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REGINA SOOBARD

A study of gymnasium students' scientific literacy development based on determinants of cognitive learning outcomes and self-perception

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A study of gymnasium students' scientific literacy development based on determinants of cognitive learning outcomes and self-perception

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PRESS

Science Education Centre, Faculty of Science and Technology, University of Tartu, Estonia

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LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original publications, which are referenced in the text by their Roman numbers:

I. **Soobard, R.**, & Rannikmäe, M. (2011). Assessing student's level of scientific literacy using interdisciplinary scenarios. *Science Education International*, 22(2), 133–144.

II. **Soobard, R.**, & Rannikmäe, M. (2014). Upper secondary students' self-perceptions of both their competence in problem solving, decision making and reasoning within science subjects and their future careers. *Journal of Baltic Science Education*, 13(4), 544–558.

III. **Soobard, R.**, & Rannikmäe, M. (2015). Examining curriculum related progress using a context-based test instrument – a comparison of Estonian grade 10 and 11 students. *Science Education International*, 26(3). (accepted).

IV. **Soobard, R.,** Rannikmäe, M. & Reiska, P. (2015). Upper Secondary Schools Students' progression in operational scientific skills – a comparison between grade 10 and 12. *Procedia Social and Behavioral Sciences*, 177, 295–299.

The Author's contributors to the original publications are stated below:

Paper I: designing the study; formulating the research questions; undertaking data collection and analysis; writing the paper as the main author.
Paper II: designing the study; formulating the research questions; undertaking data collection and analysis; writing the paper as the main author.
Paper III: designing the study; formulating the research questions; undertaking data collection and analysis; writing the paper as the main author
Paper IV: designing the study; formulating the research questions; undertaking data collection and analysis; writing the paper as the main author.

OTHER PUBLICATIONS

The following publications are related to this thesis.

1. Soobard, R., Rannikmäe, M. & Reiska, P. (2014). Upper Secondary Students' Progress in Operational Scientific Literacy Skills Compared to Their Self-perceptions Against the Same Skills. *ICERI2014 Proceedings*, 1296–1302.
2. Reiska, P., Soika, K., Möllits, A., Rannikmäe, M. & Soobard, R. (2015). Using Concept Mapping method for assessing students' Scientific Literacy. *Procedia Social and Behavioral Science*, 177, 352–357.
3. Soobard, R., Rannikmäe, M. & Lavonen, J. (2010). Monitoring High School Students' Scientific Literacy through Earth Science Related Issues. In: J. Holbrook, M. Rannikmäe, R. Soobard, B. Cavas, & M. Kim (Eds.), *Innovation in Science and Technology Education: Research, Policy, Practice: ICASE 2010*; Tartu, Estonia; June 28-July 2. Tartu: Ecoprint AS, 296–298.
4. Ait, K., Rannikmäe, M., Soobard, R., Reiska, P. & Holbrook, J. (2015). Students' Self-Efficacy and Values Based on A 21st Century Vision of Scientific Literacy – A Pilot Study. *Procedia Social and Behavioral Sciences*, 177, 491–495.
5. Rannikmäe, M., Soobard, R., Teppo, M., Valdmann, A. & Holbrook, J. (2014). Kontekstipõhine õpetamine. M. Rannikmäe, & R. Soobard (Toim.), *Paradigmaatilised suundumused loodusainete õpetamisel üldhariduskoolis* (pp. 62–70). Tartu, Eesti: Eesti Ülikoolide Kirjastus.
6. Rannikmäe, M. & Soobard, R. (2014). Loodusteaduslik ja tehnoloogia-alane kirjaoskus ja selle erinevad tasemed. M. Rannikmäe, & R. Soobard (Toim.), *Paradigmaatilised suundumused loodusainete õpetamisel üldhariduskoo*lis (pp. 11–20). Tartu, Eesti: Eesti Ülikoolide Kirjastus.

1. INTRODUCTION

A major goal for education is the development of key competences (Eurydice, 2011) while, in science education, the target is expressed in terms of scientific literacy (Estonian Government, 2011). The need for more students to reach higher levels of scientific literacy has been an educational target over many decades, even though an exact definition of scientific literacy is debatable. It has been claimed that the term scientific literacy was first used by Paul DeHart Hurd (1958) related to education in American schools at a time when the Russian launch of 'sputnik' had stirred up public debate about the role of science teaching in schools. Since then, the meaning of scientific literacy (and sometimes science literacy or scientific and technological literacy) has been subjected to various, even dramatic, changes in evolving technology-rich societies, especially in relation to the perceived needs for future citizens.

Related to these deliberations, the concept of scientific literacy has moved away from the earlier view, seeing it as solely content knowledge acquisition, to include usage of this knowledge; for example, being able to relate scientific knowledge to society-related problem solving and decision making situations (AAAS, 1989; 1993; NRC, 1996). An outcome from a 1993 UNESCO held, international conference on STE (science and technology education for all) was the initiation of Project 2000+ (a project especially recognising formal and informal aspects of STL (scientific and technological literacy) and building on a declaration from the World Conference on Education for All in 1990. The declaration stated that 'every person shall be able to benefit from educational opportunities designed to meet basic learning needs. These needs comprise both essential tools (such as literacy) and basic learning content (knowledge, skills, values and attitudes) required by human beings to be able to participate fully to improve the quality of their lives, to make informed decisions and to continue learning)' (WCEFA Jomtien conference, 1990).

The meaning of scientific literacy (both SL and STL tend to be used interchangeably depending on whether there is stress on the inevitable inclusion of technology education in science education) has further developed by recognising person-related and society-related attributes in addition to those geared to basic learning needs (Holbrook & Rannikmäe, 1997). This is in line with the need for the teaching of science to involve the development of responsible citizens and with this the need to promote skills associated with problem solving and decision making at personal, social and global levels. This focus of scientific literacy encompasses personal healthcare, safety and social problems, such as how to respond to concerns over climate changes or ecosystems (Bybee, 1993; Holbrook & Rannikmäe, 1997). Later developments further embraced the need for an emphasis on being engaged in meaningful science education, especially related to preparations for a future career, recognising students need to possess positive attitudes towards science in terms of self-perception and meta-cognition (Holbrook & Rannikmäe, 2009; Choi, Lee, Shin, Kim, & Krajcik, 2011; Tseng, Chang, Lou & Chen, 2013; Uitto, 2014).

The changing conception of scientific literacy had an impact on curriculum intentions and hence the development of curricula as well as science teaching approaches. As a result, science teaching began to place more emphasis on promoting the inclusion of real life contexts (e.g. personal healthcare, safety, environmental issues) and especially as starting points for science learning; the so-called context-based, or STS (science-technology-society) approach (Bennet, Lubben & Hogarth, 2007). Even more, such an approach recognised focused on broader educational contexts, noting the need to interrelate science education as one of many subjects within school education promoting the key educational competences (Holbrook & Rannikmäe, 1997; 2009).

The teaching approach associated with the changing conceptualisation of science education was unfamiliar to many science teachers and while textbooks and examinations remained oriented towards subject matter, the introduction of a broader education context through the teaching of science subjects became problematic. There was a recognised need for teaching to be refocused, move away from teaching in a scientist-centred way (sometimes viewed as 'science through education') towards enhancing wider educational goals at a personal and social level. In contrast, this view could be considered as 'education through science' (Holbrook & Rannikmäe, 2007). Associated with this refocusing, Choi and colleagues (2011) added teaching needs seen as strengthening the development of a person's own awareness of competence, the need for meta-cognition and the need for understanding about connections between science and society. These added to the preparedness of students to act in real life situations.

A perceived solution to encompassing these more diverse aspects of scientific literacy was for countries to move towards the adoption of competence-based curricula (Dillon, 2009; DeBoer, 2011). This move enabled teaching, as well as assessment, to focus on student learning outcomes, rather than the hitherto emphasis on isolated, teacher rather than student focused, teaching objectives (Eurydice, 2002; 2011).

In line with the European trend, Estonia, in 2011, adopted a new competence-based school curriculum with a stated purpose, for the science education component, of promoting scientific literacy. The promotion of scientific literacy within the Estonian science curricula was based on the stated need to enhance:

- students' acquisition of science-related knowledge;
- knowledge about science (referred to as nature of science);
- skills to give scientific explanations;
- problems solving attributes following appropriate scientific methods;
- making reasoned decisions (including reasoning related to socio-scientific issues);
- possession of positive attitude towards science, science learning, and
- an awareness of future careers.

(Estonian Government, 2011).

At that time, it was recognised that implementation of the new curriculum would not be easy as its impact on teaching and assessment would be affected in multiple ways. For example:

Curriculum

- The focus on a competence-based curriculum (Estonian Government, 2011) meant a move away from a concentration on single subject, isolated knowledge and skills and a focus on wider learning outcomes. It would require teachers' possessing a readiness to change as well as adopting new ways of teaching (Vaino, 2013).

Teacher and teaching

- Changing the way of perceiving science education (promoting the wider conceptualisation of scientific literacy) would be dependent on teachers' personal beliefs and be strongly associated with available learning (including assessment) materials (Vaino, 2013).
- From the science teachers' perspective, change would be dependent on necessary teachers' background knowledge, skills, experiences and willingness to change as well an ability to adopt new ways of teaching and assessing (Corrigan, Buntting, Jones & Gunstone, 2013).
- Moving away from science teachers' heavy reliance on content, as given in science textbooks (Laius & Rannikmäe, 2004; Laius, 2011), could be anticipated to be a major issue.

Assessment

- As traditionally assessment in science education was subject-focused and based on science concepts, theories, facts, laws and applications in subject contexts (Laugksch, 2000), this was also the case in Estonia (Holbrook, 2008). Moving to assess enhanced scientific literacy attributes would be problematic.
- As scientific literacy included more than a cognitive dimension (Holbrook & Rannikmäe, 2009; Choi et al., 2011), a further perceived problem for teachers would be determining assessment strategies incorporating multiple dimensions related to scientific literacy (such as, perception aspects, nature of science, career awareness and employability skills, interests) (Fensham, 2013).
- As most research studies in assessment tended to focus on one, rather than the multitude of facets within scientific literacy, usually in a cognitive sense (see Gormally, Brickman & Lutz, 2012; Rundgren, Chang Rundgren, Tseng, Lin & Chang, 2010; Jarman & McClune, 2007; Sadler & Zeidler, 2005; Miller, 1997), teacher preparedness needs were unknown.
- In fact, there was little perceived concern for implementation of the change in Estonia. Indicators assessing scientific literacy, such as from the Programme for International Student Assessment (PISA) by Estonian grade 9

(15-years) students, showed high, well ranked performances (5^{th}, based on 2006 assessment). This was the case, even though a more detailed analysis (OECD, 2007) showed that grade 9 students were strong in giving scientific explanations (above the OECD average), but not so able in identifying scientific problems (below the OECD average), or using scientific evidence (OECD average result).

The concern

No studies have been undertaken to measure the extent of Estonian students' scientific literacy at the end of the gymnasium level (based on, for example important attributes seen as problem solving, reasoned decision making, and giving scientific explanations). Noting the OECD (2007) report indicating Estonian students have difficulties in learning related to using problem solving and decision-making in grade 9, the question arises as to whether the same trend continues into gymnasium studies. Assuming teachers do implement a wider competence-based approach, can gymnasium students cope with the range of educational expectations promoted by different types of test items (open response, complex multiple choice items compared to recall only items), seen as necessary to use in assessment instruments (Fensham, 2013).

In a competence-based approach, students' attitudes, interests and perceptions need to be also a diagnostic part of assessment, as these aspects are shown to lead to a more precise indicator of students' scientific literacy (Choi et al., 2011). In Estonia, no such studies have been carried out in these areas, even though recognised as an important aspect (OECD, 2007; 2013; Fensham, 2013).

A further concern is whether teachers are sufficiently prepared, not only for implementation of the new competence-based curriculum in 2011, but also in being able to determine student progress. Identification of affective learning (e.g. perceptions of achievement, career preferences) needs to be recognised as an important part in the classroom assessment of student learning for diagnostic purposes and also as indicators determining progress.

Linked to student progress in scientific literacy, another concern is the need to ensure the use of meaningful assessment instruments during the three years of gymnasium schooling. This is crucial for enabling an evaluation of the suitability of both cognitive and affective learning aspects and, above all, providing feedback on the level of implementation of the new curriculum related to enhanced levels of scientific literacy (especially in the development of key competences).

Focus of the research

This study addresses the need to assess attributes related to indicators of scientific literacy (SL), in the Estonian situation, through the use of purposefully developed instruments aimed at targeting gymnasium students. While the PISA studies in Estonia provided evidence related to SL of 15 year olds, there is no evidence indicating how gymnasium students demonstrate their enhancement of scientific literacy and whether this relates to their needs in today's society, such as making career choices and possessing employability skills.

Based on the concerns raised, the current study attempts to provide indicators of student achievement and whether changes are needed in the teaching orientation and approach at the secondary science education level. Also such indicators are needed in planning for teacher pre- and in-service professional development, pointing out strengths and weaknesses among gymnasium students' SL-related learning.

This study seeks to assess students' learning by developing meaningful instruments, which set out to determine students':

a) active use of relevant knowledge and skills in a situation derived from real life (students utilise both knowledge and skills to answer test items) designed to enable students to demonstrate their scientific literacy skills, and
b) perceptions towards their cognitive competence, perceived science teaching and future career preferences.

In addressing the issues in science education associated with this study, the research goals are put forward as:

I. To develop valid instruments to assess gymnasium students' achievement in cognitive components of scientific literacy and their perceptions towards their competence in giving scientific explanations, solving meaningful problems and making reasoned decisions.
II. To determine and analyse gymnasium students' (grade 10 and 11) perceptions towards competence in cognitive components of scientific literacy, perceived science teaching in terms of developing scientific literacy skills and perceptions towards future careers.
III. To determine and analyse gymnasium students' progress in cognitive components of scientific literacy, approached via assessment in a real life societal context.
IV. To make recommendations associated with the progress in gymnasium students' scientific literacy through cognitive components of scientific literacy (grade 10 and 12 students).

With the above research goals in mind, this study puts forward the following research questions:

1) Can meaningful instruments be developed to assess gymnasium students' achievement in cognitive components of scientific literacy and their perceptions towards their competence in giving scientific explanation, solving meaningful problems and making reasoned decisions?
2) What changes occur in gymnasium students (grade 10 and 11) perceptions towards competence in cognitive components of scientific literacy skills, science teaching in terms of developing those skills and preparedness for a future career, over two years of study at the gymnasium level?

3) What differences occur in gymnasium students (grade 10 and 11) progress in cognitive components associated with scientific literacy when approached via a real life, context-based assessment strategy over the two years of study at the gymnasium level?
4) Can the progress in gymnasium students' scientific literacy be determined through assessment of cognitive components of scientific literacy (grade 10 and 12 students)?

The research questions are addressed in the following original publications:
Paper I explores research question 1 and addresses the development of meaningful instruments to assess gymnasium students' achievement in cognitive components of scientific literacy. This study describes and pilots preliminary instruments on testing gymnasium students and solicits additional student information useful for modifying the test instruments for later use.

