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DEVELOPMENT OF ESTONIAN UPPER SECONDARY SCHOOL STUDENTS' BIOLOGICAL CONCEPTUAL UNDERSTANDING AND COMPETENCES

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Abstract. *The main aim of this research was to measure 10th and 12th grade students' biological conceptual understanding and competences through their upper secondary school studies. Data collection started at the beginning of the upper secondary school biology studies in the 10th grade. The same students participated in this research when they were in the 12th grade. A validated instrument of covering four competences: biological conceptual understanding, problem-solving, critical thinking and divergent thinking was used. Overall, this research was meant to evaluate students' conceptual understanding and cognitive skills (problem-solving, critical thinking, divergent thinking) through the socio-scientific issue of lactose intolerance. The sample of students was formed from 42 representatively chosen Estonian schools of grade 10 (N=967) and grade 12 (N=802). The development conceptual understanding and competences of students' during three upper secondary school years of biology studies were discussed. The main results showed that during three years of schooling the students exhibited a statistically significant increase in the tasks, that measured students' biological understanding and cognitive skills. The results showed that the students achieved lower scores in tasks that measured their decision-making and socio-scientific reasoning skills.*

Keywords: *achievement levels, biology education, competences development, conceptual understanding, empirical research.*

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Introduction

More attention should be paid on the biological competences of the citizens. Globalisation and technological advantages in recent decades have led to a change in the nature of work and labour, and students need to be prepared to work in jobs that yet do not exist (Beier, 2014; Greiff & Neubert, 2014). There is a demand for scientifically literate people in the labour force, who are able to analyse, make conclusions and are able to work in teams and apply scientific knowledge in new situations (Griffin, Care, & McGaw, 2012; Holbrook, 2014). Laius, Post, and Rannikmäe (2015) indicated in their research, that different stakeholders (e.g. scientists, teachers, educators, science teachers, employers, and students) see scientific literacy as playing a major role in the future Estonian society.

The rapid developments in the field of science (especially life sciences) not only lead to changes in society but also in coping with these changes and there is a need for skills of justified decision-making in people's everyday life e. g. decisions about healthy diet and recycling. Thus, education promoting factual knowledge is no longer sufficient and there is a necessity to pay more attention to developing students' cognitive abilities and to promote scientific literacy for modern life (Zo'bi, 2014). Noting this, one of the key goals of the Estonian National Curriculum (2011) is promoting students' conceptual understanding and competences. Within this, it is important to develop students' academic competences including updated content knowledge, and abilities to solve problems incl. scientific problems.

Within science education the biology education especially focuses on enhancing students' biological conceptual understanding and cognitive skills, guiding students to meaningfully apply biological knowledge in new contextual situations (Estonian Curriculum, 2011). The curriculum builds on a range of topics which form the basis for developing the students' understanding of core biological concepts and indicates that the included biological conceptualisations comprise of three cognitive components – critical thinking (explanation skills, analysing skills), divergent thinking (scientific creativity

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skills, decision-making, and reasoning skills), and problem-solving skills (which refers to the capacity to take care of issues in an opportune way).

Within such a frame the science curriculum suggests that a new context can consist of a real-life societal problem that students can be expected to solve conceptualising the biological concepts. In developing upper secondary school students' biological content knowledge, the curriculum (Estonian Curriculum, 2011) expects students to solve problems, think creatively, make justified decisions and reason logically within biology lessons and out of school. There is a suggested need for such abilities of students to apply them in their everyday life or future careers.

Theoretical Overview

Competences in Biology Education

Various organisations with expertise in 21st-century competences have identified three broader categories in biology education: 1) cognitive competences; 2) interpersonal competences, and 3) intrapersonal competences. The cognitive category includes several specific competences including skills that educators and policymakers deem essential to success in the global economy: ability to grasp and understand core scientific content, analysing skills, and creativity. These competences all involve higher-level thinking of some kind and rarely match one another exactly (Soland, Hamilton, & Stecher, 2013).

The current research was focused to competences that incorporate content knowledge (factual and applied) and cognitive skills that are related to processing this biological knowledge. Competence has been defined in many studies (Csapó, 2004; Simonton, 2003; Weinert, 2001) and has been conceptualised as an ability to use knowledge and skills that enables the students to be effective in their future jobs.

Gaining content knowledge is an important aim in science education, but more important is to utilize this knowledge in problem-solving, decision-making, and in scientific creativity (Greiff & Neubert, 2014; Schleicher, 2014). According to Ahmad, Li, Eddine, and Khan (2018) cognitive skills are the mind-based capacities to process the data received from experience, and people need these skills to perform cognitive tasks. Improving cognitive skills could lead to better academic performance.

The aim of biology education according to the Estonian Curriculum (2011) is to enhance students' cognitive skills that enable the students to apply their biological knowledge in new contexts and situations. Cognitive skills are defined as the ability to understand complex ideas and to learn from experience (Neisser et al., 1996). The term 'cognitive skills' used in this research refers to the acquisition of biological concepts and using the cognition in the following situations: solving different problems and reasoning them; making socio-scientific decisions; and thinking creatively.

