The change in student scientific literacy levels during gymnasium studies

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Summary

Introduction

Over the last decade, much of the research in science education has focused on measuring 14-15-year-old students' achievements and attitudes in learning science (OECD, 2007; TIMMS). For example, the PISA 2006 (OECD, 2007) international study, designed to test scientific literacy gains, showed that the performances of Estonian 15-year-old (grade 9) students were ranked highly (5th in the study), whereas their ability to solve problems and make decisions was at a lower level. Fewer studies have been conducted at the upper secondary level (Choi et al., 2011) and there are no similar PISA studies for students studying at higher grade levels.

The aims of this research:

1. To develop theoretically justified instruments for determining the levels of scientific literacy among gymnasium students.
2. To describe the development of scientific literacy promoted among students throughout gymnasium studies.

Research questions:

1. What is the level of scientific literacy among gymnasium students determined through problem-solving skills, reasoned decision-making skills, use of interdisciplinary knowledge skills, understanding the nature of science and student self-perceptions of competences measured?
2. How do students' concepts and phrases interlinking scientific and socio-scientific concepts interrelate with learning skills associated with scientific literacy?
3. How do levels of scientific literacy change during gymnasium studies?

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Theoretical background

The overall goal of science education is seen as promoting scientific literacy (Roberts, 2007). For this study, scientific literacy (SL) is taken to mean developing an ability, to creatively utilise 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 socio-scientific decisions (Holbrook & Rannikmäe, 2009). Everyday life and socio-scientific situations are usually complex. Any assessment of scientific literacy needs to relate to competences, based on those motivating students to give meaningful answers (Bennett et al., 2007), those where students utilise knowledge and skills for problem-solving and decision-making in real life (Feinstein, 2010; Holbrook & Rannikmäe, 2007) and finally those related to shaping an accurate awareness of one's own competence (Baartman & Ruijs, 2011). This indicates scientific literacy goes beyond cognitive learning and includes a self-perception component (Choi et al., 2011; Tytler, 2014).

Scientific literacy changes with time; it is not a continuum and depends on many factors, including students' age and interactions with society taking place outside the science classroom (Bybee, 1993). Bybee (1993) defines four levels of scientific literacy, which are expressed in wider terms than just a measurable achievement of students' cognitive outcomes. It is clear that for identifying the levels of SL, cognitive test and questionnaires are not sufficient. A range of updated and complex tools are needed.

In Estonia, at the gymnasium level, students compulsorily study science subjects, divided into biology, chemistry, physics and geography separately, and each subject is taught by a different teacher (Gümnaasiumi riiklik õppekava, 2011). However, the Estonian curriculum is competence-based and built around an internationally accepted philosophy of scientific literacy, with the separate science disciplines still expressed through curriculum sub-divisions. This raises the issue as to whether the teaching within each of the separate science subjects is equally promoting scientific literacy components, or students perceive these sub-divisions in different ways. Research carried out by the authors showed that the gymnasium students' ability to reproduce subject-related knowledge is subject specific, the highest being biology and lowest chemistry. Students also agree that science subjects develop the competence to recognise the importance of science in society, but disagree that science subjects, in general, focus on aspects of problem solving (Soobard & Rannikmäe, 2014).

Methodology

This research was the first systematic study to investigate the change of scientific literacy (SL) levels among Estonian gymnasium level students. A representative sample was composed of 2,216 students from 42 schools. Schools were chosen based on location (the capital; cities with at least two gymnasiums, and rural areas) and the students' mean national examination results within the school. Grade 10 students were tested again at the grade 12 level, when student number dropped to 2010. Throughout the 3 year period of the study, 1335 students participated at both levels.

An instrument was created for measuring the levels of SL. The originality of the research is linked to a multi-dimensional testing approach in four categories: cognitive (science skills and knowledge), philosophical (understanding the nature of science versus pseudoscience), attitudinal aspects and analytical (creating computer-based Cmaps). This research employs the use of Cmap techniques (Cañas et al., 2015) for triangulation of students' science cognitive learning outcomes and for modelling students' socio-scientifically conceptualised behaviour in real-life situations. The total instrument was administered in four parts.

Part 1 was a carefully constructed, contextualised test instrument, consisting of 4 interdisciplinary everyday life related scenarios, each focusing on one science subject (Biology, Chemistry, Geography, Physics) and to test the students' skills to give a scientific explanation, pose scientific questions, solve scientific problems, draw evidence based conclusions, interpret graphs and figures and to make reasoned decisions. Test item constructions followed the SOLO taxonomy (Biggs & Collis, 1982). Students' responses were analysed using a three-point scale (0 – no or incorrect response, 1 – partial credit, 2 – full credit). Content validity was checked by expert opinion: four independent science teachers and four university science faculty staff members.

Part 2 was testing the students' understanding of the nature of science, including the students' ability to differentiate pseudoscience from science. Students expressed their agreements with the given statements, "agree" and "disagree." They were also asked to explain their answers. Students' reasoning was categorised into scientific, everyday-related and mistaken/misconceptions. Categorisation was validated by independent experts.

