DOI: 10.22616/REEP.2021.14.004

Trends in STEM Teaching and Learning within the Context of National Education Reform

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Abstract: STEM (science, technology, engineering, and mathematics) education nowadays is considered priority. To implement it successfully, students must acquire not only STEM "hard" skills, but also "soft" skills, therefore the choice of teaching/learning methods is essential. Problem-based (PrBL) and project-based learning (PjBL) aim both at the acquisition of science content using real life examples and the improvement of IT skills, critical thinking, decision-making, civil responsibility and cooperation skills. The aim of the research is to find out the use of PrBL and PjBL in the teaching/ learning of STEM in the context of national reform of Latvia. The design of mixed methods was used in the research. The correlative research was performed using *QuestionPro* e-platform and surveyed 128 STEM teachers and 257 secondary school students to collect quantitative data. As Latvia now is implementing the education reform, the case study for qualitative and quantitative analysis has been carried out using the AQUAD data processing programme and researching the secondary education biology basic course curriculum. This research identified that it was advisable to use practical cases, real everyday examples and project work that would increase students' interest in science subjects to enable them to solve problems creatively by integrating the content of all STEM subjects. The biology curriculum mainly stresses students' reproductive than productive work with information, the development of critical thinking by participating in discussions and cooperating, while not enough attention was paid to the use of problem solving in the teaching/ learning process and the implementation of the interdisciplinary project. The use of sensors, practical laboratory works and field study as specific methods of biology are little represented in the curriculum, which is a serious disadvantage. This means that the basic curriculum of biology in the context of national education reform is more oriented to the acquisition of transversal skills, not the development of competent science literacy.

Keywords: basic curriculum of biology, problem-based learning, project-based learning, STEM, school.

Introduction

Since September 1, 2020, schools of Latvia have been gradually implementing the new contents and approaches according to the new basic and secondary education standards (National Reforms…, 2020) which are developed by the National Centre for Education, Republic of Latvia, in the project "Competence-based approach in the teaching/learning contents" and implemented by Skola 2030. The aim of the project is to work out, approbate, and introduce sequentially such content and approach to general education in Latvia that would provide all students from preschool to secondary school graduates with knowledge, skills and attitudes necessary for the life of today (Skola2030, 2020).

At present, there are two approaches in implementing STEM in Latvia – the old and the new. The integrated course of science is taught in schools with the humanitarian direction, while usually each subject of STEM is taught separately in general comprehensive schools. There might be a situation in schools specializing in science/mathematics when one or two STEM subjects are taught at the advanced level. According to the new national education reform schools will choose the teaching/learning domains and which subjects will be taught on the advanced level. The new standard for general upper secondary education will offer three levels of curriculum (general, basic and advanced level). Approximately 70% of the time spent on acquiring the curriculum will be spent on compulsory content, while approximately 30% will be offered according to a future career path/educational pathway of the student (National Reforms…, 2020).

The education reform in Latvia is justified by the perception that children nowadays must learn to live in the continuously changing world and in the future, they should be ready to create an economic, political, social and culture environment not experienced before. At present, Latvian students can do very well those tasks that require memorization or action in well-known situations, but they lack skills and experience to investigate and process multifunctional data, work in a team, offer solutions to non-standard situations, create relations between theoretically acquired and real-life experiences, analyse the completed and set aims for future tasks (Skola2030, 2020). The vision of education activates the context of 21st century skills such as soft skills and hard skills 1) transversal skills which are not directly connected to a specific domain but are important in many spheres; 2) multidimensional which incorporate knowledge, skills and attitudes and 3) are related to skills of higher level and behaviour that reflects the ability to deal with complex problems and unpredictable situations (Voogt, Roblin, 2012).

The National education reform is implemented to introduce innovations in four aspects of the science domain: (1) teachers' mutual cooperation in the implementation of interdisciplinary themes; (2) the use of information and communication technologies as a platform for developing problem solving and reasoning; (3) experimental learning, focussing on the process of discovery, is connected with the development of students' inquiry skills that are developed through practical activities, experimenting, modelling and searching for regularities; (4) discussion-based teaching: involvement in discussions and other activities for making socially responsible decisions (Andersone, 2020).