Conceptual Understanding and Complex Cognitive Skills

Subject content knowledge impacts an immense extent that the cognitive skills and biological and chemical content knowledge are both needed for conceptual understanding the phenomenon of lactose intolerance and to solve the problems, related to this context; to make socio-scientific decisions and reasoning them; to use divergent thinking and scientific creativity skills. Students who have good biological content knowledge can solve problems much more effectively than those students whose biological content knowledge is not enough (Sadler & Zeidler, 2005).

Conceptual understanding refers to an integrated and functional grasp of scientific knowledge. Students with good conceptual understanding can see relationships between quite isolated knowledge (facts, concepts, skills, etc.), they can organise their knowledge into a coherent whole, that permits them to hold new ideas by connecting those facts and concepts. Conceptual understanding additionally supports retention. As results of facts and methods learned with understanding are connected, they are easier to reconnect and use, and that they are often reconstructed once forgotten. Conceptual understanding enables students to grasp knowledge in a transferrable way, helping them to apply their obtained knowledge across domains. It is a relevant topic in the science education today, as rote memorisation and traditional methods of teaching have become considered insufficient for real-world learning and application (Gunel, Hand, & McDermott, 2009; Jensen, McDaniel, Woodard, & Kummer, 2014; Zacharia, Lazaridou, & Avraamidou, 2016).

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A developing number of national and worldwide organisations have recognized complex cognitive abilities as basic skills for the labour force in the advanced economy (OECD, 2013). These complex cognitive skills enable people to arrange new problems into the psychological outline, and to use the knowledge from commonplace in the new complex situations. Analysts, researchers, and policy organisations have alluded to these abilities utilizing a wide range of terms including 21st-century skills, more profound learning, basic reasoning, critical thinking skills, etc. (Kraft, 2019).

Problem-Solving Skills

The ability to take care of issues is one critical importance in almost every subject, both in and out of school (Csapò & Funke, 2017). Thus, one principle reason for science education (including biology education) is to build up and develop students' problem-solving skills. In innovation, we often must deal with unpredictable situations, where we often need to solve problems. Problem-solving is a part of scientific literacy (Roberts, 2007; Roberts & Bybee, 2014). Developing students' problem-solving skills allow them to solve effectively and professionally everyday problems (Şenocak, Taşkesenligil, & Sözbilir, 2007). Critical thinking skills are flexible mechanisms for effectively dealing with sorts of new issues in new situations (Kashani-Vahida, Afrooz, Shokoohi-Yekta, Kharrazi, & Gohabari, 2017). However, performance on critical thinking assignments (problem-solving and reasoning) differs drastically as a component of, how the issues are confined. When given in a setting free way, the students frequently are mistaken in practising their problem-solving skills.

Socio-Scientific Decision-Making and Reasoning Skills

Decision-making and reasoning are parts of scientific literacy (Roberts, 2007; Roberts & Bybee, 2014). Decision-making is a demanding thinking process that is needed in every field of personal life e.g. in work (Colakkadioglu & Celik, 2016). As a part of the Estonian Curriculum, students are expected to utilise their newly acquired biological knowledge to make informed decisions concerning socio-scientific issues (Estonian Curriculum, 2011).

Students' development of their reasoning to make justified decisions leans on their understanding of the conceptions utilized (Zeidler, Herman, Ruzek, Linder, & Lin, 2013). These conceptions will have the impact on students' life. The need to pay more attention on the decision-making is acclaimed in many research (Millar, Osborne, & Nott, 1998; Zeidler, Sadler, Simmons, & Howes, 2005). Decision-making and reasoning skills are also valued by many Estonian stakeholders (Laius et al., 2016).

Divergent Thinking and Scientific Creativity

Divergent thinking is a cognitive process of thinking, used to produce innovative ideas by investigating numerous possible solutions in a short amount of time. New and unexpected associations might be drawn. In the field of science it leads to scientific creativity that makes it possible for students to solve both personal and social problems or tasks which have a scientific content, and a new creative solution to reach the current state of knowledge involved in problem-solving process, while being open to various opportunities and non-traditional approaches (Heller, 2007; Mumford, Hester, & Robledo, 2010). Creativity is also an adaptation of the existing, not only the creation of new ideas (Šorgo et al., 2012).

Scientific creativity requires awareness of scientific problems because finding creative problems to fix is a critical prospect that can be part of the effective researcher (Usta & Akkanat, 2015). It is necessity for biology teachers to develop students' biological literacy including scientific creativity and critical thinking (Estonian Curriculum, 2011). Creativity should be established through problem-solving, which takes place in their everyday life (Basadur, M., Gelade, & Basadur, T., 2014; Kirton, 2003) and this skill can promote creative solutions in many settings (Tsai, 2012). With that in mind the lactose intolerance was chosen as the context of the instrument in this research. Currently the creative problem-solving is an important skill (Trilling & Fadel, 2009) as new problems can be confronted every day. Scientific creativity has been defined by many researchers (Antink & Lederman, 2015; Hu & Adey, 2002; Usta & Akkanat, 2015). Hu and Adey (2002) defined scientific creativity as a process comprising finding and solving creative scientific problems. In this article scientific creativity is considered according to Usta and Akkanat (2015) as dependence on the past encounters and knowledge, advancement of the understanding nature of science.

