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Examining Curriculum Related Progress Using a Context-Based Test Instrument – A Comparison of Estonian Grade 10 and 11 Students

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ABSTRACT: This study was undertaken to investigate the progress in operational scientific literacy skills through demonstrating cognition associated with undertaking scientific processes. Scientific literacy is taken here to mean utilising science knowledge and skills, particularly with relevance to creative problem solving and making reasoned decisions in real life situations. The instrument was compiled based on a review of relevant international literature, plus competences emphasised in the Estonian science curriculum. Items in the instrument followed the levels of the Structure of Observed Learning Outcomes (SOLO taxonomy) and all tasks in the instrument were contextualized to relate to real life. A stratified sample of students from 44 schools gave a data set with returns from 1128 beginning of 10th grade students and 946 end of 11th grade students. Findings suggested that there was no sufficient shift from one grade to another in operational skills such as giving scientific explanations, problem solving and justified decision making. Although students did gain more knowledge and the expectation was that students would enhance their operational skills for scientific literacy, this was not reflected in their competence to solve problems. This suggested there was a need to re-think science teaching and learning approaches as well as the manner in which science was introduced to students.

KEY WORDS: Scientific literacy, context-based tasks, curriculum-related progress, interdisciplinarity, SOLO taxonomy

INTRODUCTION

It is generally suggested that the purpose of science education is to promote scientific literacy (e.g. Murcia, 2009; EURYDICE, 2011; Soobard & Rannikmäe, 2011; Aikenhead et al., 2011). While noting that a variety of definitions of Scientific and Technological Literacy (STL) exist, (e.g. OECD, 2007; Roberts, 2007), in the current study, scientific literacy is taken to mean utilising science knowledge and skills, particularly with

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relevance to creative problem solving and making reasoned decisions in real life situations (Holbrook and Rannikmäe, 2009). In this study such a definition is operationalised through three scientific literacy skills – *using scientific evidence for problem solving, giving scientific explanations, and making reasoned socio-scientific decisions*. These components are in line with multiple scientifically literate definitions focusing on cognitive component in scientific literacy (e.g. OECD, 2007; Sadler & Zeidler, 2005; Soobard & Rannikmäe, 2011; Soobard & Rannikmäe, 2014) and also included in the Estonian national science curriculum for upper secondary school students, as part of expected learning outcomes (Estonian Government, 2011).

Unfortunately, there is no clear approach to the measurement of these operational skills as a component of scientific literacy, because what is and how it is assessed, is determined by what is valued by science education policy, the curriculum and the role of science teachers in delivering the content of the curriculum to students (Corrigan et al., 2013). In Estonia, assessment of science learning is mainly undertaken by means of testing and examination (Holbrook, 2008) with the assessment against norms put forward by education policy and curriculum developers, and therefore tends to be content focused.

Biggs (1996) proposed using the Structure of Observed Learning Outcomes (SOLO) taxonomy for monitoring students' curriculum related progress, as the SOLO taxonomy can be used to describe how a learner's performance has grown in complexity and level of abstraction in moving from a uni-structural response to evidentially putting forward responses at an extended abstract level. 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.

Another important assessment component is the assessment context. It seems desirable that instruments for measuring progress in scientific literacy be connected with real life issues (Teppo & Rannikmäe, 2008; Holbrook & Rannikmäe, 2009) e.g. context-based (Bennet et al., 2007) and not focusing simply on science content (OECD, 2007; OECD, 2014).

The Purpose and Research Questions

The purpose of this study is to assess students' curriculum related progress at the end of grade 11 compared to measures at the beginning of grade 10 in operational scientific literacy skills, approached via a real life societal context. The instrument, based on the SOLO taxonomy, seeks to identify students' curriculum related progress at the gymnasium level (grades 10 - 11), through their capability to transfer both knowledge and skills to new situations, seen as important for enhancing scientific literacy. The expectation is that students at higher grade levels are better able to answer the questions posed, based on their increased operational skills in problem solving, explaining phenomena scientifically and making decisions. All these are contributing to raising the level of a person's scientific literacy. The following research questions are posed:

1. How do grade 10 and 11 students demonstrate their operational scientific literacy skills when responding to a context-based situation?
2. What progress is associated with science learning in identified components of students' scientific literacy after two years of study at the gymnasium level?

