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# SCIENCE TEACHERS' INTERPRETATIONS ABOUT INTERDISCIPLINARY TEACHING

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**Abstract**. In this paper, we target the problem, which has been much debated not only in the field of natural sciences, but across the whole comprehensive school curriculum – interdisciplinarity and interdisciplinary teaching. We first render an overview of some fundamental issues concerning the definition of interdisciplinarity and interdisciplinary teaching. We also consider its virtues and deficiencies as they have emerged in educational practice. Thereafter, we present a small-scale research conducted for examining how Estonian physics teachers (science teachers) understand the concept of interdisciplinary teaching and which aspects they regard most important. The method of *concept mapping* was used for data gathering and assessment. Estonian science teachers' understanding of interdisciplinary teaching is mostly limited to connections between different subjects and topics. Science teachers tend to use in concept maps static and very general linking words. The reason for that could be that they have very little expediencies using concept mapping.

## 1 Introduction

Traditionally, the comprehensive school curriculum has been divided into several subjects, each of which is intended to provide students with competencies in a certain area. Throughout the history of the Western comprehensive school tradition, boundaries between different subjects, or *disciplines*, have been rather well established. Sometimes this has even led educationalists to the claim that different disciplines, representing epistemologically distinct *forms of knowledge*, are mutually incommensurable and boundaries between them insurmountable (e.g. Hirst and Peters 1970, 65).

Natural sciences have commonly constituted an essential part of school curriculum. Via natural sciences, it is intended to provide students with a broad area of competencies necessary in their future educational and professional career and in daily practice.

Recently, the European educational system has experienced a drastic decline of students' interest in natural sciences (European commission 2005). At the same time the social significance of natural sciences and necessity for competent professionals in science and technology persistently grows.
Reasons for this situation are diverse and may vary from country to country. In this paper, we target the problem, which has been much debated not only in the field of natural sciences, but across the whole comprehensive school curriculum – interdisciplinarity and interdisciplinary teaching. Moreover, the topic has been hot throughout the Western higher education system and academic research community, amounting to the most fundamental epistemological, sociological and psychological questions.

Put briefly, interdisciplinary teaching is regarded necessary, since students often perceive learning subjects as isolated from each other and from everyday practice. As Strathern (2007, 125) puts it, interdisciplinarity here becomes a marker of *communicational* success – between students, teachers and scientific communities representing different disciplinary fields.

## 2 Defining interdisciplinarity and interdisciplinary teaching

Most generally, interdisciplinary teaching can be observed as an approach used to teach a unit across different curricular disciplines. Yet the concept is applied in educational literature in various meanings. Besides the term *interdisciplinarity* (and sometimes interchangeably with it), there have been used terms such as *multidisciplinarity*, *transdisciplinarity*, *cross-disciplinarity* and others.

In her seminal book, *Interdisciplinary Curriculum: Design and Implementation* (1989), Heidi H. Jacobs determines interdisciplinary teaching as constructing specific units or courses of study to bring together all the disciplines within the school's curriculum (Jacobs 1989, here: Kysilka 2003, 296). Jacobs explicitly distinguishes between interdisciplinary and *multidisciplinary* teaching, the latter meaning merely to bring together related disciplines in a formal way for analysis and study. Interdisciplinary teaching is thus a step forward from multidisciplinary teaching. However, while interdisciplinary teaching does not aim to supplant the existing disciplines, a more radical approach determined as *complete integration* is distinguished, where curriculum is determined out of the life experiences, needs and interests of students, regardless of the their initial disciplinary framework (*ibid*).

Other researchers agree that interdisciplinarity is more a matter of degree than that of clear contradistinction, whereby *inter*- and other prefixes largely determine this degree. Dillon (2008), basing on an historical account of Moran (2002), mentions that interdisciplinarity is the most widely but also the most indiscriminately used term for breaking out of disciplinary boundaries, while *inter*- refers to *between*, *among*, *mutuality* and reciprocity. Multidisciplinarity, on the other hand, is the juxtaposition of different disciplines, while multi- signifies combination (ibid). In both cases, however, the goals remain limited to the framework of disciplinary research. This leads to the more radical concept of transdisciplinarity, where the goal is the unity of knowledge and which cannot be accomplished within a framework of disciplinary research (Dillon 2008, 256-257). Strathern (2007) also observes the same sequence of multi-, inter- and transdisciplinarity in respect of their radicalism. She mentions that transdisciplinarity not only disrespects disciplinary boundaries, but disrespects institutional ones too (Strathern 2007, 124). Strathern nevertheless notes that many understandings of interdisciplinarity in fact substantially contain the characteristics of transdisciplinarity (ibid, 125).