As defined in the basic course of *Biology I* curriculum (Bioloģija I…, 2020), students are offered different forms of organizing the study process: discussions, case studies, inquiry projects and practical works to develop the student's understanding about the processes in nature and society, the interaction of nature and society as well as to consolidate problem solving and communication skills. To attain the learning outcomes of the basic course which incorporate complex inquiry skills, including the skill to use IT tools (e.g., data processing, work with sensors, data storage, and different communication platforms) it is advisable to organise the work with computers.

To find out students' readiness for the changes anticipated in the reform, a case study on the implementation of problem-based and project-based learning was performed. The choice of these teaching/learning methods was defined by that fact that they could reveal most students' learning of STEM in the context of the national education reform, including student-teacher interdisciplinary cooperation, the use of information in problem solving and discussions for making socially responsible decisions and for demonstrating complex inquiry skills. Both these terms even have a common abbreviation PBL (problem-based learning and project-based learning) although their nature is slightly different. To distinguish the terms the authors use two abbreviations PrBL – problem-based learning and PjBl – project-based learning.

Many researchers believe that STEM promotes students' skills in problem-solving, critical thinking, collaboration, leadership, self-directed learning, communication, creativity and innovation, as well as analytical thinking, real environment and conditions (Asghar et al., 2013; Capraro, Capraro, Morgan, 2013). Using project-based learning can be an effective way to engage students in learning STEM and provide them with the basic skills they need to master STEM professions (LaForce, Noble, Blackwell, 2017). L.J. Berk, S.L. Muret-Wagstaff, R. Goyal, J.A. Joyal, J.A. Gordon, R. Faux and N.E. Oriol (2014) found that students who used PjBL in their learning had a more positive attitude towards STEM and were more likely to choose a career related to STEM.

One study of PjBL found that projects increase students' interest in STEM because they engage students in solving authentic real-life problems, collaborating with others, and producing concrete end products (Fortus et al., 2005). This will help students understand the relationship between circumstances and consequences. In addition, students will be able to answer questions such as, "Why do I have to learn this?" and "Where will I ever use it?" because the projects are real, engaging for the student and knowledge-based. The outcome of PjBL is projects that are authentic and include real life problem-solving and 21st century skills, students have the opportunity to see the connections between what is taught in the classroom and the application of such knowledge in real conditions (LaForce, Noble, Blackwell, 2017; Sahin, 2015). A recent study exploring the relationship including STEM high school students' perceptions of PjBL and their interest in STEM subjects and careers found that students' higher project-based learning scores are associated with greater interest in STEM subjects and careers. It means that PjBL as a teaching tool provides critical learning opportunities for students to develop an interest in STEM (LaForce, Noble, Blackwell, 2017).

Meaning "Project-based learning" is broader than "Problem-based learning", and often is composed of several problems that students will need to solve (Capraro, Capraro, Morgan, 2013; Siew, Amir, Chong, 2015). PrBL is a student-centred approach that enables learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a solution to a defined problem, as well as to develop collaboration skills and intrinsic motivation (Hmelo-Silver, 2004; English, Kitsantas, 2013; Savery, 2006, 2015). PrBL and PjBL are two different approaches and people mistakenly assume them to be the same although they have a lot of similarities. PrBL approach is driven by the problem that is encountered by students and focuses on research and inquiry, whereas the PjBL approach is driven by the end product that students want to produce and the main focus is laid on the whole process of production. PrBL begins with a problem and that problem becomes the main focus in PrBL from which every progress, plan and work done by students in PrBL is directed towards solving the problems. On the other hand, PjBL begins with an assignment to carry out one or more tasks that lead to the production of a final product.

In any case, both these teaching methods in STEM learning are a challenge for students: they must think critically and analytically to develop higher-order thinking skills; it motivates their self-directed learning; they are interested in getting involved in science research; solving meaningful problems of the real world, linking theory with practice; creating cross-curricular connections and collaborating with classmates.