REVIEW OF RELEVANT LITERATURE

Scientific literacy

Scientific literacy has multiple definitions as illustrated in Table 1. The assessment of operational skills as part of scientific literacy has been moving towards testing using real life contexts, e.g. contexts related to real life, allowing students to apply the actual skills needed in the situation (OECD, 2007; OECD, 2014; Soobard & Rannikmäe, 2011; 2014; Fensham & Rennie, 2013). According to Roberts (2007; 2011), these ideas are more related to the Vision II of scientific literacy, where the starting point for science learning is a familiar situation for students and testing of the relevant science knowledge and skills follows. In the case of school science, the emphasis is on promoting science knowledge that helps students to link school science and everyday life situations and help them to become informed users of the knowledge in their everyday lives (Sarkar & Corrigan, 2014).

Comparisons between components associated with scientific literacy shows that (see Appendix) scientific literacy has been broadly associated with knowledge (interdisciplinary), operational skills, nature of science and perception components. Focusing on the cognitive components means that a scientifically literate person needs an interdisciplinary understanding and concepts relevant to real-life situations, as well as operational skills important for solving problems and making decisions (Miller, 1998; Norris & Phillips, 2003; Millar, 2006; OECD, 2007; Holbrook & Rannikmäe, 2007; Choi et al., 2011; Soobard & Rannikmäe, 2011; 2014). Also, although scientific knowledge is needed for being scientifically literate, it needs to be functional knowledge, ready to apply in unfamiliar situation (Rennie, 2011). This is also on the line with the PISA 2015 scientific literacy definition (OECD, 2013), which states that a scientifically literate person should demonstrate competences to explain phenomena scientifically, evaluate and design scientific inquiry and interpret data and evidence scientifically. An additional interpretation can be that is there is a need to avoid simply learning isolated facts, laws and concepts, and pay attention to interrelating them in a meaningful context, for example, in dealing with socio-scientific issues (Holbrook & Rannikmäe, 2007).

A further aspect considered integral to scientific literacy, indicated in table 1, is problem solving. Problem solving is a purposeful activity involving deliberate or controlled actions, not totally reliant on automatic processes. A problem only exists when the person trying to solve it lacks relevant knowledge to produce an immediate solution (Eysenck, 2012). However, there is no one single type of problem solving technique and different types of problems require different cognitive skills, e.g. from story-telling problems to design problems (Jonassen, 2011). In the current study, the focus is on science-related problems and solving such problems means finding a scientific solution (Holbrook & Rannikmäe, 1997; Rannikmäe, 2008; Soobard & Rannikmäe, 2011).

Decision-making, based on socio-scientific reasoning, is a further component associated with scientific literacy. According to Eysenck (2012), decision-making involves selecting from among several possibilities, e.g. it involves making a selection from various possible options. Laius (2011) suggests that the decision can also depend on the importance of various non-scientific factors, such as cost (economics), ethical and moral aspects, values, environmental concerns, etc. In the current study, decision-making with socio-scientific reasoning involves making a choice between several options and then giving reasons for the choice selected. It is seen as important to include this type of task in the assessment instrument, because, according to Sadler (2004) and Zeidler et al. (2005), students possess poor links between the science taught and its impact on society. They suggest that teaching/learning materials need to encompass a socio-scientific, issue-based approach. According to these authors, socio-scientific issues are difficult for students, because they are open-ended, ill-structured and include multiple decisions. At the same time, these issues can be promoted within a philosophy of “education through science” (Holbrook & Rannikmäe, 2007), because it may include, according to Lee and Grace (2012), thinking in multiple directions (not focusing only on science) and encompassing moral judgments. Reasoning within socio-scientific issues has been associated with the process of informal, rather than formal, reasoning (Sadler, 2004), where informal reasoning involves a person’s arguments based on one´s relevant knowledge and experiences (Eysenck, 2012). In other words, it is possible to make socio-scientific decisions based on personal experiences and not necessarily including reference to the appropriate formal scientific knowledge.

