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Dominika Koperová & Martin Rusek

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Editorial

Martin Rusek

Abstract

This editorial covers the content of the PBE 2023 proceeding finding some parallels to other work either in the previous PBE proceedings or from other sources. The editorial shows development of the topic as well as the entire conference and outlines key areas which need to become foci in the near future.

Keywords:

Editorial; PBE conference; STE(A)M education; student activation strategies

INTRODUCTION

The educational landscape in the 21st century is undergoing a significant transformation with innovative strategies such as Project-Based Education (PBE) taking centre stage. The recent conference at Charles University Prague underscored this shift, showcasing the effectiveness of these approaches in science education. This editorial expands on the key themes discussed during the conference, providing a comprehensive overview of the advancements and implications for the future of STEM education. The PBE 2023 proceedings focused on various topics from both student-activation strategies' point of view as well as related issues of STE(A)M teaching and learning.

EVOLUTION OF PROJECT-BASED EDUCATION

The content of the proceedings, based on the focus of the individual studies, indicates a significant shift from the works previously presented at the PBE conference (Rusek & Vojíř, 2018). The original focus on project-based learning, grounded in its theoretical foundations and experiences with implementing project activities, has brought forth several specific issues that need to be addressed for such a comprehensive educational strategy to be feasible in schools. Concurrently, as the understanding of what constitutes project-based education or a project in general (Rusek & Becker, 2011) becomes more precise, there is an emerging distinction between activities simply referred to as inquiry-based and those as "activities with project elements" (Bělohoubková & Krumlová, 2024; Bryxová et al., 2024) which further clarifies professional terminology.

ASSESSING EFFECTIVENESS OF PBE ACTIVITIES

Another significant shift is the emphasis on the effectiveness of proposed activities (Andriyani et al., 2019; Balemen & Keskin, 2018; Rusek, 2021). The persistent efforts to incorporate “school projects” into pre-established school schedules fundamentally contradict the definition of project-based learning. Traditional outputs such as posters and/or student conferences do not allow for adequate assessment of the effectiveness of the proposed activities. Therefore, pre-test - post-test designs (in their classic form or, for example, through the comparison of concept maps created by students (Rye et al., 2013)) are coming to the forefront. Additionally, tools that monitor students’ motivation to engage with the topic (e.g., Intrinsic Motivation Inventory - IMI (Ryan & Deci, 2000), Motivated Strategies for Learning Questionnaire - MSLQ (Pintrich & Groot, 1990), or Science Motivation Questionnaire - SMQ (Glynn et al., 2011)) are becoming increasingly important (Fiala & Honskusová, 2019; Šarboch & Teplá, 2022; Vojíř et al., 2018).

TEACHER PROFESSIONAL DEVELOPMENT

A significant theme of the conference was the importance of effective teacher professional development. The research presented by Elmas et al. (2024) emphasized that teachers prefer shorter face-to-face or hybrid training sessions that focus on 21st-century skills and practical applications. This preference highlights the need for continuous professional development that is both relevant and adaptable. For instance, Lindell et al. (2022) explored the development of materials, instruction, and culture for phenomenon-based STEAM projects, stressing the importance of integrating cultural aspects into teacher education. Rajsiglová and Přibylová (2020) highlighted micro-teaching as an effective strategy for novice teachers to learn and adapt innovative teaching methods.

PRACTICAL APPLICATIONS AND TEACHER TRAINING

The findings suggest that both pre-service teacher training as well as professional development programs must be tailored to meet the preferences of teachers to be effective. Such programs should prioritize practical skills and real-life applications, ensuring that educators can seamlessly integrate new methodologies into their teaching (Harris & Jones, 2019). This approach can lead to improved teaching practices and better student outcomes in science education. Moreover, the emphasis on practical skill-based training aligns with the broader educational goals of fostering critical thinking and problem-solving abilities among students (Darling-Hammond et al., 2017).

STUDENT OUTCOMES AND INNOVATIVE METHODS

The PBE conference has highlighted student outcomes that display their acquired skill to design and implement meaningful activities focused on everyday life topics (e.g. Bryxová et al., 2024; Dreyer & Hoffer, 2022; Horáková et al., 2019; Kuncová & Rusek, 2020), their ability to discuss everyday topics in a deeper and meaningful way (Bělohoubková & Krumlová, 2024), or the effect of innovative methods' use (e.g. Čížek & Vojíř, 2024; Fiala & Honskusová, 2019; Marcineková & Pavlasová, 2020) on their learning gains. Reports on pre-service teacher training programs within the Blended Intensive Programmes organized within Erasmus + (Mattila & Laurila, 2021) as well as teacher trainers' response to the need to foster student-centred activities (e.g. Janštová & Pavlasová, 2018; Lindell et al., 2022; Lindner et al., 2018; Rusek, 2015; Vácha et al., 2024) suggest that PBE can be particularly effective in raising awareness and shaping attitudes towards contemporary issues, making it a valuable tool in science education (Mahasneh & Alwan, 2018; Rusek, 2021; Thomas, 2000).

APPLICATIONS OF PBE IN VARIOUS DISCIPLINES

The conference also showcased the diverse applications of PBE across different scientific disciplines. Research on the environmental impact of e-cigarettes, simulations in chemistry, and the effectiveness of inquiry-based learning in zoology and plant education illustrated the broad applicability of PBE. Vácha et al.'s (2024) study on the impact of activating teaching strategies on plant education, along with Nodzyńska-Moroń and Sirotek's (2024) work on the educational potential of simulations, provided valuable insights.

The breadth of topics covered in the conference proceedings demonstrates that PBE can be effectively integrated into various scientific disciplines. This approach not only enhances subject-specific knowledge but also promotes interdisciplinary learning, which is crucial for addressing complex real-world problems (NRC, 2012). The ability to connect different areas of knowledge through PBE encourages a more holistic understanding of science and its applications (Chin & Osborne, 2008).

FUTURE RESEARCH TOPICS

To further advance the field of STEM education, future research could explore the following topics:

Longitudinal Studies on PBE: Investigate the long-term impact of PBE on student learning outcomes and career choices in STEM fields (e.g. Barron & Darling-Hammond, 2008).

Scalability of PBE Programs: Examine how PBE programs can be scaled up and adapted for different educational settings, including primary, secondary, and higher education (e.g. Bell, 2010).

Interdisciplinary Approaches: Explore the effectiveness of interdisciplinary approaches in PBE, particularly in integrating STEM subjects with humanities and social sciences (e.g. Beers, 2011).

Technological Integration: Assess the role of emerging technologies such as virtual reality and artificial intelligence in enhancing PBE and other activating strategies (e.g. Dede, 2009).

Teacher Training Models: Develop and evaluate new models of teacher training that incorporate PBE principles and assess their impact on teaching practices and student outcomes (e.g. Kennedy, 2016).

CONCLUSION

The 21st conference on Project-Based Education and Other Activating Strategies in Science Education highlighted the transformative potential of innovative educational strategies. By fostering a collaborative and dynamic learning environment, these approaches not only enhance student engagement and achievement but also prepare students for the challenges of the modern world. The ongoing commitment to professional development for educators and the integration of real-life issues into the curriculum are crucial for the continued evolution of science education.

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I. STUDENT-ACTIVATION STRATEGIES IN STEM EDUCATION

The fogged reality: e-cigarettes, the way or hidden evil?

Tereza Bryxová, Eva Marešová & Nikola Netušilová

Abstract

This study presents a proposal for a teaching block with elements of project-based education. At the beginning of this teaching block, students' attitudes towards the issue of e-cigarettes were examined. Subsequently, the other parts of the teaching block were designed to expose the students to more sides of this topic. During the sub-tasks, the students worked with information sources, used practical tasks to investigate the content and composition of e-cigarettes, collected data about public opinion on e-cigarettes and analysed the results of their work. A poster summarising the issue of e-cigarettes was the output of the whole teaching block. The students' forming attitudes towards the issue were also observed during the study - a modified Intrinsic Motivation Inventory (IMI) was used to evaluate the teaching block.

Keywords

E-cigarettes; project-based education; impacts on human health

INTRODUCTION

E-cigarettes (electronic cigarettes) have become very popular in recent years, not only among adults but also, much more frequently, among adolescents (e.g., Chomynová & Mravčík, 2021; Cooper et al., 2022; Keenan et al., 2022) and according to research conducted in the Czech Republic by the National Monitoring Centre for Drugs and Addiction, over 18% of adolescents aged 15+ surveyed in the Czech Republic reported experience with e-cigarettes. Disposable e-cigarettes are currently very popular, with many people considering them a more 'viable' option (Chomynová & Mravčík, 2021).

The following study focused on how Year 2 grammar school students (i.e. 16 or 17 years olds) perceive these (for many seemingly innocuous-looking devices). The study presents the design of an teaching block with elements of project-based education (Rusek, 2021).

At this point, it is important to note why this is a project-based education unit and not a traditional students' project. It is not a project in the true sense of the word, primarily because the topic was not proposed by the students themselves but was suggested by the teachers (cf. Rusek & Becker, 2011). Although it is not a student project in the true sense, the teaching block activities were designed based on discussion with the students. Thus, the students' requirements were considered in the teaching block, and the individual tasks were adapted to the students' needs.

Prior to the actual start of the teaching block, an evocation and, above all, a discussion took place to elicit students' attitudes, including their potential experience with e-cigarettes. Based on these activities, specific parts of the teaching block were designed to make students aware of the harmfulness of e-cigarettes and to answer students' inquisitive questions. Among others, students' forming attitudes towards e-cigarettes were observed throughout the teaching block.

The topic of e-cigarettes was chosen primarily because of its relevance and appropriateness to the age of the students for whom this teaching block was designed. There are various angles from which we can analyse the subject of e-cigarettes. We can explore its impact on human health, its potential for addiction, or its effects on the environment (Han & Son, 2022). Consequently, e-cigarettes can be a relevant topic in many areas of education. Furthermore, we consider the topic of e-cigarettes to be important in the context of regulation and legislation relevant to e-cigarettes, which is a current topic globally as much as in the Czech Republic (e.g., Amalia et al., 2022; Chomynová & Mravčík, 2021; Cooper et al., 2022).