The aim of the study is to find out the use of problem-based and project-based learning in the teaching/learning process of STEM in the context of the national education reform.

Methodology

To reach the aim of the study two research questions were set:

1. How does the use of problem-based and project-based learning influence student's STEM learning?
2. How is problem-based and project-based learning integrated in the curriculum of the basic course of biology in the context of the national secondary education reform?

Research design. The design of mixed methods was used in the correlative research for gathering and processing quantitative and qualitative data. Results obtained from the questionnaire were analysed using the data processing SPSS 24.0 program, a method of non-parametric data processing – Spearman rank correlation analysis based on the discrepancy of the empirical distribution of data with the normal ($p = .000$). Qualitative data were analysed with AQUAD 7.0 program by coding the data, defining their frequency and creating linkages. Two adapted questionnaires of the ERASMUS+ project "International Diploma for School Teachers in STEM Education (eSTEM)" – one for teachers and the other for students – were used for data collection in the quantitative part of the study.

The data were obtained using open-closed questions on a 5-point Likert scale (1 – strongly disagree, 2 – disagree, 3 – neither agree nor disagree, 4 – agree, 5 – strongly agree) in the online platform of *QuestionPro*. The survey was structured in two parts: general and conceptual. The general part of the survey characterized respondents: teachers and students and the conceptual part used questions based on the theoretical ideas of the problem and project-based learning (Asghar et al., 2013; Capraro, Capraro, Morgan, 2013; Capraro, Capraro, Morgan, 2013; Fortus et al., 2005; LaForce, Noble, Blackwell, 2017; Sahin, 2015; Savery, 2006, 2015). Indicators describing PrBL and PjBL were developed. The Cronbach's alpha test on the scale of checking the credibility ($\alpha = 81$) proves a good internal consistency.

The research involved 128 teachers of whom there were female (n = 110) and male (n = 18) participants aged 20 to >70 years and 257 students, female (n = 161) and male (n = 96) who attended Grade 10 (n = 97), Grade 11 (n = 112) and Grade 12 (n = 48).

The secondary education basic curriculum in Biology was analysed in the qualitative part of the study. This program was chosen because the previous standard, still in force in secondary education, envisaged the same number of lessons (210) for all subjects: biology, chemistry and physics but the conception of the new standard envisages a twice smaller number of lessons for biology (to compare: physics – 245 and chemistry – 210 lessons) (Regulations Regarding…, 2019). The code system rests on problem-based and project-based learning in the context of innovation in national education reform. The data analysis uses themes of the teaching/learning program as profile codes but the conceptual codes describe problem- and project-based learning, the integration of interdisciplinary themes, discussion, experiential learning emphasizing the process of discovery experience or learning by doing, technologies, laboratory works and modelling as well as transversal skills – information literacy, critical thinking, problem solving, mathematical literacy and collaboration.

The study design is presented in Figure 1.

