Development of Students' Concept Maps through High School Biology Studies

Priit Reiska, Aet Möllits
[1, 2] Tallinn University (Estonia)
[1]priit@tlu.ee, [2]aet.mollits@gmail.com

Abstract
Despite the fact that the learning process is becoming more exploratory and investigative, there is still a need for methodological diversity to evaluate learning processes in science.
To identify changes in students' thinking and their ability to orientate within and between different subject areas, it is not enough for the knowledge tests usually used at school (multiple choice, true or false etc.). To find out how new knowledge is integrating into students` cognitive thinking, there is a need for a versatile evaluation tool that fulfill more functions than just assessing students` factual knowledge.
One of the possible solutions is using a concept mapping method for assessment, first described by Joseph Novak. Several studies have shown that the concept mapping method as an assessment tool provides the opportunity to identify students' misconceptions and make sure if the learned knowledge is accurate.
The aim of the study is to find out, how students biology-based concept maps are developing during high school. There are several measures for analyzing concept maps. By using quantitative assessment method, a range of characteristics can be assessed e.g. number of concepts; number of propositions; number of cross-links.
To assess students` biology knowledge in high school the results of one large-scale study are used. Concept maps of 2216 10th grade (first year in high school) students were collected in 2012. In two years same students` were assessed again at the end of high school. The students' concept maps were analyzed in three categories: “size”, “structure” and “quality”. The quantitative characteristics of concept maps were analyzed by Cmapanalysis software, which calculates several different measures in categories “size” and “structure”. The concept maps composed in grade 12 were on a higher level than those from students in grade 10. The results show that even if the number of correct propositions is rising during the high school, then unfortunately the number of incorrect propositions stays the same.
Based on the result, we can recommend teacher to use different methods for assessment, such as concept mapping.

1. Introduction
The low motivation and unpopularity of studying natural sciences is challenge for teachers in many countries. Despite the fact that the learning process is becoming more exploratory and investigative, there is still a need for methodological diversity to evaluate learning processes in science. Assessment is an integrated part of learning and knowledge acquisition and plays an important role for parents, society and the learners themselves. Assessment in school is usually based on teachers` estimation of how students` self-express themselves in specific situations, solve problems, or put their knowledge into practice [1].
To identify changes in students' thinking and their ability to orientate within and between different subject areas, the use of the traditional knowledge tests (multiple choice, true or false etc.) is not sufficient. The efficacy of learning process is highly visible when students` are able to create links between previous knowledge and the new one [1], [2]. To find out how new knowledge is integrated into students` cognitive structure, there is a need for a new evaluation tool that fulfill more functions than just assessing students` factual knowledge [3].
One of the possible solutions is using the concept mapping method for assessment, first described by Joseph Novak in 1972. The method is based on David Ausubel`s (1968), meaningful learning theory [4], which says that: (1) learning only takes place when new knowledge is associated with that already existing in a logical system; (2) reorganization and integration with a new information facilitates meaningful learning. Several studies have shown that the concept mapping as an assessment method

provides the opportunity to identify students' misconceptions [5], [6], [7] and if the learned knowledge is accurate [8], [9], [10], [11]. It is also supporting meaningful learning activities [7], [12].
The aim of the study is to find out, how students biology-based concept maps are developing during high school. Based on concept maps created by students, conclusions are made about different aspects of their knowledge.

2. Concept mapping method

Concept mapping is a graphical tool that helps to organize and represent knowledge in a way that it indicates deeper meaning of a topic [13]. This method provides an opportunity to integrated new knowledge with previous one. During the creating process, it is recommended to define a focus question that indicates the problem for the development of the concept map. It provides a context and helps to organize the further, hierarchical structure of the map [14].
The creating process of concept maps requires understanding of concepts and the ability to find linking words between them [15]. The concepts can be words, definitions, pictures, symbols, etc., that are usually surrounded by circle or boxes. Concepts (two or more) are connected together with a line and linking word(s) that shows the relationship between them. The smallest meaningful unit in concept map contains two concepts that are connected with linking word and it is called a proposition. Important are also cross-links that show the relation between different domains in the map. They help to understand, how map composers are able to use their knowledge across different subject areas [14].
The structure of a concept map is usually depending on initial instruction. For example, concept maps can be created without any conditions with a focus question, with a one given “root” concept or with a list of given concepts. Different conditions can lead to different maps, providing the possibility to assess different aspects of knowledge [16].

2.1. Concept mapping as an assessment tool

To assess students` knowledge with concept mapping, it is important to be sure about the reliability and validity of the method [17], [15]. It needs to be clear, that the concept map evaluates students` knowledge, not the mappers computer skills or ability to create a map. For example, if the concepts are given beforehand, there is a possibility to assess the use of concepts in a meaningful subject context [3].
There are several measures for analyzing concept maps. Quantitative assessment gives numerical values for concept map characteristics [18]. By using quantitative assessment, a range of characteristics can be assessed [19] e.g. number of concepts, number of propositions or number of cross-links. Such concept maps can be assessed in three categories: a) size; b) quality; c) structure. The number of concepts, number of propositions and number of linking words are describing the size of maps. The structure of the map can be described by centrality of concepts, number of cross-links, density of concepts, inter- and intra cluster proposition count or branch point count. These map characteristics help to evaluate, how the concepts are connected to each other. Typical quality indicators are correct proposition count, average rating of propositions and relevance of concepts or propositions. Usually experts are used to assess the quality of concept maps (e.g. accuracy of propositions) [20].