The topic of e-cigarettes was also underpinned by the 17 Sustainable Development Goals that are part of the 2030+ Strategy (United Nations, 2016). Despite the variability of the SDGs, which allows for their application across different topics, the focus of the proposed teaching block was on SDGs 3 and 12 (see Figure 1). Specifically, SDG 3 - Health and Quality of Life aims to reduce premature mortality, promote mental health and well-being, and strengthen substance abuse prevention and treatment. The second SDG that can be used to highlight the importance of the topic of e-cigarettes is SDG number 12 - Responsible Production and Consumption, which contains sub-goals that include, for example, the careful management of chemicals and waste, as well as the reduction of waste production through prevention, reduction and recycling (Leyva et al., 2017; Marques et al., 2021; United Nations, 2016). In conclusion, e-cigarettes are a "hot" topic due to their health, social, economic, and regulatory aspects that affect the general public.

Figure 1: UN Sustainable Development Goals

RESEARCH OBJECTIVE

The aim of our research was to design teaching activities on the topic of e-cigarettes and subsequently examine their effectiveness and functionality in practice, as well as to map the awareness of secondary school students on the topic of e-cigarettes and to monitor their forming attitudes towards this topic based on the completion of this teaching block with elements of project-based education.

RESEARCH TIMELINE

The timeline below shows a brief overview of the individual research steps.

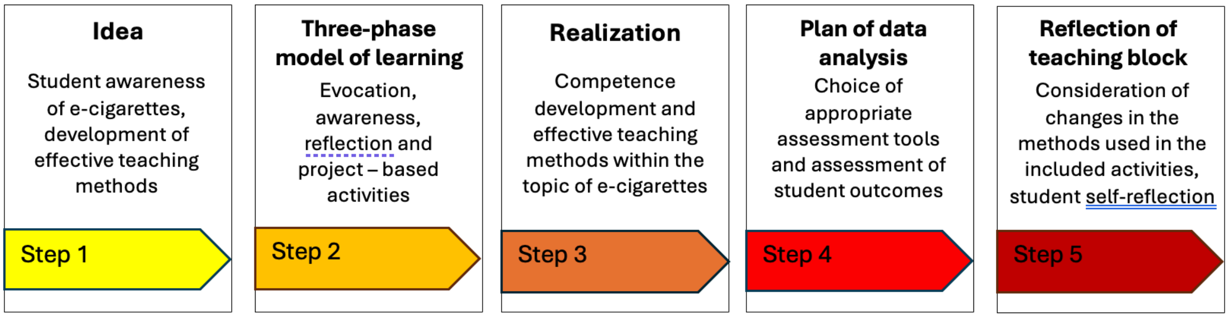


Figure 2: Research timeline

Activities included in the teaching block

The whole teaching block was divided into three parts, following the three-phase model of learning - EAR (evocation, awareness and reflection – EUR in Czech).

The evocation of the topic was carried out at the beginning of the teaching block with elements of project-based education. It aimed to motivate the students and draw them into the issues related to the use of e-cigarettes. The students were given various clues to help them discover the topic of e-cigarettes. Mentimeter was subsequently used to map their initial knowledge. This platform was chosen due to the anonymisation of their responses. The Mentimeter platform also allows for a swift collection of students' responses. In this part, the students were first asked to indicate what positives and negatives the term "e-cigarette" evokes in them. Second, they could use Mentimeter to express their interest and what they would like to explore within the issue of e-cigarettes in more depth. Based on these responses, a discussion was initiated to gather the students' preconceptions, knowledge and previous experiences. Based on this discussion, the final content of the teaching block was then designed.

In the second activity of the teaching block, random newspaper headlines or tutorials from interesting articles were shown to the students. The students' task was to determine whether these were relevant or irrelevant sources. The teaching block included the activity to develop students' skills in distinguishing between relevant and irrelevant sources. During this activity, students reviewed the principles of citing and searching for relevant articles.

The evocation phase was followed by the *awareness phase*. It included activities that aimed to develop students' knowledge and skills related to e-cigarettes in more depth. The first activity of this part was a discussion. During the discussion, the students were divided into two groups. The division was purely random. The first group was asked to take a position that approved the use of e-cigarettes. On the contrary, the second group was to be against the use of e-cigarettes. The students were given some time to study the necessary information and to prepare their lines of argumentation before the debate started (Bělohoubková & Krumlová, 2023). During the discussion, the students had to have their arguments supported. The students also had to put themselves in their assigned roles. The discussion raised interesting questions such as "How many of our acquaintances smoke?" or "Which age group uses e-cigarettes most often?".

The rather heated discussion was followed by another activity, which was the creation of a questionnaire. In this activity, the students were divided into small groups. Each student group created its own questionnaire. Each questionnaire aimed to collect data regarding the use of e-cigarettes in the students' neighbourhood. Through this activity, students independently created questions and figured out what was needed to create a good questionnaire that would provide relevant data for analysis. The students then distributed the created questionnaires to their neighbourhood and collected the necessary data.

The next activity was included in the teaching block based on the students' demands. During the evocation, students were interested in what an e-cigarette consists of and how it differs from a regular cigarette. For this reason, a practical exercise was included in the teaching block to allow students to look at the individual parts that make up a disposable e-cigarette. This activity was preceded by a safety briefing, which is an integral part of any practical exercise. Non-functioning e-cigarettes of different brands (with and without nicotine) were distributed to each student group. The students used pliers to dismantle the e-cigarette. The students then lined up the different components of the e-cigarette one by one on paper as they were placed inside the device (see Figure 3). Some students wrote a suborbital anatomy and named the components.

A still unanswered question was whether e-cigarettes were a better option than regular cigarettes. In the following activity of the teaching block, a simulation of e-cigarette use was prepared for the students. For this demonstration, we used a silicone decorator that simulated a negative pressure analogous to the negative pressure created when smoking cigarettes. The inner part of the silicone decorator was filled with cotton wool. The cotton wool represented the function of the lungs as an organ in which harmful substances released from cigarettes accumulate during smoking. The students then performed a simulation of an e-cigarette cover under expert supervision (see Figure 4).

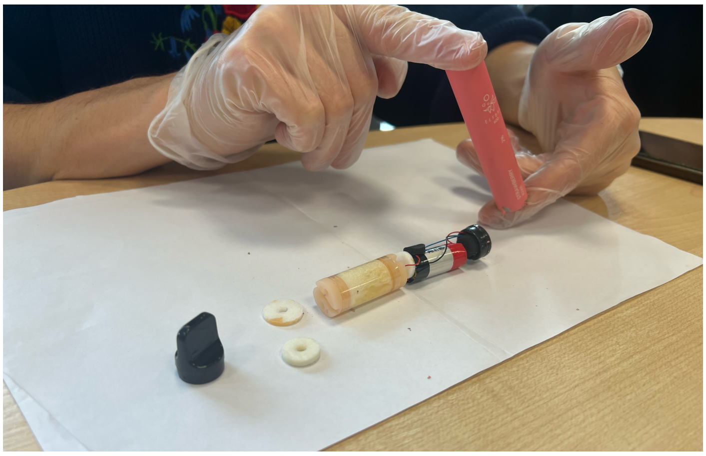


Figure 3: Components of e-cigarette, source: the authors

Figure 4: E-cigarette simulation

During the practical task, it was possible to observe gradual changes in the students' attitudes towards the use of e-cigarettes. Some students started to think about another option that would allow the simulation. During this activity, they created other models on their own initiative to simulate smoking. For example, they used a PET bottle and a balloon pump available in the classroom to develop such a mock-up (see Figure 4). At the same time, students explained the mechanism of smoking. After completing the practical tasks, the students watched a short video showing a simulation of an e-cigarette and a regular cigarette. This was again followed by a discussion during which students discussed the differences and pointed out the harmful substances of both cigarette alternatives.

The last part of the teaching block was devoted to reflection. In this part, the students had to create posters in groups. The posters were also one of the outcomes of the teaching block.

Figure 5: E-cigarette simulation via student-proposed model

Outcomes and feedback

The outcomes of the whole teaching block with elements of project-based education was a poster created by the students. They received pre-set criteria. The Canva application was recommended to the students for poster processing. The information mentioned in the poster had to be substantiated and relevant. This output aimed to test the students' ability to summarise, analyse and relate the knowledge gained during the teaching block. The poster also provided a brief overview of the topic of e-cigarettes. The feedback included whether or not implementing the teaching block with projective elements could be considered successful and effective.

REFERENCES TO E-CIGARETTE RESEARCH

The topic of e-cigarettes in schools has also been addressed by other projects and studies, such as the 2022 study "School-based programs to prevent adolescent e-cigarette use: A report card"(Liu et al., 2022). In the text, the authors point to the importance of implementing prevention programs as a means of preventing addiction and the susceptibility of adolescents to encounter nicotine and nicotine-containing products in general. Another study addressing the topic of e-cigarettes in schools was, for example, "A Middle School Program to Prevent E-Cigarette Use: A Pilot Study of ´CATCH My Breath´" (Kelder, S. H., Mantey et al. 2020), which examined the increase in e-cigarette use among adolescents in the United States.

ACTIVITY EVALUATION

Objectives of the teaching block with elements of project-based education

The teaching block with elements of project-based education aimed to introduce second-year grammar school students' to the issue of e-cigarettes and to structure knowledge of the use of e-cigarettes and other tobacco products. There were 16 students who participated in the teaching block.

The teaching block aimed, among other things, to influence students‘ attitudes through individual activities. Based on the chosen teaching methods, the students linked their knowledge and skills from different educational areas, which include toxicology, ecology and human biology. They used this knowledge and skills to solve environmental problems. The individual activities included in the teaching block also targeted the development of key competencies and literacy skills.