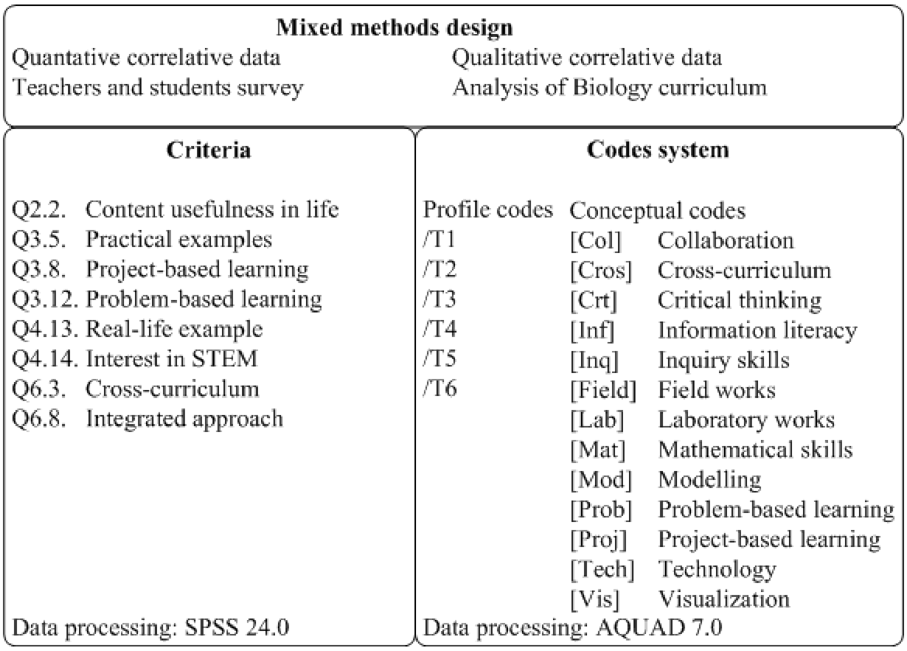

Figure 1. Study design.

Explanation of abbreviations: T denotes topics of the Biology Curriculum

T1. Environment and evolutionary changes of organisms (24 hours)
T2. Reproduction of cells (16 hours)
T3. Secrets of DNS (18 hours)
T4. Inheritance of features (10 hours)
T5. Immunity of the organism (15 hours)
T6. Functioning of the cell and organism (22 hours)

Results and Discussion

1. Findings of quantitative correlative study

The correlative study found out the mutual interconnection between students and teachers' opinions about problem-based and project-based learning and teaching.

1.1. Teachers and students' views on the impact of PrBL and PjBL on the teaching and learning of STEM

The results of Spearman's correlation analysis prove that for students the solution of creative problems using the appropriate content and skills related to all four areas of science subjects (Q16.3 – a question for teachers, N = 128) correlated statistically significantly with the use of project work in the acquisition of the content (Q3.8, r (257) = .77, p <.001; M = 3.25; SD = 0.96), the use of practical, concrete everyday examples in lessons (Q3.5, r(257)= .75, p < .001; M = 3.29; SD = 0.96), the solution of real life problems, verifying them, making decisions and applying them (Q4.13, r(257) = .73, p < .001; M = 3.38; SD = 0.97), student's interest (Q4.14, r(257) = .70, p < .001; M = 3.23; SD = 1.01) and the use of the integrated approach in assessing the use of problem situations and projects (Q6.8, r(257)= .69, p < .001; M = 3.15; SD = 0.87). (Table 1).

Table 1

Teachers and students' opinions about the creative solution of problems using the appropriate content and skills from all four STEM areas

Criteria	Spearman's rank correlation coefficient *r* (*p* < .001)				
	Q3.5.	**Q3.8.**	**Q4.13**	**Q4.14**	**Q 6.8**
Q16.3	.75	.77	.73	.70	.69

Thus, students admit that to learn creatively, it is necessary to use the respective content and skills from all four areas of the science subjects, based on the use and integration of practical, real life examples in project-based and problem-based learning, thus increasing students' interest in STEM subjects.

The above-mentioned correlations show that as indicated in *Biology I* curriculum (Bioloģija I…, 2020), it is important for the student to deepen the understanding about the processes in nature and society, the interaction between nature and man, and to apply in an integrated way the problem-based and project-based learning, focusing on real life examples in the acquisition of the content.

1.2. Students' opinions about the impact of PrBL and PjBL teaching and learning of STEM

As presented in Table 2, there is a close positive reciprocal correlation between project-based learning (Q3.8, $r(257) = .83$, $p < .001$; $M = 3.25$; $SD = 0.96$) and problem-based learning (Q3.12, $r(257) = .83$, $p < .001$; $M = 3.53$; $SD = 0.83$) in acquiring STEM teaching/learning content. In students' responses, project-based learning (Q 3.8) positively closely correlated with the applicability of teaching/learning content in everyday life (Q2.2, $r(257) = .76$, $p < .001$; $M = 3.98$; $SD = 0.97$), the use of practical examples (Q3.5, $r(257) = .73$, $p < .001$; $M = 3.29$; $SD = 0.96$), the solution of real life problems, their verification and decision making in lessons to expand student's knowledge about science and mathematics (Q4.13, $r(257) = .84$, $p < .001$; $M = 3.38$; $SD = 0.97$) as well as with increasing students' interest (Q4.14, $r(257) = .77$, $p < .001$; $M = 3.23$; $SD = 1.01$) and with using the integrated approach in assessing problem situations (Q6.8, $r(257) = .75$, $p < .001$; $M = 3.15$; $SD = 0.87$). The arithmetic mean (M) is above the mean value on the 5-point Likert scale; the standard deviation (SD), too, shows some dispersion of the data, thus, it means that students' responses are rather similar. An analogical situation is seen in problem-based learning (Q3.12).

