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Assessing student's level of scientific literacy using interdisciplinary scenarios

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Abstract
The goal of this study was to develop an instrument for assessing grade 10 and 11 student's levels of scientific literacy in the areas of problem solving and decision making. In concentrating on determining the scientific literacy of gymnasium level students, it was taken as a first; previous international studies like PISA have focused on ninth grade students. The study used four interdisciplinary situations in a personal, social and global context, taken from everyday life, and answers were expected at higher levels of scientific thinking. In addition, student's opinions were sought about their interest related to the kind of instruments used, with the intention of considering their opinions if later modifying the instrument. The sample (N=62) was composed of 10 and 11 grade students in two schools. Results indicated that it is possible to develop an instrument for dividing students' responses between levels of scientific literacy, although most students responded at the functional level with very few at the multidimensional level and this despite the fact that the questions were developed to assess higher levels of scientific literacy. In the students' opinion, the more interesting situations were those in a personal and social context. Students justified this by answering that their capability to solve problems and make decisions by utilizing science knowledge and skills was best in such situations. In reality, they still operated at a functional level as indicated by their responses.

Key words: Competence, decision making, problem solving, levels of scientific literacy, everyday life

Introduction

It has been recognised that Europe needs more scientifically literate citizens (European Commission, 2007) and that citizens should be competent to participate critically in the society in which they belong (Dam & Volman, 2004; Barak et al., 2007). The PISA (OECD, 2007) study showed that Estonian grade nine students had difficulties in utilising science in new situations involving problem solving and decision making, even though these competences are highlighted as learning outcomes in the school curriculum (Estonian Government, 2010). This raises the issue whether students are able to cope with the science curriculum at higher grades and hence, whether more attention is needed to the teaching emphasis in lower grades.

This study aims to develop an instrument, which can be used to determine levels of scientific literacy in the areas of problem solving and decision making. The study concentrates on 10 and 11 grade students (gymnasium students) because they can soon be expected to go to university, or enter the labour market and should thus be expected to exhibit competence in utilising scientific knowledge and skills in everyday life situations. The current study is a pilot for a larger longitudinal study examining how students' scientific literacy in the areas of problem solving and decision making changes over a two year period.

Theoretical overview

The aim of science education should be to enhance scientific literacy (Holbrook, 2010) and develop competencies needed to be a responsible citizen within society (Roth & Lee, 2004). Unfortunately, scientific literacy is a slogan having a wide variety of meanings depending on authors' viewpoints (AAAS, 1989; NSTA, 1991; Miller, 1996; NRC, 1996; Bybee, 1997; DeBoer, 2000; Laugksch, 2000; Norris & Philips, 2003; OECD, 2007; Bybee, et al., 2009; Holbrook & Rannikmäe, 2009; Acar et.al, 2010), although for this study it is taken to be:

> Scientific literacy can be defined as developing an ability to creatively utilize 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 decisions (Holbrook & Rannikmäe, 2009).

This definition suggests that students should be able to draw upon appropriate evidence-based knowledge and use skills in everyday life situations. It suggests the development of competence, where competence is taken to mean the ability to do something using knowledge and skills gained according to the school curriculum (Estonian Government, 2011) and to acquire positive attitudes to take the appropriate action. Therefore scientific literacy along with critical thinking focuses on being capable to utilize science purposefully for improving the quality of life and being a responsible citizen (Hurd, 1998; Norris & Philips, 2003; Sadler, 2004; Jarman & McClune, 2007; OECD, 2007; Murcia, 2009; Holbrook & Rannikmäe, 2009; Reis & Galvão, 2009). Critical thinking is an essential competence required by students to participate in society and to make their own contribution to society in a critical and aware manner (Dam & Volman, 2004). Students are expected to be capable of critically evaluating knowledge and choosing appropriate skills for utilising this knowledge in particular situations so as to undertake problem solving and decision making.

