EVALUATION OF SCIENCE AND TECHNOLOGY AREA FIRST YEAR STUDENT LEARNING OUTCOMES

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Abstract. The research proves that the first year students lack independent learning skills and they have insufficient prior knowledge in science subjects and mathematics. It is especially important to solve this problem when educating the prospective specialists of the science and technology area.The need to develop young adults' creative thinking skills is also topical. The effectiveness of the laboratory works in chemistry of the future biologists and optometry specialists was researched implementing the learning outcomes-based approach. The aim of the research is to find out how the depth of cognitive learning affects the first year students' learning. The research is focused on students' constructivist learning and the development of their logic-mathematical thinking. Tests checking the students' knowledge were developed applying a modified Bloom's taxonomy. These tests were used to check the students' knowledge and skills after doing the laboratory work. The research participants were 74 biology and optometry first year students. The test results provide a feedback for students and thus create a possibility to adjust the teaching-learning process. SPSS programme was used for statistic processing of the research findings. It can be concluded that only one third of the students are able to demonstrate the skill to analyse and evaluate attaining the learning outcomes that correspond to the university requirements. Questions of logic-mathematical character, noticing the causes of possible mistakes and evaluation of one's own work create the main difficulties for students. Learning outcomes are closely connected with the depth of the students' cognitive activity, as it is proved by statistically significant differences among high performing, middle performing and low performing students.

Key words: science and technology education, learning outcomes, tests, cognitive depth.

Introduction

The rapid development of technologies, the changing economic conditions, globalisation trends in the sustainability oriented development of the society make it necessary to pay particular attention to the real knowledge, skills and competencies gained by the person [1;2]. Global changes that often are called the advance of the 21st century skills (e.g., creativity, critical thinking, cooperation and others) help move education institutions closer to such models of learning that prepare young people better for successful learning, employment and life. Implementing a new transdisciplinary area that is connected with the exploration of the whole learning process, researchers stress that more complex studies that would emphasize the common regularities of the ideas drawn from education science and neuroscience are needed [3;4].

Thus, the increase of the importance of implementing the education process that is based on the students' learning outcomes becomes very topical in European countries, including Latvia. Learning outcomes are statements about what the student knows, understands and is able to perform after a certain stage of learning [1]. The formation of the learning outcomes-based approach is based on several theoretical stances – the taxonomy of the aims of education, learning theories – behaviourism, constructivism as well as the learner-centred approach in education. It has to be mentioned that implementing a learner-centred education the role of marks in the teaching/learning process change considerably, i.e., marks show the degree to which the learners have attained the intended learning outcomes. Thus, an objective measurement of the education results is concrete learning outcomes that the learners are able to demonstrate [5]. In order to describe the levels of the learning outcomes, i.e. to reflect the learners' achievement in increasing sequence, practitioners most frequently apply B. Bloom's taxonomy in education. B. Bloom's taxonomy of educational aims or classification is oriented towards the person's cognitive sphere; it consists of six hierarchical levels and describes the learners' cognitive activities in an increasing sequence of complexity starting with memorization of facts and finishing with the analysis of problem situations [6]. The application of this taxonomy in the process of acquiring chemistry is significant for the current study.

Several studies indicate that natural sciences, which are one of the greatest achievements of the culture of the Western society, are unable to attract the interest of young people [7], although they have a substantial role in many issues related to the development of modern society [8]. It is possible that it is due to the fact that natural sciences are usually associated with theoretical and experimental

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science and complex processes that take place in nature, scientific terms, and the structure of topics that is logical and hierarchically arranged, many multi-functional concepts that are hard to understand. Actually, as a science it is by nature a highly complex and abstract subject matter area [9] and knowledge based on applying the scientific method [10]. The laboratory works that usually are the core part of science courses ensure the application of the scientific method [11], and in them students actually perform observations, tests and experiments as part of their study of science [12]. Laboratory works increase students' interest and help them learn actively by seeing, observing and doing [13], thus developing their higher order cognitive skills: critical thinking, problem solving, application, analysis, synthesis, evaluation, decision making, creativity [12] in order to be able to deal independently with science [14].

At school, too, the learning process is more oriented to the acquisition of lower cognitive levels. This is proved also by the data of the PISA study showing that the number of learners reaching the higher levels of cognitive activity (Level 5 and 6) in Latvia is 3.6 % and 0.3 %, while the average indicator of OECD is 7.2 % and 1.1 % respectively [15]. It is permissible that the low indicators of Latvia can be explained by the fact that national tests in science are mainly intended to measure the reproductive results of the learners' activity. This means that it is more and more necessary to develop the 21st century skills, developing the deep learning approach [16]. The development of the deep learning approach coincides with the latest trends in the modernization of education, especially emphasizing the students' learning on the individual level using the personal experience and active involvement. Several studies underline that it is necessary to orient towards deep learning that is connected with the development of students' critical thinking skills and comprehensive understanding of ideas, not on the surface learning with uncritical and unreflective approach to the information that has to be acquired concentrating primarily on rote memorization [17].