Evaluation tool of the teaching block with project-based elements

The teaching block with project-based elements was evaluated using the Intrinsic Motivation Inventory (IMI) by Ryan & Deci (2000), a multidimensional instrument modified for this study. The IMI instrument is used to assess the subjective experiences of respondents (in our case, grammar school students) related to the activities performed throughout the teaching block (Kekule & Žák, 2001) and has been advantageously used to similar purposes before (Kuncová & Rusek, 2020; Vojíř et al., 2018). Through the IMI instrument, we assessed four domains in this teaching block. Specifically, we focused on students’ perceived *value/usefulness*, *interest/enjoyment*, *effort/importance* shown, and perceived *pressure/tension* during the performance of the activities included in the teaching block. The IMI assessment tool resulted in subscale scores (CSDT, 2023). Concepts with perceived choices are seen as a positive predictor of subjective intrinsic motivation responses. In contrast, pressure and strain are perceived as negative predictors of intrinsic motivation (Kekule & Žák, 2001).

The questionnaire was created in Google Forms and contained a total of 30 items that formed 7 subscales. For each item, students were asked to indicate the extent to which the statement was true or false (1 - completely false, 7 - completely true). The median for that subscale was then determined from the student’s responses. In addition to these 30 questions modeled on IMI questionnaires, the questionnaire also included other open questions that served as feedback. These questions helped us understand what aspects of the learning block the students found helpful, and what areas they felt could be improved.

Limitations of the teaching block with project-based elements

The activity was affected by several limits. The first limiting factor is the learners’ intrinsic motivation. The students need to be motivated during the teaching block. The second limiting factor is the time constraint of the teaching block. The teaching block is designed for only six lessons (i.e. 6 x 45 minutes). The teaching block can be extended with additional activities in case of a higher time allocation. Another limiting factor related to this is finance. In the case of a higher time allocation and sufficient funding, a visit from an expert could be included to flesh out the topic further for the students. Alternatively, a visit to a specialist institute specialising in the subject could be included. Finally, the limitation is that students are very inquisitive and may sometimes have requirements and questions that cannot be Practically verified and answered sufficiently.

RESULTS

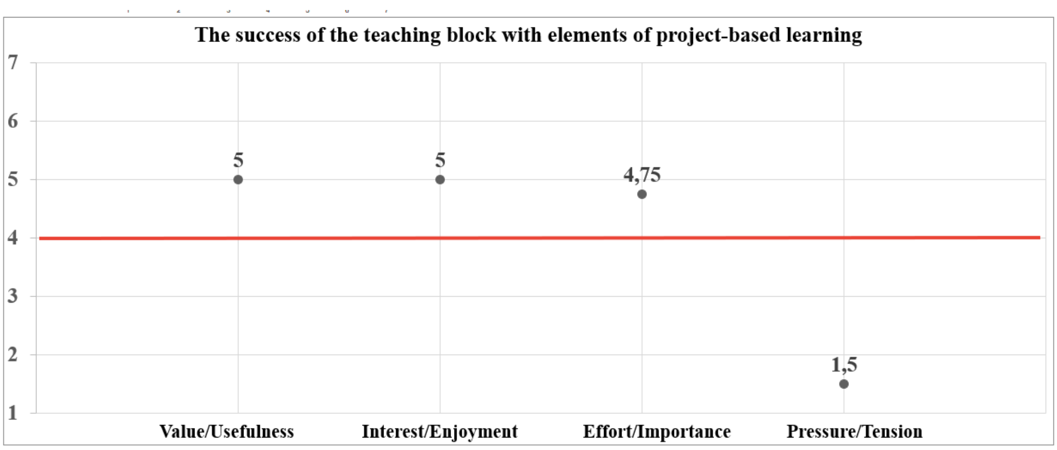
Posters

The main output of the teaching block with elements of project-based education was a poster, which students created in groups. The poster had to contain criteria given by us, which the pupils learned after scanning a QR code prepared by us. In addition to the students' creativity, their attitude towards the topic of e-cigarettes was also reflected in the final form of the poster. All students drew attention to the harmfulness of e-cigarettes through their posters. Some groups included extra information in their posters, such as what an e-cigarette looks like and what parts it consists of.

The teaching block produced three student posters, approached originally by each student group. However, only one group met all the specified criteria, as the remaining two student groups did not comment on the data obtained from their respondents nor did they have the data in the respective graphs included. Consequently, it can be concluded that these groups did not meet the criteria set forth, indicating their failure to achieve the primary output expected from the teaching block with elements of project-based education.

IMI

The IMI questionnaire was provided to the students at the end of the teaching block. The values of the student responses in the first 3 areas of interest (i.e. perceived usefulness of the topic, interest shown and effort) are in the positive part of the graph (see Graph 1) and indicate positive perceptions of the carried-out activities. Conversely, the results of the students' responses show that students did not



feel pressured during the activities performed in the teaching block (see observation 4, pressure/tension).

Figure 6: The success of the teaching block with elements of project-based education

The results of the student evaluation also show that students show a higher level of motivation for activities related to practical and creative activities. As with other subjective assessment tools, it is essential to consider self-presentation styles and student ego involvement in IMI assessment. According to Ryan et al. (1991) ego involvement influences respondents' subjective statements.

The students' feedback was overwhelmingly positive in most cases. They realized that, for example, the relevance of sources and hypothesis generation could be useful to them in other activities and in the future. Additionally, including a practical task that confirms or refutes some of their assumptions or hypotheses, like the evaluation of relevant sources, was considered beneficial. Conversely, the results of the students' responses show that students did not feel pressured during the activities performed in the teaching block (see observation 4 - pressure/tension).

The results of the student evaluation also show that students show a higher level of motivation for activities related to practical and creative activities. As with other subjective assessment tools, it is essential to consider self-presentation styles and student ego involvement in IMI assessment. According to (Ryan et al., 1991)Ryan et al. (1991) ego involvement influences respondents' subjective statements.

The students' feedback was more than positive in most cases. They realised that, for example, the relevance of sources and hypothesis generation may be useful to them in other activities and activities in the future. As well as including a practical task, which confirms or refutes some of their assumption or hypothesis, like the relevant sources.

DISCUSSION

E-cigarettes have become very popular in recent years, as evidenced by the 2020 National Survey on Substance Use conducted under the auspices of the National Monitoring Centre for Drugs and Substances. This is a population-wide study in which the sample consisted of respondents aged 15 years and older. The results for e-cigarettes show that 18.3% of the respondents have experience with this type of cigarettes, with most of them being in the 15-24 age group. Up to 1/3 of the respondents aged 15 to 24 had tried e-cigarettes. Compared to the 2016 study, experience with e-cigarettes is at about the same level. However, there has been a significant increase in the use of these types of cigarettes among the youngest age group (Chomynová & Mravčík, 2021). In this context, it should be noted that the study was conducted 3 years prior to the creation of this teaching block.

However, disposable e-cigarettes have been very popular, especially in the last two years of the (e.g., Cooper et al., 2022; Keenan et al., 2022). Therefore, from this fact, we conclude that the results of a similar study nowadays would be significantly different, and the proportion of respondents who have come into direct contact with an e-cigarette would be higher, especially in the youngest age group. This is also linked to the fact that this teaching programme was included in the 2nd year of high school. Even the students themselves found during the teaching block that it was popular with individuals much younger than themselves. Therefore, it is proposed to use this programme, for example, in primary schools, in Year 8 or Year 9, as part of prevention. Of course, after minor modifications and adaptation to the age of the students to whom the programme will be applied.

How can we implement the given results?

The resulting IMI questionnaire assisted us in obtaining data which we can subsequently implement in other teaching blocks on other topics. For example, the fact that the students did not feel any pressure/tension during each activity shows us that the activities were perceived positively by the students and therefore it is appropriate to continue to include them in other given teaching block with elements of project-based education. The results show that the inclusion of a practical activity is highly beneficial for the students and motivates them to further explore the given topic. Thus, the practical teaching methods help the students to connect their theoretical knowledge or their preconceptions on the topic, as was the case with the practical demonstration of e-cigarettes that was part of the teaching block with elements of project-based education.

CONCLUSION

Throughout the teaching block with elements of project-based education, the formative attitudes of individual students were monitored, among other things. In this respect, the teaching block can be considered a success. However, the students were not influenced radically and formed their opinions based on their experiences during the teaching block. The students who participated in the teaching block showed a more negative attitude towards e-cigarettes after the teaching block than before the teaching block.

If we were to focus on the individual activities in the teaching block, we can say that the group work was the functional part of the block. During this part, students worked together on creating posters. This activity allowed the students to showcase their strengths and creativity. Among the functional activities we shall also include practical tasks, which significantly shaped student attitudes.

In the next implementation of the teaching block, we plan to focus more on the debate regarding e-cigarettes as not all pupils participated in it. To encourage higher participation, we are considering dividing the students into two groups to have a more focused discussion or asking targeted questions to specific participants from the moderator's point of view. The sought after result shall be the higher participation from all students.

The teaching block is applicable for use in other secondary level classes and may potentially be adapted for primary school students. In such case, the activities would be simplified or changed completely. For instance, instead of holding a debate, students could work with the text itself, engage in cooperative learning methods, or use the INSERT method to develop their reading skills. Afterwards, the teacher would ask guiding questions, similar to those asked during a debate.

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Students’ opinions on various approaches in zoology teaching: the topic of owls

Filip Hašpl, Karel Vojíř & Jan Andreska

Abstract

The aim of the research was to investigate three variants of the teaching approach to the topic of owls and to find out the students' opinions about these lessons. Three lessons on the topic of owls were developed. 87 lower secondary school students took part in the research. A questionnaire was used after each lesson to find out how students perceived the lessons in terms of attractiveness, usefulness, collaboration, and information processing. It was found that students perceived the lessons on the topic of owls positively in all the variables studied. However, in the case of collaboration they perceived more constructivist lessons more positively than transmissive lesson.