Paper II addresses research questions 1 and 2. With respect to research question 1, gymnasium student perceptions are collected using an instrument devised, based on a literature search. With respect to research question 2, paper II details the findings from grade 10 and 11 perceptions related to their competence in science classes, received science teaching and future career preferences.

Paper III explores research question 3 and addresses the implementation of meaningful test instrument in cognitive components of scientific literacy among grade 10 and 11 students.

Paper IV explores research question 4 and addresses the differences between grade 10 and 12 students' achievement.

Research question 4 is further addressed in this thesis (see chapter 4/5).

This study is a detailed research component within the larger LoTeGüm project.

2. REVIEW OF THE LITERATURE

2.1 Scientific literacy

An often-stated aim of science education is to promote scientific literacy (Hurd, 1958; NSTA, 1991; Bybee, 1993; Miller, 1996, 1998; Laugksch, 2000; Norris & Phillips, 2003; Roth & Lee, 2004; Millar, 2006; European Commission, 2007; Reis & Galvão, 2009; Acar, Turkmen & Roychoudhury, 2010; Holbrook, 2010; Aikenhead, Orpwood & Fensham, 2011; Eijcik, 2012). However, there is a concern that the level of scientific literacy provided to students in school science classes is insufficient for real life situations (OECD, 2007; Holbrook & Rannikmäe, 2009; Eijcik, 2012). This concern is partly because scientific literacy consists of multiple components (subject, personal and societal issues which include science knowledge, understanding nature of science, etc.) and hence as pointed out in Papers I, II and III, its meaning is not straightforward (Bybee, 1997; DeBoer, 1997; Eijcik, 2012).

From the historical perspective, scientific literacy has had many definitions and undergone significant changes in its meaning (see table 1) illustrating that this is an evolving term, largely dependent on changes in perceptions of the purpose of education as a whole (Fernandez, Holbrook, Mamlok-Naaman & Coll, 2013) and the role of science education within this. Table 1 tries to identify significant developments or modifications in the use of scientific literacy (SL) or scientific and technological literacy (STL) in the science education literature, based on a historical perspective.

Table 1. Significant changes in the development of the conception of scientific literacy (SL)

Reference	Definition	Comments on its uniqueness development, progress, etc.
Hurd (1958)	SL as an understanding of science, its applications in social issues and preparing students for life and work as citizens.	SL is used for the first time as a goal of science education and since this time, this aspect has been often emphasised in the following definitions of SL.
Shen (1975)	SL seen as encompassing three areas: Practical (using scientific and technological knowledge to solve problems). Civic (the awareness of science and science related issues to participate actively in society). Cultural (the understanding of science and technology as human achievements).	SL description from three perspectives suitable for different countries and people, but not directly applicable in the school curriculum to achieve SL as a goal of science education.
UNESCO (1993)	Within science and technology education for all, SL is seen as the ability to utilise science knowledge creatively in everyday life involving value judgments and communication skills.	Highlights the importance of science for all students, the role of creativity in applying science knowledge, use of science in the development of everyday life and also personal attributes.

Reference	Definition	Comments on its uniqueness development, progress, etc.
Shamos (1995)	Three levels of SL: Cultural (science background information to understand scientific communication in books, newspapers etc.). Functional (the ability to use science terms and concepts meaningfully in situations when needed) True (understand scientific theories, scientific investigation)	Provided hierarchical model of SL where each following level adds something to previous one. However, these levels use the science as the starting point for achieving higher levels of SL, and not particularly the understanding how science is related with everyday life.
NRC (1996)	The meaning of SL: Knowledge and understanding of scientific concepts. Understanding scientific processes for personal decision-making, participation in civic and cultural affairs, and economic productivity. Understanding nature of science, the scientific enterprise and the role of science in society and personal life. Proper attitudes and values towards science to continue lifelong learning to deepen SL.	SL is for all students and besides making personal decisions, it means actively participating and understanding in civic and cultural affairs and economy.
Bybee (1997)	Four hierarchical levels of SL: Nominal (recognises scientific terms/concepts/ theories, but does not have full understanding). Functional (uses scientific vocabulary, but usually in a familiar school-related context, for example exams/tests). Conceptual and procedural (demonstrates relationships between concepts and uses scientific processes meaningfully). Multidimensional (understanding science concepts, scientific processes, nature of science, the role of science and technology in personal life and society).	Hierarchical model of SL, which includes, besides the growth of science content knowledge (moving lower levels to higher), understanding about the role of science and technology in personal life and society. Appreciates also considerations of age and experiences in developing scientific literacy and recognises the need for lifelong learning.
Miller (1997)	Civic SL (the understanding of science and technology needed to function as an effective citizen in today's society). Civic SL includes basic vocabulary, an understanding of the processes and methods in science to utilise science knowledge in real life situations and an awareness of the impact of science and technology on society.	Highlights the need for civic SL so as to be an active citizen within society from the perspectives of employee and responsible consumer.
OECD (2007)	Within the PISA 2006 study, SL was taken to mean: Scientific knowledge and use of that knowledge (to identify questions, acquire new knowledge, explain scientific phenomena, and draw evidence based conclusions about science-related issues), Understanding about nature of science. Awareness of the role of science and technology in our own lives. Willingness to engage with science related issues as a reflective citizen.	This study recognises the importance of applying scientific knowledge and skills in situations from real life. It also recognises that students need some understanding about nature of science and that SL is linked with perceptions towards science.

Reference	Definition	Comments on its uniqueness development, progress, etc.
Roberts (2007; 2011)	Separated two visions in scientific literacy: Vision I learning from a scientist's view and Vision II learning related to everyday life.	This was the first division of scientific literacy – from the scientist's point of view (I) and from an everyday life perspective (II).
Murcia (2009)	SL has three dimensions when applied to real life situations: Understanding importance of scientific terms and concepts. Understanding nature of science (includes way of thinking, values). Understanding interactions of science and society (applies science in real life situations and understands its effect on society and the environment).	This definition emphasise the importance of using real life contexts for promoting scientific literacy.
Holbrook & Rannikmäe (2009)	STL used in preference to SL 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.	This definition recognises the importance of technology interrelating with science and acquiring educational attributes at the subject (including nature of the subject), personal and social (socio-scientific) levels.
Choi, Lee, Shin, Kim & Krajcik (2011)	Scientific Literacy for the 21st Century seen as: Content knowledge. Habits of mind (competences to solve complex problems and making reasoned decisions). Character and values (act as responsible citizen). Science as human endeavour (understand nature of science and relationships between science and society). Metacognition and self-direction (understand one´s own cognition and cognitive abilities to become lifelong learner).	This approach recognises that students in the 21st century need to possess attributes beyond the subject content and have some understanding of their own cognition and cognitive abilities to become lifelong learners. This SL focus is not emphasized in previous approaches according to the authors.
Roberts & Bybee (2014)	Further elucidation about the usefulness and practicability of Vision I and II in current science education.	Raises the importance of a balance between Vision I and II and whether Vision II is desirable as a major focus in all science classes.
PISA 2015 Framework (OECD, 2013)	An operational view of SL taken as the ability to engage, as a reflective citizen, with science-related issues, and ideas of science. As such, a SL person demonstrates competences to: Explain phenomena scientifically Evaluate and design scientific inquiry Interpret data and evidence scientifically	In this operational definition, SL focuses on the science conceptual and process skills albeit context based, rather than its relation to personal life and society. This is an interesting turning point to draw more attention to the need to assess students' conceptual and procedural understanding compared to how well they can apply those in real life situations.

Reference	Definition	Comments on its uniqueness development, progress, etc.
		Such competences are needed to comprehend phenomena from a science point of view – this is stressed compared to the previous OECD definitions, where more emphasis was on the application of scientific knowledge to situations from real life.

A meta-analysis of the definitions presented in table 1 draws attention to the fact that the promotion or enhancement of scientific literacy relates to a widening interpretation of the term, with the following perceptions and components highlighted in the literature. In general, the literature tends to suggest scientific literacy:

1. Is the main goal for science education.
2. Is important and essential for all students in school for being active and reflective citizens.
3. Includes possessing competence related to major scientific concepts, theories, facts and terms (ranging from recognising terms to applying these in unknown contexts).
4. Includes appropriate scientific process abilities (e.g. inquiry-based learning, scientific methods).
5. Involves conceptualising the nature of science, especially science as a human endeavour and the inter-relationships between science, technology and society.
6. Includes creatively using science concepts in resolving everyday life issues through incorporating scientific explanations, solving reasonable problems and thus enabling reasoned, evidence-based, socio-scientific decisions.
7. Is dependent on the person's age, personal and educational experiences and familiarity with the contexts (refers to achieving different levels of SL).
8. Includes acquisition and undertaking behavioural actions associated with values, attitudes and an understanding of one´s own cognition and cognitive abilities for dealing with science-related situations and for education for sustainable development, making career choices and becoming lifelong learners to sustain or deepen levels of SL.

Despite a perceived evolving meaning for scientific literacy, there seems no common position on how to develop scientific literacy within students e.g. whether it is appropriate to use science phenomena as the starting point for teaching, or whether it is more appropriate to stress familiarity and to use issues derived from the real life as the starting point. The dilemma in clarifying the focus on ways to promote scientific is well illustrated by the two visions put forward by Roberts (2007; 2011) when referred to Vision I and Vision II. In

Vision I, the reason for learning science is self-evident and there is no need to justify this: it is needed for understanding natural phenomena (including personal and social interactions) from a science perspective. Vision I uses science conceptualisations as the focus for learning (products or processes of science for science learning) and expects students to understand scientific fundamentals much as scientists do (Roberts, 2007). Vision II focuses on ideas related to how science strives to influence and interact with many areas of human engagements and everyday life situations (Roberts & Bybee, 2014). In other words, this uses appropriate contexts from real life to relate, and give relevance, to the learning of science content (Roberts, 2007). Even more, developments beyond the real life situation, are essential for encompassing education for sustainable development for promoting the common good in the face of developments towards a global society and an inequality of resources and international influence (Holbrook, 2009). Understandably, studies point out that it is desirable to use Vision II in science classes as it helps students to relate their everyday life with science and they can see the usefulness of science in their own lives (OECD, 2007; Sarkar & Corrigan, 2014). However, this is not a dominant position among all educators and researchers. There is even a call for two directions for science teaching – one for students wishing to undertake further studies in science and the other for those who see science as valuable for responsible citizenship (Fensham, 2007). Furthermore, according to Roberts & Bybee (2014), the degree of emphasis for Vision II needs to be carefully considered in school science, because:

1. Vision I measures are less complex compared to Vision II (a reference to decisions made in the curriculum being in the hands of bureaucrats rather than professional science educators, when the preference is for clear, specific measures).
2. Vision II can be seen as so vast as to be over-dominant in teaching time at school (a danger of overemphasising the social aspect resulting in diluting science conceptual learning needed for forming an important base for scientific problem solving and socio-scientific decision-making).
3. Vision II requires modifications to match teachers' teaching style, new teaching materials and familiarity with wider teaching approaches.

Nevertheless, it is important to recognise that not all students prefer to take-up a career in science-related fields. Yet all students in the 21st century need to develop expertise in handling personal and social science-related issues in their own lives and therefore Vision II needs to be present in science classrooms (Treagust & Tsui, 2014). Furthermore, student motivation needs very careful consideration and not forgetting that as future citizens, today's students need to learn to cope with rapidly changing demands on the workforce, new technological equipment, creative and innovative technical solutions (Griffin, McGaw & Care, 2012).

This study adopts the view that the development of scientific literacy in the school context is dependent on students seeing the relevance of school science in everyday life and for careers, as well as conceptually through a school science context (Sarkar & Corrigan, 2014). This means that students do need knowledge and skills in science, but they also need the opportunities to apply those skills in situations derived from real life, supporting the need to be responsible future citizens and ready to deal with science-related issues. This also includes affective components and an understanding about scientific processes for problem solving and decision-making.

Based on the above, this study finds it useful to adopt the definition of scientific and technological literacy (STL) provided by Holbrook & Rannikmäe (2009) – *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*. Nevertheless, this study takes the definition further. Also recognised is (table 1) that scientific literacy means *understanding one´s own cognition and cognitive abilities for dealing with science-related situations, choosing a career and becoming a lifelong learner in deepening the level of SL* (e.g. OECD, 2007; Choi et al., 2011). With the latter component in mind, students' perceptions and career orientations are added as components within this study.

2.2 Competences as components of scientific literacy

In Paper I, based on the Estonian curriculum, competences are taken to mean the capabilities to do something using knowledge and skills gained in accordance with the school curriculum and to acquire positive attitudes to undertake appropriate action (Estonian Government, 2011). Based on this meaning, the components of scientific literacy can be considered as scientific competences (OECD, 2007; 2013). For example, in PISA 2006, scientific literacy is operationalised as three cognitive and three affective scientific competences (Fensham, 2013). This suggests that in order to promote scientific literacy among school students, it is important to identify the competences determining students' levels of scientific literacy.

Based on the literature review indicating the changing meaning of scientific literacy (see table 1), the cognitive components within scientific literacy seem to be operationalised and evaluated through the involvement of science in a variety of situations and by demonstrating multiple skills. One competence put forward in this regard is *giving scientific explanations* (OECD, 2007; 2013). Treagust and Harrison (1999) state that a scientific explanation means using correct scientific terminology and is strictly characterized as theory and evidence-driven. Paper III points out that using scientific terminology and concepts correctly has been one of the major areas used in defining scientific literacy (e.g. Shamos, 1995; Bybee, 1997; OECD, 2007; 2013; Choi et al., 2011).

Another competence traditionally associated with scientific literacy, identified in Papers I, II, III and IV, is problem solving (e.g. Shen, 1975; UNESCO, 1993; NRC, 1996; Holbrook & Rannikmäe, 1997; Rannikmäe, 2008; Holbrook & Rannikmäe, 2009). According to Bybee (1993), problem-solving in science is often associated with undertaking scientific experiments. Thus, it is closely linked with the process of obtaining and using information, doing experiments, analysing data and drawing conclusions (e.g. inquiry, investigation, making use of a scientific method). Those activities are put forward as fundamental in science education and students need to develop such competences in science class (Bybee, 1993; 1997). At the same time, there is no one single type of problem-solving technique and different types of problems across the disciplines require different knowledge and cognitive skills, e.g. from logic and story-telling problems to design problems (Jonassen, 2011). Science education needs to guide students to utilise appropriate evidence-based scientific knowledge and skills for solving personally challenging, yet meaningful scientific problems and solving such problems means finding a scientific solution (Holbrook & Rannikmäe, 1997; Rannikmäe, 2008).

A third competence often associated with scientific literacy and identified in papers I, III and IV is reasoned decision-making often related with socio-scientific issues (e.g. Sadler, 2004; Zeidler, Sadler, Simmons & Howes, 2005; Sadler & Donnelly, 2006; Holbrook & Rannikmäe, 2007; Sadler, 2009; Choi et al., 2011; Laius, 2011). Christensen and Fensham (2012) indicate that decision-making with reasoning is a common purpose of science education. They suggest this process requires more than the application of scientific knowledge as usually expected. Socio-scientific decision-making is influenced by a person's socio-cultural background (Laius, 2011), experiences to identify and choose between multiple possible alternatives and values (Bybee, 1993) and therefore goes beyond using only science knowledge (Eysenck, 2012).