Critical and systemic thinking, the ability to analyse and evaluate, comprehensive and profound knowledge, ability to apply them creatively depending on the situation and the problem task, lifelong self-directed or motivated learning competency are the necessary qualities for the pre-service and in-service specialists in any sphere of employment, which largely points to their competitiveness [18; 19].

Recent studies prove that the first year students of the science area at the University of Latvia have rather high assessment in science subjects when they enrol and they adapt well in the learning environment of the university. However, the considerably large amount of information to be processed at the university requires certain skills of independent work that causes problems to a part of students. These are the students, whose cognition is based on fragmentary knowledge, who do not delve into the theme to be acquired in order to understand the causal relations and regularities [20].

One of the general comprehensive subjects that all first year science students have to acquire at the University of Latvia is General Chemistry. During the semester they have to do regular tests, including tests on laboratory works. The present study uses laboratory works, the performance of which require diverse knowledge and skills, to judge about the learning outcomes of the first year students, thus the analysis of the assessments of the laboratory works can give valuable information for the improvement of the teaching/learning process.

Research questions are the following.

- How do the learning outcomes of the first year students correspond to the university requirements?
- What is the impact of the depth of cognitive activity on the learning outcomes?

Materials and methods

Science education in the university is focused on constructivist learning and development of logic mathematical intellect.

The study uses the laboratory works in general chemistry that students perform during the 1st semester. Knowledge tests that are designed in correspondence with the learning outcomes of the respective course are used to assess the laboratory works [21]. The tests used multiple choice questions with four possible answers; they include questions about the theoretical justification of the laboratory work, the run of the work, the performed calculations and the obtained results. The total number of questions was 39, the maximum assessment of each question was 1 point.

In order to assess the depth of the cognitive activity, Bloom's taxonomy of the cognition process [6] and its two-dimensional model [22] were used as a basis. The model is modified adjusting it to the assessment of the laboratory works. Five cognitive levels of Bloom's taxonomy were used: remembering, understanding, application, analysis and evaluation. Three dimensions of knowledge are singled out:

- Knowledge of facts (theoretical justification of the laboratory work, basic principles);
- Procedural knowledge (run of work, method, technique);
- Logically mathematical knowledge (connections, formulas, calculations).

Students did the tests electronically after having performed the laboratory work in Moodle environment. The total number of students was 74, 54 (73 %) of them are the 1st year biology students and 20 (27 %) – 1st year optometrists. The study includes the results of the tests of the students', who did not leave their studies after the 1st semester.

The students were classified into three groups (A, B, and C) according to their performance in the first study semester. Group A ("high performing" students) consisted of students with assessment 8-10 on 10-point scale. Group B ("medium performing" students) – assessment 6-7 and Group C ("low performing" students) – assessment 4-5.

The reliability (inter-item consistency) of the test questions according to the Cronbach's alpha coefficient was 0.76. Applying the One sample Kolmogorov-Smirnov test, it was stated that the set of the questions corresponded to the normal distribution. The obtained qualitative data were processed with the SPSS program.

Results and discussion

Laboratory works are a significant part of the general chemistry course that allows getting acquainted with the chemical processes in practical action, thus gaining useful knowledge for more general and deeper acquisition of the chosen speciality.

Assessments obtained in the tests of laboratory works prove that in general students have passed the laboratory works well (average mark $M = 6.9$). The distribution of assessment shows that students' achievement is rather different. The connection that, if the cognitive level increases, the assessment gradually decreases, is well seen (Table 1). Higher assessment goes together with the test questions that correspond to the lowest cognitive level – remembering and the questions that correspond to the highest cognitive level – evaluation - have received the lowest assessment.

Table 1

Distribution of assessment corresponding to knowledge dimensions and levels of cognitive activity

Knowledge dimensions	Level 1 Remember	Level 2 Understand	Level 3 Apply	Level 4 Analyze	Level 5 Evaluate
Knowledge of facts	**M = 0.70** SD = 0.37	**M = 0.46** SD = 0.50	-	-	**M = 0.42** SD = 0.39
Procedural knowledge	**M = 0.80** SD = 0.35	**M = 0.72** SD = 0.32	**M = 0.70** SD = 0.48	**M = 0.67** SD = 0.43	**M = 0.56** SD = 0.37
Logical mathematical knowledge	**M = 0.84** SD = 0.33	**M = 0.83** SD = 0.38	**M = 0.66** SD = 0.34	-	-

Note: M – average mark, $0 \leq M \leq 1$; SD – standard deviation

The students have a comparatively poor understanding of facts ($M = 0.46$) and the skill to evaluate the facts connected with the laboratory work ($M = 0.42$). For instance, in the work "Determination enthalpy of dissolution" students know the definition of enthalpy of dissolution, but it is hard for them to understand it. There is relatively higher assessment for the knowledge that students have used or gained during the laboratory work, including the logical mathematical knowledge that is necessary for calculating and assessing the results of the laboratory work. Thus, comparing the dimensions of knowledge, it is possible to judge that students assess insufficiently the theoretical knowledge they had to acquire before starting the laboratory work. However, practical cognitive activity is more motivating and thus considerably more productive.