Keywords

Students’ view; students’ opinions; zoology education; inquiry-based learning; IBSE

INTRODUCTION

The success of learning depends not only on the content but also on the way in which the content is presented and how students are engaged in the learning process. In the Czech curriculum, there is no strictly defined subject matter and therefore one topic can be approached from different ways of conveying it (see MŠMT, 2021). These approaches can of course develop different knowledge, competencies, and skills.

Adequately developed skills such as critical thinking, question-asking, decision-making, and problem-solving are essential for solving today’s society’s complex problems (Zoller, 2012). For society’s future prosperity in the 21st century, it is crucial to expand science education so that it should promote the all-around development of student’s personal skills and prepare them for a successful transition to the following levels of education or their professional life (Gošová, 2011). Simple classical transmissive methods, however, do not promote skills acquisition enough (Howell, 2021). Nonetheless, it seems that among other approaches inquiry-based learning (IBL) has the potential to allow students to deepen and develop their various skills (see Ali & Ulker, 2020; Duran & Dökme, 2016; Chu, 2008; Spronken-Smith et al., 2008). However, by its critics IBL is often criticized as inappropriate for understanding of science content and procedures. They argue that the emphasis on other educational goals should not be at the expense of students’ understanding of science concepts and practices. They argue that it is difficult to imagine genuine enthusiasm and engagement with science without first acquiring basic conceptual knowledge and understanding of it (see Zhang et al., 2022).

To achieve adequate learning and acquisition of skills, the content of education should be delivered in a way that actively engages and motivates students, fostering their curiosity and independent thinking (Marco-Fondevila et al., 2022). Students should see the usefulness of their studies and activities.

In the Czech curriculum, there is a chapter on zoology, and even birds are mentioned, but the main focus is on the development of various competencies and skills. The curriculum aims to develop many skills that range over a relatively broad spectrum (see MŠMT, 2021). Therefore, it is possible to use both transmissive and constructivist methods of teaching successfully. There is a large amount of teaching material available on birds and owls in general (see e. g. Řezníček, 2013). However, to be truly effective in teaching, it is necessary to know how the students themselves perceive it. However, so far, the evidence on how students perceive them is limited.

RESEARCH AIM AND QUESTIONS

The aim of the study was to validate three different model approaches on how to teach about owls and find out how do lower secondary school students perceive them.

Considering this aim, two research questions were formulated:

- How do students perceive constructed lessons on the topic of owls in terms of interestingness, usefulness, information processing and collaboration?
- Is there a difference in students' opinions of constructed lessons on the topic of owls?

In the Czech curriculum, there is no strictly defined subject matter and therefore one topic can be approached from different ways of conveying it (see MŠMT, 2021). Therefore, identifying the benefits and limitations of different teaching approaches, as students perceive, can help adapt teaching and increase students' engagement. Inquiry-based learning can be motivating and enjoyable for students as they engage in activities, discover new information and actively work on problem-solving themselves (cp. Ergül et al., 2011; Chvojová & Ehler, 2022). However, some students may have different perceptions of teaching methods (see Chvojová & Ehler, 2022). Understanding the students' perception of particular educational content selected and elaborated can help create a more appealing and engaged learning environment.

METHODOLOGY[1]

To answer the research questions, a survey was conducted in which all students participated in all the three different model lessons on the topic of owls. Immediately after each lesson, students completed a questionnaire. The data obtained in this way was processed and quantitatively evaluated.

Research sample

The research sample consisted of 87 Czech lower-secondary school students (7th grade). The research was carried out in three parallel classes in the biology subject. The lessons were taught by the same teacher.

Lessons

For this research, three separate lessons were constructed. These lessons had a common theme - owls. The topic of owls was chosen as not yet discussed and motivating for the students. As demonstrated by the successful Owls in Schools project (Kassová, 2005), owls are a popular topic among students. Exploring these birds of prey provides an exciting and attractive context for learning. Owls are fascinating and mysterious creatures and have had a mysterious effect on human society since ancient times (Andreska, 2020; Závalský, 2023). In this topic the lessons were constructed with different approaches.

Lesson A: Characteristic of owls and selected species. In this lesson students were introduced to the order of owls. The main objective of that lesson was to enable students to recognise owls as unique creatures among other birds and introduce them to several representatives of this order. At the same time, it focused on owls' essential characteristics and behaviour. The lesson was structured as classical transmissive teaching, using a PowerPoint presentation. In addition, students were involved in a short group work that allowed them to collaborate and share their knowledge and opinions.

Lesson B: Owl pellet analysis. In this lesson students were introduced to the food of owls, explicitly using the example of the long-eared owl. The lesson aimed to explain the owl's dietary choices in more detail and to enable students to practice using the identification key to identify mammals based on their bones. This approach taught students more about owls' composition and dietary preferences. The lesson was designed as a lesson with structured IBL aspects. Students had the opportunity to participate actively and gained practical skills in working with magnifiers, identification keys, and small mammal bone identification.

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[1] The methodology and results presented in this paper were used in the first author's master thesis (Hašpl, 2023).

Lesson C: Owls living in urban environments. In this lesson students were introduced to owls living in urban environments and the species found near the school. The lesson aimed to broaden students' awareness about the presence of owls in urban areas and showed that these nocturnal birds of prey could be a regular part of the urban environment. The lesson was designed as a lesson with guided IBL aspects. Students were set a research question and had to devise a solution in groups. They then set up a procedure leading to answering it.

Research tool

In this research, a questionnaire based on the Czech version of IMI tool (Kekule & Žák, 2001) was used. The questionnaire consisted of four domains related to students' opinions: interestingness, usefulness, information processing and collaboration. The domains studied were chosen based on similar research aimed at validating lessons in other science topics (see Fiala & Honskusová, 2020; Šarboch & Teplá, 2022b; Vojíř et al., 2019). Two items related to each of the domains. All items were formulated to relate directly to the lesson just taken, e.g.: *I believe, this lesson could be of some value to me*. In all items, a 3-point scale (agree, neither agree nor disagree, disagree) which seems to be suitable for use by lower secondary school students (see Mellor & Moore, 2013).

Cronbach's alpha was calculated for each domain to assess the reliability of the tool: α (interestingness) = .836, α (usefulness) = .754, α (information processing) = .823, α (collaboration) = .819. According to Tavakol and Dennick (2011), all these values are good or acceptable. Therefore, the domain items can be considered sufficiently internally consistent, and the tool can be used.

Data evaluation

Data evaluation was carried out by analysing the responses to the questionnaire survey. The respondents' answers were recorded in a table in Microsoft Excel. Items related to the same scales were grouped and evaluated together. The relative frequencies of students' opinions were calculated. In the next step, the Kruskal-Wallis H test and the post-hoc Dunn's test were used to assess differences in students' opinions towards particular lessons. An Epsilon square (ε^2) was used to assess the effect size. The values of the epsilon square were interpreted via Rea and Parker (2014).

RESULTS AND DISCUSSION

All three lessons were evaluated by the students rather positively in terms of interestingness. Students' responses revealed that they perceived lesson B as the most interesting, with positive responses around 65%, see Figure 1.

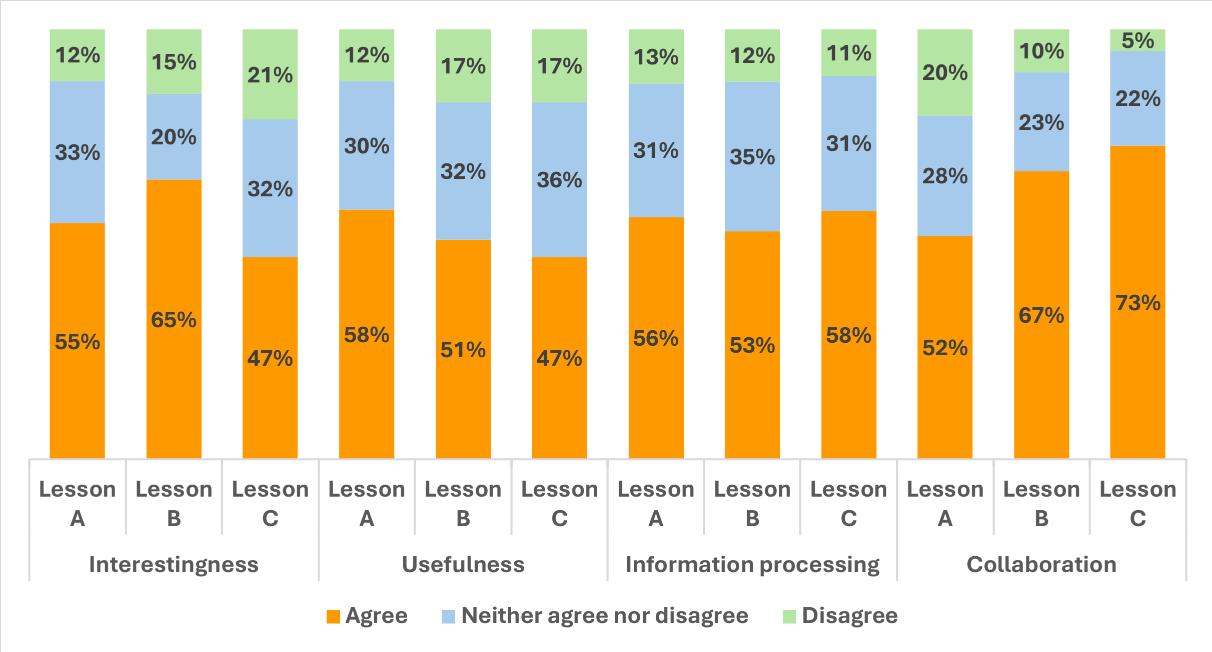

Fig 1: Student perception of the lessons

There is a statistically significant difference in students' perceptions of interestingness among the lessons conducted (H = 10.06, p = .007). The effect size of this difference is moderate (ε^2 = .117). Based on post hoc analysis, it was indicated that there is a significant difference in students' piercement between l*esson B* and *lesson C* (p = .002). *Lesson B* was perceived as more interesting than *lesson C*.