Still, there are more terms applied in relevant context, such as post-disciplinarity and paradisciplinarity (Dillon 2008, 257), or complementary teaching (Widmer 2005). Without an attempt to dissolve this controversy in this paper, we stay to the term 'interdisciplinary' as the most generic one. As Moran (2002, quoted in Dillon 2008, 257) has pointed out, interdisciplinarity 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.

Although multi-, inter- and transdisciplinary teaching involve somewhat different interpretations, they are commonly perceived as being a clear step forward from the traditional, subject- centered teaching. Issues concerning interdisciplinary teaching and curriculum integration have gained enormous attention by educational and scientific institutions as well as in professional literature and conferences (e.g. Kysilka 2003, 292; Strathern 2007, 125).

Of many attempts to summarize the advantages of interdisciplinary teaching, the Marcella Kysilka's listing is indicative [Although she explicitly applies term *integrated curriculum* in this context, it can be seen throughout her text that she equates it with interdisciplinary teaching in a broad meaning of the term (e.g. *ibid.* 297)]. Kysilka (2003) argues that most advocates of integrated curriculum base their arguments on some fundamental beliefs, supported by positions of many eminent educationalists throughout the 20$^{th}$ century. Her recapitulation of these arguments comprehends the following:

1) Genuine learning takes place as students are engaged in meaningful, purposeful activity.
2) The most significant activities are those which are most directly related to the students' interests and needs.
3) Knowledge in the real world is not applied in bits and pieces but in an integrative fashion.
4) Individuals need to know how to learn and how to think and should not be receptacles of facts.
5) Subject matter is a means, not a goal.
6) Teachers and students need to work co-operatively in the educative process to ensure successful learning.
7) Knowledge is growing exponentially and changing rapidly, it is no longer static and conquerable.
8) Technology is changing access to information, defying lock- step, sequential, predetermined steps in the learning process. (Kysilka 2003, 292-293)

Kysilka warns that all these beliefs are obviously not new, nor are they necessarily confined to an integrated approach to curriculum, nor must they be packaged as a whole (*ibid*, 293). However, the Kysilka's listing embraces lucidly the generally espoused philosophical, psychological and sociological virtues of interdisciplinary teaching. It amounts to propositions about the essence of knowledge as well as about how knowledge should be organized and intermediated for students in constantly changing social circumstances.

This list has been reworded and supplemented by other authors, alternately highlighting whether the advantages of interdisciplinary teaching or deficiencies of the traditional subject-centered teaching. Labbudde (2003), for example, distinguishes between seven pro-arguments for interdisciplinary instruction:

1) Constructive learning approach
2) Comprehension of scientific processes
3) Key problems of mankind
4) School as a place for working through experience: learning from projects
5) Interdisciplinary competence
6) Finding and processing of information in the era of ICT

Conversely, Rogers (2003, 67) summarizes the common objections to the traditional subject-centered teaching, which include a fragmented nature as well as the fixed and one-dimensional quality of attained knowledge, the passivity fostered in students' learning, and the distance from the real-world concerns of many students.

Holbrook and Rannikmäe (1997) have brought out the fundamental criteria for interdisciplinary teaching:

- interdisciplinary teaching covers also the educational purposes, where students actively participate in the learning process;
- teaching a theme begins with relevant student's standpoint;
- students are involved in the learning process and active thinking;
- teaching and learning is student-centered;
- students are involved in acquiring communication skills;
- interdisciplinary teaching is closely connected to natural sciences, components of natural science are almost always entwined into the context of interdisciplinary teaching;

Based on literature we can define different dimensions of interdisciplinary teaching (Kremer & Stäudel, 1997; Labudde, 2003):

1) interdisciplinary form, where one subject uses the knowledge of other subjects
2) subject- binding form, where concepts characteristic to several subjects are systematically and mutually combined
3) theme-oriented form, where one *(or?)* more general theme is studied in different subjects
4) subject complementary form, where cross-curricular themes are studied separately in addition to subject lessons
5) integrated form, where concepts characteristic to different subjects are studied together with interdisciplinary themes, subjects are not taught separately

From the point of view of European teachers the most essential aspects of interdisciplinary instruction are: development of social competences, teamwork with colleagues, transmission of knowledge into other fields, connection of different contexts and considering different perspectives (Szlovak, 2002).