Previous research has shown that students tend to have difficulties evaluating evidence and making decisions in socio-scientific issues (Sadler, 2004; Sadler & Donnelly, 2006; OECD, 2007; Sadler, 2009) and it is predicted that this is related to student's poor critical thinking ability. Through realistic and relevant situations, critical thinking can be developed (Bailin, 2002; Dam & Volman, 2004). Realistic situations have been taken to meaning related to everyday life and it has been shown that students' interest towards science learning can change as students recognise the usefulness of science in their everyday lives (Teppo & Rannikmäe, 2008). Van Aalsvoort (2004) has suggested that relevance of the socio-scientific learning is important and hence this should be taken into consideration in identifying situations for study. However, relevance can be considered from three perspectives: personal relevance considering relevance from the student's perspective and related with a person's own needs; social relevance, seen as relevant from a society perspective and providing insights into the role of science in social situations, and global relevance, seen as relevant from a global perspective, providing insights into the role of science in a general global context and providing an opportunity to engage with these situation. Relevance at personal, social and global levels is seen to be important in attempts to develop scientific literacy.

Bybee (1997) proposed a framework for determining an individual's level of scientific literacy in a particular situation, dependent on the given situation, age, experiences and capabilities. This framework indicated four levels of scientific literacy:

Nominal – an individual demonstrates that a term, question or topic is scientific, but has misunderstandings, has naïve theories and in general, demonstrates minimal understanding.
Functional – an individual uses scientific vocabulary, defines terms correctly in particular activity or situation (in test, for example), memorizes scientific responses from textbook.
Conceptual and procedural – an individual understands principles, theories in science, understands how conceptual parts of a discipline relate to the whole discipline, understands process of science and has an understanding about inquiry.
Multidimensional – an individual understands nature of science, history of science and role of science in personal, social and global life, understands how to make connections within science disciplines, between science, technology and society – in other words, an individual has an interdisciplinary understanding.

While originally these levels of scientific literacy were developed referring to school science programmes and teaching, levels of scientific literacy can also be identified in assessing student's achievement in science education. For example, Murcia (2009) asked students to answer questions, based on science news and their responses were classified, validated by participants and divided into levels of scientific literacy by researchers.

The approach to assessing student's scientific literacy in PISA (Programme for International Student Assessment) (OECD, 2007) was to answer questions based on an introductory scenario. The scenario allowed questions to be related with real life situations. Estonian grade nine students' scientific knowledge was determined to be above the European average and it was speculated that this was because science teaching focuses on an understanding of what is important from a scientist's perspective rather than a viewpoint of the learner or society (Holbrook & Rannikmäe, 2007). On the other hand, students` scientific literacy can be questionable as Estonian students exhibited poor capabilities in areas of utilising science knowledge in new situations (including everyday life situations) and have problems in using evidence to solve problems and justifying their decisions (OECD, 2007).

Based on the chosen definition for scientific literacy and the identified poor levels of scientific literacy in grade 9 level as indicated above, this study concentrates on determining problem solving and decision making ability at the grade 10-11 level. This study uses interdisciplinary scenarios which are everyday life related. Interdisciplinary scenarios allow monitoring of the way students` utilize science in everyday life situations in order to solve problems and make decisions (NSTA, 1991). The instrument addresses problem solving and decision making abilities in personal, society or global situations, encouraging responses at higher, critical thinking levels. To determine the quality of student responses, answers are marked against identified levels of scientific literacy, allowing a measure of scientific literacy among gymnasium students over a two year learning period. For this purpose, problem solving is taken to mean recognition of a problem coming from everyday life and then finding a scientific answer (Holbrook & Rannikmäe, 1997; Rannikmäe, 2008), while decision making is taken to mean the making of socio-scientifically justified decision in personal, society or global situations.

Research objective and research questions

This research, through the development of an instrument, attempts to show the change in level of scientific literacy through assessing 10 and 11 grade students in the areas of problem solving and decision making presented through interdisciplinary personal, social and global contexts, taken from everyday life. Additionally, students are asked to assess their own level of achievement. The following research questions are posed:

1. Are the questions developed able to distinguish student's responses at different levels of scientific literacy?
2. How do the opinions of students correspond with their actual achievement in terms of level of scientific literacy in the different problem solving and decision making situations?