The science curriculum and science teachers in Estonia

The Estonian science curriculum at the gymnasium (upper secondary) level was investigated to ensure that the development of the test instrument is in line with expected learning outcomes in gymnasium level. The National Curriculum of Estonia for upper secondary school indicates competences through the following learning outcomes, which should be promoted in each science subject (Estonian Government, 2011):

1. Solving problems using scientific methods (e.g. posing scientific questions, planning scientific investigations, controlling variables, analysing and interpreting results, drawing conclusions).
2. Making reasoned decisions taking into account scientific, environmental, social, economic, political and ethical-moral considerations.
3. Using and relating (referring to interdisciplinary) knowledge from Biology, Geography, Chemistry and Physics subjects for problem solving and decision-making.

The Estonian science curriculum includes four compulsory science subjects (chemistry, biology, geography and physics) at the upper secondary school level and all, accordingly to the purposes of these science curricula, are expected to contribute to enhancing scientific literacy. Until 2012, it was compulsory for grade 12 students to take national examinations and it was common that students sat at least some examinations in science subjects. An analysis of the latest state examination items showed that geography items followed Bloom`s taxonomy (National examination commission (Geography), 2013), while in biology, the focus was on the content knowledge and its applications in real life (e.g. interpreting tables, schemes, graphs, relations applications in everyday life, drawing conclusions, transferring knowledge into a new context) (National examination commission (Biology), 2013). In chemistry and physics, the main focus was on science content (Klooster, 2013; National examination commission (Chemistry), 2013).

In Estonia, a Teacher Needs Questionnaire (TNQ) was administered among 30 experienced gymnasium science teachers. Findings from this study showed that science teacher's self-confidence was high, for example, in interdisciplinary teaching, but lower in promoting inquiry-based learning, putting forward the goals of education and in assessing students. However, their self-perceived training need was high in all subscales (e.g. assessment, classroom learning environment, motivation, inquiry based learning) (Holbrook, Rannikmäe & Valdmann, 2014).

Even more, when gymnasium students in Estonia were asked to indicate their perceptions against received science teaching, they did not perceive that science subjects (especially chemistry and physics) were expected to support either the development of problem solving and decision making skills, or other components of scientific literacy (Soobard & Rannikmäe, 2014). Only the development of interdisciplinary knowledge was highlighted and this was also the field where science teachers seemed to have higher perceived self-confidence (Holbrook, Rannikmäe & Valdmann, 2014). Based on an analysis of student perceptions, operational skills do not appear to be promoted in a sufficient manner (Soobard & Rannikmäe, 2014).

Context-based learning

Cognitive processes in schools focus more on simple algorithms than their use in multiple everyday contexts (for example, one learns to use the algorithm with speed, but not its applications in varying situations) (Biggs, 1996). At the same time, everyday situations are concerned with personally valued content and experiences in context. Therefore, it is suggested to use context-based items to assess students' learning (Bennet et al., 2007; Fensham & Rennie, 2013). According to research (Bennet et al., 2007; Rannikmäe, 2008; Feinstein, 2010; Fensham & Rennie, 2013; Sormunen, Keinonen & Holbrook, 2014), using context-based items to assess students learning:

- influences students' interest and motivation to answer;.
- provides a deeper sense of students' conceptual understanding;
- promotes transfer of science learning to real life situations;
- allows students to see the usefulness of their own knowledge in real life situations;
- allows students to apply competences in a context derived from actual situations.

Based on this, student assessment of learning in science education should encompass context-based situations (using scenario derived from real life).

SOLO taxonomy

Research has found that despite enhancing scientific literacy through the development of multiple competences, a gap exists between students' competences in passing formal assessments based on their knowledge and their understanding of its applications in the real world e.g. demonstrating scientific literacy in real world situations (Soobard & Rannikmäe, 2011; OECD, 2014). One possible solution for alleviating this gap has been to pay more attention to the student perspective when designing assessment tasks for students (Biggs et al. 1991). Here the meaning of student perspective was taken to be the knowledge and skills, useful and meaningful for students in their own lives, and applied in a meaningful context for students (Feinstein 2010; Fensham and Rennie 2013). This further supported the development of scientific literacy, because a major expectation for scientific literacy was to ensure that students were capable of applying science knowledge and skills gained in real life situations (Holbrook & Rannikmäe, 2009; Soobard & Rannikmäe, 2014).