Researche shows that the teachers' understanding of interdisciplinary instruction in natural science is varying (Szlovak, 2002, Widmer 2005). The concept of interdisciplinary instruction is used in many different ways in the literature of science didactics (Kremer & Stäudel, 1997; Labbudde, 2003). There are lots of arguments for interdisciplinary instruction and the results of several empirical researches support it too (Yager, 1993).

## 3 Teachers' interpretations about interdisciplinary teaching

As a result of the above mentioned and many other factors, teachers' interpretations of interdisciplinary teaching may combine in numerous ways. In turn, interpretations of surrounding people, especially of those having a high status, is probably itself a factor influencing one's attitudes towards the interdisciplinary teaching. By the previous sub-chapters, it was intended to indicate that how one interprets interdisciplinary teaching may depend on substantially different factors. One may, for example, build his or her interpretation on some fundamental epistemological standpoint. In this case, one (most probably, a teacher or a dedicated researcher in the field) may hold his or her subject or its methodology as a model applicable for all other sciences and wish to call this *interdisciplinary* teaching. Alternately, one may hold that differences between disciplines are so radical that interdisciplinary cooperation is nearly impossible. In history of philosophy of science, these two theses – *disciplinary hierarchy* thesis and *irreducibility* thesis – have had strong support and have combined in different ways. Attitudes of this kind are relatively secure from sociological factors such as general acceptance or collegiate or institutional support. However, these attitudes may seriously inhibit successful interdisciplinary cooperation.

Another common option is that one's interpretation of interdisciplinary teaching is derived from a sociological factor such as the relative success of interdisciplinary issues in his or her institution or within a certain academic community or professional literature. In school context for example, students' interpretations may be determined by the attitudes of the most evaluated and enthusiastic teachers in the field. All this, in turn, can be shaped in a unique way in case of each student. In sum, number of mutually intertwined factors – epistemological, sociological and psychological – may ground one's interpretation of interdisciplinarity and interdisciplinary teaching.

## 4 Gap between knowledge and attitudes of students in Estonia

The unpopularity of sciences with students is not a new problem in Estonia (Mullis, Gonzalez, Chorstowski, 2004). The poor motivation caused by small interest is one of the reasons of estrangement (Teppo, Rannikmäe, 2005). Thus a conflict between the social needs and the traditional goals and content of teaching sciences and natural science has evolved, which doesn`t guarantee the sufficient number of career choices in the specialties of sciences and technology. The results of the international comparative study (TIMSS) show clearly that the problem of the Estonian students is not the knowledge level in these subjects but the attitudes to science (Martin, Mullis, Chrostowski, 2004).

The isolated instruction of different subjects and its low connection with practical life dominates at our schools. There is also lack of ability to do practical work. In secondary school students should pick up the literacy in natural science, the ability of finding information from literature and media and also the basic knowledge in the writing, forming and presentation of a research work (Henno, 2005). The current curriculums and classes are often too subject dominant. The real work in several subjects is orientated to the state exams and won`t allow the students to see the problems and phenomena as integrated with other subject fields. At the same time the main purpose of teaching should be the formation of relevant knowledge in the subject (Rannikmäe, Reiska, Holbrook, 2005).

In the planned scientific, development and innovation strategies of Estonia - Knowledge based Estonia 2002-2013 - it is considered important to involve students in science research (Haridusministeerium, 2001). Research as a method is being applied in schoolwork in order to eliminate the gap between theory and practice in science education and also to improve the students` technological awareness. It is essential to make the learning of natural sciences important and at the same time to raise the awareness of students in choosing jobs in the field of science and technology (Haridusministeerium, Majandusministeerium, 2001).

A comparative survey carried out in Estonia and Germany 1996-1999 showed that Estonian students have got very good declarative academic results whereas German students were more successful in applying their knowledge to computer simulated activities (Dahncke, Behrendt, Reiska, 2001; Reiska, 1999). The research was carried out among grade 9 students. The concept mapping method designed by the research group was used to test the knowledge (Reiska, 2005, Fischler etc., 2001).

