Assessing the biological literacy cognitive components of 10th and 11th grade students

Aveliis Post[a1], Helin Semilarski[a], Anne Laius[a]

[a] *Centre for Science Education, University of Tartu*

Summary

According to the PISA 2006 and 2015 surveys, 15-year-old Estonian students are among the top level of scientific literacy worldwide (PISA 2015 Eesti tulemused, 2016). However, when these students enter university, they fail to show a high level of scientific literacy, and there is little or no impact made on the Estonian economy by these gymnasium graduates (Kübarsepp, 2006; Teichmann & Kübarsepp, 2008; Majandus- ja Kommunikatsiooniministeerium, 2013). A study investigating students' scientific literacy is needed at gymnasium level to discover the reasons why this situation exists.

A future society can be expected to face the huge problem of how to educate young people capable of being able to sustain levels of scientific literacy when solving problems, or making everyday life decisions. Future students must be prepared to work in areas that, as yet, do not exist and work with tools that have yet to be developed (Greiff & Neubert, 2014; Schleicher, 2014). Besides a need for people to be able to use their scientific knowledge when solving problems, and make decisions both at work and at home, there is also a need for developing innovative and creative thinking skills. Linked to this is the need to acquire the ability to adjust and adapt to new situations, people and challenges (Brown et al., 2005; Bybee & Fuchs, 2006; European Commission, 2010; Fensham, 2004; Holbrook, 2014; Ravenscroft et al., 2012).

Stakeholders, including employers, scientists, educators, etc. (Laius et al., 2015a), see scientific literacy, within the workforce, as playing a major role for the future of Estonian society and these skills need to be developed and nurtured at gymnasium level. The current research focuses on the state of the current biological education. Given that all the scientific subjects (physics, chemistry, biology and earth sciences) have conjoined scientific practices and cross cutting concepts and are in line with the New Generation Science Standards (Quinn et al., 2011), each one of them

[1] Centre for Science Education, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia; aveliis.post@ut.ee

maintains specific disciplinary core ideas or subject knowledge. When considering the above-mentioned situation, the term biological literacy is coined in place of scientific literacy to stress a focus on teaching and learning within biology lessons.

In striving to determine the biological literacy levels of students, this study focuses on a context of lactose intolerance. It devises an instrument for measuring biological literacy within 4 cognitive components, of which only the biological content knowledge is specific to biology and the other 3 cognitive components (problem solving, decision making and reasoning and creative thinking skills, measured as divergent thinking fluency) are mutual to both biological literacy and scientific literacy.

Lactose intolerance, which affects some 25% of the Estonian population, is chosen as a context, because the topic has gained much attention in the country and public awareness of the context has risen among the population. The number of lactose free dairy products has also increased in recent years (Ida-Tallinna Keskhaigla, 2009; Lember et al., 2007; Tervise Arengu Instituut, 2016).

The goal of biology education according to the new Estonian National Curriculum (2011) is to enhance biological literacy so that by the end of their compulsory education students are expected to be able to apply biological knowledge to new contexts. The aim of this study is to use a context-based instrument to measure 10th and 11th grade students' biological literacy through 4 cognitive components: biological knowledge; problem solving; decision making and reasoning, and the fluency aspect of the scientific creativity (afterwards simply referred to as scientific creativity). The study also aimed to determine differences in achievement levels between certain factors, such as the gender and age of the students. The preliminary results, based on descriptive statistics, are as presented at the international conference – *Global Conference on Contemporary Issues in Education* (Laius et al., 2015b).

These four cognitive components of biological literacy were selected for assessment to meet the needs of the Estonian labour market according to the opinions of Estonian stakeholders, which were revealed from a study conducted by Laius and co-authors (Laius et al., 2016). The National Gymnasium Curriculum and school biology textbooks were analysed to ensure that the prerequisite biological background could be expected to enable students to effectively complete the biological literacy test tasks in the context of lactose intolerance.