3. Procedure

To assess students` biology knowledge in high school the large-scale study LoTeGym was carried out in 2012 and 2014 [21]. In 2012, the PISA-like, three-dimensional tests [21] and computer-based concept maps of 10th grade (first year in high school) students were collected from 2216 students in 44 different representative schools. In 2014, same students` were tested again at the end of high school. For the purpose of this study, 374 concept maps by 187 students from 42 different Estonian high schools, were analyzed.
The data collection was divided into two phases. In the first phase students solved PISA-like three-dimensional, scenario-based exercises. In the second phase they constructed concept maps, based on a given focus question and 30 concepts. For this study the students had to create concept maps based on the focus question: “Milk - is it always healthy?”. Experts divided concepts into 4 subject categories: “biology”, “chemistry”, “physics” and “everyday life”. In the PISA-like test a short interdisciplinary scenario and tasks (multiple choice and open questions), based on the problem, were given [21].

The students' concept maps were analysed in three categories: size, structure and quality. To assess the quality of concept maps, two experts assessed the quality of all propositions. There were over 12 300 propositions, which were rated from 0 to 2 points. 0 points showed that the proposition was incorrect, 1 point was given if the proposition expressed everyday life knowledge and 2 points were given if the proposition had a scientifically correct meaning. The quantitative characteristics of concept maps were analyzed with Cmapanalysis software [16], which allows determination of the size and the structure of the concept map. In addition the correlation between the measures of concept maps and PISA-like test results were calculated [22]. The data were analyzed using MS Excel, Cmapanalysis and SPSS Statistics 20. In the study, correlation analysis, t-test and descriptive statistics were used.
To determine the reliability of the concept mapping assessment procedure, the overlap value of two experts was calculated. Two independent experts assessed the correctness of every proposition, the overlapping value was 97%.
We also looked at the compatibility with different assessment methods. In this study, the correlation between the concept map measures and PISA-like test results were calculated.

4. Findings

The concept maps composed in grade 12 were on higher level than those from students in grade 10. However, although the results showed a statistically significant increase in the number of high quality propositions, the number of incorrect propositions did not decrease. Paired Samples T-Test was used to determine the significance of the differences.

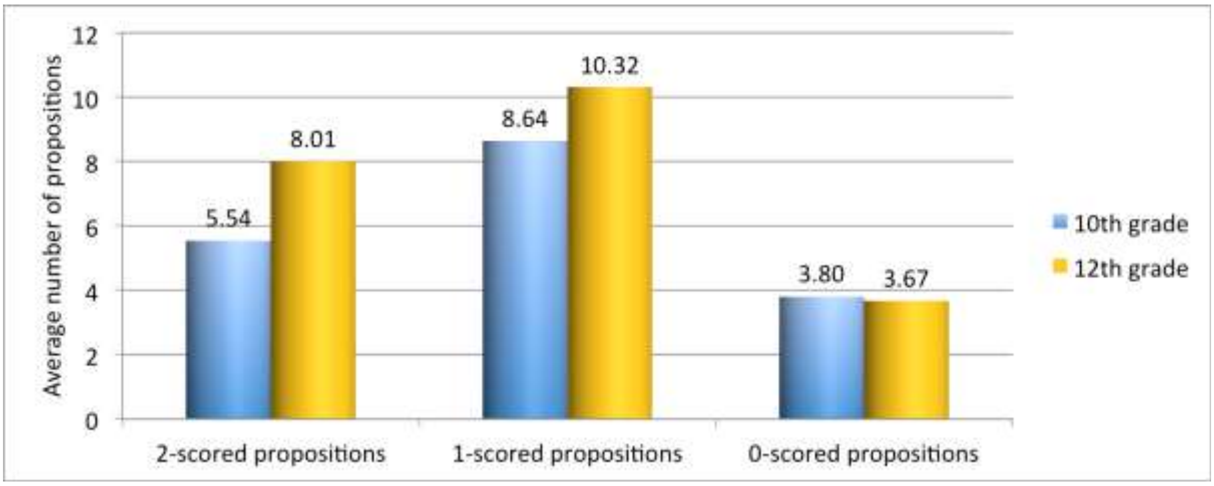

Fig. 1. Average number of composed propositions in grade 10 and 12

In grade 12 the students composed more 1-scored propositions (M=10,32; SD=4,11) than in grade 10 (M=8,64; SD=3,58). The difference was significant (t = 6,31; p = 0,00). Also the average number of 2-scored proposition was higher in grade 12 (M=8,01; SD=4,38) than in grade 10 (M=5,54; SD=3,78). The difference was also significant (t=9,49; p=0,00). The difference in 0-scored propositions was not significant (p=0,63).
The results show that even if the number of correct propositions is rising during the high school, then the number of incorrect propositions stays at the same level.