This finding shows that an approach to teaching the topic of owls with using model structured inquiry activity aiming on food specifications of the owls may be more interesting to students. Due to the simplicity of the implementation of the activity aimed at pellet analysis, this educational content can be considered suitable for teaching zoology. IBL in appropriate form appears to be a way to increase students' motivation for the subject and may be a good way to solve the problem of low popularity of science subjects (cp. Rajović et al., 2020).

Similar findings were also presented in a study by Wang et al. (2015), which compared inquiry-oriented workshops with traditional biology teaching in secondary schools. It was found that student interest increased in all schools studied but at different rates. Other studies have achieved similar results (see Andy, 2015; Röllke et al., 2021). However, it was also found that the higher cognitive difficulty of IBL may be a limiting factor (Scharfenberg & Bogner, 2010).

In terms of perceived usefulness, the students perceived all three lessons mostly positively and the difference in perceived usefulness between the lessons is not significant (H = 4.05, p = .132).

Students' perceptions of all three lessons as useful appear to be positive for their learning. At the same time, there was no clear preference for their perceptions in the context of a different choice and elaboration of the owl theme. The confirmed positive perception of the educational topic of owls as a whole (cf. Kassová, 2005) allows its good applicability to teaching with regard to the development of various skills. Students' opinion implies, this topic can be used not only for learning factual knowledge but also for developing inquiry skills. Thus, the topic can be effectively used to address situations where students subjectively perceive transmissive instruction as more useful than instruction focused on inquiry skills (see Smimou & Dahl, 2012).

In terms of information processing, students perceived all lessons positively, with a frequency of around 55%, see Figure 1. Based on the data obtained, there is a non-significant difference in information processing between the lessons ($H = .726$, $p = .696$).

It turns out that students do not perceive significant differences in information processing in transmissive and active learning, despite the fact that students learning with IBL seem to perform better than students learning with traditional methods in aspects related to information processing and argumentation (Wilson et al., 2010).

In terms of perceived collaboration, most students perceived all lessons positively. However, *Lesson B and lesson C* were perceived overwhelmingly positively, with around 70% agreement see Figure 1. The obtained data indicate that there is a significant difference in the perceived collaboration between the lessons ($H = 22.78$, $p < .001$). The effect size of this difference is relatively strong ($\varepsilon^2 = .265$). Based on post hoc analysis, it was indicated that there is a significant difference in students' perception between *lesson A* and *lesson B* ($p = .001$) and *lesson C* ($p < .001$).

These findings suggest that *lesson B and lesson C lesson* has the potential to provide more opportunities for collaboration. It appears that the inclusion of IBL aspects in the classroom enables students to have more opportunities for collaboration and thus achieve better results and be more motivated (Gillies, 2003). Therefore, IBL in teaching appears to be a way to increase the level of collaboration in classrooms. When students work together, they learn to offer and accept assistance, exchange thoughts, considering other opinions, resolving issues, etc. (Gillies, 2003). Chen (2021) also came to this conclusion in his study. His study showed that IBL contributed to improving students' communication skills in the work environment and their collaborative mindset in the learning environment. Specifically, it was argued that implementing IBL promoted student engagement in learning. Students had to work in teams and communicate progressively to achieve the set goal.

Limitations

Several limitations need to be considered regarding this study and findings cannot be fully generalized. The research was designed as a pilot study. The results are therefore limited by the sample size and sample selection. Only three model approaches to processing the topic of owls in education were considered. Lessons are very complex, and their perception can be influenced by a number of factors such as the specific sub-topic, teaching methods, etc. Thus, the research presents perceptions of specific validated teaching approaches that can be used for teaching zoology and shows their potential from the students' perspective. It can also serve as a starting point for investigating the influence of particular factors in follow-up research.

CONCLUSION

The intention of this research was to find out how lower secondary school students perceive constructed lessons on the topic of owls with different model approaches in the teaching process. It was found that students perceived the lessons on owls as interesting and useful. However, a lesson focused on food specifications of owls was perceived by students as the most interesting. Students also perceived that they can work more collaboratively with their classmates during the *lessons* focused on owls' food specifications and urban living environments using the IBL aspects. On the other hand, students perceive the information processing opportunities, similarly in all of the verified lessons.

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What are the pros and cons of living here?

Kateřina Bělohoubková & Eliška Krumlová

Abstract

This project-like activity aims to enhance students' scientific literacy and data handling skills, emphasizing graph manipulation awareness, and improving communication and collaboration. Students were grouped to debate the pros and cons of living in different Prague districts, using data on infrastructure, population, and ecology. Each group created and presented original and manipulated graphs to support their arguments, culminating in a class-wide debate and vote to evaluate argument effectiveness. Effectiveness was assessed using a pre-test and post-test administered through the IMI (Intrinsic Motivation Inventory) questionnaire. The results from the IMI questionnaire showed that student responses in the observed areas—expressed interest and effort, perceived usefulness of the subject, and competence—were within the positive range, whereas the students did not feel pressured during activities. This points to the suggested activity's usefulness.

Key words

Statistics; working with data; debate; scientific literacy development

INTRODUCTION

Project-based education has proven to be a dynamic and engaging approach to education, transforming traditional classroom experiences into interactive and immersive educational adventures. This teaching method focuses on practical real-world projects that allow students to delve deeply into subjects and encourage a deeper understanding and mastery of various skills (e.g. Thomas et al., 1999). On itself, it is based on the method of students working on projects, leading them towards independence in their work and motivating them to acquire practical skills through experiments and other hands-on activities (Solárová & Kubicová, 2013). Instead of relying solely on textbooks and lectures, students engage in projects that require critical thinking, problem-solving, and collaborative efforts. The aim is not just to impart knowledge but to cultivate a complex set of skills that extend beyond subject expertise. Literature shows this approach can be efficient when handled well (Rusek, 2021).

Project-based education is a comprehensive method that allows students to connect with the real world, solve problems, and gather information from various fields and sources. It provides space for self-realization, motivates, and supports teamwork. It encourages thinking in relationships and the ability to solve specific tasks or problems (Tomková et al., 2009). Similar to the concept of a "project," the term "project-based learning" (or education) also exhibits significant alignment in defining the concept. Morgan et al. (2013) specify project-based learning (or teaching) as a broader theme encompassing several smaller issues that students face. Project-based teaching emerges from context, relying on authentic experiences essential for meaningful student learning about scientific knowledge, technologies, mathematical concepts, complemented by languages, arts, and other humanities.

Project-based education is often confused or falsely interchanged with other methods. Rusek and Dlabola (2012) categorize school activities based on the level of involvement of students and teachers, and based on outcomes as school events, educational programs, integrated thematic education, and project-based learning. It involves the highest student engagement and requires their utmost initiative. Distinguishing between these terms is crucial for university teachers, leading professionals, and teachers. Patton (2012) points out the similarity with research-oriented teaching and problem-based learning. A significant difference between project-based teaching and these two approaches to education is the publicly presented output, which serves as a significant motivational factor.

Overall, project-based learning represents a shift towards a more interactive and captivating educational model that instils students with a lifelong love for learning and prepares them to confidently and expertly navigate the complexities of the modern world (Janštová & Rusek, 2015).

The main benefit of project-based learning is linking students' everyday experiences with real natural phenomena. By utilizing practical experiences as means to deepen their understanding of scientific principles, project-based learning fosters deep and lasting comprehension of natural sciences among students. This comprehensive approach not only expands their knowledge but also equips them with skills necessary to tackle the challenges presented by the dynamic and ever-evolving world around them (Thomas et al., 1999).

This contribution presents a proposed educational block with project elements focused on scientific literacy and data literacy development. The multifaceted benefits of project-based learning extend beyond mere academic achievement. It serves as a catalyst for the development of crucial competence essential in the modern world. These include but are not limited to enhanced communication abilities, refined collaborative aptitude, and adeptness in navigating an array of informational resources.

Basic characteristics of the designed educational block

The proposed project-based-like module was subsequently divided into three parts: The first segment focused on instruction commenced with education on graph manipulation. The students were extensively introduced to the principles and techniques of graph manipulation through a lecture and interactive presentation with examples. The presentation emphasized identifying possible modifications to graphs and their impact on presented data. The goal of this part was to equip students with the knowledge and skills necessary for the subsequent independent phase and simultaneously acquaint them with the phenomenon of graph manipulation, demonstrating where they might encounter this issue.

The second phase of the block focused on individual student work. The class was divided into three groups, each choosing a specific district in Prague (the choice could be adapted to the school or specific requirements, such as regions or towns). These groups were further divided randomly into two subgroups: those opposed to and those in favour of living in a particular district. After obtaining general information about the selected areas and processing the data, the students embarked on creating graphs. Each group was tasked with creating an original and adjusted graph representing data concerning infrastructure, population, and ecology in the specified urban district (*17 Goals to transform our world*, n.d.). Emphasis was placed on the accurate processing of information and creating graphs in line with the principles of data manipulation (Bryan, 1995).

The third and final part of the instruction concluded with a debate between the competing sides. The participants divided into sides were assigned a role and responsibility to express arguments and information supporting their viewpoint. Debaters had to be able to analyse and respond to opposing views while effectively presenting and defending their own arguments. Debates are commonly used in educational programs or public discussions to explore various perspectives, develop argumentation skills, and critical thinking (Tumposky, 2004). During this phase, each group presented and argued based on their knowledge and created graphs—either original or adjusted. This activity allowed students to apply their communication skills and information presentation abilities. The debate also provided an opportunity for the parties to use valid or invalid graphs to support their arguments. The conclusion of the entire debate involved an anonymous vote by classmates (or a wider jury within the school) on the debate's winner. Following the vote, students were required to submit both versions of the graphs for all three themes, totalling six graphs, for the entire process to be evaluated. This phase enabled students to independently present their newly acquired knowledge and created graphs apart from the rest of the class for assessment and discussion.