For a more in-depth analysis of this research, the following 3 research questions are posed:

1. What is the status of gymnasium students' biological literacy measured within a scenario of lactose intolerance, determined from the following four cognitive components: biological knowledge, problem-solving, decision-making and reasoning and creativity skills?
2. What are the differences in biological literacy among 10th and 11th grade students associated with the following four cognitive components: biological knowledge, problem-solving, decision-making and reasoning, and creativity skills?
3. Do gender differences occur in biological literacy based on the following four cognitive components (biological knowledge, problem-solving, decision-making and reasoning and creativity skills)?

The sample for this study, taken from 44 Estonian gymnasiums, consisted of 1116 grade 10 students (598 girls and 518 boys) and 932 grade 11 students (498 girls and 434 boys), amounting to a total of 2048 students (1096 female and 952 male students).

The validity of the instrument was determined by piloting the test with 35, 10th grade students and using three independent experts (two science education researchers and one experienced biology teacher who validated the relevance of the tasks in the test). The reliability measure for internal coherence (Cronbach $\alpha = 0.63$) of the instrument indicated that the instrument is sufficiently robust (Loewenthal, 2004) considering the low number of tasks (8) used in the instrument.

The reliability of the study was achieved by using a representative sample, while content reliability was provided by coding the test results from two different biology teachers, with another two experts who approved the coding criteria. Cronbach α was used to measure the internal consistency of the biological literacy test. A Chi-square test was used to determine the significance of the sampling distribution of the achievement level groups (for all three groups p=0.000).

The data was analysed using the programme IBM SPSS 22. In addition to descriptive statistics, the non-parametric tests of Mann-Whitney and Kruskall-Wallis were used to measure the significance between investigated samples. The effect size (Cohen's d) was used to indicate the magnitude of the difference between groups (Cohen, 1988).

Students' answers were coded using a 4-point scale. The mean results were expressed as a percentage of the maximum result and then grouped, based on achievement rates at three hierarchical levels (high achievement level 70% and above; medium achievement level 51–69%; low achievement level 50% and below). These levels were chosen, based on the assessment criteria of the Estonian Curriculum.

The results show that the tasks measuring biological content knowledge in the lactose intolerance context (high achievement level) were answered better than the other cognitive components, in line with the results from PISA 2015 (PISA 2015 Eesti tulemused, 2016). This indicates that students' biological knowledge is at a mean achievement level of 78% and this cognitive component of biological literacy has developed more than the other cognitive components during gymnasium studies.

Results of the tasks addressing problem-solving skills showed that students had a mean achievement level of 66%, which is less than the level of expectation expressed by Estonian stakeholders (Laius et al., 2015a; Laius et al., 2016).

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. Good decision making and reasoning skills are highly valued competencies that Estonian stakeholders expect from graduating students (Laius et al., 2015a; Laius et al., 2016).

Scientific creativity skills which 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 generating different ideas at their lessons.

The lowest achievement rate (44%) was obtained by students solving a complicated scientific problem (task 5) that presumed a profound understanding of the process of digestion and enzymatic decay. This indicates that the students are not able to transform their biology and chemistry knowledge, thus solving a problem in new situation.

The comparative results of the 10th and 11th grade students indicate that the measured cognitive components of biological literacy do not differ significantly between the 10th and 11th grade students during the two years of gymnasium studies. Girls from 10th and 11th grade perform statistically significantly better than boys (in both grades) based on four of the tasks, but the effect size (Cohen's d<0.2) shows that due to the large sample the difference is not meaningful.

In conclusion, the results indicate that different cognitive components of biological literacy can be measured by creating a context-based test such as that based on lactose intolerance. The comparison between 10th and 11th grade do not show significant difference in the results. Despite an extra year of studies in 11th grade, the results in comparison with their earlier 10th grade results do not show a significant increase during 2 years of gymnasium biology studies.

The results of this study provide a foundation for devising a further action plan for developing gymnasium students' cognitive components of biological literacy. The authors of the study suggest the development of a model for a teacher in-service training course that concentrates on the four cognitive components addressed in the study, with a special focus on creative problem-solving, decision-making and reasoning skills all components having low levels of achievement.

Keywords: biological literacy, context-based assessment, lactose intolerance, gymnasium students