According to Biggs (1996), it is important to state the learning objectives in terms of what students are expected to be able to do after learning and to design assessment tasks to determine how well students are progressing in those activities. Biggs proposed the SOLO taxonomy for assessing expected learning outcomes at five levels. The first level (pre-structural) was not applicable to this study. The remaining four levels were (Biggs, 1996; Moseley et al., 2005):

- Uni-structural – At this level, students can make simple connections, but no deeper meaning is presented. Items at this level usually require students to name, acquire terminology, and learn simple procedures. Learning goals include acquiring terminology, to accomplish the first step in mastering a task. For developing items in this level, one piece of information coming directly from the question stem (scenario) can be used.
- Multi-structural – At this level, students can make multiple connections between bits of information, but relationships are missing. Items at this level require students to combine, describe, list, how many ways can you …, what are the main points… Learning goals require coverage of “knowing about” and performing algorithms. For developing items in this level, two or more discrete and separate pieces of information can be used, all contained in the scenario.
- Relational – At this level, students can provide relationships between information provided. Items at this level require students to analyse, criticize, argue, justify, explain, apply and relate X with Y. Learning goals emphasize understanding, application, problem-solving, conceptualizing, reasoning and inquiring. For developing items in this level, multiple pieces of information can be used, each directly referring to an integrated understanding.
- Extended abstract – At this level, students can make connections not only within the single subject area, but, beyond this, showing the ability to generalise and transfer. Items at this level require students to hypothesise, reflect, generate and generalise. Learning goals emphasise both in-depth understanding, requiring students to theorize about a topic, and generalizing to new applications. For developing items in this level, an abstract (or general) principle or hypothesis can be used, which is derived from the scenario.

According to Biggs (1991), uni- and multi-structural levels are concerned with the progressive growth of knowledge and skills in a quantitative sense, with the last two (relational and extended abstract) with qualitative changes in the structure and nature of what is learned. Thus, the sequence from pre-through uni- to multi-structural student learning has a focus on the accumulated knowledge; in the move from multi-structural to relational with the organisation and structuring of knowledge and in the shift from relational to extended abstract with how knowledge may be theorised and generalised. Therefore, using taxonomy for describing the change in operational skills allows considerations to go further than just stating outcomes and allows qualitative changes in learning to be shown.

METHODOLOGY

The Sample

This was a comparative study – comparing outcomes provided by one group of students at the beginning of grade 10 and another at the end of grade 11, tested in the same schools and taught by the same teachers. The students were not the same.

As the unit of analysis was the school, a school-related representative sample was compiled from students in 44 Estonian schools. Schools were grouped based on location (the capital; towns with at least two gymnasiums; rural areas). Location was taken into account to ensure that schools in all areas had an equal possibility to be involved. After grouping schools based on the locations, schools were then ordered based on average national examination results. Every 4th school was chosen and all students from these schools were involved in the study. The final data set contained returns from 1128 10th grade and 946 11th grade students.

The Instrument

The test instrument provided a contextualised situation, related to extraordinary phenomena in nature (e.g. Dead Sea). It required students to possess curriculum-related, interdisciplinary science knowledge and skills and to transfer these to a new context compared to well-known textbook and workbook examples, giving indicators of scientific literacy identified through measures of scientific explanation, problem solving and the manner in which decisions made were justified.

The instrument consisted of 8 items, where one item was related to each SOLO structural level and three items geared to relational and extended abstract respectively. This was done noting that in the PISA international test (OECD, 2007), 15 year old students (grade 9 in Estonia) performed well above average on structured items, but much less so on items related to problems-solving and decision making i.e. SOLO relational and extended abstract levels. Students' responses were coded using a three-point scale (0 - no answer or incorrect answer to 2 - correct answer). An overview of the Dead Sea scenario items, levels of SOLO taxonomy, task content and skills are presented in table 1.