Acquisition of scientific literacy requires, based on the literature (Bybee, 1997; Choi et al., 2011; OECD, 2013), an understanding about scientific processes (e.g. inquiry). It thus seems reasonable when applying science knowledge (for example for solving problems) that skills related to scientific processes are also needed (e.g. reading a graph, drawing evidence-based conclusions, identifying a scientific question to solve a problem). Therefore, the cognitive competence part of scientific literacy requires meaningful acquisition of knowledge and skills, such as that needed to deal with issues from real life instead of only applying knowledge and skills to isolated science contexts. Based on this, the cognitive competences of scientific literacy are identified in Paper III as operational skills of scientific literacy referring to the use of relevant knowledge and skills.

Based on an analysis of the definitions of scientific literacy (table 1) and the major thrust in this thesis to assess cognitive competence, the following key cognitive components of scientific literacy are selected to be major components for this study:

1) Explaining phenomena scientifically.

2) Solving scientific problems.
3) Making reasoned decisions related to a scientific or socio-scientific issue.

2.3 The Estonian situation

Science curriculum

Estonia introduced a new curriculum at the gymnasium level (grades 10–12) in 2011 and its implementation became compulsory no later than 1st of September 2013 (Estonian Government, 2011). In this curriculum, promoting scientific and technological literacy (STL) is indicated as the main target for the four science subjects included (geography, chemistry, biology and physics). The targets are expressed explicitly as:

1) "acquiring and utilising empirical knowledge about biological and physio-chemical systems (definitions, laws and theories defining the substance of the specific subject corresponding to modern scientific achievements) in exploring environmental and societal issues" (nature of science domain);
2) "mastering scientific methods, including scientific ethics such as admitting mistakes and utilisation of safe working practices, undertaking risk assessments and valuing the need for life cycle analysis. The use of scientific methods is a link between all science subjects and thus forms their common basis" (nature of science domain);
3) "developing scientific problem-solving and socio-scientific decision-making skills, taking into consideration scientific, economic, political, environmental, social, ethical and moral aspects" (social domain), and
4) "developing students' personal competences, including creative ability, gaining communication, interpersonal and teamwork skills, shaping students' attitudes towards science, technology and society, risks assessment and becoming conscious of the role of science in the home, in choosing a career, and in society as a whole" (personal domain).

(Estonian Government, 2011)

The targets indicate that the Estonian science curricula are aligned with the STL definition, which follows the concept of three domains of science education (nature of science, personal and society domains) (Holbrook & Rannikmäe, 2007).

Expected learning outcomes

Table 2 illustrates how the four science subjects align with the overall expected natural science learning outcomes at the end of grade 12.

Table 2. Interpretation of the expected natural science learning outcomes at the end of grade 12 within subject-specific domain (Based on the Estonian Curriculum – Estonian Government, 2011)

Expected learning outcomes at the end of grade 12		Expected learning outcomes in the four science subjects at the end of grade 12			
		Biology	**Geography**	**Chemistry**	**Physics**
1	Analyses, explains and interprets phenomena in nature (directly and indirectly (by using models) perceived phenomena).	Undertake a systematic overview of the main objects and processes in the organic world, relationships between organisms and interactions with the inorganic world.	Explain spatial location aspects of phenomena and processes occurring in nature and society, their interrelations and dynamics.	Undertake a systematic overview of the laws and theories in chemistry and able to use the language of chemistry in a meaningful way.	Use physical quantities, definitions and relations to describe, explain, and predict natural phenomena and their technical applications. Solve situational, computational and graphical exercises and critically evaluate outcomes. Use SI units and convert between units. Create drawings about physical objects, phenomena's and applications. Transform physical models (e.g. verbal to graphical or formula).
2	Finds, uses and evaluates critically information from multiple sources (verbal, numeric, symbolic).	Use various sources to find, analyse, synthesize and critically evaluate information and apply this in explaining phenomena and solving problems scientifically in the organic world.	Use various sources to find relevant information and evaluate critically such information.	Use various sources to find relevant information; analyses and evaluate this information critically.	Use various sources to find information related to physics content.

	Expected learning outcomes at the end of grade 12	Expected learning outcomes in the four science subjects at the end of grade 12			
		Biology	**Geography**	**Chemistry**	**Physics**
3	Identifies problems in an environment, uses scientific methods to solve scientific problems (e.g. gather information, pose scientific questions/hypotheses, control variables, collects data/evidence through observations/ experiments, analyse and interpret results, present conclusions and solutions/ limitations and undertake research project if needed).	Apply scientific methods to solve biological problems (plan, carry out, analyse observations and experiments, present outcomes in correct verbal and visual forms). Use appropriate ICT in studying biology and carrying out research.	Use scientific methods to solve problems occurring in the environment and everyday life.	Apply scientific methods to solve chemistry problems, develop logical thinking, creativity and competence to analyse and draw conclusions. Apply skills in carrying out experiments to solve complicated problems while paying attention to safety issues.	Able to pose research questions based on a given situation, plan and carry out experiments, analyse results and draw conclusions.
4	Uses systematic information obtained from biology, geography, chemistry and physics to solve scientific, technological and socio-scientific problems and to make reasoned decisions, which take into account other social, political, environmental, economic, ethical and moral aspects.	Able to make reasoned, socio-scientific decisions and predict consequences of these decisions.	Apply geography knowledge to new situations to solve scientific, technological and societal problems and to make reasoned decisions (including career planning).	Able to make competent decisions while solving everyday life problems and evaluate the consequences of these decisions.	Solve scientific problems in everyday life.

Expected learning outcomes at the end of grade 12		Expected learning outcomes in the four science subjects at the end of grade 12			
		Biology	Geography	Chemistry	Physics
5	Explains and applies relationships between science subjects (both in terms of their interdisciplinarity and individual specialities).	Recognise the interrelations between science, technology, and society and can explain their influence on the environment and society.	Not Specified.	Not Specified.	Not Specified.
6	Explains the nature of science as a process for gathering scientific knowledge in its historical and modern contexts, appreciates the role of creativity in scientific discoveries and recognises science limitations in real life.	Not Specified.	Not Specified.	Not Specified.	Not Specified.
7	Evaluates and predicts the impact of science and technology on the environment, based on scientific, economic, political, ethical and moral standpoints and also considers legislation.	Not Specified.	Not Specified.	Not Specified.	Not Specified.

Expected learning outcomes at the end of grade 12		Expected learning outcomes in the four science subjects at the end of grade 12			
		Biology	Geography	Chemistry	Physics
8	Puts forward reasoned values associated with the environment and society as a whole and the role of science for sustainable modern lifestyle and becoming responsible citizen.	Show responsible attitudes towards the living environment and value biological diversity and sustainable lifestyle.	Understand the relationship between nature and society in local, regional and global level and value sustainable development. Analyse possibilities and consequences of human activities in different geographical conditions, value a multicultural environment and natural diversity.	Able to explain the interrelationship between nature, technology and society and their impact on the environment and sustainable development. Value sustainable development and responsible citizenship.	Promote sustainable development and a responsible attitude towards nature and society.
9	Shows a willingness to discuss and make use of conceptual science in local and global phenomena taking place in the environ-ment and society, as well as new developments in science and technology. Is capable to make reasoned decisions in choosing a career and exhibits motivation for lifelong learning.	Value knowledge, skills and attitudes towards biology and possess intrinsic motivation towards lifelong learning. Gain an overview of professions connected to biology and relate knowledge and skills in biology to planning careers.	Show interest in local and global phenomena's associated research and science-related fields of life.	Show interest in che-mistry and other science subjects, understand the importance of chemistry in economic, cultural and technological develop-ments within society and be ready for lifelong learning. Gain an overview of pro-fessions linked to che-mistry and use knowledge and skills in chemistry in planning careers.	Value physics-related professions based on received learning in lessons.

Table 2 shows learning outcomes amplified for each subject, but with different emphasis based on their description. All subjects emphasise subject-specific content knowledge (learning outcome (LO) 1), especially in chemistry and physics. Furthermore, the idea of using information found from multiple sources (LO2), promoting scientific methods to solve problems (LO3) and making reasoned decisions (LO4) are also presented in each individual science subject. However, decision-making is not explicitly presented for the subject of physics. Physics focuses more on the ability to undertake physics-related experiments.

Expected learning outcomes are also included related to developing appropriate values and attitudes and aspects of values, sustainable development and lifelong learning, as are career awareness and an interest towards phenomena in nature and society (LO8, LO9).

Unfortunately, the curriculum document does not state the development of expected learning outcomes at the end of grade 12 equally in all four science subjects. Furthermore, not all aspects associated with scientific literacy are included (e.g. nature of science, the impact of science and technology on the society in each subject level). This makes it difficult, within the curricula, to create meaningful interdisciplinary assessment instruments to incorporate the components of scientific and technological literacy. Based on table 2, it seems that the more life-related subjects (geography and biology) are more in the line with SL than subjects with more abstract science content (chemistry and physics). There is thus evidence that the science subjects seem to have different interpretations of scientific literacy. This is also reflected in the content and focus of assessment instruments in the national science subject examinations set until 2013, as described in Paper III (Klooster, 2013; National examination commission (Biology), 2013; National examination commission (Chemistry), 2013; National examination commission (Geography), 2013).

Science teachers

In Paper II, students were asked about the science teaching they had received. The students pointed out that they did not perceive that science subjects (especially chemistry and physics) supported either the development of problem-solving and decision-making skills or other components of scientific literacy. Only the development of interdisciplinary knowledge was highlighted and this was the field where science teachers seemed to have higher perceived self-confidence (Holbrook, Rannikmäe & Valdmann, 2014).

Paper III points out that the self-confidence of Estonian science teachers is high in aspects such as interdisciplinary teaching, but lower in inquiry-based learning and assessment. Science teachers perceive they need extra professional development (Holbrook, Rannikmäe & Valdmann, 2014). This suggests that teachers are not sufficiently ready for implementing the new competence-based curriculum, where difficulties can be expected, because of:

(a) a confusing and an individual subject learning outcome focus in science subjects;
(b) a history of teachers drilling students for final examinations;

(c) missing competence-based assessment materials, and
(d) evidence of teachers' lack of readiness to change and adopt new ways of teaching to promote SL (Laius & Rannikmäe, 2004; Kask, 2009; Laius, 2011; Vaino, 2013; Holbrook, Rannikmäe & Valdmann, 2014).

2.4 Context-based assessment

Noting that the concept of scientific literacy has undergone major changes (table 1), this is expected to indicate that changes also occur in tests and final examinations used for students' assessment. However, it appears little attention is being paid to assessment of a wider range of competences seen as aspects of scientific literacy.

To assess competences towards levels of attained scientific literacy (Bybee, 1997), the definitions (see table 1), suggest the appropriateness of not only possessing the ability of acquiring competences, but also the capability to use such competences in relation to real life situations. Thus, it is not enough to merely ask students to explain and analyse isolated concepts, principles, etc. in a classroom science context (Biggs, 1996). Students need to be asked to demonstrate their competence in a relevant situation based on real life, where they can actually implement competences (Hurd, 1998; van Aalsvoort, 2004; Bennet, Lubben & Hogarth, 2007; OECD, 2007, 2009, 2013; Murcia, 2009; Fensham & Rennie, 2013). Even more, through relevant real life situations, as written in paper I, critical thinking can also develop (Bailin, 2002; Barak, Ben-Chaim & Zoller, 2007; Dam & Volman, 2004). Based on this, Paper III suggests that student assessment of learning in science education needs to incorporate context-based situations (using scenarios derived from real life). Paper III lists the advantages of context-based assessment as:

- influencing students' interest and motivation to answer;
- providing a deeper sense of students' conceptual understanding;
- promoting transfer of science learning to real life situations;
- allowing students to see the usefulness of their own knowledge in real life situations;
- allowing students to apply competences in situations similar to actual situations.

(Johnson, 2002; Bennet et al., 2007; Rannikmäe, 2008; Feinstein, 2010; Fensham & Rennie, 2013).

Using contexts from real life and practical applications as a starting point for learning science is seen as a useful way to overcome difficulties, such as the irrelevance of school science, content overload, learning for examinations, lack of opportunities to discuss the science content and its implications in real life (Gilbert, 2006; Lyons, 2006; Murcia, 2009; Tytler, 2014). Paper III points out that context-based items can also be part of assessment for determining levels of scientific literacy. This is in-line with statements by Millar and Osborne (1998) indicating that assessment instruments in science education need to reduce the emphasis on testing students' ability to recall scientific knowledge and instead increase the emphasis of testing students' ability to use understanding for explaining major phenomena in science and also assess competences likely to be required in real life.

Paper I points out that context-based assessment instruments have been used in PISA studies (OECD, 2007), adopting the idea that scientific literacy is the focus of assessment and that it has multiple dimensions e.g. knowledge of science, competences, understanding about nature of science and attitudes. The PISA studies use contexts derived from real life as the starting point for asking questions to determine underlying scientific knowledge, useful skills for the situation, attitudes, and an understanding about nature of science. Through this approach, student actual application of acquired science knowledge and skills in real life situations can be identified (Kelly, 2014).

Rundgren and his colleagues (2010) conducted a study using the media as the context for asking questions to determine students' scientific literacy. For this, they used an instrument developed for civic scientific literacy measurement (SLiM), based on media coverage and focusing on the most common scientific terms appearing in the media. Gormally, Brickman and Lutz (2012) used also contextualised items derived, for example, from various sources of media. They called their instrument a Test of Scientific Literacy Skills (TOSLS) and measured undergraduate`s evaluation of scientific information and arguments. They related skills like recognising and analysing the use of methods in inquiry with the ability to organise, analyse and interpret quantitative data and scientific information.

Orion and Libarkin (2014) noted that context-based assessment materials could align with problem solving situations. They introduced assessment material, developed in Israel, called the "Dead Sea Problem Solving Inventory" for high school. In this material, students were asked to recognise environmental influences on the Dead Sea. They suggested that an understanding of Human-Earth interactions is an important research direction in today's society and Earth science serves a concrete context for better understanding of basic concepts from physics, chemistry and biology (referring to the need for an interdisciplinary approach).

Research has pointed out multiple societal, personal and global issues, which can be used as a starting point for determining students' scientific literacy. For example:

- energy sources (Bybee, 1993; Murcia, 2007);
- environmental issues (use of pesticides and fertilisers, water resources, forests, soil salinity, waste disposal, erosion) (Bybee, 1993; Murcia, 2007);
- climate change (greenhouse effect, ozone depletion) (Jarman & McClune, 2007; Murcia, 2007);
- cloning (Murcia, 2007);

- health and lifestyle (childhood immunisation, antibiotics, health and healthy eating, heredity, disease) (DeBoer, 2000; Jarman & McClune, 2007; Murcia, 2007);
- food production and hunger (Bybee, 1993);
- population growth (Bybee, 1993).

Engaging with these issues requires an interdisciplinary understanding of science and an understanding of the complex relationships between science and society in a context that also includes political, economic, moral, ethical and religious aspects (Murcia, 2007). All those situations refer to real life and, for coping in such contexts, it is important to recognise the underlying interdisciplinary science content (Jarman & McClune, 2007).