Methodology

Sample

The sample (N=62) for this study was drawn from two classes of students in two schools: 36 students from 11th grade and 26 students from the 10th grade. This was taken as a convenient sample (Cohen et.al, 2000).

In Estonia, science is taught through four subjects - biology, geography, physics and chemistry, although geography was taken to be the context of this study. Geography comprises two parts, one physical geography and other human (or economical) geography although it depends on the teacher as to which part of geography is taught in the 10 or 11 grade. Students in the current sample studied human geography in grade 10 and physical geography in grade 11.

Instrument and Procedure

The framework for the instrument was constructed to incorporate:

1. Interdisciplinary situations, keeping in mind that students should be able to utilize science in everyday life situations.
2. Situations in personal, social and global contexts with the intention of determining whether there were differences in competences depending on context.
3. Problem solving and decision making - as those were seen as important for being scientifically literate.
4. All four situations had a similar structure, first was a scenario which was followed by scenario-related questions.

Table 1 provides an overview of the instrument in which four situations are used and the total number of tasks was ten. Number of questions and tasks were arbitrary and were determined as sufficient to identify students` problem solving and decision making abilities. The interdisciplinary concepts in table 1 indicate concepts that students were expected to utilize in the problem solving and decision making, although it was not expected that student should necessarily utilize all concepts indicated.

In PISA, a scenario was the starting point for developing the situation although the scenario was more related to a subject context. In this study, scenarios were related to student interest, which was determined with respect to usefulness in everyday life and was the starting point for asking individual questions which were more specific and coming directly from the scenarios.

Students were asked also to mark the most interesting situation, in their opinion, and also answer two additional questions: 1) in which situation they felt their capability to solve problems and make decisions was the best, and 2) in which situation they felt their capability to solve problems and make decisions was the weakest. This information was collected so as to be used in modifying the instrument for later use.

Table 1. Overview of the instrument

Situation from everyday life	Nr of quest.	Context	Competences	Interdisciplinary concepts
Hiking in the Grand Canyon	3	Personal	Problem solving Decision making	Climate; weather; dehydration; metabolism; food properties; electrolyte; respiratory disease; respiratory system; canyon formation; human body temperature; circulatory system; energy; heatstroke
Travelling in Egypt	3	Personal and social	Problem solving Decision making	Vaccination; infection diseases; vaccines; metabolism; light reflection; heatstroke; dehydration; skin properties; skin diseases
Visiting a Rainforest	2	Global	Problem solving Decision making	Biotope; rainforests; deforestation; biodiesel; CO_2 emission; climate change; soya; agriculture; natural diversity
Vacationing near the Dead Sea	2	Personal	Decision making	Formation of salts; salt properties; salt solubility; density; climate zone, rainfall and transpiration; respiratory system; aerosols; ions; ion transport; respiratory diseases

The first situation (see appendix 1) included three questions, the first related to problem solving and the other two to decision making. The second situation also included three questions, one related to problem solving and two to decision making. In the third situation, one question was problem solving and the other, decision making. In the last situation, both questions related to decision making.

The instrument was validated by three experts in the field of science education. The reliability of the instrument was determined to be acceptable using Cronbach alpha (0,753). Responding to the instrument took 45 minutes, although five students needed an extra 10 minutes to complete. This was permitted.

Data Analysis

Student's answers were divided into four levels of scientific literacy, based on the Bybee (1997) framework for scientific literacy as described in table 2. The two competences of problem solving and decision making were analysed together due to the small sample size and the fact that only three questions out of ten included problem solving. In order to ensure a statistical difference between achievements in the two classes, Wilcoxon test was applied using SPSS 17. In this test, Z marks the differences between two classes and p shows, if there is any statistically significant difference.