ACTIVITY EVALUATION METHOD

The aim of the educational block was to familiarize students with the issue of graph manipulation and expand their knowledge about the environment in which they live. The educational block was piloted at two high schools with the same grade levels. At Gymnázium Evolution, 30 students from the second year participated in the educational block, and at Gymnázium Joachima Barranda in Beroun, 20 selected students from the second year also took part in this educational block.

At the beginning of the block, the students completed a pre-test related to graph manipulation issues. They answered questions about working with data, such as which applications they use to create graphs, whether they have encountered graph manipulation issues in the past, and if they know the essentials a graph must contain.

The questions in test were focused on assessing the knowledge of creating manipulated graphs, understanding the issue of graph manipulation, and the ability to recognize manipulation and provided valuable insights to teachers regarding students' awareness in this field. The test containing questions focused on interpreting graphs, verifying sources, and reasons for investigating the source proved to be an effective tool for enhancing students' skills in evaluating and analysing information. Additionally, this test allowed for the selection of the correct and credible graph with subsequent justification of the choice, thereby promoting the use of critical thinking and the ability to logically argue for the credibility of a given graph.

The educational block was metaphorically divided into three parts based on the "EUR" method - Evocation, Awareness, and Reflection. During the evocation phase, efforts were made to motivate and introduce the topic of graph manipulation to the students. For this purpose, a brief presentation with appropriately chosen examples of valid and invalid graphs was created. In the awareness phase, students worked independently while the teacher acted solely as a moderator. Students searched for suitable topics to counter arguments on the opposing side and subsequently created tables with data and graphs related to those topics. In the final phase, known as reflection, students debated among themselves on the chosen areas. They presented their data and processed graphs to the other students and engaged in discussions about the issues reflected in the graphs. The entire teaching block concluded with a post-test utilizing the IMI questionnaire.

Tools

Within the learning sequence, students filled out two questionnaires. The questionnaires were distributed to the students by the teacher, and subsequently, they returned them back to her/him. At the beginning of the educational block, students completed a graph manipulation questionnaire, which was knowledge-based and focused on the issue of graph manipulation. At the end of the educational block, then, students filled out the second questionnaire, which consisted of two parts: the first contained a knowledge section that included questions similar to those in the first test, allowing us to compare students' knowledge before and after the learning sequence. The second part was the IMI (Intrinsic Motivation Inventory) questionnaire, designed to express respondents' attitudes in various areas. In this case, it involves the subjective assessment of students who participated in the learning sequence (Ryan et al., 1991). This tool has been widely used in assessing various types of activities, such as research-oriented activities, as indicated, for instance, in the studies by Vojíř et al. (2019) and Kuncová and Rusek (2020). The IMI questionnaire was given to students by the teachers at the end of the learning sequence. All students had the same set of questions in the questionnaire, adapted to the theme of graph manipulation issues.

Data analysis

The knowledge questionnaire on graph manipulation was scored with one point for each item. The resulting scores compared data from the pre-test and post-test, which were then plotted on a graph to compare the students' level of knowledge at the beginning and end of the learning sequence.

Using the IMI method in this learning sequence, we assessed five aspects. Specifically, we focused on how students perceive the value/utility, their interest/enjoyment, perceived effort/importance, pressure/tension experienced, and perceived competence during the activities included in the learning sequence. The results from the IMI assessment tool provide subscale scores (Intrinsic Motivation Inventory, 2022). The IMI questionnaire data were analysed using the median, which was calculated for each subscale based on the students' responses. The median was chosen because the IMI questionnaire can contain responses that are extremely high or low compared to the majority of other responses. These outliers can skew the average score and inadequately represent the common experience or attitude of the participants. As a middle value, the median is more resistant to such extremes and can better reflect the typical response of the group.

Limitations of the learning sequence

There were several limitations that can impact this project-based learning sequence. The first one is the motivation of the students, which can influence the course of the instruction. It is crucial to maintain and support students’ motivation throughout the learning sequence.

The second limitation is the time frame of the learning sequence. It is designed with a constraint of 6 teaching hours. It’s essential to consider the number of students participating in the learning sequence. If the number of students is lower, it might be possible to shorten the learning sequence, and vice versa.

Another limiting factor is an access to digital technologies. Students’ use of tablets or desktop computers to fulfil the necessary outputs of the learning sequence are essential.

OUTPUTS AND EVALUATION

The intrinsic motivation

IMI (Intrinsic Motivation Inventory) by Ryan et al. (1991) was utilized to acquire the results and impacts of the entire learning sequence. This tool was employed as a feedback questionnaire administered to students at the end of the learning sequence as it has found its use in several similar projects (Horáková, 2021). One of the questions in the IMI questionnaire pertained to evaluating the student's success in graph manipulation. The task assigned to students was to rate each item based on how true it seemed to them (1 - completely untrue, 7 - completely true).

The values of the students' responses in the first four observed areas (expressed interest and effort, perceived usefulness of the subject, and competence) fall within the positive range on the graph (refer to Table 1). These results indicate that students perceive the activities positively in terms of their effort/importance, interest/enjoyment, value/utility, and perceived competence. Conversely, the results of student responses indicate that students do not feel pressured during activities within the learning sequence (as indicated by the surveyed item - pressure/tension). Furthermore, based on the student assessment values, it is evident that students exhibit a higher level of motivation towards activities associated with practical and creative tasks.

Table 1: IMI questionnaire

Dimensions	Median
Interest/pleasure	5
Perceived competence	4,5
Effort/importance	5
Pressure/tension	3
Value/utility	6

Debate

One of the outcomes of the project-based learning sequence was a structured debate involving two opposing sides. Each debate lasted for 15 minutes, moderated by a teacher. The results of the debate were subsequently decided upon by a panel comprising members of the school through anonymous voting.

Most of the feedback received from students was highly positive. Students recognized the importance of utilizing relevant sources to either refute or verify their hypotheses and assumptions. They acknowledged that working with data is beneficial not only in the context of the project but also in various future activities and tasks.

Results of pre-test and post-test

Figure 2 illustrates the results from the pre-test and post-test assessment of the students' knowledge of working with graphs during the learning sequence. The questionnaire aimed to assess knowledge in creating manipulated graphs, understanding graph manipulation issues, and the ability to identify manipulation. The results provided essential insights into students' awareness levels in these areas. During the last test, the question regarding the selection of manipulated graphs achieved outstanding results. Initially, only 40% answered this question correctly, but by the end, this figure increased significantly to 90%. On the other hand, the question about sources showed a lesser improvement. At the beginning, 50% answered this question correctly, which rose to 75% by the end. This increase was considerably smaller than that observed in the graph selection question. From the positive test results, it was evident that up to 82% of students significantly improved their skills in graph manipulation. None of the participants worsened, and 18% maintained their initial level of knowledge. It is evident that the students' knowledge in the field of graph manipulation significantly increased during this teaching period, clearly demonstrating the benefits of the designed learning sequence for their education and their ability to work with data and graphs.

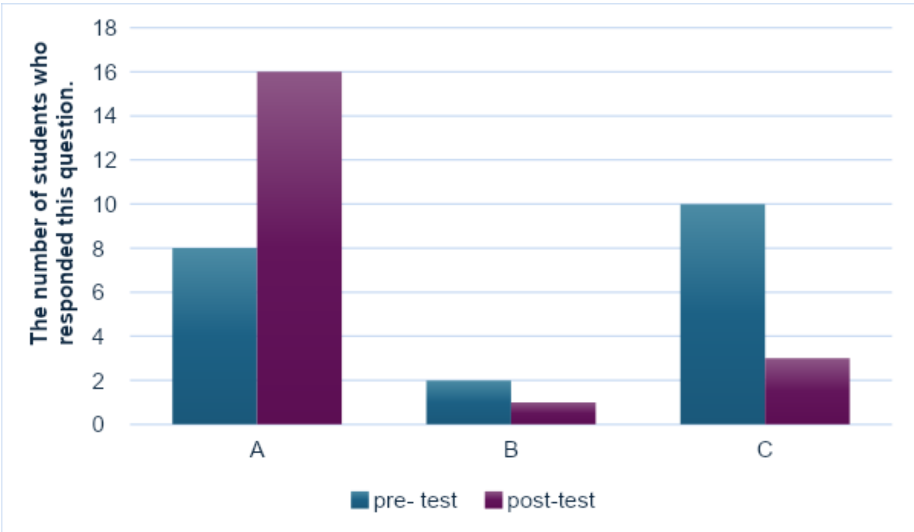

Figure 2: What should I observe when looking at the context of a graph?

Note:

A: I am observing whether the graph sufficient information for understanding the issue.

B: I am checking if the graph has title that includes the topic the graph is about.

C: I am checking if the graph has at least 5 columns to provide enough context for understanding the issue.

The students created a set of graphs representing original data and subsequently adjusted graphs derived from their experiments. The original graphs (see Figure 3) illustrate the data trends from their data collection, while the adjusted graphs (see Figure 4) resulted from deliberate alterations or manipulations with the data, such as changes in scales, distortion of data, or other modifications that alter the results' interpretation. Comparing these two sets of graphs provides insight into how data manipulation can influence information presentation and lead to distorted interpretations. Through this exercise, students explored the impact of graph manipulation on result presentation and gained a better understanding of the importance of maintaining data accuracy and integrity when creating graphs for various purposes.