In the case of Estonia, students indicate that they find the more interesting contexts relate to health/disease and extraordinary phenomena in nature (Teppo & Rannikmäe, 2008).

2.5 SOLO taxonomy

To better follow students' progress, a meaningful taxonomy is needed for developing assessment items, indicating levels of progress (Moseley, Baumfield, Elliott, Gregson, Higgins, Miller & Newton, 2005; Krajcik, 2011). An important approach to determining student assessment is the introduction of the SOLO taxonomy (Biggs & Collis, 1982; Biggs, 1991; 1996). As stated in paper III, Biggs (1996) proposed the use of SOLO taxonomy for following students' progress in achieving expected learning outcomes. According to Biggs (1996) the SOLO taxonomy can be used for developing items requiring growth of knowledge as well as items requiring a demonstration of operational skills, e.g. students' active participation during assessment, not simply remembering and re-producing learned science content. In other words, this approach goes beyond assessment for tests and examinations that focus on school science content complexity and focuses on expected learning outcomes compared to Bloom's taxonomy (Biggs, 1996).

The SOLO taxonomy has five levels (pre-structural, uni-structural, multi-structural, relational and extended abstract) (Biggs, 1996). The first level was not used in this study, because this study was not about using SOLO taxonomy to assess students' responses, but to design assessment items. This study used remaining four levels to design assessment items as described in Paper III.

2.6 Student perceptions

Based on a literature review, this study identified the following components appropriate to gaining students' recognition of their scientific literacy:

- perceived competence;

- received science teaching (referring to the activities occurring during learning in science classes for developing the cognitive components of scientific literacy); and
- future career preferences.

These components are seen as providing a portrait of students' views against their own cognitive competence (current situation), views of what is happening in science classrooms (the component influencing students' views towards self-cognitive abilities and future preferences) and career preferences (looking forward to the future). These components, called perception in this study, reflect on students' inner understanding, but do not require determination of cognition as is the case for actual problem-solving or decision-making.

Students' perceptions related to science education have traditionally been areas of research (OECD, 2007; Choi et.al, 2011; Bybee & McCrae, 2011; Tytler, 2014). Examples using multiple perception components associated with scientific literacy are:

- students attitudes towards science and scientists (e.g. interest in scientists activities, perceptions of scientists and their work) (Osborne, 2003; Simon & Osborne, 2010; Tytler, 2014);
- attitudes towards school science (e.g. liking or doing science) (Tytler, 2014);
- interest towards science and science-related activities (short-term, long-term activities) (Osborne, 2003; Treagust, 2007; Tytler, 2014);
- perceptions towards future careers and the development of an interest or commitment to pursuing a career in science or science-related work (Bybee, 1993; Lavonen, Gedrovics, Byman, Meisalo, Juuti & Uitto, 2008; Tytler, 2014);
- understanding and appreciating the nature of science, valuing evidence-based approach characteristics of science and adopting scientific attitudes (e.g. objectivity) (Abd-El-Khalick & Lederman, 2000; Bell & Lederman, 2003; Schwartz, Lederman & Crawford, 2004; Tytler, 2014);
- perceptions towards students' own abilities and a sense of self-efficacy related to science (Choi et al., 2011; Tytler, 2014);
- motivation to undertake and learn science (Tytler, 2014).

Perception of cognitive ability

Paper II highlighted views on the meaning of, and value associated with, students' perceived (or felt) competence. This citing multiple researchers e.g. Harter, 1978; Hansford & Hattie, 1982; Pajares, 1996; Deci & Ryan, 2000; Ryan & Deci, 2000; Taras, 2002; 2010; Wong, Wiest & Cusick, 2002; Blumenfeld, Kempler & Krajcik, 2005; Park, Khan & Petrina, 2009; Westera, 2010; Cho, Weinstein & Wicker, 2011; Deng, 2011; Huang, 2011; Law, Elliot & Murayama, 2012; Vaino, Holbrook & Rannikmäe, 2012; Froiland & Oros, 2014. Choi et al. (2011) stated that scientifically literate students need an understanding of their own cognition and cognitive abilities to become lifelong learner and that this had not been the focus of previous studies. Marsh and

Craven (2006) emphasised that the measurement of students' perceptions needed to be context-based: distinguishing actual achievement in mathematics and perceptions towards achievement in mathematics in actual situations. The importance of this aspect was also emphasised by other researchers as described in Paper II (Chang & Cheng, 2008; Thomas, Anderson & Nashon, 2008). Paper II also discussed the idea, that if students had an opportunity to receive feedback about their learning (e.g. teachers provide students with the situations, which allow getting feedback through perceptions), then feedback about performance enhanced the extent to which individuals continue to improve their achievement and this could also lead to lifelong learning (Fraser & Greenhalhg, 2001).

Perceptions towards received science teaching

As learning is occurring in science classes under the guidance of the teacher, students' perception towards received science teaching is also an important factor when discussing students' achievement in relation to enhancing scientific literacy (Fraser, 2014; Tytler, 2014).

Research into students' perceptions against received science teaching or learning experiences is often related with students' achievements (Tytler, 2014). However, Fraser (2014) indicate that these may not match because measures of learning outcomes cannot provide a complete picture of the students' educational process, as this is also influenced by the classroom learning environments. Nevertheless, according to Fraser (2012), students are good at making judgments about classroom activities, because they have encountered different learning environments and have formed accurate impressions. Teacher's activities from day to day may vary, but in the long-term, they provide a consistent picture for students about the learning environment created.

Studies on students' perceptions of school science classrooms and received teaching-learning experiences have highlighted insights showing that students are not satisfied with school science offerings (Lindhal, 2007; Lyons, 2006; Osborne & Collins, 2001). According to Lyons (2006), school science is not relevant and interesting to students, there is too much science content, there is a lack of opportunities to discuss the science content and its implications or to express opinions, it is too difficult, and students spend much of their time copying notes from the blackboard or from teaching materials. Even more, science in school is seen as a large collection of facts to be learned and reproduced in exams, which are presented through lectures and which lack challenges for students (Tytler, 2014).

Career preferences

A third component associated with scientific literacy is students' perceived future career preferences (Bybee, 1993; Holbrook & Rannikmäe, 2007; OECD, 2007; Lavonen et al., 2008; Tytler, 2014). Perceptions can be influenced by attitudes. This suggests that attitudes towards future career preferences can be investigated related to the need to provide students with needed competence to promote responsible citizenship and future workforce needs (Bybee & Fuchs, 2006).

Research has shown that science teachers lack knowledge of career opportunities in science (Stagg, 2007). As a result, studies have reported that student's lack knowledge about science-related professions (Osborne & Dillon, 2010; Lavonen et al., 2008; Lindahl, 2007; Stagg, 2007). Therefore, Tytler (2014) suggests there is a need to pay more attention to informing students about possible career choices.

3. RESEARCH METHODOLOGY

3.1 Design of the study

This quantitative study was designed to assess components of scientific literacy in the Estonian situation through purposefully developed instruments targeting a representative sample of gymnasium (grade 10–12) students. The study was carried out in three stages, the 1st stage being a pilot exploration of the preliminary instruments, while the 2nd and 3rd stages were taken as the main study, with the further developed instruments being used. The development of the instruments for all stages were based on:

- A meta-analysis of the relevant literature (including the PISA study) to identify components of scientific literacy (as well as cognitive and perception) (Paper I, II and III).
- An analysis of expected learning outcomes in four science subjects with respect to scientific literacy identified in the curriculum (chapter 1, table 2).
- Previous research related to determining the relevant contexts for students (Paper I and III).
- Pilot testing of students based on definition of scientific literacy in the Estonian curriculum (Paper II and III).

3.2 Stage 1

3.2.1 Sample

For stage 1, this study used a non-representative convenient sample (Cohen, Manion & Morrison, 2007) because at this stage the major focus was piloting the preliminary instruments rather than making conclusions about students' progress. The number of students participating in stage 1 was as presented in table 3.

Table 3. Overview of student sample sizes

Stage	Title of stage	Date	No. of students	
			Grade 10	Grade 11
1	Piloting test instruments (consisting of four scenarios)	2009/2010	26	36

3.2.2 Instruments

The study used interdisciplinary scenarios in testing students with respect to problem-solving and decision making, as explained in Paper I. The scenarios were chosen to cover scientific literacy expectations related to the students' personal, social and global lives (Bybee, 1993).

Findings showed (Paper I) that the most suitable situation to consider for further modifications was "Vacationing near the Dead Sea" because:

a) the distribution of students' answers between the four levels of scientific literacy was most similar to a normal distribution (Paper I);
b) this situation was marked as one of the most interesting due to its connection with extraordinary phenomena in nature (Paper I), and
c) students' perceived competence to comprehend this situation was higher (Paper I).

3.2.3 Data collection

In the first stage (2009/2010), the context-based test instruments (consisting of four scenarios) was developed for assessing students' progress in components of scientific literacy (associated with problem-solving and decision making) and piloted in grades 10 and 11 (Paper I). Additionally, information was collected from students and used in modifying the instruments for later use (Paper I). The additional information comprised three short questions (*What was the most interesting scenario? In which scenario my capability to solve problems and make decision was best? In which scenario my capability to solve problems and make decisions was weakest?*). Students' answers were obtained by recording the specific scenario (Paper I).

3.2.4 Data analysis

As indicated in Paper I, the analysis for the 1st study was carried out using Bybee's (1997) elaborated descriptions of levels of scientific literacy (Paper I, table 2) and differences were calculated using the Wilcoxon test to compare the differences between the mean scores for the two grades.

3.2.5 Validity and reliability

The validity and reliability of the instruments and methodology used was determined as shown in table 4.

Table 4. Validation and reliability of instrument used in this study

Instrument/method	Validity/reliability	Validation/reliability method used
Piloting preliminary instruments	Content validity	Expert opinion method: three independent experts in the field of science education.
	Construct validity	Analysis of Estonian gymnasium science curriculum to ensure that items are valid in terms of expected learning outcomes.
	Reliability	Cronbach alpha = 0.75

3.3 Stage 2 and 3

3.3.1 Sample

For stages 2 and 3, the representative sample was defined in terms of the Estonian situation (table 5).

Table 5. Overview of student sample sizes for data collection stages 2 and 3

Stage	Title of stage		Date	Sample size (N)		
				Grade 10	Grade 11	Grade 12
2	Perception questionnaire		Autumn 2011 (grade 10); Spring 2013 (grade11) (cross-sectional)	2217	1821	
	Test instruments 4 scenarios in combinations of 2	Scenario 1 (Dead Sea)		1128	946	
		Scenario 2		1116	932	
		Scenario 3		1129	953	
		Scenario 4		1102	894	
3	Scenario 1 Dead Sea	All students in grade 12	Autumn 2013 (longitudinal)			764
		Grade 10 & 12 in common				316

The unit of analysis for the sampling was taken to be the school and schools were chosen based on 3 location divisions: (1) the capital; (2) towns with at least two gymnasiums and (3) rural areas. This choice of location ensured that schools in all areas had an equal probability to be involved. After arranging schools based on location, schools were ordered based on the average national examination results in 2010. Then every fourth school was chosen in each subgroup. This sampling design was developed for the LoTeGüm project (Rannikmäe, Reiska & Soobard, 2014) and also utilised in this study.

The resulting school-related representative sample comprised students in 44 Estonian schools. All students' from grade 10 and 11 in the selected 44 schools participated in this study. Although all students were tested in grade 12, the grade 12 sample of interested were those students who has also taken the test in grade 10, approximately 3 years earlier.

3.3.2 Instruments

The outcomes from the main study (stage 2 and 3) were based on two instruments, one for cognitive components compiled in terms of operational scientific literacy (used in stages 2 and 3) and the other for student perceptions of their learning (used in stage 2).

3.3.2.1 Cognitive test instrument

In this study and the LoTeGüm project, the cognitive instrument was composed of 4 scenarios, one of which was related to the Dead Sea (scenario 1). Only data from the use of scenario 1 was used in this study.

Scenario 1 was modified, based on the outcomes from the pilot study (Paper I). During the modifications, more items were added and the instrument was again piloted to ensure the scenario was suitable for gymnasium students. The total set of items was 8, sub-grouped as *giving scientific explanation, solving scientific problem and making reasoned decision* (Paper III). The structure of the instrument was as presented in table 6.

In scenario 1, the interdisciplinary context was used to cover major concepts from each science subject valid in terms of science knowledge (figure 1). The content knowledge in this situation covered:

1) plate tectonics (formation of Dead Sea, item 1);
2) atmospheric phenomena (refers to weather near the Dead Sea, item 2);
3) salt solubility (mineral resources in Dead Sea, items 3–5);
4) heredity (healing properties of Dead Sea salts in case of genetic predisposition to disease, items 6–7), and
5) knowledge about food production, landscape, water resources, agriculture, economics, climate, salts production, social interactions (possible economic activities near the Dead Sea, item 8).

All content knowledge aspects were within the Estonian curriculum (Estonian Government, 2011) and were incorporated into the skills tested (the knowledge was not separately assessed, but was integrated into testing of skills as components of scientific literacy).

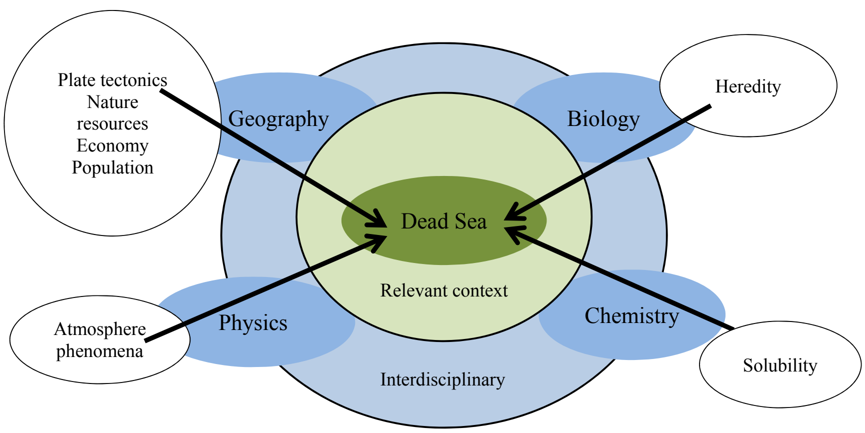

Figure 1. An overview of the science knowledge included in the scenario 1

In this study, the scenario was followed by test items, derived based on the SOLO taxonomy levels. This taxonomy was used as it could describe how a learner's performance grew in the level of complexity by developing items requiring growth of knowledge as well as items requiring demonstrating necessary skills (Paper III). The application of SOLO levels to the test items and how the ideology of SOLO was used to compose the instruments was as described in table 6.