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Socio-Scientific Issues (SSIs)

Recently advised concepts for expanding the curiosity in studying biology are caused with the use of socio-scientific issues in education (Lee, Yoo, Choi, Kim, Kajcik, Herman, & Zeidler, 2013). Socio-scientific issues (SSIs) are effective in improving students' conceptual understanding and competences (Eastwood, Sadler, Sherwood, & Schlegel, 2013; Sadler, 2005).

Romine, Sadler, and Kinslow (2017) defined socio-scientific reasoning as a process, which students use to resolve different complex SSIs. According to Sadler, Foulk, and Friedrichsen (2017) socio-scientific reasoning includes connected competences: 1) bookkeeping; 2) analysing; 3) inquiry; 4) critical analysis; 5) investigation, how science can help to resolve the problems. For those reasons, a socio-scientific issue as lactose intolerance is used in this research (shown in appendix 1). Socio-scientific issues have been used in assessing students' scientific competences in several studies (Foong & Daniel, 2010; Tsai, 2018).

Research Problem

According to Programme for International Student Assessment (PISA) 2015 results (9th grade, 15-year-old), the level of Estonian lower secondary school students is among the top-level with respect to scientific literacy level worldwide (Estonian results, 2016). Unfortunately, no similar large-scale survey has been conducted in Estonia for measuring the same for the upper secondary school level. There is a need for further enhancement of science education in the upper secondary school to support the students' meaningful learning. The current research was undertaken as one part of a larger project of evaluating the upper secondary students' scientific literacy (Soobard & Rannikmäe, 2015) with the respect to biological literacy.

As lactose intolerance has gained much attention in Estonia, this research focused on a context of lactose intolerance and compared the biological cognition levels of conceptual understanding for 10th (16–17 years old) and 12th (18–19 years old) grade students. Bybee (1997) has defined conceptual understanding as an individual's capacity to explain concepts and theories of science. Lactose intolerance integrates the diverse field of science knowledge and is an important topic for health of society.

Research Focus

This research aimed to use a context-based instrument to measure 10th and 12th grade students' biological conceptual understanding and cognitive skills through the following components: biological conceptual understanding, critical thinking, divergent thinking, and problem-solving skills. These cognitive components of biological literacy were selected for assessment to address the goals of Estonian curriculum, the needs of Estonian labour force, according to the opinions of Estonian stakeholders, which were revealed from the previous research (Laius, Post, & Rannikmäe, 2016). The research aimed to determine the development of students' achievement levels of biological conceptual understanding and cognitive skills during three years of upper secondary school studies from grade 10 to grade 12. To conduct this research, a context-based instrument for assessing conceptual understanding and cognitive skills in the context of lactose intolerance was fulfilled, analysed and validated. The following research questions were put forward to achieve the aim of this research:

RQ1: What kind of achievement levels can be identified based on the 10th and the 12th grade students' levels of biological conceptual understanding and cognitive skills, identified through the topic of lactose intolerance?

RQ2: How have changed the students' achievement levels of biological conceptual understanding among the 10th and the 12th grade students during 3 years of biology studies?

Research Methodology

General Overview

This research encompassed the analysis of one fourth of the scientific literacy test (Soobard & Rannikmäe, 2015) that is focused on biology and chemistry knowledge. This research sought to determine upper secondary school students' development of the biological conceptual understanding and competences through their biology studies.

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Sample

The stratified sample for this research, was from 42 out of the 151 schools from the total list of Estonian upper secondary schools (Estonian statistics, 2019), and consisted of 967 grade 10 students (16–17 years old) and 802 grade 12 students (18–19 years old) amounting to a total of 1769 students. Sample consisted of 503 female and 464 male students participating from 10th grade and 489 female and 313 male students participating from the 12th grade.

Every third school was chosen from three layers (schools from the Capital city; schools from cities with at least two gymnasiums; schools from the rural areas) to form the sample.

A representative sample was composed of 1769 students from 42 schools. Criteria for the representativity of the sample formation were described within all the LoteGym project by Rannikmäe, Soobard, Reiska, Rannikmäe, and Holbrook in 2017. The amount of the students in the upper secondary school has varied from 25 200 to 22 500 from year 2011 to 2013.

Headmasters from every participating school signed the agreement/consent form with the Estonian Ministry of Education and Research. Then codes were given for every participant to ensure their anonymity.

Instrument and Procedures

The context-based assessment instrument of biological conceptual understanding and cognitive skills was one fourth part of scientific literacy test of the LoteGym project and was created based on:

- learning outcomes of Estonian Curriculum and syllabus of biology (2011);
- expectations of Estonian stakeholders for the future workforce (Laius et al., 2016);
- conceptualising of the new concept of biological literacy (Semilarski & Laius, submitted in 2019);
- scientific competences (Csapó, 2004; Simonton, 2003; Weinert, 2001).