Table 1 Overview of student test instruments

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 Economic	Decision making (choosing correct claims, writing claims, making justified decision)

To monitor the curriculum related progression, items in the test were sequenced so that initial items were less demanding (items in the test followed the same sequence as in table 1). This was intended to give students the feeling that they could respond to at least some items. The first two items were multiple-choice. Item 1 required students to transfer their knowledge about plate tectonic to a new context and choose correctly the scientific explanation from the four available options to explain what happens in areas around fault lines. Item 2 required students to choose two correct scientific explanations related to the formation of fog.

Items 3-5 introduced a problem-solving situation. In item 3, students were asked in interpret data scientifically from a graph of solubility curves choosing the first three salts likely to be precipitated under the given conditions. In item 4, students were asked to give scientific explanations for their choices. In item 5, changed conditions were introduced compared to the initial text in item 3 requiring students to give scientific explanations for the solubilities of salts at night when the water temperature dropped from 35°C to 10°C.

Items 6-8 focused on extended abstract thinking associated with decision-making. In item 6, students were introduced to a situation requiring them to choose correctly evidence to support the generalisations related to heredity and psoriasis. In item 7, students were required to put forward as many claims as they could (by listing) related to increasing the trustworthiness of the given study related to psoriasis. In item 8, students were required to make a decision, based on the given three options (hypothetical economic activities in the area of the Dead Sea) and giving argued reasons for their decision.

The instrument was validated using:

a) The expert opinions of four school science teachers and two university science staff members. Based on their recommendations, the instrument was modified to make it more suitable for both the upper secondary level and expectations at the university level. Considerations related to the University level were included, because many upper secondary students were likely preparing to go to university.
b) A pilot study was also conducted on the revised instrument among upper secondary school students.

The reliability, calculated using Cronbach alpha for the overall instrument, was 0.62 and considered acceptable for this under ten item test instrument. The data gathering period was November 2011 (for grade 10) and April/May 2012 (for grade 11). The test was designed to be answered in 45 minutes.

Data analysis

To explore whether the test instrument followed item distinction, principal component factor analysis with Varimax rotation was undertaken. This analysis described 68% of the variance and identified a 4 factor solution: uni-structural (factor loading 0.975, item 1), multi-structural (factor loading 0.983, item 2), relational (factor loadings 0.863-0.553, items 3, 4, 5) and extended abstract (factor loadings 0.746-0.628, items 6, 7, 8). To ensure that Principal component factor analysis was applicable, a Kaiser-Meyer-Olkin Measure of Sampling Adequacy (0.707) and Bartlett's Test of Sphericity were conducted (sig. 0.000). The same factors were found in both grades.

IBM SPSS Statistics 21 was used to describe students' responses frequency distribution and to determine how responses to single item mean scores varied between grades by using an Independent Sample T-Test. Cohen`s d was used to calculate the effect size to eliminate sample size influence.

RESULTS

Results showed that in both grades (table 2), students achieved at the uni- and multi-structural level in a similar manner. For the first two items, there was no significant difference between grades in giving scientific explanations. The effect size was very small and not taken to be meaningful.

At the relational level, students in both grades exhibited difficulties. To item 3, grade 10 students gave more correct answers (M=0.62) compared to grade 11 (M=0.55) and this difference was statistically significant (p=0.008), but due to the large sample size, the effect size was also calculated; this statistic was found to be small and not taken to be meaningful. In items 4 and 5, grade 11 students were generally more able to write the scientific explanation on their own than was the case for grade 10 students. In item 5, there was a statistically significant difference between grade 10 and 11 students' means scores (p=0.000), but the effect size remained small and was not taken to be meaningful.

At the extended abstract level, students in both grades did well in responding to item 6 and the response distribution was similar for both grades (no statistically significant difference was found, p=0.143). For item 7, students in grade 11 gave more correct responses compared to grade 10. The only item that had a meaningful effect size (as well as the statistically significant differences based on t-test) was item 8. However, the mean score by students in grade 11 was still relatively small.