## 5 Methodology and data collection

The aim of this research was to discover how Estonian science teachers understand the concept of interdisciplinary teaching and which aspects do they value as the most important ones. The method of concept mapping was used to gather and assess their knowledge about interdisciplinary teaching. That method was chosen due to an essential similarity- interdisciplinary teaching and concept mapping both requires the ability to create connections and combine various themes and subject fields.

35 teachers from different schools all over Estonia were participants in this research. During several trainings for science teachers they were asked to electronically create a concept map of interdisciplinary teaching using a CmapTools program (Novak & Cañas, 2008). The task was accomplished individually. No specific concepts or thematic areas were given, so while composing the concept map teachers could only rely on and base their map on their own knowledge and personal experience. During the research all created concept maps were analyzed in comparison with the Labudde model.

Labudde, Heitzmann, Heiniger and Widmer (2005) base their model of interdisciplinary teaching on six main dimensions: forms, themes, interdisciplinary competencies, the roles of teachers, methods and assessing, all of which can be further split into a number of sub-dimensions. For example the forms of interdisciplinary teaching divide into the level of subjects and the level of schedule (curriculum). The level of subjects is made of disciplinary-, interdisciplinary- and theme oriented teaching, the level of schedule consists of complementary and integrated teaching etc.

The analysis was mostly based on concept level, it was compared how the concepts used by Estonian science teachers fit into the Labudde model. To express and compare the results a table was created where each row stood for one teacher and columns stated: all concepts, all propositions, propositions with medium quality, propositions with high quality, subjects, collaboration and additionally six dimensions from Labudde`s model (forms, themes, interdisciplinary competence, roles of teachers, methods, assessments and evaluation) (Table 1).

## 6 Results

In figure 1. a typical concept map from an Estonian science teacher is represented.

