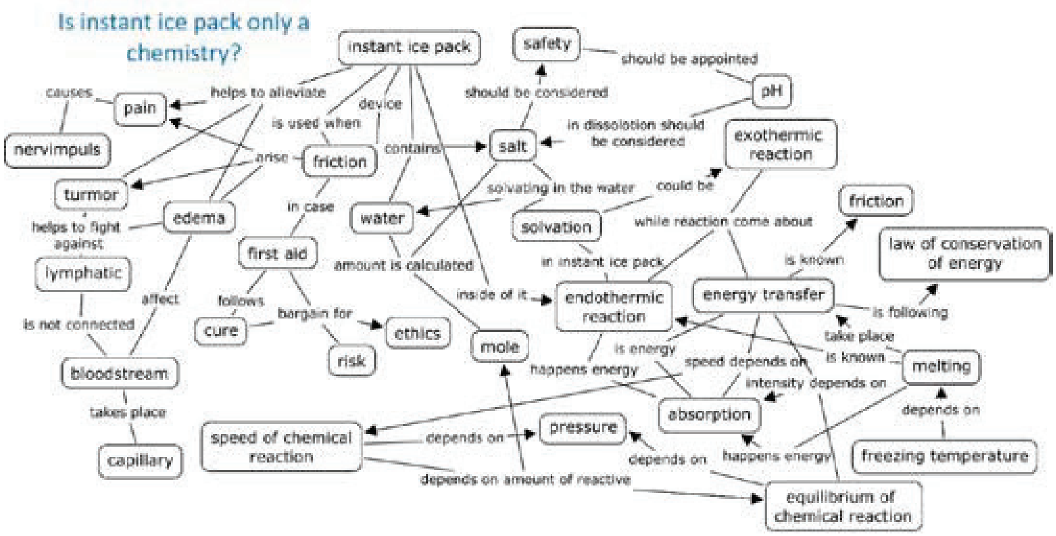

Figure 6. An example of an interdisciplinary concept map.

On figure 6 there is a concept map with 21 interdisciplinary propositions, the structure is “net” shape expressing higher meaningful thinking ability. There are 18 2-scored experts marked propositions and 16 branch points. The interdisciplinarity index of the map is 2,1.

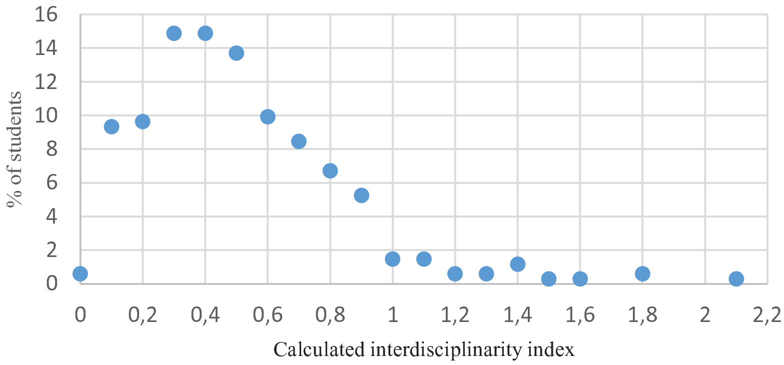

Figure 7. The distribution of calculated interdisciplinarity index.

The results of the interdisciplinarity index varied from 2,1 to 0 as shown in figure 7. Analysis pointed out that only 18,8% of created concept maps achieved 25% of possible interdisciplinary index points. The concept map that has the highest interdisciplinary indexed (2,1) was illustrated in Figure 6. Most of the students (93,6%) got less than 50% of the points of the best concept map found based on interdisciplinary index.

4 Summary

This study pointed out that for assessing students’ interdisciplinary approach, which is one component of scientific literacy skills multidimensional literacy level, we need a flexible and innovative assessment method, for example concept mapping. There are a few studies, where interdisciplinarity has been assessed with concept mapping by measuring or calculating certain data. Therefore, this field should be researched more deeply.

The analysis of the concept maps pointed out that high percentage of the students do not create highly valuated interdisciplinary concept maps. They prefer connecting one subject based concepts to other one subject based concepts. The reason for that could be the poor use of interdisciplinary teaching approach at Estonian schools. The research also brought out that there are several possibilities for describing concept maps’ interdisciplinarity, but not all the options were used here. There are different sides in interdisciplinary concept maps: a) quantity of concept maps’ interdisciplinary: assessed by interdisciplinary propositions count and count of branch points b) the quality of concept maps’ interdisciplinary: assessed by highly subject based scored propositions and also by count of branch point.

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