Table 6. The description of the levels of SOLO taxonomy, keywords and number of items at each SOLO level (taken from Paper III, table 2)

Level	**Biggs (1996)**		**Scenario and items in the current study**		
	Criteria	**Key words**	**Dead Sea** (items)	**Knowledge area**	**Component of scientific literacy**
Uni-structural	One obvious piece of information	Name, acquire, terminology	1	Plate tectonics	Giving scientific explanation (name one correct explanation)
Multi-structural	Use two or more discrete and separate pieces of information	Combine, describe, list, list the main points	2	Atmospheric phenomenon	Giving scientific explanation (list two correct explanations)
Relational	Use two or more pieces of information, each directly related to an integrated understanding	Analyse, criticise, argue, justify, understand, apply, relate, explain, solve problems, inquiry, conceptualise	3 4 5	Solubility of substances	Problem-solving (interpreting and analysing graph, writing scientific explanation)
Extended abstract	Use abstract general principle or hypothesis	Hypothesise, reflect, generate, generalise, depth understanding, theorising about the topic, generalising new applications	6 7 8	Heredity Science Economics	Decision making (choosing correct claims, writing claims, making justified decision)

3.3.2.2 Student perception instrument

This instrument consisted of three sections (Paper II, table 1) through which data was gathered on students' perception of:

a) cognitive components of scientific literacy,
b) received science teaching determined in terms of operational skills promoted in science subjects,
c) their future career.

A more details overview of the instrument is given in table 7 (table drawn based on the text in Paper II)

Table 7. An Overview of the perceptions instrument

Section	No of items	Purpose	Content
1	8	Perceptions of their own scientific literacy ability	The 8 items covering perception of process skills are expected to be acquired, at least to some degree, before grade 10 and enhanced during gymnasium teaching. These relate to problem-solving through scientific inquiry (items 1–5), familiarity with figures and graphs (item 6), giving explanations (item 7), and undertaking decision-making (decisions made in the face of multiple options) (item 8). The items used did not bear any relationship to specific content areas associated with lessons in biology, chemistry, geography and physics.
2	32	Perceptions towards received science teaching	8 items were used, with these items repeating for each of the 4 science subjects. Item coverage went beyond process skills included in section 1 and also incorporating values (item 1), nature of science (item 5) and creativity (item 8).
3	10	Perceptions towards a future career	Section 3 sought to interlink learning in science lessons with career expectations (items 1, 2, 3 and 4). In addition, items 5 and 6 sought to relate careers to specific skills promoted in section 2. The remaining items sought, more specifically, the careers domains students had in mind.

3.3.3 Data collection

Data collection in stages 2 and 3 (Paper II–IV, research question 4) took place in the period November 2011 – November 2013. Testing time for students was 90 minutes (including cognitive test and questionnaire about perceptions).

The study used two approaches for data collection:

(1) a comparative study (comparing student outcomes from the beginning of grade 10 and at the end of grade 11, tested in the same schools with students taught by the same teachers within these schools, but students differed), and

(2) a longitudinal study (testing the same students at the beginning of grade 10 and at the end of gymnasium studies in grade 12).

When initiating the second stage (2011/2012), it was recognised that student perceptions, besides students' actual achievement, was a valuable addition.

With this in mind, an instrument measuring grade 10 and 11 students' perceptions of their abilities in components of scientific literacy was developed and piloted with a sample of grade 10 and 11 students (not participating in the main study) and among pre-service science teachers (Paper II). The final version of the developed instrument also asked students' impressions of the science teaching received and their future career preferences (Paper II). The instrument (comprising three sections) was validated by soliciting opinions from 5 experienced science teachers whose role was to ensure that all items were relevant with respect to science teaching (Paper II). The students' role during the piloting was to ensure that questions were understandable by upper secondary school students. The reliability for the overall instrument, calculated using Cronbach alpha, was 0.93.

In developing the second stage, the Estonian curriculum for the gymnasium level was analysed to identify how far the overall purpose (to achieve scientific literacy) as stated in the general part of the science curricula is supported by each of the single science subject curricula (biology, chemistry, geography, physics) existing at this level. For this, the expected learning outcomes, in terms of SL at the end of gymnasium studies, indicated generally in terms of science, were listed and compared with those stated for the individual expected learning outcomes in each separate science subjects. Outcomes were identified and stated in chapter 2, table 2.

Also before initiating stage 2, the test instruments were suitably modified, while maintaining the focus on assessing grade 10 and 11 students' progress in problem-solving and decision-making.

The revised test instrument, based on the Dead Sea scenario, underwent further scrutiny by expert opinions from four school geography teachers and two university science staff (geography and chemistry) members. Based on their recommendations, the instrument was modified to make it more suitable for both the upper secondary level and, because many upper secondary students were likely preparing to go to university (Paper III), on expectations at the university level (Paper III). The reliability of the final overall instrument, calculated using Cronbach alpha, was 0.62 and considered acceptable for this under ten item test instrument (Paper III).

The end of the preparations for the second stage was the starting point for the main large-scale comparative data collection for the LoTeGüm study among grade 10, to be followed later in the school year by the testing of 11 students. This data comprised both the developed test instruments and the questionnaire on students' perceptions. All students in grades 10 and 11 answered the perception questionnaire, while test scenario data (4 in total in the LoTeGüm project) were obtained as twin combinations (e.g. scenarios 1 and 2, 2 and 1, 2 and 3, 2 and 4, etc.). This resulted in approximately 50% students responding to the re-developed Dead Sea scenario.

In the third stage of the study (2013), the grade 10 students (initially tested in 2011) were re-tested in grade 12 allowing longitudinal data from a sub-set of grade 10 students, retested in grade 12. This data is a sub-set because:

a) some students had left the school or were absence from school on the testing day in grade 12;
b) the use of a two scenario combination test was such that only one scenario from four could be taken as common, the common scenario being, for this study, scenario 1.

3.3.4 Data analysis

The analysis shown in Paper II was based on the students' answers to a 4-point Likert-scale questionnaire. A 4-point Likert-scale was chosen in order to eliminate an undecided response and allow later determination whether students agreed or disagreed with the provided statements in the questionnaire. Responses 1 and 2 (*strongly disagree/disagree*) were considered as disagreement, while 3 and 4 (*agree/strongly agree*) were considered as agreement. PASW (SPSS) Statistics was used to investigate how responses in a single group (grades, examination groups and gender) varied. Rasch analysis (RUMM2030) was also used in Paper II to determine how well items and persons matched each other (Oon & Subramaniam, 2013).

Paper III and research question 4 focused on the analysis of cognitive learning outcomes from stages 2 and 3, where the analyses were based on a distribution of students' answers as described in table 8.

Table 8. Assessment structure

Points	Description
0	No credit (minimal response) Answer is missing or it is an incorrect response.
1	Partial credit (medium response) Answer is generally correct, but something is missing for a full credit response.
2	Full credit (maximum response) Answer is given and it is accurate.

The analysis was undertaken using frequency distribution, Mann-Whitney U-Test (for calculating the differences between frequency distributions), mean scores and T-test (for calculating the differences between mean scores) and effect size for eliminating the sample size influence on the findings.

With respect to research question 4, the responses were weighted (extra criteria-based points were added to selected items in SOLO level 3 and 4 items) and based on the total scores students were divided into four levels based on +/- 1 or more standard deviations.

3.3.5 Validity and reliability

The validity (content and construct) and reliability of the instruments and methodology used was determined as shown table 9.

Table 9. Validation and reliability of instruments used in the study

Instrument/method	Validity/ reliability	Validation/reliability method used
Questionnaire administered to determine students' perceptions towards: (1) their achievement in cognitive components of scientific literacy, (2) received science teaching, and (3) future career preferences	Content validity	Expert opinion: five experienced science teachers. Piloting among pre-service science teacher students and a sample of grade 10 and 11 students who did not participate in the actual study.
	Construct validity	Analysis of Estonian gymnasium science curriculum to ensure that items are valid in terms of expected learning outcomes.
	Reliability	Cronbach alpha determined for each component (1) = 0.79 (2) = 0.92 (3) = 0.72
Test instrument for students to assess their cognitive progression in components of scientific literacy	Content validity	Expert opinion: four independent science teachers and two university science faculty staff members. Piloting among upper secondary school students who did not participate in the actual study.
	Construct validity	The analysis of Estonian gymnasium science curriculum to ensure that test instrument is valid in terms of learning content and expected learning outcomes.
	Reliability	Cronbach alpha = 0.62 (Dead Sea)

4. FINDINGS

4.1 Findings from stage 1

The findings from stage 1 are given in Paper 1. This showed that it was possible to develop an instrument for determining student's achievements at different levels of scientific literacy. Student responses from grades 10 and 11 were distributed between different levels of scientific literacy. The description of the levels of scientific literacy originally created by Bybee (1997) was modified in the context of stage 1 (Paper I, table 2), because this study only focused on problem solving and decision making competences, while the original levels of scientific literacy created by Bybee referred to a wider context.

In general, students in both grades responded at the functional level (54% of responses), but had difficulty operating at the higher levels of scientific literacy (structural and multidimensional) (Paper I). Only in the social context were 10% students able to give maximal response (Paper I, table 3) suggesting that they were able to utilise interdisciplinary concepts in real life situations. Findings indicated that student achievement was scenario specific (for example, higher when related to a personal or societal scenario, but lower in a global scenario) (Paper I, tables 1 and 3). This aspect was considered in further modifications for the main study instruments (see chapter 3).

Paper I also gave findings from students' perceptions about the scenarios (Paper I). In general, students perceived as interesting those scenarios seen as needing strong competence to solve problems and make decisions. The finding that the most interesting scenarios perceived by students was "Hiking in the Grand Canyon," indicated that students were interested in extraordinary phenomena in nature (Paper I, table 6). The least interesting scenario perceived by students was "Visiting a Rainforest" which was presented in a global context (Paper I, table 6). Not surprising, students indicated that they found scenarios interesting when they felt their competence to solve problems and make decisions was strong ("Travelling to Egypt"). Also, the reverse occurred when students felt their competence to solve the problems and make decisions was poor ("Visiting a Rainforest").

4.2 Findings from stage 2

4.2.1 Findings from student responses to cognitive test items in scenario 1

Based on findings from responses to test items related to scenario 1, Paper III reported that there was no significant effect size between grade 10 and 11 students' responses on items 1 and 2, associated with giving scientific explanations at the uni- and multi-dimensional SOLO levels.

For SOLO relational level items, focusing on problem-solving situations and requiring the use of information from figures and tables (item 3), and giving scientific explanation (items 4 and 5), no significant effect size was detected between mean scores for both grades of students (Paper III, table 3). However, grade 11 students gave more maximal responses to items 4 and 5. At the extended abstract level (item 6–8), there was similar responses distribution between the two grades. However, grade 11 students gave more maximal responses to item 7 and more medium responses to item 8 compared to grade 10 students (Paper III, table 3).

As scenario 1 in this study formed part of the LoTeGüm Project (Rannikmäe, Reiska & Soobard, 2014), it is useful to compare how students responded to the 4 different LoTeGüm scenarios and determine the validity of items in the different scenarios. This is undertaken by a comparison of findings for the different SOLO levels in relation to the test instruments as a whole.

Table 10 indicates, based on grade 10 data, the sub-set of students responses to scenario 1, as well as responses in another scenario, taken in combination with scenario 1 (each student responds to 2 scenarios from 4). The table gives the mean percentage responses for items, grouped according to the specified SOLO level. Response % refers to incorrect or no answer (I), partially correct answer (P) and correct answer (C).

Table 10. Distribution of students' responses per SOLO level, to different scenario

Student sub-set of scenarios	**Uni-structural**			**Multi-structural**			**Relational**			**Extended abstract**		
	Response %			Response %			Response %			Response %		
	I	P	C	I	P	C	I	P	C	I	P	C
Scenario 1 (The focus for this study)												
All grade 10 students tested with this scenario (N=1128)	22	28	50	13	69	18	60	39	1	26	70	4
Student sub-set tested in grade 10 and retested in grade 12 (N=316)	22	26	52	14	71	15	58	41	1	22	75	3
Scenario 2												
All grade 10 students tested with this scenario (N=1116)	3	62	35	59	14	27	19	70	11	42	52	6
All grade 10 students tested with this scenario and scenario 1 (N=360)	3	66	31	57	13	30	21	68	11	42	53	5
Student sub-set tested in grade 10, retested in grade 12 on this scenario plus scenario 1 (N=131)	3	66	31	62	11	27	23	68	9	40	56	4
Scenario 3												
All grade 10 students tested with this scenario (N=1129)	47	4	49	12	59	29	29	58	13	76	19	5
All grade 10 students tested with this scenario and scenario 1 (N=363)	47	5	48	13	56	31	26	60	14	78	18	4

Student sub-set of scenarios	Uni-structural			Multi-structural			Relational			Extended abstract		
	Response %			Response %			Response %			Response %		
	I	P	C	I	P	C	I	P	C	I	P	C
Student sub-set tested in grade 10, retested in grade 12 on this scenario plus scenario 1 (N=111)	52	6	42	12	51	37	24	62	14	78	18	4
Scenario 4												
All grade 10 students tested with this scenario (N=1102)	4	35	61	2	65	33	25	57	18	59	24	17
All grade 10 students tested with this scenario and scenario 1 (N=367)	4	33	63	2	65	33	21	61	18	63	20	17
Student sub-set tested in grade 10, retested in grade 12 on this scenario plus scenario 1 (N=126)	5	35	60	4	67	29	25	61	14	66	17	17

Key: I = incorrect answer or no answer, P = partially correct, C = correct answer

Based on this data (table 10), it appears likely that there is no difference in the student responses to each sub set.

4.2.2 Findings from student responses to items in the perception instrument administered in grade 10 and 11

Perceptions towards cognitive competence

Paper II findings showed that grade 10 and 11 students tended to hold higher perceptions in some areas of learning compared to others. For example, in making use of information from tables and figures (nearly 79% students agreed), in drawing conclusions (nearly 77% agreed), but in recognising the problems (less than 56% of students agreed) (Paper II, table 2). In other sub-groups (both grade levels, division by gender and from students in the 3 separate examination groups, derivation based on school mean examination results) students agreed and disagreed with the same items, although the percentage of students agreeing or disagreeing varied (Paper II).

Perceptions towards received science teaching

Students' perceptions towards received science teaching were also analysed (Paper II, table 4). Overall, grade 10 and 11 students' agreed that the received science teaching promoted understanding of the importance of science and technology in society (52% agreed), understanding about nature of science (59% agreed) and in giving scientific explanations (52% agreed).

At the same time, based on their perceptions towards received teaching, students' indicated that science subjects were not promoting skills for posing scientific questions (nearly 66% disagreeing), solving scientific problems (55% disagreed), planning scientific investigation (71% disagreeing), making decisions (nearly 64% disagreeing) and creativity (59% disagreed) (Paper II).

An analysis of received science teaching in each of the four science subjects showed that biology and geography were seen as more supportive for the development of operational skills for scientific literacy as well as values, nature of science and creativity compared with perceptions related to the subjects of chemistry and physics (Paper II). A similar pattern again emerged in the analysis of findings based on grade level, gender and examination groups (Paper II).

Perceptions towards future career

Students' perceptions towards future career were also investigated and analysed (Paper II). In general, students' perceptions were not favourable towards continuing science-related studies (nearly 74% disagreeing) and careers in science (nearly 77% disagreeing) (Paper II). An interesting outcome was that according to students' perceptions, their received science teaching had not introduced science-related professions (Paper II). Students from grade 10 and 11 preferred professions related to creativity (75% agreed) and reasoned decision-making (nearly 77% agreed). Professions related to problem-solving were not popular (nearly 71% disagreed). Again, these perceptions were similar across grades, gender and examination groups (Paper II).