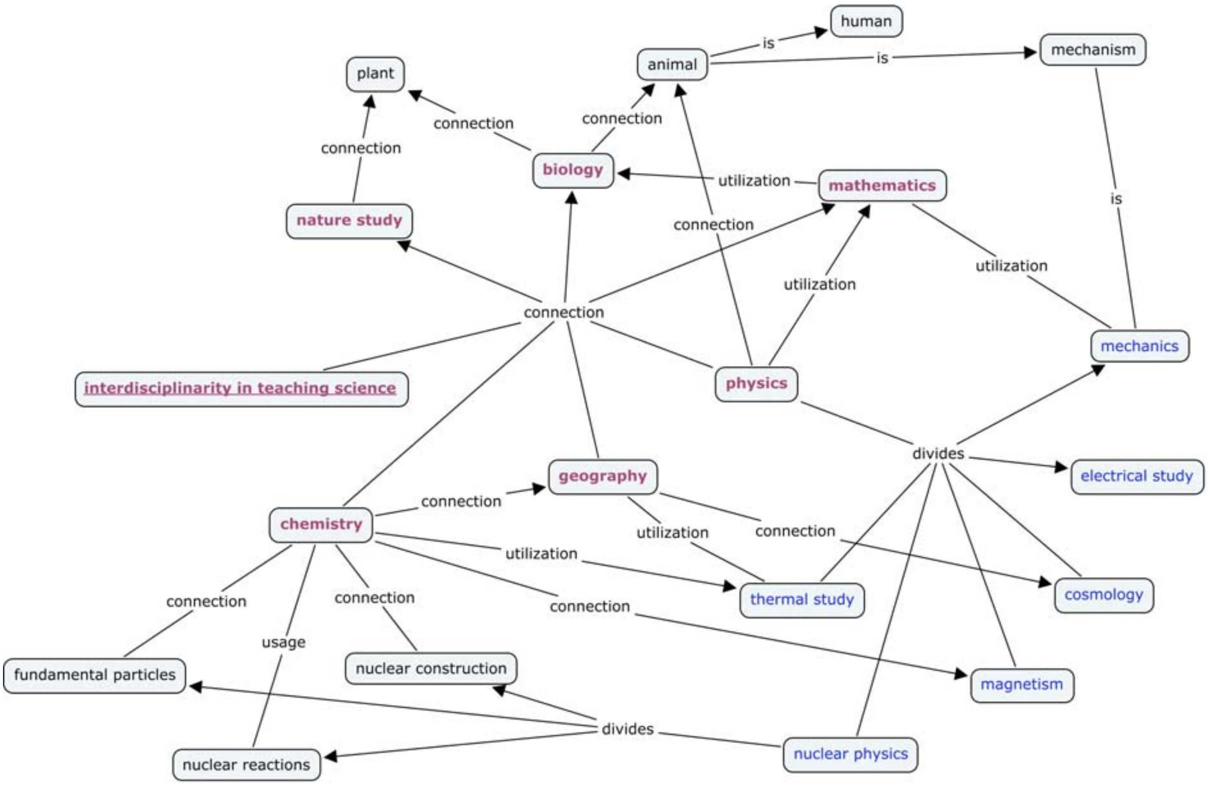


**Figure 1.** A typical concept map from an Estonian science teacher about interdisciplinary teaching

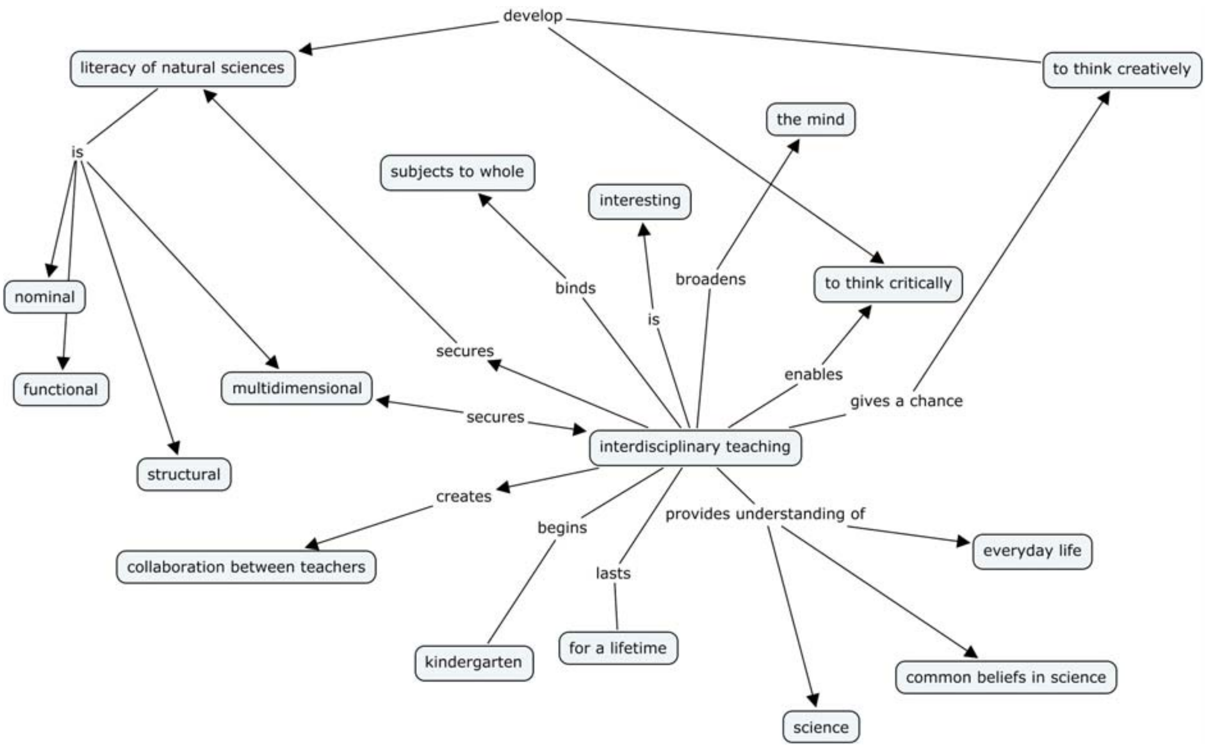


**Figure 2.** A concept map which represents different dimensions of interdisciplinary teaching

Estonian science teachers interpreting usually the interdisciplinary teaching just on curriculum level. This means that they tend to find connections between different subjects and topics. It's also common that they describe the connections in the most general way (see Fig. 1.). On the map in the figure 2 are also other dimensions of interdisciplinary teaching represented (e.g. collaboration). In table 1 all the data from science teachers' concept map are presented.