Table 2

Interconnection of students' responses to questions about project-based and problem-based learning

Criteria	**Spearman's rank correlation coefficient *r*** ($p < .001$)					
	Q 2.2.	**Q 3.5.**	**Q 3.8.**	**Q 3.12.**	**Q 4.13.**	**Q 4.14.**
Q 3.5.	.81					
Q 3.8.	.76	.73				
Q 3.12.	.69	.80	.83			
Q 4.13.	.70	.82	.84	.69		
Q 4.14.	.70	.72	.77	.77	.79	
Q 6.8.	.82	.85	.75	.80	.71	.83

Thus, teachers and students assess positively the use of project-based and problem-based learning in the acquisition of STEM because the use of practical real-life examples increases their interest in learning STEM and gives a possibility to acquire these subjects in an integrated way. J.M. Ritz and S.C. Fan (2015) consider that knowledge acquired in STEM subjects is most useful in everyday life. It is especially important to use real life examples in the acquisition of STEM (Capraro, Capraro, Morgan, 2013; LaForce, Noble, Blackwell, 2017; Sahin, 2015). Project-based and problem-based learning are suggested as one of the best pedagogical approaches for their integration in the teaching/learning process (Nistor et al., 2018).

2. Findings of the qualitative study

Analysing the curriculum of the basic biology course, its content was coded according to the codes indicated in the methodology, the frequency of the used codes was identified and then using the choice of the linkage construction, the reciprocal connections between the used codes in the analysed fragments of texts were determined.

2.1. Usage of problem- and project-based learning in the biology curriculum in the context of national reform

As seen in Table 3, the curriculum places the greatest focus on the development of critical thinking for formulating one's personal opinion, discussing it based on arguments and mutually collaborating. Gaining information is more directed to its search, e.g., students search for information, get acquainted with information and its sources, obtain information, and update it, not on the evaluation of the information: evaluate, analyse, substantiate and judge. Yet, it is not clear what searching for information in reliable sources means. These data, to a certain extent, coincide with the conclusions drawn by R. Andersone and I. Helmane about media literacy in the basic school curriculum stating that "finishing

Grade 6 the skills to find information in different sources and to analyse the found information are developed purposefully and their development continues until the end of Grade 9" (Andersone, Helmane, 2019, 20). However, the development of the skill to evaluate the credibility of information is little paid attention." Essentially, students need to develop skills to differentiate real information from false information (Anspoka, Kazaka, 2019).

Table 3

Frequency of codes in the biology curriculum

Code	Explanation	T1	T2	T3	T4	T5	T6	Total
[Col]	collaboration	3	9	11	6	6	2	37
[Cros]	cross-curriculum	2	0	1	0	1	1	4
[Crt]	critical thinking	12	18	13	17	16	6	82
[Inf]	information literacy	4	10	7	12	19	12	64
[Inq]	inquiry skills	1	1	0	0	0	4*	6
[Field]	field works	2	0	0	0	0	0	2
[Lab]	laboratory works	0	0	0	0	1**	1	2
[Mat]	mathematical skills	0	1	0	1	1	0	3
[Mod]	modelling	2	0	3	3	4	1	13
[Prob]	problem-based learning	0	0	0	1	0	0	1
[Proj]	project-based learning	0	0	0	0	0	1***	1
[Tech]	technology	6	0	1	2	3	2	14
[Vis]	visualization	4	10	5	8	9	6	42