One part of the LoteGym project, was used in this research to go more in-depth with this biology assessment.

Lactose intolerance test was compiled to assess biological conceptual understanding and four cognitive skills: applying biological content knowledge; problem-solving; scientific creativity and socio-scientific decision-making and reasoning (Table 1).

A context-based instrument for assessing students' biological conceptual understanding and cognitive skills including eight tasks in the context of lactose intolerance considered also research literature (Ahmad et al., 2018; Anderson Koenig, 2011; Holbrook, Rannikmäe, Reiska, & Ilsley, 2008; Kraft, 2019), Estonian Curriculum (2011) and the opinions of Estonian stakeholders about the needs of society and which careers experts estimate important for students to learn in the future (Laius et al., 2016).

Lactose intolerance is a relevant topic (Lactose Intolerance test was chosen because this topic is very actual in the Estonia society because a big part (25% of grownups) of the Estonian population is lactose intolerant (Lember, Torniainen, Kull, Saadla, Rajasalu, Lepiksoo, & Järvelä, 2007). The eight tasks of instrument are testing abilities to transfer the biology knowledge into new everyday situations and is meant to measure the biological knowledge, creative thinking skills, problem-solving, socio-scientific decision-making and reasoning skills.

Every task was created in the context of lactose intolerance as a separate problem-based sub-unit to assess biological conceptual understanding and cognitive skills.

The instrument was piloted in 2011 with 36 10th grade students in one of the Estonian cities (Tartu) schools. Following feedback, some minor changes were made in the formulation of the tasks.

The tasks of biological conceptual understanding and problem-solving were scored as follows:

1) wrong answer or no answer – zero points;
2) partially correct answer – one point;
3) correct answer – two points;
4) correct answer with the correct explanation – three points.

The tasks of divergent thinking skills were coded as follows:

A. Scientific creativity skills:

1) wrong answer or no answer – zero points;
2) one possible and correct evolutionary advantage of lactose tolerance – one point;
3) two possible and correct evolutionary advantages of lactose tolerance – two points;
4) three or more correct evolutionary adequate advantages of lactose tolerance – three points.

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B. Socio-scientific decision-making and reasoning:
1) no answer – zero points;
2) just generally describing the decision – one point;
3) reasoning the decision from one aspect – two points and
4) reasoning the decision from two or more aspects – three points.

Table 1. The task description of the test and needed knowledge for performing the tasks.

Needed competence	Needed skills	Needed knowledge	Task	Task description
Conceptual understanding.	Applying biological content knowledge (assessing and analysing information). Explanation Skills.	Knowledge about the metabolism and symptoms of lactose intolerance.	1	Recognising and understanding the concept of lactose intolerance from the description of SSI based situation.
		Knowledge about the genetic divergence of triplets' gender and lactose intolerance.	7	Explaining the reasons whether the described triplets are identical or not.
Critical thinking.	Analysing information and Explanation Skills.	Knowledge of enzymatic decomposition of lactose in dairy products.	2	The justified choice of dairy products that can be tolerated by lactose intolerant person.
	Assessing and analysing information from the table. Explanation Skills.	Knowledge about the influence of lactic acid bacteria and fungi on the composition of dairy products.	3	Analysing the data of the chemical composition of milk and kefir during fermentation and explaining the reasons for the changes.
Problem-solving.	Analysing information and solving a scientific problem- solving and explanation skills.	Knowledge about the results of lactose intolerance – calcium deficiency as a possible cause of bone fractures and osteoporosis in case of lack of other calcium sources.	6	Explaining the risk of fractures and osteoporosis in case of lactose intolerance and explaining the possible alternatives in feeding to avoid bone fractures and osteoporosis.
	Complex problem-solving, analysis and scientific reasoning.	Integrated knowledge about the nature of digestion (biology) and enzymatic degradation of disaccharides (chemistry). Knowing the bases of diagnosing lactose intolerance according to the results blood test. Need to conceptualise the nature of digestion (biology) and enzymatic degradation of disaccharides (chemistry).	5	Making the conclusion on the bases of sugar content results of blood tests before and after drinking 50 g sugar solution and diagnosing whether the person is lactose intolerant or not.
Divergent thinking.	Scientific creativity.	Knowledge about lactose tolerance advantages in surviving in biological evolution through the struggle for existence and natural selection.	4	Presenting as many advantages of being lactose tolerant as possible in Surviving in the struggle for existence and natural selection during biological evolution.
	Decision-making and socio-scientific reasoning.	Knowledge about the needs of lactose intolerant persons for special food and the ratio of them in society and their rights to equality.	8	Deciding whether to prepare and offer a lactose-free menu for lactose-intolerant people in a personal restaurant and reason this decision from as many aspects as possible.

Reliability and Validity of The Test

The instrument's reliability was determined using Cronbach α (.69), which was taken to be sufficient even though the number of instrument tasks was small (Loewenthal, 1996; Taber, 2018). Based on Creswell (2005) a correlation of .60 or above indicates a significant correlation (Table 2).