**Table 1.** Data from science teachers' concept maps.

| | Variables | | | | | | Concepts from Different Dimensions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Teacher | All Concepts | All Propositions | Prop. with Medium Quality | Prop. with High Quality | Subjects | Colloboration | Forms | Themes | Interdisciplinary competences | Teacher Roles | Methods | Assessment and Evaluation |
| 1 | 13 | 14 | 0 | 0 | 5 | 0 | 5 | 0 | 3 | 1 | 1 | 3 |
| 2 | 14 | 21 | 4 | 0 | 5 | 0 | 6 | 7 | 0 | 0 | 1 | 0 |
| 3 | 11 | 10 | 4 | 6 | 8 | 0 | 8 | 3 | 0 | 0 | 0 | 0 |
| 4 | 14 | 18 | 0 | 0 | 4 | 0 | 6 | 2 | 1 | 1 | 2 | 2 |
| 5 | 14 | 19 | 19 | 0 | 5 | 0 | 5 | 9 | 0 | 0 | 0 | 0 |
| 6 | 13 | 24 | 0 | 0 | 5 | 0 | 6 | 4 | 1 | 0 | 2 | 0 |
| 7 | 13 | 14 | 8 | 0 | 4 | 0 | 5 | 4 | 1 | 2 | 1 | 0 |
| 8 | 13 | 16 | 11 | 0 | 5 | 0 | 6 | 0 | 3 | 2 | 1 | 1 |
| 9 | 7 | 21 | 0 | 0 | 6 | 0 | 7 | 0 | 0 | 0 | 0 | 0 |
| 10 | 13 | 16 | 0 | 0 | 5 | 0 | 6 | 7 | 0 | 0 | 0 | 0 |
| 11 | 10 | 9 | 0 | 0 | 0 | 0 | 0 | 9 | 1 | 0 | 0 | 0 |
| 12 | 15 | 11 | 0 | 0 | 5 | 0 | 5 | 9 | 0 | 0 | 1 | 0 |
| 13 | 20 | 33 | 0 | 0 | 5 | 0 | 6 | 13 | 1 | 0 | 0 | 0 |
| 14 | 12 | 14 | 0 | 0 | 4 | 0 | 5 | 7 | 0 | 0 | 0 | 0 |
| 15 | 9 | 12 | 0 | 0 | 4 | 0 | 5 | 2 | 1 | 0 | 1 | 0 |
| 16 | 22 | 38 | 0 | 0 | 5 | 2 | 7 | 0 | 3 | 1 | 9 | 2 |
| 17 | 5 | 7 | 7 | 0 | 0 | 0 | 3 | 0 | 3 | 1 | 1 | 0 |
| 18 | 13 | 15 | 0 | 0 | 4 | 0 | 4 | 9 | 0 | 0 | 0 | 0 |
| 19 | 7 | 6 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 1 | 1 |
| 20 | 12 | 15 | 5 | 10 | 0 | 0 | 1 | 3 | 4 | 1 | 3 | 0 |
| 21 | 9 | 15 | 10 | 0 | 5 | 0 | 7 | 0 | 2 | 0 | 0 | 0 |
| 22 | 8 | 15 | 0 | 0 | 5 | 0 | 6 | 0 | 1 | 1 | 0 | 0 |
| 23 | 12 | 12 | 10 | 0 | 0 | 0 | 1 | 5 | 4 | 0 | 2 | 0 |
| 24 | 18 | 14 | 0 | 0 | 7 | 0 | 9 | 6 | 3 | 0 | 0 | 0 |
| 25 | 15 | 15 | 0 | 0 | 5 | 0 | 6 | 8 | 0 | 0 | 1 | 0 |
| 26 | 5 | 7 | 0 | 0 | 5 | 0 | 5 | 0 | 0 | 0 | 0 | 0 |
| 27 | 9 | 16 | 0 | 0 | 8 | 0 | 8 | 1 | 0 | 0 | 0 | 0 |
| 28 | 8 | 10 | 0 | 0 | 6 | 0 | 7 | 1 | 0 | 0 | 0 | 0 |
| 29 | 16 | 19 | 8 | 0 | 1 | 1 | 4 | 0 | 7 | 1 | 4 | 0 |
| 30 | 11 | 16 | 7 | 0 | 9 | 0 | 8 | 0 | 1 | 0 | 1 | 0 |
| 31 | 11 | 10 | 0 | 0 | 6 | 0 | 6 | 5 | 0 | 0 | 0 | 0 |
| 32 | 9 | 8 | 0 | 0 | 0 | 1 | 5 | 0 | 1 | 1 | 2 | 0 |
| 33 | 12 | 12 | 0 | 0 | 8 | 0 | 8 | 2 | 2 | 0 | 0 | 0 |
| 34 | 7 | 7 | 0 | 0 | 3 | 0 | 4 | 3 | 0 | 0 | 0 | 0 |
| 35 | 12 | 18 | 8 | 0 | 5 | 0 | 8 | 4 | 0 | 0 | 0 | 0 |
| **Avg.** | **11,77** | **15,06** | **2,89** | **0,46** | **4,34** | **0,09** | **5,43** | **3,51** | **1,29** | **0,37** | **0,97** | **0,26** |