Students' preferred fields of working were also analysed (Paper II table 5). Overall, students preferred careers in the social sciences (economics, law) (57% agreeing). At the same time, they did not prefer working in the natural sciences (chemistry, physics, biology, geography) (nearly 74% disagreeing), medicine (75% disagreeing) and in engineering/technology (nearly 56% disagreeing). A similar pattern was found from perceptions among grade 10 and 11 students, examination groups and perceptions by girls versus boys (except in engineering and technology where 67% boys agreed, but girls were much more negative (76% disagreeing).

4.3 Findings from stage 3

The grade 10 students were re-tested in grade 12. However, the grade 12 sample formed was only a sub-set of those tested in grade 10, because of drop out, absenteeism and change of school. It was therefore necessary to determining whether the results from the grade 12 sample were still representative.

It was not possible to determine representativeness based on the cognitive test, even considering the total LoTeGüm study, as the students undertook different test combinations in grade 12 from those in grade 10. However, all students in grade 10 answered the items on the same perception instrument and hence results for those students can be compared to the results for the sub-set of grade 10 students who later undertook the cognitive test involving scenario 1 (the instrument of interest for this study) in grade 12.

Part A. Percentage findings based on grade 10 students' agreement or dis-agreement related to the 8 components included in the Likert scale perception instrument were as presented in table 11.

Table 11. Students' perceptions by all grade 10 students compared to the sub-set of grade 10 students involved in this study in grade 12

Items in section 1		Grade 10		Grade 10 students in grade 12	
		Agree	**Disagree**	**Agree**	**Disagree**
Recognising problems	N %	**1245** **56.6**	956 43.4	**177** **56.4**	137 43.6
Posing scientific questions for investigation	N %	1022 46.2	**1191** **53.8**	**166** **52.7**	149 47.3
Planning scientific investigation	N %	855 38.7	**1351** **61.3**	135 42.9	**180** **57.1**
Solve scientific problems	N %	847 38.4	**1358** **61.6**	120 38.3	**193** **61.7**
Drawing conclusions	N %	**1706** **77.3**	500 22.7	**244** **77.5**	71 22.5
Figures and tables as a source of information	N %	**1785** **80.7**	426 19.3	**238** **75.3**	78 24.7
Explaining phenomena scientifically	N %	1032 46.7	**1176** **53.3**	146 46.3	**169** **53.7**
Evidence based decision making	N %	**1264** **57.5**	934 42.5	**199** **63.4**	115 36.6

Findings showed that in general, similar pattern emerged from all students perceptions given in grade 10 (given in the column labelled grade 10) compared to the sub-set of the same students' perceptions from grade 10 who also participated in grade 12 (given in the column labelled grade 10 students in grade 12). The only exception is in responses to item 2 (posing scientific questions for investigations), but the difference between agreement among all grade 10 students (46.2%) and the sub-set of grade 10 students participated also in grade 12 (52.7%) is less than 7% and therefore the change in agreement/disagreement is not high.

Part B. Percentage findings based on perceptions of future careers.
Table 12 showed that the grade 10 students in the grade 12 sub-sample responded in a similar manner as all grade 10 students. This suggested the grade 10 (grade 12) sub-sample was sufficiently representative to be compared to the whole grade 10 sample, even for the cognitive test findings.

Table 12. Students' perceptions towards future career by all grade 10 students compared to the grade 10 sub-set tested in grade 12

Items in section 3		**Grade 10**		**Grade 10 students in grade 12**	
		Agree	**Disagree**	**Agree**	**Disagree**
Science related studies	N %	586 26.7	**1614** **73.3**	86 27.3	**229** **72.7**
Science related career	N %	520 23.6	**1680** **76.4**	72 22.7	**244** **77.3**
Introduction of science related professions	N %	853 39.0	**1333** **61.0**	124 39.5	**190** **60.5**
Professions requiring problem-solving	N %	653 29.8	**1541** **70.2**	83 26.4	**232** **73.6**
Profession requiring creativity	N %	**1645** **74.8**	556 25.2	**235** **74.3**	81 25.7
Profession requiring decision making	N %	**1673** **76.6**	510 23.4	**243** **76.9**	73 23.1
In the future I wish to work in the following fields:					
• Medicine	N	551 25.9	**1580** **74.1**	71 23.4	**233** **76.6**
• Social science (e.g. economics, law)	%	**1291** **59.8**	867 40.2	**185** **59.7**	125 40.3
• Natural sciences (e.g. chemistry, biology, geography, physics)	N %	573 26.9	**1557** **73.1**	86 28.5	**216** **71.5**
• Engineering and technology	N %	985 45.9	**1161** **54.1**	134 43.6	**173** **56.4**

Findings from re-testing student on the cognitive test in grade 12

Table 13 compares findings of mean scores related to each test item in each SOLO level from the sub-set of grade 10 students and the same students when re-tested, after three years of additional learning. Table 13 also indicates whether the differences in mean scores leads to a meaningful effect size.

Table 13. Longitudinal data (N=316) comparing student outcomes on the cognitive test related to scenario 1 (Dead Sea)

SOLO level	Item	Grade	Mean score	SD	t	p	Effect size Cohens d
Uni-structural	1	10 12	1.31 1.24	0.81 0.83	1.051	0.294	0.085
Multi-structural	2	10 12	1.01 1.01	0.54 0.58	-0.075	0.941	0.000
Relational	3	10 12	0.60 0.55	0.52 0.54	1.414	0.158	0.094
	4	10 12	0.45 0.54	0.65 0.72	-1.822	0.069	0.131
	5	10 12	0.20 0.23	0.44 0.49	-0.652	0.515	0.064
Extended abstract	6	10 12	1.60 1.57	0.55 0.65	0.554	0.580	0.049
	7	10 12	0.35 0.65	0.62 0.75	-6.330	0.000	0.435
	8	10 12	0.40 0.68	0.56 0.68	-5.866	0.000	0.449

Table 13 shows that after three years of extra learning, there was only a significant difference in mean scores for two items (7 and 8), both at the extended abstract level. Those were also the items where effect size indicated changes in students learning outcomes after three years of learning in science subjects at the gymnasium level. No significant difference was found in the case of the other items indicating that little progress was made after three years of study.

To better identify students' progress in cognitive competence, students in grade 10 and the same students in grade 12 were divided into four levels based on total scores in the test for scenario 1. An assumption was made that the distribution of scores represented a normal curve so that 67% of student's score were in the range Mean +/- 1 SD. Convenient adjustments were made at the boundaries to ensure all students gaining the same mark were assigned to the same level. The allocation was determined as shown in table 14.

Table 14. The determination of levels of students' scores

Levels	Determination of levels	Student scores based on all items in scenario 1
Level A	Less than (mean – 1 SD).	< 7
Level B	Between mean and (mean – 1 SD).	7–9
Level C	Between mean and (mean + 1 SD).	10–12
Level D	More than (mean + 1 SD).	> 12

The findings are illustrated in the figure 2.

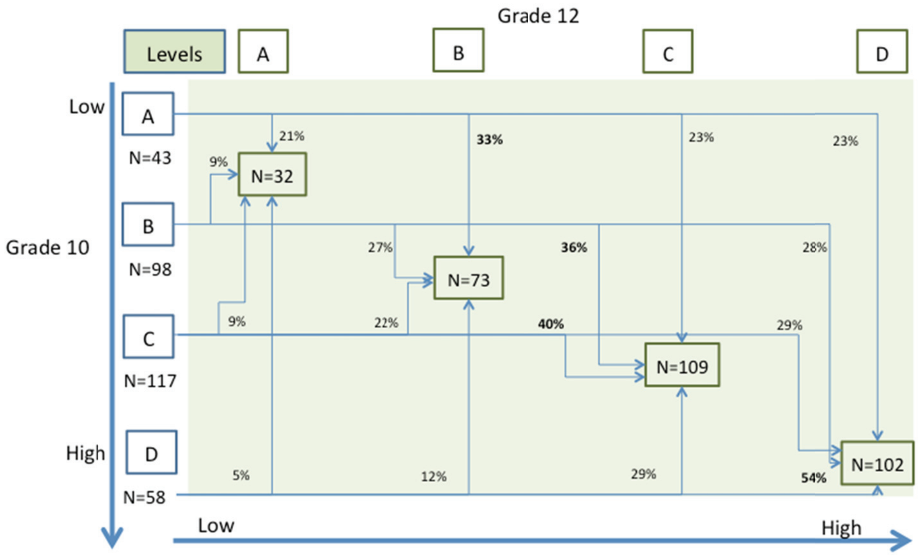

Figure 2. Distribution of students per level in grade 10 and for the same students in grade 12 showing the number and percentages of students changing levels

Figure 2 illustrates that whereas 43, 98, 117 and 58 students scored at levels A, B, C, D respectively in grade 10, the student's numbers distributed in grade 12 at the same levels were 32,73,109 and 102 respectively. In general, students who attained levels A and B in grade 10 scored at a higher level in grade 12. However, surprisingly only 54% students scoring at level D in grade 10 stayed at level D in grade 12. Almost the same percentage of students scoring at levels A, B, and C in grade 10 gained level D in grade 12. More interestingly, while 21% and 27 % stayed at level A and B when retested in grade 12, 40% students at level C continued to attain level C in grade 12.

Figure 2 shows that progress is mainly for level A and B students, limited for level C students and negative for nearly half of level D. During the three years of schooling, more than 50% students attained scores moving from levels B and C to level D, but at the same time, 50% of level D students dropped to a lower level.

5. DISCUSSION

This study recognised the need to assess learning progression in components identified as contributing to scientific literacy in the Estonia situation, based on curriculum expectation through purposeful developed instruments targeting gymnasium students at different grade levels. The study investigated gymnasium students' comprehension and application of relevant knowledge and skills in a situation derived from real life. The study also sought students' perceptions towards their cognitive competence, perceived science teaching and future career preferences.

5.1. Validity of sub-samples

In using various sub-samples, this study took care to ensure that all sub-samples could be considered valid and hence representative. The validity of the various sub-samples was determined through comparing response patterns for the different sub-samples related to the scenarios and also student perceptions.

5.1.1 Validity of student sub-samples when testing using scenarios

The analysis of students' responses to the scenario test items showed that similar patterns (see chapter 4, table 10) emerged in all grade 10 students' responses in all scenarios for items at all SOLO levels, with more students giving correct responses for items at SOLO levels 1 and 2 compared to SOLO levels 3 and 4. This suggests that the sub-samples can be taken to be representative of the population, even though numbers were reduced and omission of non-tested students was not under the control of the study.

5.1.2 Validity of sub-samples based on perceptions responses

Grade 10 students' perceptions against cognitive competences were compared with those grade 10 students who formed the sub-sample for grade 12 testing (table 11). These findings indicated that the grade 12 sub-sample of students, while still in grade 10, could be considered representative, as their perceptions matched well with those for the total grade 10 sample.

5.2 Students cognitive competence with respect to SOLO taxonomy among grade 10/11 and 10/12 students

5.2.1 Uni- and Multi-structural levels – SOLO I and II

Grade 10, 11 and 12

The analysis of students' responses to items testing operational skills (Paper III and research question 4) showed that students can be classified as 'better' at giving a scientific explanation, in items at the first two SOLO taxonomy levels (in grade 10, 11). However, there was no significant change between grade 10 and 11 students' responses to items at first two SOLO taxonomy levels (Paper III, table 3). This suggests there was a similar emphasis on students' requirements to give scientific explanation, indicating that grade 10 and 11 students possibly received science teaching in a similar manner, especially noting that although the students were different, schools and science teachers were the same. However, as there was no difference in students' responses pattern, associated with responses to test items at those levels, it was seen as reasonable to assume that students already had the skill to give scientific explanation in grade 10. Hence, despite the growth of content knowledge (extra year of learning), the competence to give scientific explanation remained at the same level in grade 11. As grade 10 students were tested at the beginning of grade 10, the major learning tested came from basic school. The international PISA study (OECD, 2007) showed Estonian 15-years students (commonly grade 9) above the OECD average.

Another reason, why students achieve relatively well in items at these levels is the fact that items at these two levels were similar to traditional assessment items in science teaching and well-practiced by students. Previous research has indicated teachers in Estonia tend to focus on the assessment of science knowledge (giving scientific explanation) instead of the use of this knowledge in real life situations (Holbrook, 2008).

The comparison of grade 10 students' achievement in grade 10 and 12 showed that the responses pattern remains similar after three years of extra learning and there was neither significant difference nor reasonable effect size in the comparison of two grades achievement.

5.2.2 Relational level – SOLO III

Grade 10 and 11

At the relational level, students were asked to respond to a problem-solving situation (heavily related to concepts taught in chemistry lessons). The findings from grade 10 and 11 indicated that it was equally difficult for students to solve problem, despite the nearly 2 years additional learning by grade 11 students. This finding suggested that developing students' ability to solve problems was not taken as a major focus of science studies during gymnasium years. Further, noting the content of the problem-solving situation was chemistry related in the

Dead Sea test, students pointed out that their science subjects (especially chemistry and physics) did not support the development of problem-solving and decision making skills (Paper II). This suggested that students could lack the opportunity to develop high order thinking associated with problem-solving skills in science subjects. In fact, based on the findings of this item set, it could be assumed that students had not been appropriately introduced to enhancing scientific literacy through operational skills, even though they were included in the Estonian goals of science education at this level. As no meaningful effect size was found between outcomes from grade 10 and 11students at this SOLO taxonomy level, it was reasonable to assume that the learning in this context derived heavily from pre-gymnasium years (Paper III). This could be taken to lead to the interpretation that little advancement in scientific literacy was being promoted with respect to problem solving ability in grades 10 and 11.

Grade 10 and 12

The longitudinal data from grade 10 and 12 showed, in case of scientific problem-solving, students in grade 12 achieved higher mean score compared to when they were in 10 (except for item 3). However, similarly to grade 10/11 at this SOLO taxonomy level, there was no statistically significant change in mean scores, or effect size. It could be assumed that despite the expectations in the curriculum, where proficiency in problem-solving skills is one of the expected learning outcomes at the end of gymnasium (grade 12), students did not demonstrate this competence in a sufficient manner. Unfortunately, only 1% of longitudinal study students achieved highest score in this SOLO taxonomy level while 58% of students gave no response or the response was incorrect. The outcomes seemingly indicating a lack of progression in problem solving ability from grades 10–12 was in agreement with the outcome from the testing of students in grade 11. This was also in agreement with students' perceptions of received science teaching and their perceptions (Paper II) that problem-solving was not introduced in science subjects (especially in chemistry and physics). Also, it was noted that teachers in Estonia indicated that they need additional training for implementing problem-solving situations in science subjects (Holbrook, Rannikmäe & Valdmann, 2014).

5.2.3 Extended abstract – SOLO IV

Grade 10 and 11

At an extended abstract SOLO level, students did relatively well in one item, but poorly in the other two items in both grades. However, the main focus of items at this level was on the decision-making process and previous research had indicated that reasoned decision-making was difficult for students (Sadler, 2004; Cavagnetto, 2010). The outcomes suggested that Estonian students find reasoned decision making difficult.