Figure 3: Valid graph of unemployment

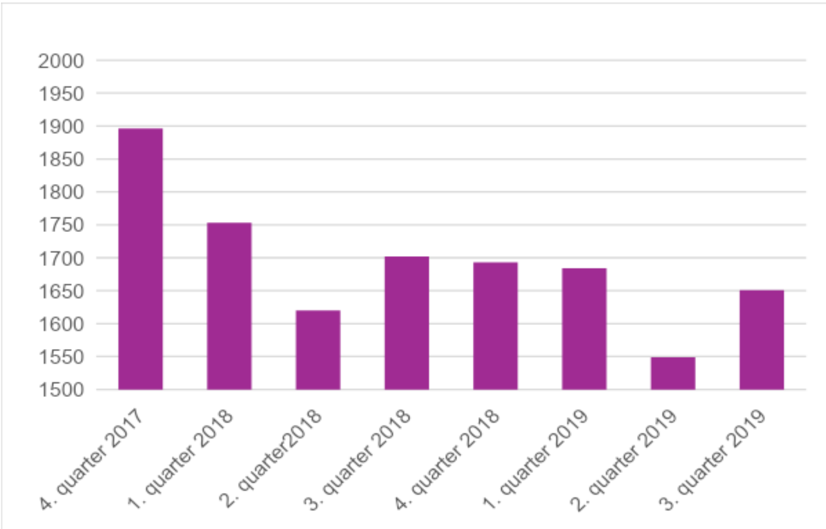

Figure 4: Invalid graph of unemployment

DISCUSSION

This educational method focuses on specific real-world projects, enabling students to deepen their knowledge in the subject and fostering the development of various skills (Thomas et al., 1999). Its goal is not only to convey information but rather to develop a comprehensive set of abilities that go beyond mere expertise in a particular field. According to Rusek (2021), the effectiveness of project-based education has gradually improved from the study by Thomas (2000) through the findings of Markham et al. (2003) to the research conducted by Chen and Yang (2019). However, there are also authors who argue that project-based learning is too complex to be easily measured (Kokotsaki et al., 2016).

In today's era, numerous publications are available that support the development of scientific literacy. One of these resources is the contributions found in the compilation "Project-based Teaching in Science Subjects" (Stárková & Rusek, 2014) encompassing articles such as "Utilizing m-Technologies in Problem-solving, Investigative, and Project-based Learning," "Ecological Life Starts with Us," and "EKO Project." Another valuable resource for project-based learning could be the module "Project Teaching: Cross-cutting Themes with a Scientific Focus" (Válek et al., 2014), which covers topics like "Explore Your Environment" and "Noise." Finally, there is another beneficial source in the form of the PBE proceedings.

It is evident that our project-based learning sequence exceeded our expectations. The students' enthusiasm for seeking information was remarkable, and their ability to organize and collaborate effectively within groups led to the successful completion of the project's final phase.

Throughout the ongoing discussions, diverse topics emerged, covering a wide array of subjects. The discussions gradually gained depth and breadth, focusing on areas related to ecology, infrastructure, and population. Students delved into topics ranging from issues like road noise and population density to environmental conditions, crime rates, or the ratio of population to hospital beds in a given area.

At the beginning of this interaction, the teacher encouraged students to consider all these aspects. This prompted discussions on various topics, which progressively became deeper and expanded to include aspects related to environmental impacts, infrastructure needs, and population dynamics.

As the interaction progressed, the teacher gradually assumed the role of a moderator, guiding the flow of debates and encouraging participants to engage more actively and explore different perspectives on the issues. This approach allowed the discussions to deepen, resulting in a richer understanding of the complex interrelations between ecology, infrastructure, and population characteristics in the specified area. Eventually, the teacher took on the role of debate moderator.

CONCLUSION

The results from the IMI questionnaire indicated that the values of student responses in the observed areas—expressed interest and effort, perceived usefulness of the subject, and competence—are within the positive range, therefore the designed learning sequence can be considered positive as long as the intrinsic motivation is concerned. Based on the students' feedback, they enjoyed learning, found it engaging. From the authors' perspective, the entire learning sequence surpassed expectations. The students were intrigued by the topics, and the arguments and data they were able to find were on a high level. Additionally, at the Evolution Gymnasium, students were proficient in citing and referencing data sources, which simplified their work making the outcome more professional.

Moreover, during the pilot phase of this project, it became evident that a desktop computer or a laptop is more suitable for working with data compared to a tablet, which made creating graphs more challenging. This is considered a valuable aspect as readers are encouraged to employ similar activity in their lessons.

Rigorous testing of knowledge during the educational block revealed that up to 82% of students significantly improved their skills in graph manipulation. The remaining 18% maintained their initial level of knowledge without any decline among participants. The overall evaluation of the project by students showed a highly positive reception and its significance for their future academic and life paths. This educational block was designed for second-year high school students, yet minor adjustments could allow its implementation in elementary schools. It would serve as a tool for better understanding the area where students live and subsequently lead to a more profound exploration of the specific locality in relation to their education.

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Strengths and weaknesses of using the EduScrum method in science education

Tomáš Čížek & Karel Vojíř

Abstract

Project-based learning presents a complex challenge for students, particularly in honing skills related to planning, self-management, and collaboration. Addressing this challenge requires a systematic approach to develop these competencies. The EduScrum method, known for its structured framework, offers a potential solution for effective teamwork management. This study explored student perceptions of the EduScrum method within the context of biology education. A questionnaire survey was administered to 86 lower secondary school students, revealing that the most highly valued element of EduScrum was its emphasis on team cooperation.

Key words

Project-based education; biology education, lower secondary education

INTRODUCTION

Today's society is undergoing rapid changes that bring a number of challenges. To prepare students for life beyond school, teaching cannot be thought of in terms of factual knowledge alone. This is emphasised in strategic documents on education (e.g. Council recommendation, 2018). Also, Czech curriculum documents directly state that teaching should develop students' key competencies, which are also psychomotor and affective in nature (see MŠMT, 2023). To ensure the development of these aspects of the pupil, it is necessary to choose appropriate teaching methods that put the pupil in an active position. Teaching through activating methods enables learning in which the individual is not a passive recipient, but shows his/her own initiative, acts, is active (Průcha et al., 2003, p. 35). Many publications deal with the characteristics of activating methods which are active work with learning sources, team cooperation, communication, time management and planning (e.g. Kotrba & Lacina, 2015; Petty, 2013). Many methodological materials with specific assignment suggestions are also published (see Rusek & Vojíř, 2018). However, despite methodological support for teachers, implementing open-ended activation methods such as project-based learning is proving to be complicated (see Aldabbus, 2018). Many of the challenges are on the side of students, for whom high autonomy in learning and time organisation is quite challenging. These students' skills therefore need to be developed gradually. At the same time, there appears to be a need to provide them with sufficient scaffolding (see Butler & Lumpe, 2008). It turns out that Czech textbooks, as a concretization of the curriculum, do not provide support in this respect through assignments (Vojíř, 2021) and teachers use them as a source of educational content (Vojíř & Rusek, 2022). Therefore, for its didactic transformation (see Knecht, 2007), which will also include the targeted development of skills related to project solving, it is necessary to look for complementary educational methods. As such a method, the EduScrum method (see Delhij, 2019) can be used, which by its nature systematically targets structured self-directed teamwork of students.

Characteristics of the EduScrum method

The EduScrum educational method is based on the Scrum system, which belongs to the group of agile methods used in the business sphere. These methods are characterized by tools for rapid adaptation to environmental conditions, and constant feedback provided by daily communication of all parties involved. A solid core is formed by good teamwork (Fernandes et al., 2021).

The EduScrum method was developed in 2011 to improve students' preparation for the dynamic labour market (EduScrum, 2021). By modelling the adoption of the system used in the work environment into an educational method, this method fulfils key aspects of project-based learning related to the authenticity of problem-solving and connection to the real world (cf. Kokotsaki, 2016).

In the EduScrum method, the teacher plays the role of a product specifier. He has the primary responsibility for explaining the rules of the method and monitoring their compliance throughout the process. Furthermore, he is responsible for understanding all the criteria of the work by the students, giving continuous feedback and facilitating the whole process (Delhij et al., 2019).

The method is characterized by a list of tasks. Each task has a title briefly describing what topic the task covers and specific criteria for the form of the output. The work criteria may be explicitly listed or hidden in a coherent text, depending on the experience and maturity of the students. The assignment also includes the due date and the form of assessment of the assignment (Delhij et al., 2019). For solving the assignments, students are divided according to an anchored methodology, which directs students to perceive the competencies of individual students and to learn the strategy of forming variable teams with respect to the needs of the assignments. Students organise their own work (there is no set way to achieve results), team members have collective responsibility for the outcome and individual members are free to decide which tasks to work on (Delhij et al., 2019).

In each team, one student plays the role of EduScrum master. In the beginning, he is selected by the students or the teacher when the teams are formed. He is responsible for balancing the team's composition according to skills and abilities, keeping the Scrum Board up to date and overseeing the ceremonies (Delhij et al., 2019).

Scrumboard is an essential tool for managing student work in solving tasks. On a large sheet of paper, students record the project topic, team name, team members, and any assignments. First, they write the names of the tasks in the Stories section and add any Celebration Criteria alongside. Next, they plan the work using sticky notes. At the same time, they give each task a point value on the paper according to its expected difficulty. All the sticky notes are in the To Do section at the beginning. As the students work on them, they move them to the Busy section, and when they finish, they end up in the Done section. This gives the whole team an overview of what they are currently working on and how much work still needs to be done (EduScrum, 2021).

There are four more help sections at the bottom of the bulletin board. The first is the definition of done (D.o.D.), in which students specify what it means when a job is finished. Next is the definition of fun (D.o.F.). This is used for students to set criteria for having fun while working. The run-up chart is used to record progress. The curve is created by recording the point value of the tasks as they are completed over time. The last section is the Impediments section, which records anything that hinders or makes the team's work impossible (EduScrum, 2021). Rituals include pre-determined activities set for all students, such as team divisions, a meeting at the beginning of each lesson involving planning the next solution (typically at the scrum board), a review of the solution, or personal reflection (Delhij et al., 2019).