DISCUSSION

This study investigated the progress in rational scientific literacy skills through testing cognition associated with undertaking scientific processes and investigated whether curriculum related progress occurred during the two years of upper secondary schooling.

In analysing student responses, based on the grade level at the uni- and multi-structural level, percentage distributions between three response categories were similar in both grades.

Table 2 Frequency distribution and differences in student responses for grades 10 and 11

SOLO level	**Item**	**Grade 10 (N = 1128)**					**Grade 11 (N = 946)**					**Independent sample t-test (comparison of mean scores)**		**Effect size Cohen’s d**
		%			**Mean score**	**SD**	**%**			**Mean score**	**SD**	t	p	
		0	**1**	**2**			**0**	**1**	**2**					
Uni-str.	1	22.2	28.0	49.8	1.28	0.80	25.5	27.3	47.3	1.22	0.82	1.642	0.101	0.074
Multi-str.	2	13.6	69.2	17.2	1.04	0.55	12.8	71.7	15.5	1.03	0.53	0.370	0,712	0.018
Relational	3	40.2	58.1	1.8	0.62	0.52	45.7	53.2	1.2	0.55	0.52	2.663	0.008	0.135
	4	65.0	27.7	7.4	0.42	0.63	63.2	26.6	10.1	0.47	0.67	-1,587	0.113	0.077
	5	86.7	11.8	1.5	0.15	0.39	81.3	15.6	3.1	0.22	0.48	-3.558	0.000	0.160
Extended abstract	6	5.9	34.9	59.2	1.53	0.60	4.5	33.8	61.7	1.57	0.58	-1.465	0.143	0.067
	7	73.2	20.6	6.2	0.33	0.59	61.0	25.9	13.1	0.52	0.71	-6.572	0.000	0.291
	8	69.4	25.9	4.7	0.35	0.57	48.6	47.0	4.3	0.56	0.58	-8.0.81	0.000	0.365

Items created at the first two SOLO taxonomy levels were more similar to traditional testing in science education through examinations and example questions in science textbooks. In those items, students were required to respond to a clear question, e.g. demonstrating one skill – giving scientific explanation, but not to demonstrate multiple skills together. As the results were similar in both grades, it could be assumed that there was no significant effect size in giving scientific explanations related to those SOLO taxonomy levels illustrated by these test items.

At the relational level, results showed that students at both grades 10 and 11 found it difficult to solve problems. One reason for this could be that in the three items (3-5), students were required to undertake multiple activities by themselves. First, they needed to interpret data and evidence from the text and graph scientifically and then explain their own choice scientifically. Of importance, students needed to make a choice, not given in the item and this placed more interpretative responsibility on the students, compared to items 1 and 2. Results indicated that if students were required to utilize multiple skills together, and hence take more responsibility, students faced difficulties. Even more, in the second part of this problem solving set (item 5), the salt production conditions were changed (night time, temperature drop for the water) and again scientific explanation was needed. In this item, students were required to return to the original graph and text and again interpret the data and evidence once more. Results showed that this type of problem solving was difficult for students in both grades. Based on this single scenario, little gain was indicated. A reason for this could be that the operational skills, needed for solving such items, were not commonly promoted in science subjects in either grade despite the extra years of learning and therefore students lacked the necessary skills. In fact, as there was no important effect size between grade achievements, it could be assumed that no effective teaching and learning occurred in terms of scientific literacy, as measured by this study. Possible reasons for this could be related with received science teaching. Teachers in Estonia said that their self-efficacy was rather low in inquiry-based learning (closely related with problem-solving situations) (Holbrook, Rannikmäe & Valdmann, 2014). Even more, students in both grades involved with this study indicated that problem solving was not a perceived focus in their science classes (especially in chemistry and physics) (Soobard & Rannikmäe, 2014).

Based on the outcomes from this study, it was apparent that students were not being prepared to think rationally (school science vs. real life needs) by themselves, and as Rennie (2010) pointed out, science concepts in school are simplified, idealised and separated from other affecting factors occurring in real life.