Grade 10 and 12

This was the only SOLO taxonomy level in which there was a small effect size gain (items 7 and 8). However, the effect size was small and indicated that little learning was occurring in gymnasium level, even at this level with regard to this item. This was further highlighted by the relatively low percentage of students receiving full credit, far less that could be expected for meaningful promotion of scientific literacy after three years of learning at the gymnasium level. Again, little emphasis was placed on this decision making process at the gymnasium level according to students perceptions (Paper II). This should be of major concern for the Estonian Ministry of Education and those at the university level expecting a sound foundation in SOLO level 4 attributes.

5.2.4 Overall – SL indicators

Based on the instrument administered (Paper III), findings showed that students' gains related to problem-solving and decision-making were not high, based on effect size. For meaningful learning, it was expected that student progression took place in their learning from grade 10 to 12, especially with regard to attributes contributing towards the enhancement of scientific literacy. The findings suggested that little learning was taking place during the gymnasium years, in terms of developing the components of scientific literacy. However, it was worthy to note that Miller (1997) conducted a study 'The Longitudinal Study of American Youth,' in which he concluded that the strongest predictor of grade 12 science achievements was grade 9 science achievement, thus suggesting that students' science achievement changed very little during high school years. This seemed to be also the case in Estonia. In Estonia, learning in science lessons during the gymnasium years seemed to add little to the development of competences promoting scientific literacy, as stated in the Estonian curriculum (Estonian Government, 2011). Nevertheless, accepting that implementing the new competence-based curriculum would need time to be implemented and required change in teaching, learning and assessment approaches by science teachers, this study indicated that there was a need to address the new perspectives within the educational policy as a matter of urgency.

Findings from this study indicated that there was a mismatch between expected scientific literacy (written in the curriculum) and actually demonstrated scientific literacy (outcomes from the current study). Possible reasons for such outcomes are elaborated below:

1. The teacher component. Teachers lacked experience and self-confidence in introducing problem-solving and decision making tasks into science classrooms. This was shown in the study undertaken by Holbrook, Rannikmäe and Valdmann (2014). Findings from their study showed that despite the higher self-confidence in some aspects, teachers still perceived the need for further training in components of scientific literacy, which also included problem-solving and decision making. All aspects considered in that study

were not identified as the focus in Estonian science education before 2012 (at the time when national examinations were being conducted). Therefore this study, in agreement with other findings, tended to show that teachers needed to adopt new ways of teaching to implement the new competence based curriculum. Even more, students also perceived their received science teaching in a different manner in different science subjects (Paper II). Therefore there was a perceived need to support competence-based pre- and in-service teacher professional development.

2. The structure of school science. Traditionally, school science in Estonia has been divided between four science subjects and taught by different teachers (e.g. Mikser, Reiska, Rohtla & Dahncke, 2008), with subject content dominating the teaching. Even more, teachers faced a conflict in choosing between interdisciplinary teaching (not all knowledge comes from the science subjects) vs. focusing on the single science discipline (Rennie, 2011). In this regard, Mikser et al. (2008) pointed out that interdisciplinary approaches in teaching were not widely used in Estonia. It could be suggested from this study that the lack of interdisciplinary teaching might be the reason for poor responses to items 3–8 (see the interdisciplinary knowledge content from figure 1) compared with responses to items 1–2 at both grades 10 and 11 levels. Items 3–8 required more interdisciplinary understanding than item 1 (focusing only on geography) and 2 (focusing on geography and physics content). This could also explain why, in agreement with findings by Feinstein (2010), students had difficulties perceiving the usefulness of school science in real life situations.
3. Re-orientation with respect to expected outcomes from science subjects. For decades, assessment at the end of grade 12 science studies was by means of completing national examinations and teachers focused their teaching on the requirements of the exams. As those examinations had different emphases, it could be understood why integration between different subjects was difficult. Fortus and Krajcik (2012) also pointed out that teachers tended to focus only on those aspects in science education, which were assessed (high-stakes examinations, large-scale international comparisons).

   However, national examination in Estonian science subjects were no longer in use, but even so, schools could develop their own 'final exams' and therefore as the teachers' perception and teaching focus became even more important training needs with respect to enhancing scientific literacy should be considered very important in further studies. It was up to teachers to develop their own values and ideas about important aspects in science education and the enhancement of scientific literacy.
4. Students' own responsibility for their learning. It was important to note that for improving students' achievement in science education, students' opinions and perceptions need to be gather against their performance as noted by Marsh and Craven (2006). However, as the assessment of perceptions was also a skill (Dearnley & Meddings, 2007), the link between perception and achievement in this study was not pursued.

The analysis of students' progress in scientific literacy gains, when moving from grade 10 to 12, showed little change towards higher levels of learning. The majority of the students remained at the lower levels. However, this was seen as a matter of concern for those associated with tertiary level institutions, because the study suggested that students from the grade 12 were ill prepared for studies at university level. A change of emphasis towards enhancement of scientific literacy skills might mean a lack of specific knowledge and skills expected on entering the first year in university. But on the other hand, scientific literacy attributes were more related with self-determination and ability for self- and lifelong- learning, major attributes perceived of importance for advancement in tertiary level studies.

5.3 Student perceptions

5.3.1 Perception related to cognitive aspects

From an analysis of students' perceptions, in terms of agreement/disagreement (Paper II), students in general (grade 10 and 11) perceive higher competence for operational scientific literacy skills which are more frequently promoted in science teaching, such as using scientific information derived from tables and figures and drawing evidence-based conclusions (Paper II). However, students' perceived competence is lower for operational skills related to problem-solving, formulating scientific questions for investigation and planning scientific investigations. This suggests that the development of such operational skills is not a focus in science teaching (Paper II). However, problem solving and scientific inquiry are highly emphasised in the Estonian competence-based curriculum (see chapter 2, table 2) and therefore need to be part of the teaching in science subjects. Through such enhancements students' perceptions related to those cognitive aspects, can be expected to increase.

As no significant difference in responses patterns is identified in students' perceptions of their ability in operational skills associated with scientific literacy, over the two years of schooling (at the beginning of grade 10 and at the end of grade 11) (Paper II, table 2), this suggests students don't feel their ability is high in these important operational skills. In turn, this points to students receiving similar learning emphases across the two years, which is not focusing on the development of operational skills enhancing scientific literacy, even though these are components of the intended curriculum. A similar pattern in students' responses emerges among examination and gender groups and therefore indicates that despite some school having a higher mean score with respect to examination results and hence a perceived opportunity to diversify, students' perceptions still show a similar pattern (Paper II, table 2 and 3).

Some operational skills are promoted more than others, according to students' perceptions. Group 1 students (Paper II, table 3) tend to agree more that their perceived competence is higher, but the general pattern is the same for all groups. However, group 1 includes schools with higher average examination results, and as these school also select students by administering entrance tests, it can be expected that this has an effect on students' perceptions.

As others have shown, perceived competence plays a role in students' actual achievement (Deci & Ryan, 2000; Marsch & Craven, 2006). The findings in this study indicating students' low perceived competence in operational skills as components of scientific literacy need to be taken into consideration as a matter of concern. This is important, because students' perceptions against one self could influence their achievement (Choi et al., 2011).

5.3.2 Perceptions related to received science teaching

Students' perceptions against received teaching show there is a response gap between perceptions emanating from geography and biology studies compared with those from physics and chemistry (Paper II). This is supported by findings indicating that students in biology and geography generally agree that operational skills and creativity, value and nature of science are being promoted (Paper II, table 4), while for studies in physics and chemistry they mainly agree that giving scientific explanation and understanding about nature of science are the major foci of attention. This difference in perceptions of science subjects can result from teaching orientations based on curriculum traditions, which are still being upheld by teachers. This can be speculated to be, because:

(a) Chemistry and physics have been traditionally presented in a more abstract manner and thus not directly applicable for the students' own lives (Gilbert, 2006).
(b) Examination traditions, through which subjects present different expectations (Paper III). For example, if the physics examination is mainly focusing on recalling and calculation tasks, then it is not surprising that this is also the focus of physics subject teaching and it becomes of little surprise if students don't perceive that this subject supports the development of decision making, or real life-related problem-solving.

Noting the final examination has been a major focus for science teaching in all 4 subjects, it becomes clear why operational skills for enhancing scientific literacy are not, in general, gained by students – they are simply not a focus of teaching (Paper II). And as the components often related with scientific literacy are not part of the common assessment in science subjects, students' have little opportunity to reflect on their perceive competence against the feedback given by science teachers. It is worthy to note research has shown that if teachers change their teaching methods and activities, this is an aspects which is perceived by students (Vaino, 2013).

5.3.3 Perceptions on careers

One purpose of science education quoted in the literature and endorsed by the Estonian curriculum was to raise students' career awareness in science. In this study, students were asked about their perceptions of future careers. The outcomes showed grade 10 and 11 students had not received information about science related professions (Paper II). While recognising that not all students' should choose science related professions in the future (Simon & Osborne, 2010), nevertheless, science education should prepare students with the necessary operational skills to cope in real life situations (Bybee & Fuchs, 2006). In this study, students' perceptions towards science related career and further studies were, in general, not high (Paper II) this being in line with previous studies (OECD, 2007; Lavonen et al., 2008). This agrees with outcomes from a study among Estonian grade 9 students (Teppo & Rannikmäe, 2006). Possible reasons why students' perceptions towards future career in science were not high were suggest to be because students were not introduced to possible careers in the field of science (Stagg, 2007).

6. CONCLUSIONS AND IMPLICATIONS

6.1 Conclusions

In undertaking this study, four research questions were addressed:

1. Can meaningful instruments be developed to assess gymnasium students' achievement in cognitive components of scientific literacy and their perceptions towards their competence in giving scientific explanation, solving meaningful problems and making reasoned decisions?

Findings showed that:

- The evidence indicated in this thesis points to the conclusion that it is possible to develop a meaningfully instruments to assess students' achievement in cognitive components of scientific literacy. The instrument (scenario 1) based on SOLO taxonomy focuses on expected learning outcomes and focuses on the skills important for enhancing scientific literacy.
- For such an instruments, items need to cater for students answering at different ability levels. This leads to the use of a specific taxonomy, such as SOLO, to devise the assessment instruments. For example, easier or simpler items plus more sophisticated ones, demanding higher levels of cognition.
- It is meaningful to include items to discover students' perceived competence. This allows determination of how students think about their competence and how this correlates with the actual outcomes in the test.

2. What changes occur in gymnasium students (grade 10 and 11) perceptions towards competence in cognitive components of scientific literacy skills, science teaching in terms of developing those skills and preparedness for a future career, over two years of study at the gymnasium level?

Findings showed that:

- Students' perceived competence in using operational skills changes little among grade 10 and 11 students. This suggests that despite the extra years of learning, students, in general, don't perceive any change in their abilities to utilise operational scientific literacy skills.
- Based on students' perceptions, the learning emphasis in science teaching is similar over the two years of learning. Biology and geography teaching is seen as being more supportive of the need to enhance operational skills of scientific literacy than the teaching in physics and chemistry. This suggests that the learning focus of science subjects depends on its curriculum portrayal; where it is more content knowledge oriented and more likely to be abstract, less attention is paid by teachers to its relatedness with real life issues and hence operational skills.
- Students' career preferences change little over the two years of science study. Generally students do not hold positive perceptions related to a science career or towards further studies in science. Students' also indicate

that science subjects do not provide an overview about science related careers. However, students' do prefer professions related to creativity and reasoned decision-making, both of which are closely related with curriculum perceived scientific competence and hence identified as aspects of scientific literacy.

3. What differences occur in gymnasium students (grade 10 and 11) progress in cognitive components associated with scientific literacy when approached via a real life, context-based assessment strategy over the two years of study at the gymnasium level?

Findings showed that:

- In general, there were no differences in achievement between grade 10 and 11 students despite the extra years of learning. This indicates little or no progress is taking place and students are being poorly prepared for future education situations where scientific literacy attributes are important. Although the amount of knowledge may be enhanced due to the extra learning, students' still lack knowledge of how to utilise it to solve problems and make reasoned decisions.

4. Can the progress in gymnasium students' scientific literacy be determined through assessment of cognitive components of scientific literacy (grade 10 and 12 students)?

Findings showed that:

- It is possible to determine gymnasium students (from grade 10 to 12) progress in cognitive components of scientific literacy. However, taking a representative group of the same students and testing both – grade 10 and 12, little progress occurs over the 3 years from grade 10 to 12 in students' ability to undertake operational skills enhancing scientific literacy. Students identified as being at level A in terms of achievement in grade 10 mainly moved to level B, while students from level B moved to level C. The majority of students, who were already at level C or D in grade 10, remained at the same level when tested in grade 12. However, test outcomes suggest a sizeable minority of students moved from higher to lower levels after three years of schooling.

6.2 Implications

I. The instrument is shown to be useful, valid and sufficiently reliable to be used for assessing components of scientific literacy among gymnasium students in Estonia (for use in regular science lessons and for test/exams).

II. There is a need to revise the portrayal of the intentions from each of science subjects within the curriculum. As the major stated purpose in the Estonian curriculum related to science education is to develop scientific literacy, each science subject separately needs to explicitly focus on the development of this, above and beyond subject-based content knowledge. Although this is likely to lead to a reduction of science subject content (or an increase in the number of science lessons), the focus becomes more real life oriented paying more attention to the related competence development. Without this, there is little evidence that gymnasium students will achieve the intended curriculum outcomes.

III. To refocus the portrayal of the curriculum in science subjects, there is a perceived need to promote more competence-based teacher pre- and in-service professional development. This study points out that there is little evidence of teacher change with the introduction of the new curriculum and the removal of the final examinations in science subjects. Without more detailed guidance for teachers, student perceptions of their competences are likely to remain low, as will their actual achievement. Therefore, further studies should develop learning and teaching activities and materials that stimulate the development of scientific literacy among students.

IV. As the teaching content depends also on public expectations (e.g. future employers), curriculum developer's expectations and is also related with outcomes from international large-scale studies, it is also important to consider expectations of interest groups while modifying assessment material and considering what to assess. Participating in international comparative studies at the gymnasium level can provide a useful indicator of progress.

V. The findings from this study indicate that the science teaching received by students does not meaningfully support the development of scientific literacy. Students' actual outcomes also point out that their competence to operationalise components of scientific literacy is not matching learning and curriculum expectations in tackling problem-solving and decision-making scenarios. These findings can be the starting point for developing in-service courses for science teachers by pointing out students' weaknesses and strengths. However, this study points to the need for courses to have an interdisciplinary context (scenario in this study was interdisciplinary), raising teachers' confidence to bring interdisciplinary topics into science classes.

VI. To promote students' operational skills in scientific literacy and also to guide students to think more in terms of their perceived competence, it seems schools need to implement more intensively courses that promote the development of scientific literacy in both actual achievement and thinking about achievement.

VII. This study point to zero or very little enhancement of progress of scientific literacy at the gymnasium level. This needs to be taken to be of much concern to tertiary level institutions, especially universities, as students are being ill prepared for further studies. It is not a question of what students' can actually do, but more it is related to the ability to embrace lifelong learning in terms of self-development and a readiness to acquire new knowledge and skills in order to achieve at the tertiary level.