In table 1 we can see that the quality of propositions is weak. The main reason for that is, that the teachers don't describe the links exactly enough and they use very general linking words. They use mostly concepts from "subject" category. Comparing the maps with the Labudde's model we can see that the teacher are using concepts mostly just from two dimensions: "Forms" and "Themes".

## 7 Summary

Estonian science teachers' understanding of interdisciplinary teaching is mostly limited to connections between different subjects and topics. Other dimensions of interdisciplinary teaching are in maps very rarely presented. Science teachers tend to use in concept maps static and very general linking words. The reason for that could be that they have very little expediencies using concept mapping.

## References


Ausubel, D. P., Novak, J. D., & Hanesian, H. (1978). Educational psychology: A cognitive view (2nd ed.). New York: Holt, Rinehart and Winston.

Brophy, J. and Alleman, J. (1991). A Caveat: Curriculum Integration Isn't Always a Good Idea, Educational Leadership 49 (2), 66.

Dahncke, H., Behrendt, H., Reiska, P. (2001). A Comparison of STS-Teaching and Traditional Physics Lessons – On the Correlation of Physics Knowledge and Taking Action. In: Behrendt, H., Dahncke, H., Duit, R., Gräber, W., Komorek, M., Kross, A., Reiska, P. (Ed.): Research in Science Education – Past, Present, and Future. Kluwer Academic Publishers, 77-82.

Dillon, B. (2008). A pedagogy of connection and boundary crossings: methodological and epistemological transactions in working across and between disciplines, Innovations in Education and Teaching International 45 (3), 255-262.

Fischler, H., Peuckert, J., Dahncke, H., Behrendt, H., Reiska, P., Pushkin, D., Bandiera, M., Vicentini, M., Fiscer, H., Hucke, L., Gerull, K., Frost, J. (2001). Concept Mapping as a Tool for Research in Science Education. In: Behrendt, Dahncke, Duit, Gräber, Komorek, Kross, Reiska (Eds.): Research in Science Education – Past, Present and Future, p. 217-224. Kluwer Academic Publishers, The Netherlands, Dordrecht.

Henno, I. (2005). Loodusteaduslik kirjaoskus kui prioriteet rahvusvahelistes võrdlusuuringutes ja riiklikus õppekavas. – Loodusainete õpetamisest koolis I osa. Tallinn: Riiklik Eksami- ja Kvalifikatsioonikeskus, 15-24.

Hirst, P. H. and Peters, R. (1970). The Logic of Education. London: Routledge and Kegan Paul.

Holbrook, J., Rannikmäe, M. (1997). Suplementary Teaching Materials – Promoting Scientific and Technological Literacy. Tartu.

Hyerle, D. (1996). "Visual Tools for constructing knowledge", ASCD press. Alexandria, Virginia.

Jacobs, H.H. (1989). Interdisciplinary Curriculum: Design and Implementation. Alexandria, Va.: Association for Supervision and Curriculum Development.

Katz, C. (2001). Disciplining interdisiciplinarity, Feminist Studies 27 (2), 519-525.

Kremer, A. & Stäudel, L. 1997. Zum Stand des fächerübergreifenden naturwissenschaftlichen Unterrichts in der Bundesrepublik Deutschland. Zeitschrift für Didaktik der Naturwissenschaften, 3/3, 52-66.

Kysilka, M. L (2003) Understanding integrated curriculum, Curriculum Studies. Major Themes in Education II (ed. Scott, D), London: RoutlegdeFalmer, 292-303.