Contribution

Based on the result, we encourage teacher to use different methods for assessment, such as the concept mapping. Using concept mapping allows to detect misconceptions and to follow developments in students' conceptual knowledge. Today are available several computer-based concept mapping analysis programs, such as the Cmapanalysis, which allow assess the concept maps of whole class at once. In addition to that it gives an immediate virtual feedback for each student [16].

References

[1] Gouli, E., Gogoulou, A., & Grigoriadou, M. 2003. A coherent and integrated framework using concept maps for various educational assessment functions. Journal of Information Technology Education, 2, 1, 215-239.

[2] Mintzes, J., Wandersee, J., Novak, J.D., 2000. Learning, teaching and assessment: A human constructivist perspective. In *Assessing science understanding: A human constructivist view.* (Mintzes, J., Wandersee, J., Novak, J.D, eds.) pp. 1-13. Elsevier Academic Press, New York.

[3] Soika, K., Reiska, P. 2013. Large scale studies with concept mapping. *Journal for Educators.Teachers and Trainers,* 4, 1, 142-153.

[4] Ausubel, D. P. 1968. Educational Psychology: A Cognitive View. Holt, Rinehart and Winston,inc., New York. pp. 45-46; 107-110; 509-514.

[5] Kinchin, I.M. 2000a. The active use of concept mapping to promote meaningful learning in biological science. Unpublished PhD thesis, Surrey University, Guildford.

[6] Clayton, L.H. 2006. Concept mapping: an effective, active teaching-learning method. *Nurs.Educ. Prespect.* 27, 4, 62-86.

[7] Hay, D., Kinchin, I.M., Lygo-Baker, S. 2008. Making learning visible: the role of concept mapping in higher education. *Studies in Higer Eduation.* 33, 3, 295-311.

[8] Kinchin, I.M. 2000b. Concept mapping activities to help students understand photosynthesis - and teacher understand their students. School Science Review. 298, 82, pp. 11-14.

[9] Eskilsson, O., Hellden, G. 2003. A longitudinal study on 10-12-years-olds` conceptions of the transformation of matter. *Chemistry Education: Research and Practice.* 4, 3, 291-304.

[10] Hay, D. 2007. Using concept mapping to measure deep, surface and non-learning outcomes.*Studies in Higher Education.* 32, 1, 39-57.

[11] Kinchin, I.M. 2010. If concept mapping is so helpful to learning biology, why aren`t we all doing it? *Int. J. Sci. Educ*. 23, 12, 1257-1269.

[12] Novak, J.D. 2011. Concept mapping: A useful tool for science education. *Journal of Research in Science Teaching.* 27, 10, 937-949.

[13] Davies, M. 2010. Concept mapping, mind mapping and argument mapping: what are the differences and do they matter? *High. Educ.,* 62, 3, 279-301.

[14] Novak, J.D., Cañas, A. J. 2008. The theory underlying concept maps and how to construct them. Pensacola, FL: Institute for Human and Machine Cognition (IHMC) [WWW] http://cmap.ihmc.us/Publications/ResearchPapers/TheoryCmaps/TheoryUnderlyingConceptMaps.htm (03.01.2016),

[15] Keppens, J. 2007. On concepts map assessment methods and their application to teaching computer programming. [WWW] http://www.kcl.ac.uk/study/learningteaching/kli/research/hern/hern-j1/JeroenKeppenshernjvol1.pdf (6.01.2016).

[16] Cañas, J.A., Bunch, L., Novak, J.D., Reiska, P. 2013. CmapAnalysis: an extensible concept mapanalysis tool. *Journal for Educators, Teachers and Trainers*. 4, 1, 36-46.

[17] Ruiz-Primo, M. A. (2004). Examining concept maps as an assessment tool. In *Concept Maps:Theory, Methodology, Technology, Volume 1* (Alberto J. Cañas, A.J, Novak, J.D., González, F.M., eds). pp. 555-563. NovaText, Spain.

[18] Keppens, J., Hay, J. 2008. Concept map assessment for teaching computer programming.*Computer Science Education*, 18, 1, 31-42. 60.

[19] Croasdell, D.T., Freeman L.A., Urbaczewski A. 2003. Concept Maps for Teaching and Assessment. *Communications of the Association for Information Systems.* 12, 396-405.

[20] Reiska, P., Cañas, A.J., Novak, D., Miller, N.L. 2008. Concept mapping as a tool for meaningful learning and assessment. In: *The Need for a paradigm shift in science education for post-soviet societies (*Holbrook, J., Rannikmäe, M., Reiska, P., Ilsley, P., Lang, P. eds) Germany.

[21] Rannikmäe, M., Soobard, R., Reiska, P. & Holbrook, J. 2014. Student scientific literacy development from grandes 10 to12. *International Journal of Science Education*.

[22] Reiska, P., Soika, K., Möllits, A., Rannikmäe, M. Soobard, R. 2014. Using concept mapping method for assessing students' scientific literacy. *Science Direct.* Global Conference on Contemporary Issues in Education. Las Vegas, USA.