Table 2. Overview about students answers division between different levels

Level of scientific literacy	Description in context of current study	Answers examples
Nominal	Student agrees to what others have said without bringing in his/her own ideas. Student recognizes the scientific term to utilize and writes it down, but is not capable to justify this term or has misconceptions.	I will eat salty snacks and drink water during hiking, because the authorities say so.
		It is not possible to swim in the Dead Sea, because salts will raise you up in the water.
Functional	Student was able to recall information from the textbook (for example) and write down basic facts, but was not capable to justifying those based on the given text or graph. The student might even name interdisciplinary concepts, but was not able to describe relations between those concepts.	It is recommended to use salt chambers, because these are healthy and have a healing quality.
		It is clear that hiking during winter time is not recommended, because it is then cold with lots of rain.
Conceptual/ procedural	Student utilized interdisciplinary concepts and demonstrates an understanding, how those were interrelated. Student had some understanding about inquiry, by justifying the answer with correct information from the text, graphs or tables. Student was able to analyze alternative solutions.	It can be seen that when deforestation is high, then the level of CO_2 emission rises also and as a result of deforestation, soya growing became more intensive.
		Winter time is not suitable for hiking, because the temperature is around zero and there is lots of rain compared to other seasons. Average temperature in winter is +13C, but in April +28C. It can be said that hiking in winter means that you must be careful with your health and you may need to take extra luggage with you.
Multidimensional	Student utilized interdisciplinary concepts and demonstrated a capability to associate those concepts with everyday life. Therefore a student understood how science, society and technology were interrelated and influenced each other. The student also demonstrated an understanding about the nature of science through answers given.	It is recommended to eat salty snacks during hiking, because the body sweats and loses important salts. Those must be replaced, because otherwise you don't feel very well and have health problems. You must definitely drink lots of water also.
		It is recommended not to eat fruits directly from the market, because you never know who has touched them before you and whether this person had clean hands. You must also consider that the salesperson might have lied to you just to sell the products. It doesn't matter if you are vaccinated against one disease; you might get another.

Results

Student achievements, in terms of levels of scientific literacy, are presented in table 3.

Student's answers, in all four situations, were mostly at the functional level (54% of student's answers). This is the level, which is usually assessed in school examinations (Bybee, 1997) and based on this sample, it can be said that those students responding at this level had gained the level needed to do well in examinations. It could thus be speculated that students answered mostly at this level, because they had become accustomed to answer in this way.

Students clearly had difficulties operating at the multidimensional level, relating the interdisciplinary concepts and utilizing those for problem solving and decision making needed in everyday life situations. Although it is not clear how far the questions had construct validity, students in general were not capable of giving responses at the higher level to all ten questions. On closer inspection, table 3 shows that questions answered at the higher level were mostly in the second situation ("Travelling in Egypt"). This question was the only one to include a social context component and 10% of the student responses were able to provide multidimensional answers. This raises the issue whether question is functioning in a different manner to the rest. Results tended to indicate that incorporating a social context encouraged multidimensional responses and that the potential for the students to function at the higher levels was enhanced.

Table 3. Student (N=62) answers at the different levels of scientific literacy

			Number (%) of student responses			
Situation from everyday life	**Nr of questions**	**Nr of responses**	**Nominal**	**Level of scientific literacy** **Functional**	**Conceptual**	**Multi-dimensional**
Hiking in the Grand Canyon	3	186	32(17)	116(62)	31(17)	7(4)
Travelling in Egypt	3	186	31(17)	90(48)	46(25)	19(10)
Visiting a Rainforest	2	124	51(41)	52(42)	20(16)	1(1)
Vacationing near the Dead Sea	2	124	34(27)	76(61)	13(11)	1(1)
Total	**10**	**620**	**148(28)**	**334(54)**	**110(18)**	**28(4)**

As the study was conducted in both grades 10 and 11, student achievement, in terms of levels of scientific literacy, could be considered separately. This is shown in table 4.