VIII. Further studies need to focus more carefully on how science teachers actually assess students' expected learning outcomes in terms of components of scientific literacy and how they actually develop scientific literacy in classrooms (not just asking students perceptions as was undertaken in the current study).

6.3 Limitations of the study

This study has the following limitations:

1. Not all components of scientific literacy are measured in this study (for example communication with others, evaluative searching of information sources). This is not considered possible with paper-and pencil, large-scale tests.
2. No prior training or practice was provided for students in completing the perceived learning instrument. Students' evaluation of their own perceived competence was recognised as a skill like any other and therefore needs practice and an ability to meaningfully interpret the questions posed. Practice in this was not feasible for this study.

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SUMMARY IN ESTONIAN

Gümnaasiumiõpilaste loodusteadusliku kirjaoskuse uuring tuginedes õpilaste kognitiivsetele õpitulemustele ning enesehinnangutele

Käesoleva doktoritöö põhieesmärgiks oli uurida gümnaasiumiõpilaste loodusteaduslikku kirjaoskust gümnaasiumi õpingute jooksul, kasutades selleks spetsiaalselt koostatud uuringuinstrumente ning kogudes nii võrdlus- (10. ja 11. klass) kui ka longituuduuringu andmeid (10. ja 12. klassi samad õpilased). Lähtuvalt tööle seatud eesmärgist püstitati neli uurimisküsimust:

1. Kas on võimalik koostada teaduslikult põhjendatud uurimisinstrumendid, hindamaks gümnaasiumiõpilaste loodusteadusliku kirjaoskuse taset läbi oskuste anda loodusteadusliku sisuga selgitust, lahendada loodusteadusliku sisuga probleeme, teha põhjendatud otsuseid ning uurimaks õpilaste endi hinnanguid oma oskustele?
2. Millised erinevused ilmnevad õpilaste enesehinnangutes (10. ja 11. klass) enda oskustele loodusteadusliku kirjaoskuse kognitiivsete komponentide suhtes, hinnangutes loodusainete tundides toimuvale õpetamisele ning tulevasele karjäärile kahe aasta õpingute vältel?
3. Millised on erinevused gümnaasiumiõpilaste (10. ja 11.klass) loodusteadusliku kirjaoskuse kognitiivsetes komponentides hinnatuna läbi reaalse eluga seotud kontekstiga ülesannete?
4. Kas gümnaasiumiõpilaste (10. ja 12. klass) loodusteadusliku kirjaoskuse tasemeid on võimalik määratleda loodusteadusliku kirjaoskuse kognitiivsete komponentide kaudu?

Loodusteadusliku kirjaoskuse kujundamine on ülemaailmselt loodusainete õpetamise üks peamisi eesmärke ning esile tõstetud ka Eesti õppekavas. Sellest tulenevalt peaks loodusteadusliku kirjaoskuse kujundamisele tähelepanu pöörama iga üksiku loodusaine (geograafia, bioloogia, keemia ja füüsika) õpetamisel. Kuna PISA uuringu sihtgrupiks on põhikooli lõpuklasside õpilased (OECD, 2007), siis kahjuks puuduvad sarnased süstemaatilised teadusuuringud gümnaasiumi vanuseastmel. Käesoleva uurimistöö innovatiivsus seisneb teaduslikult põhjendatud uurimisinstrumentide koostamises ja nende kasutamises Eesti gümnaasiumiõpilaste loodusteadusliku kirjaoskuse hindamisel.

Loodusteadusliku kirjaoskuse määratlustes on läbi aegade olnud mitmeid erinevaid rõhuasetusi (Hurd, 1958; Shen, 1975; UNESCO, 1993; Shamos, 1995; NRC, 1996; Bybee, 1997; Miller, 1997; OECD, 2007; 2013; Roberts, 2007, 2011; Murcia, 2009; Holbrook & Rannikmäe, 2009; Choi, Lee, Shin, Kim & Krajcik, 2011; Roberts & Bybee, 2014). Nende järgi on loodusteaduslik kirjaoskus:

1. Peamine loodusainete õpetamise eesmärk.
2. Vajalik kõigile inimestele osalemaks aktiivselt ühiskondlikus elus.
3. Teaduslike mõistete, teooriate, faktide mõistmine ja rakendamine uues, õpitust erinevas kontekstis.
4. Asjakohased ja vajalikud uurimuslikud oskused.

5. Arusaamine teaduse olemusest.
6. Loov teadmiste ja oskuste rakendamine igapäevaelus ettetulevates situatsioonides loodusteadusliku sisuga selgituse andmiseks, probleemide lahendamiseks ning põhjendatud sotsiaalteaduslike otsuste tegemiseks.

Käesolevas töös määratleti loodusteaduslikku kirjaoskust kui loodusteaduslike teadmiste ja oskuste loovat rakendamist igapäevaelus ettetulevate loodusteadusliku sisuga probleemide lahendamisel ning põhjendatud otsuste tegemisel (Holbrook & Rannikmäe, 2009). Uurimused on näidanud, et õpilaste enesehinnangu kaudu saavad õpilased ise ja ka õpetajad võrrelda õpilase tegelikku sooritust tema arusaamisega oma võimetest, mis annab võimaluse areneda, mõista ja mõtestada neid valdkondi, milles on vaja veel tööd teha ning see omakorda annab aluse elukestvaks õppeks (Taras, 2002; 2010; Choi et al., 2011). Tulenevalt sellest käsitleti antud uurimistöös õpilaste enesehinnanguid oma teadmistele ja oskustele loodusteadusliku kirjaoskuse osana. Lisaks uuriti, milline on õpilaste hinnang loodusainete tundidele kui loodusteadusliku kirjaoskuse kujundamise keskkonnale. Uurimused on näidanud, et õpilased on head hindajad loodusainete tundides toimuva osas, õpetajad võivad küll igapäevaselt kasutada erinevaid õppemeetodeid, kuid pikemas perspektiivis on arusaadav, millele loodusainete tundides enim tähelepanu pööratakse ja millele mitte (Fraser, 2014). Kuna loodusteaduslikku kirjaoskust seostatakse ka õpilaste karjäärivalikutega (Bybee & Fuchs, 2006), siis uuriti käesolevas töös ka seda valdkonda. Käesolev uuring oli osa LoTeGüm projektist (Rannikmäe, Reiska & Soobard, 2014).

Loodusteadusliku kirjaoskuse tasemete määratlemiseks tuleb otsustada, milliste komponentide kaudu seda teha. Käesolevas töös keskenduti oskustele, mida paljud autorid seostavad loodusteadusliku kirjaoskusega (UNESCO, 1993; Shamos, 1995; NRC, 1996; Bybee, 1997; Holbrook & Rannikmäe, 1997; Sadler, 2004; Zeidler et al., 2005; Sadler & Donnelly, 2006; OECD, 2007; 2015; Rannikmäe, 2008; Choi et al., 2011; Laius, 2011) ning mis tulenesid ka valitud loodusteadusliku kirjaoskuse definitsioonist – loodusteadusliku sisuga selgituse andmine, loodusteadusliku sisuga probleemide lahendamine ja põhjendatud otsuse tegemine. Erinevalt varasematest uurimustest on antud töös nimetatud oskuste hindamine seostatud SOLO taksonoomia (*The Structure of Observed Learning Outcomes)* tasemetega (Biggs, 1996) – üheplaanilisus (*uni-structural*), mitmetahulisus (*multi-structural*), seostatus (*relational*) ja üldistatus (*extended abstract*).

Varasemad uuringud on näidanud, et õppimine ja õpetamine loodusainete tundides peaks olema kontekstipõhine – õpilasel kujuneb oskus seostada ja rakendada loodusainete tundides omandatud teadmisi igapäevaelulistes situatsioonides (Bennet et al. 2007; Murcia, 2009; Fensham & Rennie, 2013). Tulenevalt sellest, peaks ka hindamine loodusainete tundides olema igapäevaelulistel kontekstidel põhinev, sest siis on õpilasel võimalik demonstreerida oma teadmisi ja oskusi reaalsemates situatsioonides võrreldes tavapäraste ainealaste testide ja eksamitega.

Uuringuinstrumentide koostamisel lähtuti:

- Ulatuslikust kirjanduse analüüsist, mis oli seotud loodusteadusliku kirjaoskuse määratluse ja hindamisega.
- Varasemate loodusteadusliku kirjaoskuse uuringute tulemustest.
- Õpilastele relevantsetest kontekstidest, mille kaudu loodusteaduslikku kirjaoskust hinnata.
- Eesti riiklikus õppekavas toodud loodusteadusliku kirjaoskuse määratlusest ja oodatavatest õpitulemustest.

Põhiuuringu loodusteadusliku kirjaoskuse kontekstipõhise testi ülesanded järgisid SOLO taksonoomia nelja taset ning hindasid õpilaste oskust anda loodusteadusliku sisuga selgitust, lahendada loodusteadusliku sisuga probleeme ja võtta vastu põhjendatud otsuseid. Hinnangute küsimustik koosnes kolmest osast, millest esimeses paluti õpilastel anda hinnang oma oskustele, mis on olulised loodusteadusliku kirjaoskuse seisukohalt, seejärel paluti õpilastel hinnata, kuivõrd ja mil määral loodusainete tundides kujundatakse neid oskusi. Viimase osa moodustasid õpilaste hinnangud oma tulevasele karjäärile.

Uuring viidi läbi kolmes etapis, millest esimeses piloteeriti esialgset uuringuinstrumenti. Kahes järgmises etapis kasutati pilootuuringu tulemuste põhjal modifitseeritud uuringuinstrumente. Andmeid koguti Eesti koolide suhtes representatiivselt valimilt. Võrdlusuuringus (10. ja 11. klass) koguti andmeid loodusteadusliku kirjaoskuse testi ja hinnangute küsimustikuga ning longituuduuringus (10. ja 12. klass) ainult loodusteadusliku kirjaoskuse testiga.

Uurimistulemused näitasid, et õpilaste enesehinnang oma oskustele ei muutu olulisel määral, liikudes 10. klassist 11. klassi. Mõlemas klassis on kõrge enesehinnang oskusele kasutada informatsiooni joonistelt ja tabelitest, kokkuvõtete tegemisele uurimistulemustest ning loodusteadusliku sisuga probleemide äratundmisele. Madalamalt hinnatakse oskusi lahendada loodusteadusliku sisuga probleeme, anda loodusteadusliku sisuga selgitust ning teha põhjendatud otsuseid.

Õpilaste madalat enesehinnangut nimetatud oskustes toetasid nende hinnangud loodusainete tundidele, millest selgus, et loodusainete tundides ei pöörata õpilaste jaoks olulisel määral tähelepanu loodusteadusliku sisuga reaaleluliste probleemide lahendamisele ja põhjendatud otsuste tegemisele. Ilmnes, et õpilased hindavad bioloogia ja geograafia tunde kõrgemalt kõigis käesolevas uuringus käsitletud valdkondades võrreldes keemia ja füüsika tundidega.

10. ja 11. klassi õpilaste hinnangutes tulevasele karjäärile selgus, et enam ollakse huvitatud karjäärist sotsiaalvaldkonnas kui loodusteadustega seotud valdkonnas. Õpilased pigem ei nõustunud väitega, et loodusteaduslike õppeainete tunnid on andnud ülevaate elukutsetest, mis eeldavad loodusteaduslikke teadmisi.

10. ja 11. klassi õpilaste kontekstipõhise testi tulemused näitasid, et loodusteadusliku sisuga selgituse andmisel olid õpilaste sooritused sarnased ning statistiliselt olulist erinevust kahe klassi õpilaste tulemuste vahel ei esinenud (SOLO taksonoomia üheplaanilisuse ja mitmetahulisuse tasemed). Probleemi

lahendamise ülesandes (SOLO taksonoomia seostatuse tase), mis eeldas õpilastelt oskust lugeda ja interpreteerida informatsiooni jooniselt ning seejärel selgitada oma vastust, ei ilmnenud samuti olulist erinevust arvestades efekti ehk mõju suurust. SOLO taksonoomia üldistatuse tasemel põhjendatud otsuse tegemist eeldavas ülesandes vastasid 11. klassi õpilased mõnevõrra paremini (kuigi efekti ehk mõju suurus oli väike) võrreldes 10. klassi õpilastega, ent ka selle ülesande puhul jäi maksimumpunktid saanud 11. klassi õpilaste arv väikseks.

Longituuduuringu raames 10. klassi õpilaste uus testimine 12. klassis näitas (316 õpilast), et õpilased oskavad anda loodusteaduslikku selgitust SOLO taksonoomia üheplaanilisuse ja mitmetahulisuse tasemel ning statistiliselt olulist erinevust pärast kolme aastat gümnaasiumis õppimist ei esinenud. Statistiliselt olulist erinevust ei olnud õpilastel ka probleemi lahendamise ülesandes seostatuse (SOLO taksonoomia 3. tase) tasemel. Uurimistöö tulemused näitasid, et üldistatuse tasemel (SOLO taksonoomia 4. tase) oli statistiliselt oluline erinevus võrreldes 10. klassi tulemustega põhjendatud otsuse tegemisel, kuid keskmine punktisumma jäi endiselt madalaks olles 12. klassi õpilastel 0.68 punkti maksimaalselt kahest. See tulemus on siiski madal eeldusel, et lähtuvalt õppekavast on eelnimetatud oskuse kujundamine oluline loodusainete tundides.

Analüüsides õpilaste liikumist loodusteadusliku kirjaoskuse tasemete vahel, mis on moodustatud kognitiivse testi tulemuste põhjal ilmneb, et muutus oli kõige suurem neil õpilastel, kes olid 10. klassis madalamatel loodusteadusliku kirjaoskuse tasemetel ning väiksem neil, kes olid selleks ajaks jõudnud 3. või 4. tasemele. Liikumist madalamatelt loodusteadusliku kirjaoskuse tasemetelt kõrgematele võib selgitada õppekavaga määratud teadmiste juurdekasvuga.

Uurimistöö tulemustele tuginedes võib välja tuua järgmised soovitused:

- Loodusteaduslike ainete tundides on vaja enam tähelepanu pöörata loodusteadusliku kirjaoskuse kõrgemate tasemetega seotud oskuste kujundamisele (näiteks probleemi lahendamine ja põhjendatud otsuste tegemine).
- Oluline on analüüsida, kuidas õpilased saavad aru oma oskustest, sest see võib mõjutada nende tegelikku saavutustaset.
- Vaja on muudatusi õpetajakoolituses (nii põhiõppes kui täiendkoolitustel) tagamaks, et õpetajad on valmis kujundama 2011. aastal vastuvõetud kompetentsuste-põhise õppekava eesmärke ja oodatavaid õpitulemusi, mis seostuvad loodusteadusliku kirjaoskuse kõrgemate tasemetega loodusvaldkonnas.
- Õpilaste loodusteadusliku kirjaoskuse hindamiseks peaks kasutama kontekstipõhised instrumente, mis võimaldavad anda vastuseid erinevatel tasemetel (nt SOLO taksonoomia järgi) ja hinnata õpilaste loodusteadusliku kirjaoskuse taseme muutust.

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