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Expert method was used for determining the content validity of the instrument by one biologist, one experienced biology teacher (20 years of biology teaching) and two biology education researchers. These experts also helped to ensure the construct validity of the test who evaluated all the tasks of the instruments based on the following terms:

1) Are the tasks measuring what was intended in the case of biological conceptual understanding, critical thinking and divergent thinking (content validation);
2) Are the scores collected by this test useful and have a purpose (construct validation); and
3) Whether the data follow a normal distribution.

Table 2. The reliability and validity of the test.

Reliability (Cronbach α)	Validity	Validation method
.69	Content validity	Expert method: One biology researcher, one expert biology teacher, two biology education researchers. In total four independent experts in the field of biology education.
	Construct validity	Analysis by whom of Estonian upper secondary school biology syllabus to ensure that tasks are valid in terms of expected learning outcomes.

Data Analysis

Descriptive statistical methods were used to calculate means and standard deviation. According to the normality test, values for Skewness and Kurtosis fall within the acceptable level of +2 or -2, making the data appropriate for use (George & Mallery, 2010). Nonparametric statistical tests were used as the gathered data were ordinal.

Cohen's *d* was used to calculate the effect size (magnitude of a phenomenon) to eliminate sample size influence in IBM SPSS Statistics 25 (Lakens, 2013). Mann-Whitney *U* test was used to compare the 10th and 12th grade students' results as the Mann-Whitney *U* test is the nonparametric independent *t*-test and is appropriate analysis to compare differences that come from the same population (Leech, Barrett, & Morgan, 2005).

Data were analysed using MS Excel and IBM SPSS Statistics 25 to describe students' responses distribution and to determine how responses to different tasks within the achievement levels varied.

Mean results were expressed in percentages of the maximum possible outcome that formed the basis of creating the three achievement levels of students: 1) low, 2) medium, and 3) high level (Figure 1).

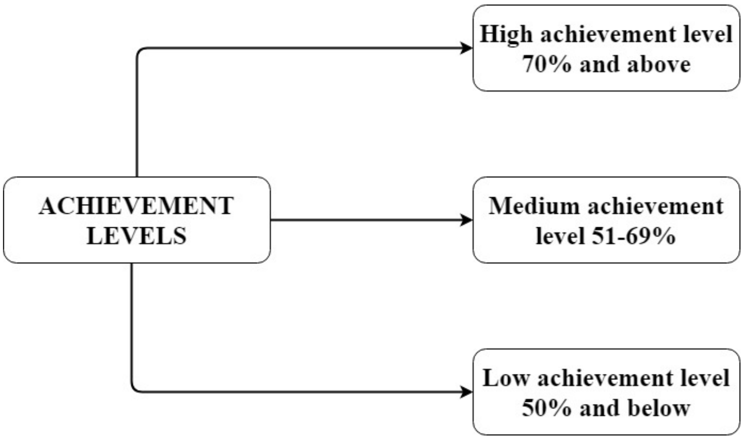

Figure 1. Three achievement levels of students' biological conceptual understanding and cognitive skills.

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Research Results

Comparison of Students' Achievement Levels Through Upper Secondary School' Biology Studies

Comparative analysis of the 10th and the 12th grade students' results has shown (Table 3) that the achievement levels of the 12th grade students were higher in all tasks. Results showed that 12th grade students had statistically better results ($p < .05$) in the first task (students' conceptual understanding), in the fourth task (students' scientific creativity) and in the sixth task (students' problem-solving skill). In these three tasks, the effect size (Cohen's $d > .2$) showed that the difference between the 10th and 12th graders' results were statistically significant and also pedagogically meaningful. Also, the 12th grade students had statistically significantly better results ($p < .05$) in the third task (critical thinking, using information from the table) and in the fifth task (complex problem-solving skill and reasoning skill), but the effect size (Cohen's $d < .2$) showed that the difference was not pedagogically meaningful.

Table 3. Comparison 10th and 12th grade students' performance.

Grade	Task (Points 0–3)	Mean results of task (*SD*)	Level of achievement (%)	Mann-Whitney Test *U*	*p*	Effect size (Cohen's *d*)
10	1	1.66 (0.99)	55.5	212609.0	< .001**	.978***
12		2.44 (0.54)	81.3			
10	2	1.68 (0.88)	56.0	382002.0	.562	.079
12		1.75 (0.89)	58.3			
10	3	1.65 (0.96)	55.1	356190.5	<.001**	.187
12		1.82 (0.85)	60.7			
10	4	1.12 (0.84)	37.3	311140.5	< .001**	.354***
12		1.43 (0.91)	47.7			
10	5	1.13 (0.80)	37.6	349033.5	< .001**	.188
12		1.28 (0.80)	42.7			
10	6	1.98 (0.69)	66.0	342711.5	< .001**	.265***
12		2.15 (0.59)	71.7			
10	7	2.35 (1.05)	78.4	377164.5	.215	.090
12		2.44 (0.95)	81.5			
10	8	1.48 (0.76)	49.3	372873.0	.081	.136
12		1.58 (0.71)	52.7			

** Significant at the .05 level (two-tailed)*
***Significant at the .01 level (two-tailed)*
****Cohen's d > .2 shows that the difference scientifically meaningful*

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Students from the 12th grade had significantly better results than the 10th grades in five out of eight tasks. They indicated better results in conceptual understanding, in scientific creativity, in problem-solving and in critical thinking. The 12th grade students did not show statistically better results in three other tasks that measured socio-scientific decision-making; reasoning their answers about conceptual understanding; and analysing information of the data table and explaining their conclusions.