Part 3 was testing self-perceptions against the skills important for scientific literacy using a 4-point Likert scale. The instrument was validated by using expert opinion.

For part 4, a Cmap instrument was linked with interdisciplinary scenarios from the cognitive test in part 1. To create Cmaps, 30 different types (science processes, everyday social issues-related) of concepts were given to students. This part of the total instrument was used for triangulation and the number of students involved in this part was smaller. The results were analysed in terms of the total number of links between the concepts, structure and nature of central concepts and correctness of the sentences between the concepts.

The complex instrument was piloted among upper secondary school students who did not participate in the current study. Construct validity was undertaken by an analysis of Estonian gymnasium science curricula in the four subjects to ensure that the test instrument was valid in terms of its learning content and expected learning outcomes. The reliability, calculated using Cronbach alpha for section 1 was 0.85, for section 2, 0.82 and for section 3, 0.93. The first three parts were administered at the same time (90 min.). One scenario was kept the same for each student in both grade 10 and grade 12 testing, while the second scenario varied for every student. Cmap construction took place in a computer class (45 min.) within 2 weeks following the first testing.

Results and discussion

Students' cognitive skills are at the same level among grade 10 and grade 12 students. However, the means are statistically different (the sample was large), although the overall mean values are relatively low and there is little increase. Although the mean score of higher order skills for grade 12 is notably low – in general, the ability of students' to solve problems remained at a low level even after two years of learning. These findings confirm that the warning messages from PISA studies (OECD, 2016) are being experienced at gymnasium level. Memorisation of science content and the use of interdisciplinary knowledge in student familiar situations achieve better results than higher order thinking skills. More detailed analyses show that approximately 60% of students fail to exhibit, or show very little change at the various skills levels, and at the same time there is little difference between those students whose scores have risen or fallen.

Thus the questions arising are: What is happening at gymnasium level? Are we to understand that all competences related to scientific literacy in the Estonian curriculum (Gümnaasiumi riiklik õppekava, 2011; Holbrook & Rannikmäe, 2009) are being assessed? Were teachers following Robert's vision II, or only focusing their assessment along the lines of vision I? As there was almost no difference in grade 12 students test results between the school groups, compiled against the mean of the final examination results per school, it became obvious that the final school examination was targeted towards assessment of curriculum content. Analyses of Cmaps created by students showed a correlation between meaningful links formed between the concepts and cognitive test results, confirming the necessity to include this type of analytical measure into assessment tools (Soika & Reiska, 2014). However, students' decision making and reasoning skills were poor (less than 20% of students exhibited excellence in this area), while students' self-perception of their metacognitive skills showed high attainment of these skills. From a positive viewpoint, students whose understanding of the nature of science, measured in terms of the type of reasoning, remained constant and were interchangeable among both grade levels (defined by Wellington, 2000).

Table 1 illustrates the differences at individual student levels, and shows that whilst there is no change of level among 30% of students, 40% of students change across only one level. The outcome of the study points to no statistical change in the levels of SL during grade 10 to 12 studies. This suggests that little learning is taking place beyond content knowledge and referencing, based on the Bybee (1997) description of levels of SL, and that most students remain at the structural and functional levels of SL. Our research confirms the need to concentrate on students with the lowest achievement levels, to push them to achieve at a higher level, and on students achieving at the highest level, to prevent them dropping to lower SL levels. However, the new competence-based curriculum, launched in 2011 (Gümnaasiumi riiklik õppekava, 2011), indicates the need for a paradigm shift in interpreting the curriculum and widening the scope of science teaching (Holbrook, 2008).

Table 1. Change of the levels of cognitive component of SL throughout the gymnasium studies where -3 is dropping 3 levels in grade 12 compared to grade 10

		Change of SL							
		–3	–2	–1	0	1	2	3	Total
Level at 10	1	0	0	0	79	98	34	22	233
	2	0	0	107	193	95	79	0	474
	3	0	62	177	103	104	0	0	446
	4	8	45	59	70	0	0	0	182
Total		8	107	343	445	297	113	22	1335

Outcome from the study points to no statistical change in the levels of SL from grade 10 to 12.

Further considerations

During their gymnasium years, students' levels, related to SL cognitive components, show little change. If there is change, it is in content acquisition rather than in abilities in problem solving, or decision-making. Whilst it is important to teach the skills contained in the curriculum, teachers should pay more attention to promoting problem solving and the decision-making skills of the students.

There is a need to overcome the gap between the skills promoted in the different disciplines so that the education offered is seen as promoting the range of education goals, linked to the development of levels of scientific literacy. This is in line with the concept of more emphasis on interdisciplinary, 'education through science' rather than isolationism of subjects associated with 'science through education' (Holbrook & Rannikmäe, 2007).

A new type of Cmap analysis is being developed for analysing student skills to create concept maps and a formula created for diagnosing students' levels of interdisciplinary knowledge using Cmaps. The outcomes suggested that there was a need to initiate discussion at the political level to seek ways to update the teaching of science in schools.

Keywords: scientific literacy, Cmaps, nature of science