To evaluate the knowledge more precisely, the students were divided into three groups – A, B and C. Each group had the following average assessment about one question in the tests on the laboratory work: $M_A = 8.1$, $M_B = 0.68$, $M_C = 0.61$. The *t*-test shows that there are statistically significant differences among all groups. The groups have different assessment both regarding the dimension of knowledge and the cognitive levels, the *t*-test results are summarized in Tables 2 and 3.

Table 2

Comparison of groups according to dimensions of knowledge

Knowledge dimensions	Groups to be compared	*t*	*df*	*p*	Groups to be compared	*t*	*df*	*p*
Knowledge of facts	A and C	-4.94	40	< .01	B and C	-3.83	46	< .01
Procedural knowledge		-6.19	39	< .01		-4.54	45	< .01
Logical mathematical knowledge		-4.88	41	< .01		-2.90	46	< .01

Table 3

Comparison of groups according to cognitive levels

Cognitive level	Groups to be compared	*t*	*df*	*p*	Groups to be compared	*t*	*df*	*p*
Remember	A and C	-2.96	40	< .01	B and C	-2.56	46	.01
Understand		-5.36	28	< .01		-3.97	32	< .01
Apply		-6.30	41	< .01		-2.79	46	.08
Analyse		-6.46	41	< .01		-5.54	46	< .01
Evaluate		-3.16	40	< .01		-2.03	45	.05

In order to find out whether there exists a connection between separate dimensions of knowledge, the analysis of correlations was carried out. In the case of the high performing students (Group A), knowledge of facts correlate well with procedural knowledge, $r\,(19) = .58$, $p = .01$ and also with logically mathematical knowledge, $r\,(19) = .61$, $p = .01$. There is no correlation between dimensions for the students with medium performance (group B). In the case of the low performing students, knowledge of facts and logically mathematical knowledge correlate well, $r\,(25) = .46$, $p = .01$, but there are no other correlations. It can be concluded that co-linked knowledge develops for the high performing students, while the knowledge of the B and C groups is more or less fragmentary.

The analysis of correlations for the comparison of knowledge according to the cognitive levels also shows significant differences. Average indicators of the tests are summarized in Table 4 and they show that in general there exists a correlation among the levels, except the highest level that describes the skill to evaluate the outcome of the work and the possible causes of mistakes. It allows judging that the evaluation of results presents difficulties to the first year students.

Table 4

Correlations among cognitive levels

	Level 1 Remember	Level 2 Understand	Level 3 Apply	Level 4 Analyse	Level 5 Evaluate
Remember	1	.48**	.30*	0.36**	.17
Understand	-	1	.32*	.49**	.25
Apply	-	-	1	.36**	.11
Analyse	-	-	-	1	.18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Considering the connection among the cognitive levels for each group of students separately, it is seen that there are some features in which the learning skills of the A, B and C group students differ significantly. Only the best students show strong positive correlation between level 2 and 3, $r\,(19) = .55$, $p = .05$. The correlation for the middle group among these two levels is negative, $r\,(27) = -.50$, p = .05, besides, there is no correlation among the other cognitive levels. This proves that the knowledge of the B group students is unstable and there does not develop a true understanding about the performed laboratory work. A strong correlation between level 1 and 3 describes the group of low performing students, $r\,(25)$, $p = .01$. This points to certain diligence; however, these students form their knowledge based on mainly remembering (formal learning). Taking into consideration that the students, who due to different reasons dropped out of studies, were not included in the study, these "weak" students can be described as persistent and purposeful, who need to pay more attention to the development of analytical thinking skills. It means that in higher education we should think about laboratory work as structuring student learning for assisting students in reaching the desired levels of skills at the higher levels of Bloom's taxonomy [23]. Student motivation, study methods and the teaching strategy influence student's selection of approaches to learning [17]. If laboratory work is made more with orientation to inquiry-based learning, it can be more effective than other, more expository instructional approaches [24]. The application of knowledge can improve students' higher-order thinking. Therefore, the student applied theory they learned to an unaccustomed situation with a range of planned instructions by doing so, students' higher-order thinking can be stimulated [25].

Conclusions

In general, the learning outcomes of the first year students show that the students have a positive attitude to learning as well as purposefulness and awareness of the aims of their studies. However, not all students have sufficiently developed learning skills. The evaluation of the results of laboratory works prove that the learning outcomes of only one third of the first year students correspond fully to the university requirements confirming the presence of constructivist learning and a good enough skill of logical mathematical thinking. The reason for the lack of these skills intrinsically important for science spheres, what is characteristic of the first year students, could be the dominant learning style, which develops only the cognitive dimension of mechanic acquisition of the information and its reproduction.

The research problem of the depth of students' cognitive activity in the teaching and learning process is connected with the areas of science education and cognitive psychology and mark the necessity to expand a multidisciplinary view in further studies.

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