The highest possible score in the test was 24 points (all totally correct answers with explanations). Results showed that the 10th and 12th grade students had similar total results of all test tasks. In the 12th grade there was a little bit more students who got the highest score in the test than they had received being the 10th grade students (Figure 2).

The shape of the total score histograms shown in Figure 2 suggested that although the content validity of the instrument was relatively low (.65), the test was well-calibrated with respect to the two populations.

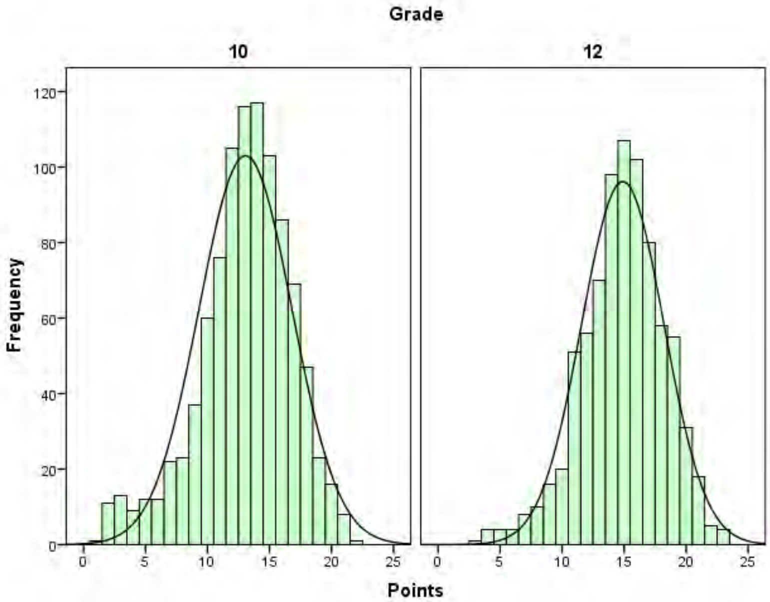

Figure 2. The distribution of students who got different total test score (0–24) of the lactose intolerance test in the 10th and 12th grade.

To get a better overview about the concordance between the complexity of tasks, indicated by the number of students, who got maximum points, and the students' mean achievement levels are presented in Table four:

Table 4. The students' max and min scores in lactose intolerance test through all tasks.

Task	Students' achievement level	Percentage of students scoring max. points (%)	The complexity of tasks according to max scores	Percentage of students scoring min. points (%)
1.	High	59.4	Low	3.5
2.	Medium	25.8	Medium	5.4
3.	Medium	15.8	Medium	6.4
4.	Low	8.6	High	11.1
5.	Low	11.2	High	13.2
6.	Medium	18.9	Medium	5.5
7.	High	70.8	Low	7.2
8.	Low	8.8	High	8.1

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The higher number of students who got maximum points indicated that this task was not complicated for students and the lower number of maximum scores reassured that the task was difficult for students. Based on this the tasks were categorised according to the mean achievement of students in concordance with the complexity of tasks, measured by the number of students scoring maximum points. The number of students scoring minimum points in the test tasks was not so good indicator as there is no direct correlation between the complexity of tasks and achievement level of students, depending evidently on more than one factor (e.g. the familiarity of the task, the bigger social component of task, etc.).

Students' Achievement Levels

Analysis of the lactose intolerance test results (Table 5) showed that students' mean results, as well as the percentage of students not answering to a task, varied highly. Students received the highest points (achievement level was 73.5%) on tasks, which measured students' biological conceptual understanding. These results showed that two tasks (one, seven), measuring biological conceptual understanding in the lactose intolerance context, were answered better than other cognitive components. The results of three tasks (two, three, six), which measured critical thinking and simple problem-solving revealed the students' medium achievement level of 61.1%.

According to the test results, the students' decision-making and reasoning skills were at a low achievement level (45.2 %), meaning that students had a poor appreciation of how to make effective decisions and reason them. Divergent thinking skills, which were assessed through the aspect of fluency (evaluated by the number of different responses of students), were also at a low achievement level. This refers to the case that students are not used to find solutions to unfamiliar tasks that presume to generate different concepts in their biology lessons.

The lowest achievement level (Table 3) for both 10th and 12th grade students (37.6 % and 42.7 %) was obtained by students solving a complex problem (task five) that presumed a profound understanding of the process of digestion and enzymatic decay. This indicates that the students were not able to transform their biology and chemistry knowledge, thus solving a problem in a new situation.

Table 5. 10th and 12th grade students' mean results of biological conceptual understanding and cognitive skills in case of the achievement level of the tasks.