Within the extended abstract items, an interesting outcome was that item 6 was shown to be easier for students than items 7 and 8. However, extended abstract has its range (Biggs 1996). In item 6, students from both grades gave mainly maximal responses. In this item, students were given text related to research findings; but rather than being asked to write down the correct claims by themselves, students were given possible claims related to research outcomes, based on the evidence given in the table, from which they were asked to decide the correct claims. This relatively simple item, as judged by students, was used in this study, because based on the factor analysis, it correlated heavily with the other two extended abstract level items focusing on the decision making process. Thus choosing correct claims to support the findings was considered as a first step towards effective decision-making. However, in item 7, students were asked to write single claims by themselves to raise the trustworthiness of the given study and item 7 showed, in general, students found writing claims unguided was more difficult. The outcomes, based on those two items, indicated that students could recognise claims, but did not possess skills to express claims on their own, as shown by the low effect sizes when comparing grade 10 student outcomes with those from grade 11 (table 3). This outcome was similar to the set of items on problem solving, where students' responses were not only at lower levels on the three-point scale, but the effect size was low if more responsibility on finding the solution was given to students.

In item 8, students were expected to go beyond stating science knowledge and skills and to justify a decision made. Students from both grades responded poorly to this item and there was almost no difference in percentage of correct responses between the grades. The main change between grades emerged from the percentage of students at the no or incorrect (0) and partially correct (1) response levels (table 3). This type of item had not been the focus in the Estonian national examinations in science according to students' perceptions; it was also not a focus in the teaching of science subjects (Soobard & Rannikmäe, 2014). The findings support the idea that assessment in science subjects was strongly related to that valued by educators, policy makers and society (Corrigan et al., 2013). There seemed to be a mis-match between curriculum expectations on the one hand, and on the other, the past national examination thrust and with it, the current expectations by science teachers in their teaching. Further research was required to elucidate this more specifically. Nevertheless, justified decision-making was heavily appreciated as part of scientific literacy in the literature (e.g. Choi et al., 2011). A further reason that extended abstract thinking appeared not to be taught in science subjects, could be teachers' lack of experience and low self-confidence to include issues arising from real life, these being controversial and going beyond a single discipline requiring an interdisciplinary understanding about phenomena in nature. However, Rennie (2011) stated that this conflict was an outcome because education in school was arranged around single disciplines and therefore teachers, as well as students, did not promote interdisciplinary components in the everyday school context. Nevertheless, according to the Estonian curriculum (Estonian Government, 2011), decision-making was an expected learning outcome at the end of grade 12 in all science subjects.

Results from this study indicated that gymnasium students' demonstrated abilities in operational skills at the uni- and multi-structural level, seemingly well developed at pre-gymnasium levels, but poor acquisition of relational and extended abstract level skills, even after two years of gymnasium study. In general, results showed that responses by grade 10 and 11 students, spread similarly between levels for all items (particularly for the correct answers), did not exhibit the expected shift for grade 11 students, compared to those in grade 10. Regrettably, percentages of correct responses were very low for end of grade 11 students, after nearly two years of schooling at the upper secondary level; for example, in item 5, the maximal student response was only 3.1% (table 3). This suggested there was a need to re-think and change the focus of science teaching and the emphasis of learning approaches in schools and the manner how science subjects were assessed. The impression gained was that examination and test items had tended to focus on school science content and its applications within science, but not on real life (at least as a rationale for science learning). As a result, students were unlikely to receive feedback about their success in applying science in everyday situations and their only action was to apply school science in a school science context. Even more, teachers were not in a position to support students, as they were not receiving feedback on students' actual progress (Corrigan et al., 2013). Some may feel the limited number of test items (8) in the current study is a weakness, but findings indicate that it is sufficient to develop substantive findings for this study. Furthermore, this study used representative sample to implement the instrument and draw conclusions.

CONCLUSIONS

The main outcomes showed that despite two years of schooling, grade 10 and 11 students exhibited little effect size gains in components of scientific literacy. Even though, students exhibited a small yet noticeable improvement, for operations involving higher levels of SOLO taxonomy such as making reasoned decisions and solve scientific problems, outcomes were very poor.