Labudde, P. (2003). Fächer übergreifender Unterricht in und mit Physik: Eine zu wenig Genutzte Chance. Physik und Didaktik in Schule und Hochschule, 1 (2), 48-66.

Labudde, P., Heitzmann, A., Heiniger, P., Widmer, I. (2005). Dimensionen und Facetten des fächerübergreifenden naturwissenschaften Unterrichts: Ein Modell. Zeitschrift für Didaktik der Naturwissenschaften.

MacKenzie, J (1998). Forms of Knowledge and Forms of Discussion, *Educational Philosophy & Theory* 30 (1), 27-49.

Martin, M.O., Mullis, I.V.S., & Chrostowski, S.J. (Eds.) (2004). TIMSS 2003 Technical Report. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Ministry of Education (2001). Estonian education strategy “Learning Estonia”. Tallinn.

Ministry of Education, Ministry of Economic Affairs (2001). Knowledge-based Estonia: Estonian research and development strategy 2002-2006. Tallinn

Mullis, I.V.S., Gonzalez, E.J., & Chrostowski, S.J. (2004). TIMSS 2003 International Science Report, Chestnut Hill, MA; TIMSS & PIRLS International Study Center, Boston College.

Novak, J.D. (1995). Concept Mapping: A Strategy for Organizing Knowledge. In: Glynn, S.M., Duit, R. (Hrsg.): Learning Science in the Schools: Research Reforming Practise. Mahwah, New Jersey: Lawrence Erlbaum Associates Publishers.

Novak, J. D. (1998). Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations. Mahwah, NJ: Lawrence Erlbaum Associates.

Novak, J.D., Cañas, A.J. (2008): The Theory Underlying Concept Maps and How to Construct and Use Them. Technical Report IHMC CmapTools 2006-01 Rev 01-2008. Florida Institute for Human and Machine Cognition.

Novak, J. D., & Musonda, D. (1991). A twelve-year longitudinal study of science concept learning. American Educational Research Journal, 28(1), 117-153.

Rannikmäe, M.; Dahncke, H.; Reiska, Priit; Holbrook, J. (2005). Using socially derived teaching approaches in science classes-can we change students attitudes towards science learning? Barcelona:, 2005, (Proceedings of the Fifth International ESERA Conference on Contributions of Research to Enhancing Students' Interest in Learning Science).

Reiska, P. (1999). Physiklernen und Handeln von Schülern in Estland und in Deutschland. Eine empirische Untersuchung zu zwei unterschiedlichen Unterrichtskonzepten im Bereich von Energie und Energieversorgung mit den Methoden Concept Mapping and Computersimulation. Frankfurt a. M.: Peter Lang.

Reiska, P. (2005). Experimente and Computersimulationen. Empirische Untersuchung zum Handeln im Experiment und am Computer unter dem Einfluss von physikalischem Wissen. Frankfurt a. M.: Peter Lang.

Rhoten, D. (2004). Interdisciplinary Research: Trend of Transition? Social Science Research Council Items and Issues.

Rogers, B (2003) Informing the shape of the curriculum: new views f knowledge and its representation in schooling, Curriculum Studies. Major Themes in Education II (ed. Scott, D), London: RoutlegdeFalmer, 65-94.

Szlovak, B. (2002). Fächer übergreifender Unterricht in Berufsschulen: Der Status quo aus der Sicht von Lehrpersonen. Bern.

Strathern, M (2007) Interdisciplinarity: some models from the human sciences, Interdisciplinary Science Reviews 32 (2): 123-134.

Teppo, M.; Rannikmäe, M. (2005). Possibilities for making school science relevant for students. Proceedings of ESERA Contributions of Research to Enhancing Students Interest in Learning Science.

White, A.M. (1981). Putting case-based instruction into context: Example for legal and medical education. The Journal of the Learning Science, 2(4).

Widmer, I. (2005): Realizing integrated science instruction at the upper secondary level – The chances and challenges of assessment from the teacher´s perspective. In Fischer, H. (Ed.). Developing standards in research on science education. London: Taylor and Francis (pp 241-245).

Yager, R.E. & Tamir, P. (1993): STS Approach: Reasons, Intentions, Accomplishments, and Outcomes. Science Education 77, 637-658.