Achievement level	Task	Grade	Mean results of tasks (*SD*)	Level of achievement (%)	Wilcoxon Test *Z*	*p*	Effect size (Cohen's *d*)
High	1; 7	10	2.01 (0.72)	66.9	250281	<.001**	.671*
		12	2.44 (0.55)	81.4			
The difference of means / Level of achievement			0.43	73.5%			
Medium	2; 3; 6	10	1.77 (0.57)	59.1	340445	<.001**	.202*
		12	1.91 (0.80)	63.6			
The difference of means / Level of achievement			0.14	61.1%			
Low	4; 5; 8	10	1.24 (0.57)	41.4	341546	<.001**	.339*
		12	1.43 (0.55)	47.7			
The difference of means / Level of achievement			0.19	45.2%			

*** Significant at the .01 level (two-tailed)*
**Cohen's d > 0.2 shows that the difference is meaningful*

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Discussion

It is widely recognised today that rapid changes are occurring in our world and society. Perhaps most importantly, being able to use our biological content knowledge to solve problems, think creatively and make the decision and reason them are necessary skills in this rapidly changing world. The results of this research showed that before mentioned skills need more attention in the secondary school level. It is important for students to develop a range of skills and knowledge that they can be competent in their daily lives and in their future careers.

Three achievement levels (low, medium, and high) were identified based on the students' biological conceptual understanding and cognitive skills. Based on the results of this research, the decision-making and reasoning skills were at a low achievement level, meaning that students had a poor appreciation of how to make effective decisions and reason them. This is concerning especially previous research, Laius et al., (2015) emphasised that for the different stakeholders' decision-making skills and reasoning skills are important skills to develop for students.

All the more in today's world, searchable information can be found with a few clicks on a computer, but the found information should be interpreted and it is needed to make decisions and reason which information source is trustful and which information is better to use. This research also showed that socio-scientific decision-making with reasoning was more difficult for students than applying biological knowledge, Soobard and Rannikmäe (2015) found similar results in the context of scientific content knowledge. It is important to develop students' socio-scientific decision-making with reasoning because these strategies are also used in teaching and learning to approach students in meaningful understanding and empowering the learned concepts, facts, etc. (Zeidler et al., 2013).

The results of this research show that it is important to develop decision-making and reasoning skills for students and to include more socio-scientific context into learning activities and assessments in biology lessons. It is important that biology lessons should develop students' lower-order skills (e.g. thinking, reading, etc.) and higher-order skills (e.g. decision-making, problem-solving, etc.) at the same time.

Scientific creativity skills that were assessed through the aspect of fluency (evaluated by the number of different responses from students) were also at a low achievement level. This refers to the case that students are not used to finding solutions to unfamiliar tasks that presume to generating different concepts at their lessons. This is problematic as we face unpredictable and novel problems in our daily lives that require urgent solutions. Scientific creativity skills and problem-solving skills are needed to successfully handle various kinds of unfamiliar problems which enhance adaptive behaviours in these new settings (Kashani-Vahida et al., 2017). It can be supposed that students had lower results in the 10th grade because they weren't used to give answers to tasks which had SSI-related context.

The main results showed that despite three years of secondary school biology studies, grade 10 and 12 students exhibited effect size gains in components of cognitive skills. Soobard and Rannikmäe (2015) had similar results when they measured the difference between 10th and 11th grade students' scientific literacy. Students received the highest points of tasks, which measured their conceptual understanding. Students didn't have good results in other tasks. Further research is needed to identify the reasons behind it.

Students received the highest points (level of achievement was 73.5%) of tasks, which measured their biological conceptual understanding. The results showed that the tasks (one, seven) measuring biological conceptual understanding in the lactose intolerance context were answered better than other cognitive components. Results of the tasks (two, three, six), which address critical thinking and simple problem-solving skills showed that students had a medium achievement level (61.1%). It is needed to develop students' problem-solving skills. One way to do that is to use biological knowledge in the problem-solving process (Greiff & Neubert, 2014).

Complex problem-solving (task five) turned out to be very complicated to the 10th and 12th grade students, for the solution it was necessary to understand the nature of digestion and lactose intolerance (task achievement rate was lowest 45.2%).

Altogether, the results of measuring cognitive skills are strongly influenced by the difficulty of content knowledge that is needed for performing the tasks.

Conclusions

The 10th and 12th grade students' achievement levels of their biological conceptual understanding and cognitive skills were distinguished into three achievement levels: high, medium and low achievement levels.

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The results showed that the easiest tasks for both 10th and 12th grade students were tasks one and seven that were assessing biological conceptual understanding.

The results of problem-solving tasks (three, five and six) depended on the complexity of content knowledge needed for solving the problem. The tasks of decision-making (task eight) and scientific creativity (task four) were also very unfamiliar for the students of both 10th and 12th grades. Using integrated biological and chemical content knowledge to solve a complex problem (task five) turned out to be very complicated for most of the students as it needed to understand the process of digestion and physiological nature of lactose intolerance.