Table 4. Grade 10 and 11 students (N=62) responses in terms of levels of scientific literacy

				Number (%) student responses			
Situation from everyday life	**Nr of questions**	**Nr of responses**	**Grade**	**Nominal**	**Functional**	**Conceptual**	**Multi-dimensional**
Hiking in the Grand Canyon	3	108 78	10 11	17(16) 15(19)	69(64) 47(60)	18(16) 13(17)	4(4) 3(4)
Travelling in Egypt	3	108 78	10 11	19(18) 12(15)	55(51) 35(45)	28(26) 18(23)	6(5) 13(17)
Visiting a Rainforest	2	72 52	10 11	29(41) 22(42)	36(50) 16(31)	6(8) 14(27)	1(1) 0(0)
Vacationing near the Dead Sea	2	72 52	10 11	21(29) 13(25)	45(63) 31(60)	5(7) 8(15)	1(1) 0(0)
Total	**10**	**360** **260**	**10** **11**	**86(24)** **62(24)**	**205(57)** **129(50)**	**57(16)** **53(20)**	**12(3)** **16(6)**

There is little difference in responses between grade 10 and grade 11 students and in all situations differences were not statistically significant. In the situation on "Hiking in the Grand Canyon" (Z=-1.826; p=0,068), neither class was able, in general, to function at the multidimensional level and they had also difficulties functioning at the conceptual level. A similar picture is painted for "Vacationing near the Dead Sea" (Z=-1,095; p=0,273).

However in the other two situations, there was a notable change of level of scientific literacy between responses from grade 10 and 11 either to the conceptual level "Visiting a Rainforest" (Z=-0,730; p=0,465) or to the multidimensional level "Travelling Egypt" (Z=-1,289; p=0,197), although the percentage of nominal responses changed little. This suggested that for some students, at least, there was development in the level of critical thinking, although no statistical significant difference was determined.

The analysis of students` responses showed that they had difficulties in utilising science into new, everyday life situations, which had been indicated also for lower grades in previous research (Holbrook & Rannikmäe, 2007; OECD, 2007). As the capability to utilize science for problem solving and decision making were major indicators of being scientifically literate (Norris & Philips, 2003; OECD, 2007; Holbrook & Rannikmäe, 2009), it could be said that despite the fact that students had scientific knowledge, they were not reaching higher levels of scientific literacy and most students` were operating at a functional level of scientific literacy.

Table 6 presents' students choices related to the most interesting situation and also indicates situations where their capability to solve problems and make decisions were the best, and where their capability to solve problems and make decisions was the weakest. As the tendency of opinions expressed by students across two classes were similar, responses from the two classes were analysed together.

Table 6. Students (N=62) answers related to interest and capability to solve problems and make decisions

	Number of students choosing		
Situation from everyday life	**Most interesting situation**	**Capability to solve problems and make decision was best**	**Capability to solve problems and make decision was weakest**
Hiking in the Grand Canyon	20	15	19
Travelling in Egypt	22	29	2
Visiting a Rainforest	8	7	25
Vacationing near the Dead Sea	12	11	16
Total	**62**	**62**	**62**

In the students' opinion, "Hiking in the Grand Canyon" (marked by 20 students) was considered to one of the most interesting situations. Although "Travelling in Egypt" (marked by 22 students) was also considered an interesting situation, backed up by nearly half the students feeling their efforts in answering were the best (marked by 29 students). The least interesting situation was "Visiting a Rainforest" (marked by 8 students) and this was also the situation where students thought they had the weakest capability to solve problems and make decisions. This was the only situation in a global context and the only situation which required utilizing novel concepts that they had just started to study.