* practical inquiry activity is not mentioned, but aspects connected with the bioethics of using animals in research are discussed
** simulation as a laboratory work
*** interdisciplinary project in chemistry

The use of inquiry is more theoretical because there are very few practical tasks (one interdisciplinary field study and several tasks on using modelling in practice). It is recommended to use technological possibilities in visualization – watching media, video, animations, simulations and the use of different schematic possibilities (diagrams, schemes) for structuring information while at the same time the biological drawing is used rarely. Science specific technologies are very little recommended, e.g., sensors are used only in one practical task. The study performed by R. Birzina and T. Pigozne (2020) also proves that such science-specific technologies are little used or not used at all. It means that a significant role is not assigned to the use of modern technologies in the teaching / learning process, which allows the learner to perform specific tasks flexibly and individually (Andersone, 2017).

Yes, the curriculum of basic *Biology I* (Bioloģija I…, 2020) states that it aims to develop inquiry skills, collaborating in practice, experimenting, modelling and concluding, yet a more detailed analysis of the curriculum does not confirm it. There is also no evidence about acquiring the experience of solving complex, authentic science and technology-related problems and working on long-term interdisciplinary projects and making primary mathematical calculations although it has been indicated that performing the field study students acquire skills to work with primary data. According to the research of D. Cedere, R. Birzina, T. Pigozne and E. Vasilevskaya, the new generation of students is oriented towards active and practical involvement in the learning process, which is little provided by the curriculum of *Biology I* (Cedere et al., 2020).

As regards the integration of the following transversal skills in the curriculum (National Reforms…, 2020), it has to be mentioned that the main emphasis is laid on information literacy, critical thinking and collaboration when assessing societal well-being, modelling situations and giving arguments for personal opinion, developing the habit of evaluating the reliability of information sources (Bioloģija I…, 2020). However, PrBL contributes not only to the development of content knowledge, but also to a wide range of skills such as communication and collaboration skills, decision making, problem solving, critical thinking and self-directed learning (Wilder, 2015, 414), which also includes the mentioned transversal skills.

Acquiring science knowledge is a long process that requires both subject knowledge and training in how this knowledge is structured. Therefore, a significant amount of content and practical work in the laboratory is usually required (Winberg et al., 2019). Although the authors apply this to higher education, it is also important in secondary education. Biology is the most complex of all scientific disciplines because living systems are integrated into many hierarchical systems and related to the social sciences (Lamanauskas, 2016). J.A. Ejiwale (2013) points to the badly developed teaching/learning content of the curriculum, discrepant guidelines, selecting inadequate teaching/learning methods and the assessment form as well as the lack of hands-on training for students as obstacles in the acquisition of STEM.

2.2. Constructed relations

To find out the reciprocal relations between codes and text fragments, linkages were constructed.

Linkages were not stated between

1. Problem-based learning [code Prob] – Inquiry skills [code Inq] - Laboratory works [code Lab];
2. Inquiry skills [code Inq] – Laboratory works [code Lab] – Mathematical skills [code Math];
3. Modelling [code Mod] – Technology [code Tech] – Visualization [code Vis].

As the code frequency (Table 3) shows, problem solving actually is not connected with the use of inquiry and laboratory works in the biology curriculum, which confirms that problem solving is more theoretical than practical when students learn about a subject through the experience of solving an open-ended problem found in the literature (Barak, 2020). Probably, it can be explained by the fact that the biology curriculum anticipates only one laboratory work, two microscopy works, one interdisciplinary field study, two field works (not mandatory) and does not emphasize the use of mathematical calculations.

It is stated that there is a connection (Figure 2) between students' collaboration, information literacy and critical thinking as well as between problem-based learning, information literacy and critical thinking. It means, as proved also by R. Andersone's (2020) conclusion, that student's information literacy is important for developing problem solving and reasoning; however, problem solving is very little used in the biology curriculum. The present analysis of the curriculum shows that by decreasing the number of lessons in biology from 210 in the previous standard to 105 lessons in the new standard, it is not possible to attain all learning outcomes set in the biology curriculum if only schools in determining a flexible number of lessons do not exercise their right to change the number of lessons by 10-25 % (National Reforms…, 2020) and the choice of methods is considered the teacher's priority.