Outcomes showed that grade 10 and 11 students demonstrated their operational scientific literacy skills situations in a similar manner when responding to context-based test items, suggesting little teaching was taking place in these aspects of learning.

IMPLICATIONS AND RECOMMENDATIONS

This outcome must be of concern pointing to a serious need to re-assess the teaching and learning expected at the end of grade 11.

Based on the outcomes from this study, the following recommendations are put forward for science teaching:

1. To overcome the difficulties related to school science simplifications, idealisations and the fact that science is separated between disciplines, more real life related issues and interdisciplinary approaches need to be used in science subjects and examinations.
2. Based on the outcomes of this study, there is a need to focus more on learning progression in operational scientific skills development. This can support the situation where more students are capable to solve scientific problems in their lives and make reasoned decisions in everyday life situations.
3. Science teachers need to take interested in finding out students' perceptions and be ready to modify their science teaching based on the findings, e.g. supporting students when needed (giving more guidance, analysing students' difficulties). However, these activities are also related with science teachers' own perceptions against themselves and their science teaching.
4. Teachers need to re-consider the way science is presented and assessed. The focus of assessment in science subjects needs to move towards including real life contexts and actual operational skills leading towards higher levels of scientific literacy. There is also a need to investigate student's progress from moving one grade to another (a longitudinal study) to give insight about students' progress.

LIMITATIONS

This study compared student's outcomes from grade 10 and 11. Although studying in the same schools and taught by the same teachers, the students were different. Therefore, it was not possible to make conclusions about the development of specific students from one grade to another.

The number of test items used to develop the substantive findings in this study, for each of the SOLO categories, were limited and only one specific context was used to develop the questions asked.

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APPENDIX

Appendix Relating scientific literacy components in this study with the multiplicity of definitions in the literature

Components associated with scientific literacy	**NRC, 1996**	**Norris and Phillips, 2003**	**OECD, 2007**	**Holbrook and Rannikmäe, 2009**	**Choi et al., 2011**	**Components of scientific literacy used in this study for item development based on the relevant literature**
Science knowledge and application	Knowledge and understanding of scientific concepts, facts, principles, laws, theories.	Understanding basic scientific ideas.	Scientific knowledge and use of this knowledge.	Utilising appropriate evidence-based scientific knowledge.	Inter-disciplinary under-standing of science knowledge and use if this knowledge.	Application of (interdisciplinary) science knowledge in real life related context.
Operational skills	Ability to make informed personal decisions. Ability to pose/evaluate arguments based on evidence and to draw conclusions. Ability to describe, explain and predict natural phenomena. Ability to use inquiry process (e.g. to evaluate the quality of scientific information based on its source and methods).	Applying scientific knowledge for problem solving; participating in science-based social issues.	1. Explaining phenomena scientifically. 2. Using scientific evidence. 3. Identifying scientific issues.	Solving meaningful scientific problems, making reasoned socio-scientific decisions.	Competencies to solve problems, reasoning, finding and using resources, applying core ideas, arguing for and against based on evidences.	Use of scientific literacy cognitive operational skills: 1. Explaining phenomena scientifically. 2. Problem solving based on real life context. 3. Decision making and reasoning based on real life context.

Appendix Relating scientific literacy components in this study with the multiplicity of definitions in the literature (Cont.'d)

Nature of Science (NOS)	Understanding about science and its interactions to society.	Understanding science and its applications; knowledge what counts as science; understanding NOS.	Knowledge about science.		Understanding nature of science (e.g. testable, creative, theory-laden, evidence).	*These components (NOS and perceptions) while recognized as components of scientific literacy, are not emphasised in the current study which focuses on the student's operational skills and application of science knowledge.*
Perception components (attitudes; values; interest, views towards one self, career and science, etc.)	Appropriate attitudes and values towards science.	Lifelong learner; participating in science related issues. Appreciation of science, curiosity.	Attitudes towards science (e.g. interest, support, responsibility).		Beliefs, understanding one's own cognitive abilities, appreciating life-long learning.	