Discussion

Based on the outcomes from this research, it is evidently possible to develop an instrument which can be used for dividing student's achievements at different levels of scientific literacy. However, there is a need to be prepared for students' answers in such situations to be mainly at a functional and nominal level, with few responses at a conceptual or multidimensional level. Although this is disappointing, because an instrument such as this is wishing to cover all levels and especially the higher levels of scientific literacy, previous studies show students tend to have difficulties in the areas of problem solving and decision making (Sadler, 2004; Sadler & Donnelly, 2006; OECD, 2007; Sadler, 2009). The outcomes suggest that any instrument attempting to cover all levels of scientific literacy can expect few responses at the higher levels. But it is not yet clear whether students are capable to give answers at higher levels of scientific literacy where questions require this, or whether students are not able to answer at this level. Students might still simply answer at the functional level in a similar manner to that which they have become accustomed in their learning in school lessons and in examinations. Further studies are needed in this area, due to limitations of the current study in making generalizations beyond the students who participated in this study. Such studies are important as there is some evidence that students are not reaching their true potential and are simply operating at a level which the school and examination system demand.

The most interesting situations based on students views were those where they believed their capability to solve problems and make decisions was best. Furthermore, those situations were in a personal and social context. This is pointing to the importance of relating learning to relevance in real life. Not surprising, the students did not find situations interesting in which they believed their capability to solve problems and make decisions was weak. Such situations were shown to be those in a global context. As science concepts in these situations were novel for students, then perhaps there was a tendency for students to associate a lack of interest with difficulty. Further studies should indicate, whether there is a connection between difficulty, interest and capability to utilize science into everyday life.

Conclusion

The goal of the current study was to explore theoretical constructs which can underpin the development of an instrument for assessing 10 and 11 grade student's levels of scientific literacy in the areas of problem solving and decision making. This research showed that it was possible to develop an instrument which could be used for dividing student's responses between levels of scientific literacy. This type of instrument was shown to be worthy of further consideration.

Although questions were developed allowing responses at higher levels of scientific literacy, students' answers were mostly confined to the functional level. As this was associated with the usual level required in school examinations, the hypothesis put forward is that students were not sufficiently well taught to rise to higher levels of scientific literacy where the situation demands.

The instrument further showed that student's capabilities to solve problems and make decisions were different in personal, social and global situations and there was no significant difference related with knowledge, as would be expected due to students in different grade level. There was thus evidence that students responses were in line with their achievement in terms of scientific literacy, although this seems to be clouded by the level of scientific literacy expected from the teaching and examinations being set.

Based on the non-representativeness of the sample, it cannot be said that, in general, students lack skills to apply their science learning to problem solving and decision making situations in everyday life situations.

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Appendix 1

An Example of a Question - Hiking in the Grand Canyon

1. You are hiking in the Grand Canyon. Below are several tips you should know about hiking.
   - Plan your trip before you start.
   - Balance your food and water intake. Eat salty snacks and drink water or sports drinks.
   - Go slowly, rest often, and stay cool. Allow the weaker hikers to set the pace.
   - During summer, hike during the cooler, shadier times of the day.
   - Expect summer thunderstorms.
   - Hike in spring and fall for the most enjoyable and safest weather conditions.

(http://www.nps.gov/grca/index.htm)

The tips suggest you should hike during spring or fall. Based on the tables, explain why it is not recommended to hike during the winter.

Temperature inside canyon												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
High (°C)	13	17	22	28	33	38	41	39	36	29	20	14
Low (°C)	2	6	9	13	17	22	26	24	21	14	8	2

Temperature on the *South Rim*												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
High (°C)	5	7	10	15	21	27	29	28	24	18	11	6
Low (°C)	-8	-6	-4	0	4	8	12	12	8	2	-3	-7

Rainfall											
Average precipitation (631,6 mm)											
J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
82,7	83,0	86,1	35,	25,2	19,5	45,4	57,8	47,6	36,0	34,3	77,8

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2. You are hiking in the Grand Canyon. The weather is very warm and you feel the need to eat or drink something. You are carrying some food and drinks. Make a decision, what you should eat or drink and justify our answer.

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3. Your friend is suffering from bronchitis. Is it suitable for your friend to join you when hiking in the Grand Canyon? Justify your answer.