After three years of secondary school biology studies, the 12th grade students had significantly better results in five out of the eight tasks than they had received earlier in the 10th grade. They indicated better results in tasks of conceptual understanding, scientific creativity, problem-solving and critical thinking. The 12th grade students did not show statistically better results in three tasks that measured socio-scientific decision-making, explaining and reasoning their problem solving and analysing and explaining the data table information. In the 12th grade there were more students who achieved the highest score in the test than three years before in the 10th grade.

The categorisation of tasks according to the mean achievement levels of students' test results are in concordance with the complexity of tasks, measured by the number of students scoring maximum points. The number of students scoring minimum points in the test tasks is not so good indicator as there is no direct correlation between the complexity of tasks and achievement levels of students.

Recommendations

More SSIs should be used in biology teaching which can affect the students' biological literacy level. More attention should be put on the enhancement of the cognitive skills rather than the students' biological knowledge and to use more complex assessments in the biology lessons.

The results of this research reveal several practical applications worthy of the future research.

Firstly, it would be valuable to investigate more factors impacting the development of the upper secondary school students' biological conceptual understanding and cognitive skills.

Secondly, further investigation is needed to throw light on what contexts are more effective in promoting students' competences during biology studies.

Limitations

As the data for current research represent only one fourth of the larger scientific literacy test, the number of tasks is limited and only one context was used out of four to analyse the students' biological conceptual understanding and cognitive skills.

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Appendix 1.

CODE							

Student Checklist!

1. Read the text in the exercises and the tasks carefully.
2. Answer all the tasks in the test.
3. Some multiple-choice tasks may have more than one correct answer. Where more than one correct answer is expected this will be mentioned in the task.
4. Please answer the tasks using a blue or black pen. Please do not use a correction pen and please do not answer the tasks using a pencil. If you need to make corrections, draw a line through the text that you do not want to be marked.
5. You are not permitted to use additional material when answering the tasks.

Your friend went on an exchange visit to England. In the following summer, he wished to invite the family with whom he had lived to Estonia. The family included triplets, two boys and a girl. While the girl and one of the boys liked to eat cornflakes with milk for breakfast; one of the boys is not able to join them because the milk would cause him to suffer from diarrhoea. The same happens to the mother, who in addition has developed thinning of the bones, or osteoporosis. It seems the diarrhoea is caused by their intolerance to lactose. This is a metabolic disorder, where there is a deficiency in the lactase enzyme that breaks down lactose into glycose and galactose.

Task 1. *Which of the following best describes lactose intolerance?*

a) An inherited disease, in which the milk sugar in the milk causes diarrhoea.
b) An infectious disease that can be caught by drinking milk.
c) An inherited disease where a person cannot drink sour milk.
d) A disorder with a genetic predisposition that results in the development of lactase enzyme deficiency in adulthood.

Task 2. *Lactic acid bacteria catalyst the fermentation of lactose into lactic acid when the resulting sour milk contains much less lactose. With this in mind, it seems the lactose intolerant mother and daughter will be expected to be able to eat cornflakes with which of the following:*

a) boiled milk
b) fresh cream
c) yoghurt
d) fat-free milk

Which if the following is the correct explanation for your earlier answer?

a) The fat from the milk is removed together with the milk sugar.
b) If the percentage of fat is greater than the percentage of milk sugar, then the milk sugar does not affect the metabolism.
c) This is the result of the acidification of milk.
d) The lactase enzyme is added to the product, which breaks down the milk sugar.

Task 3. *Draw a conclusion about how and why the composition of milk changes as a result of the activity of lactic acid bacteria and yeast (during acidification)?*

Content 100 g	**2, 5 % milk**	**2,5% kefir**
Protein	3,3 g	2,9 g
Carbohydrates	4,7 g	4,0 g
Fat	2,5 g	2,5 g
Calcium	120 mg	120 mg

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Content 100 g	**2, 5 % milk**	**2,5% kefir**
Vitamin A, D, E, K	2 mg	2 mg
pH	5,8 – 6,8	4,2 – 4,6
Energy content	54 kcal wrong units Use kJ	50 kcal

Task 4. *What advantages does the retaining of the lactic acid degrading enzyme have on the ageing of people?*
Task 5. *Diagnose of lactose intolerance.*

If someone is suspected to have hypolactasia (or a deficiency in the enzyme that degrades lactic acid), a lactose intolerance diagnostic test (LTT) can be taken. The LTT test is carried out in the morning when the patient has not eaten nor drank for the past 12 hours. The patient is asked to drink a glass of water in which 50g of lactose has been dissolved. The blood sugar level is then measured. The procedure requires three blood tests to be taken:

a) before drinking the lactose solution,
b) 20 minutes after drinking the lactose solution and
c) 40 minutes after drinking the lactose solution

What kind of results would represent lactose intolerance? Explain your answer!
Task 6. *Is the lactose intolerant boy also in danger of frequently developing fractures? Explain your answer!*
Task 7. *Are the triplets in the family invited by your friend identical, or from different eggs?*
Explain your answer!

Task 8. *Almost 25 % of the Estonian population suffers from lactose intolerance. If you owned a restaurant, how would you compile the menu so that it would please all your clients as well as yourself? Give reasons for your choices!*

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