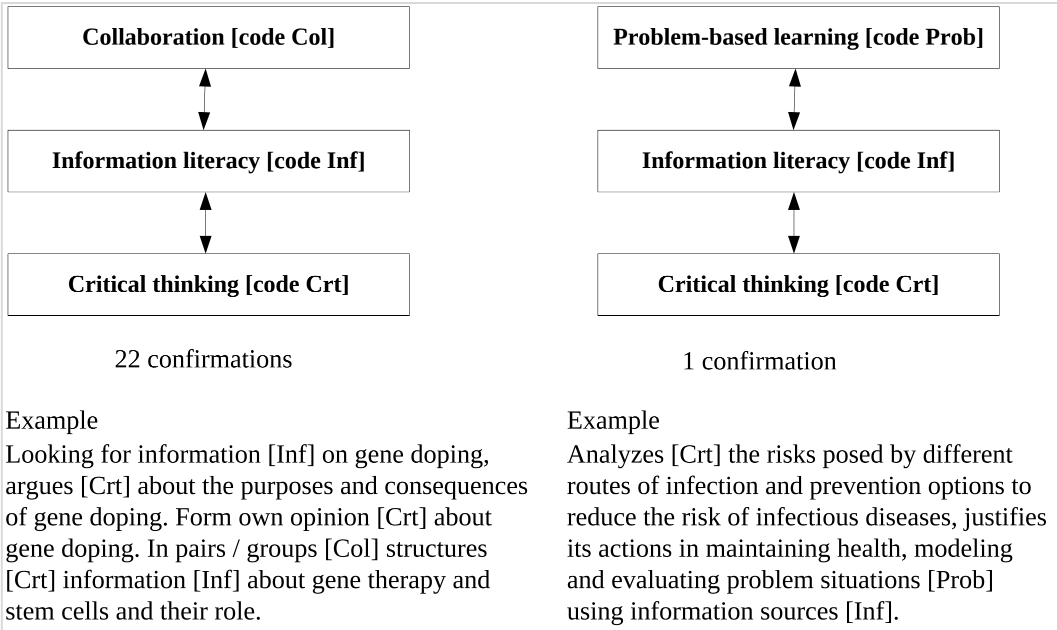

Figure 2. Constructed linkages (within a distance of maximally 5 lines of text).

Conclusions

Teachers and students consider that project-based and problem-based learning are significant in science teaching and learning. Such an approach in the teaching/learning process ensures an integrated acquisition of science content and, using real life examples, increases students' interest in science.

The results of the qualitative study show that it is not possible to attain all innovative aims set by the national education reform with a decreased number of lessons in the curriculum of the basic biology course. The curriculum is mainly oriented to soft skills – gaining information, developing critical thinking, participating in discussions and promoting students' collaboration, with little using problem-based and project-based learning. A serious drawback is the fact that it does not offer the use of methods acquiring skills specific to biology: there are few practical, inquiry and laboratory works (only one in all biology course) Thus, if a student chooses to learn the directions of other study domains in the secondary school then his education level in biology will be insufficient to be science-literate in biology in the future. This issue is topical also in the situation of today's Covid19 pandemic. Probably, this problem can be partly eliminated already in the secondary education process if schools themselves design their curricula according to the teaching/learning standard with a considerable improvement of the biology curriculum. The students can encounter problems also in the development of his/her further career. If they after graduating from the secondary school, having not acquired biology on an advanced level, decides to study the field that requires biology knowledge, then it will be rather difficult to study with just what has been acquired in the basic course. This means that universities already today have to think about developing levelling biology study courses for the student to study successfully.

The results gained in the study prove that there is a gap between students and teachers' opinions on how problem-based and project-based learning affect STEM learning and teaching and the offer of teaching/learning methods used in the present basic biology course. The question remains open – will other basic science courses with a greater number of lessons promote the development of science literacy?

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