EduScrum-oriented research so far is quite limited. This method has been validated in the context of tertiary education (e. g. Atencio et al., 2022; Quintero, 2021). The use of the EduScrum method has been shown to have a positive impact on the quality of student collaboration and projects. The method was more widely applied, especially in programming and mathematics courses (e. g. Cardoso et al., 2017; Pinto et al., 2018). However, the EduScrum method has not yet received wider research attention in other disciplines and lower levels of education.

Research aim and questions

The EduScrum method is a relatively new method, which has not yet been studied in the Czech environment. The aim of this qualitative study was to pilot test the possibility of using the method in teaching biology in lower secondary education and to find out how the method is perceived by students. This intention was concretised through descriptive research questions:

- Which strengths and weaknesses do lower secondary students perceive in relation to the EduScrum method in teaching biology?
- What risks do lower secondary students perceive in relation to the EduScrum method in biology education?

- What personal benefits do lower secondary students perceive in relation to the EduScrum method in biology education?

METHODOLOGY

A pilot study was conducted at Elementary school Angel in Prague 12 to answer the research questions. The research sample consisted of 86 students from four classes. These were two grade 8 classes (40 students) and two grade 7 classes (46 students). All students completed one programme guided by the EduScrum method. In the seventh grade, the program focused on amphibians. In the eighth grade, the program targeted the topic of mammals. The students had no previous experience with the EduScrum method. For this reason, the first lesson was devoted to explaining the principle of the method and further clarification of the tasks. In each class, students were divided into teams of four or five students.

Immediately following the programs, the students completed a questionnaire consisting of four open-ended questions analogous. Specifically, students were given a paper with the following questions: What are the strengths of the EduScrum method? What are the weaknesses of the EduScrum method? What risks do you see in the method? What useful you take away from working with this method?

The students' statements were qualitatively evaluated using the open coding method. In the first coding step, particular statements were identified on the basis of their semantic consistency. A complete linguistic structure consisting of one or more sentences related to one topic was considered as a statement. In the next step, each statement was assigned a code reflecting its main meaning. To ensure reliability, each of the statements was evaluated by two independent researchers. In case of disagreement, a decision was made based on the principle of consensus by agreement. Subsequently, the identified codes were grouped into main categories and the identified categories were qualitatively described.

Characteristics of the teaching programme

The teaching programme was conducted in the seventh and eighth grades of the second primary school. In the seventh grade the topic was amphibians, and 8 lessons were allocated for the work. In the eighth grade, the topic was mammals which is more comprehensive, and 20 lessons were devoted to it. In addition, this programme was supplemented by a visit to the Zoo Prague. These topics were chosen because they are complex blocks corresponding to the thematic curriculum of the research school.

7th grade

The programme for the grade 7 included four tasks: dubbing a video about amphibians, creating an atlas about amphibians, a picture of amphibians' life cycle, and a year of the Czech amphibian representative. They worked on the tasks according to the given criteria.

In the first task, they translated keywords from English into Czech (e.g. amphibian, lungs, breathing...). Next, they dubbed the video from English into Czech using an iPad according to the original text. The criterion was that the voice of all team members was heard. The finished task was exported to a prepared repository (Google classroom). The learning goals were that students use the terminology of the topic, and they list the characteristics of amphibians.

In the next task the students worked in Bookcreator. They worked on 4 amphibian representatives. For each representative, they set the mandatory information: picture, description, occurrence, food and interesting facts, which were given as a continuous text. Each amphibian had one separate page in the book. The learning objective was that students will identify four selected amphibians.

In the art task, the students created a picture on an A3 quarter sheet according to a picture found and checked by the teacher. The criterion was to use tempera or watercolours. The purpose of the assignment was that students describe the life cycle of amphibians.

In the last task, the work was done in Fakebook, to which students added 10 entries from the whole year of a selected Czech amphibian representative. Finally, they sent the link to the teacher by e-mail. The learning goal was that students will describe the life strategy of one Czech amphibian.

8th grade

The program on mammals included 6 tasks: create a natural history dictionary, a zoo travel plan, a zoo interview, a mammal website, an anatomical picture of a mammal, and a podcast focusing on mammal adaptations in different biomes. The glossary included selected terms (e.g. hibernation, bipedal, biome...) for which students provided definitions and examples. The dictionary also had to have an original cover with the team name and team members' names. The learning objective of this assignment was that students master the terminology of the topic.

In the next task, students planned a public transport journey to Prague Zoo and found out the total cost of the trip. They also chose 3 representatives of mammals to visit. They planned the trip in mapy.cz. They compiled everything into a document and sent it to the teacher's e-mail. The purpose of this task was that students plan a trip to the Prague Zoo.

The aim of the next task was to film a fiction interview with the selected representatives. The students divided the roles into experts on the mammals and a moderator. The length of the video was 6-8 minutes. Finally, they uploaded the video to the prepared repository. The learning goal was that students explain the way of life of selected mammals.

In the next task, students created the website content prepared by the teacher. They described two mammal orders. The required information was: brief characteristics, distribution, food, body description, interesting facts and three order representatives. Furthermore, they supplemented the text with pictures, links for more information and a revision activity (quiz, puzzle...). The aim of this assignment was to make a website about mammals according to the given criteria.

In the art activity, the students worked on an A3 quarter sheet. They used only watercolours or tempera. The picture had to be accompanied by descriptions of the different organs and their function. The learning objective was that students describe the anatomy of a selected mammal and explain the function of each organ.

In the last task, students divided their roles into experts and moderators. The criteria were to choose 3 world biomes and within them two mammals on which they could demonstrate adaptation to the environment. The time span of the podcast was 5-8 minutes. Finally, they exported the whole work again to a prepared repository. This task was aimed at explaining the adaptation of mammals to their environment using examples.

RESULTS AND DISCUSSION

In characterizing the strengths of the biology education using the eduscrum method, students made 138 statements. Although the results cannot be fully generalized due to the limited research sample, they show the main aspects that students consider in relation to teaching with EduScrum.

Strengths of the biology education using the EduScrum method

Teamwork was the most frequently highlighted strength of the biology education using the EduScrum method, mentioned in 40 (29%) statements. Also considered were fun (27 statements, 20%), self-direction (17 statements, 12%), practicality (13 statements, 9%) and coherence of the method (11 statements, 8%).Other strengths mentioned (always less than 5% of statements) related to communication, social aspects, transparency of the solution process, the role of the teacher, planning, understanding of the learning content, depth of processing of the topic, achieving quality outcomes, democracy, creativity, development of patience and attitude to learning.

Students' perceived strengths in terms of collaboration and self-management indicate that the method may be suitable for acquiring these skills, thus appearing to prepare students for fully project-based learning and, consequently, life beyond school (see Kokotsaki, Menzies, & Wiggins, 2016). The perceived aspect of fun appears to be essential given the long-standing unpopularity of science subjects (Höfer & Svoboda, 2005), and the EduScrum method may thus be instrumental in popularizing them with students.

Concerning the perceived personal usefulness of the biology education using the EduScrum method, students made 103 statements. 29 (28%) of these statements related to deepening knowledge. In addition, the development of skills in working with people (19 statements,18%), the development of skills in general (13 statements, 13%), the applicability of the skills acquired to life (10 statements, 10%) and the development of organisational skills (9 statements, 9%) were mentioned by students as benefits of the education using the EduScrum method for themselves. In other statements (always less than 5% of the statements), students considered the development of text-handling skills, communication skills, social skills, information-seeking skills, mutual respect, independence, and the ability to work under pressure.

The students' perceived usefulness of the method in terms of knowledge and skills appears to be positive concerning their motivation to learn. This significantly impacts the internalisation of knowledge and self-regulation of learning (cf. Deci et al., & Leone, 1994). The activity-based nature of teaching also targets skill development (Petty, 2013; Kotrba & Lacina, 2015), which confirms students' perceptions of skill development. Students' perceptions of the benefits of EduScrum confirm its strengths as an effective activation method, for which Kotrba and Lacina (2015) highlight the potential for social and organisational skills development. The perceived applicability to life indicates a positive perception of the work as meaningful and sets a positive motivation for the activities (cf. Petty 2013).

Weaknesses of the biology education using the EduScrum method

Concerning the weaknesses of the biology education using the eduscrum method, students made 97 statements. The most frequently mentioned statements related to possible problems with non-cooperation in the group. This weakness was mentioned in 22 (23%) statements. In addition, students mentioned problems with team dysfunction (13 statements, 13%), the difficulty of self-management (12 statements, 12%) and time commitment (12 statements, 12%). In fewer than 5% of the statements, students also mentioned possible boredom at some stages of the solution, less knowledge gained, pressure for group work, difficulty of the work, risk of underdevelopment of some students, possible problems with motivation and liking of the method, or problems with the technology used.

Students made 117 statements about possible risks. The risk of possible lack of cooperation was the most frequently mentioned risk, mentioned in 29 (30%) statements. Other risks mentioned by students were the absence of group members (18 statements, 15%), the fear of poor evaluation (14 statements, 12%) and not being able to complete tasks in time (14 statements, 12%). Students reported perceiving no risks in 9 (8%) statements. In units of statements, students also mentioned risks associated with risk of accidents, misunderstanding the assignment, poor group management, irresponsibility in solving, low pupil motivation, loss of output, inadequate time, deterioration of classroom relationships, fun over learning and poor team composition.

Non-cooperation was among the most frequently cited weaknesses of the method and risks to its implementation. This can be seen in the context of self-determination theory, as a concern about unmet needs, particularly the need for relationality (Ryan, Deci, 2017). Similarly, the absence of group members and their lack of involvement are risk factors that places more demands on other members. When a group is dysfunctional or overloaded by the absence of members for long periods, the risk of missing assignments and receiving a poor grade increase. Thus, the teacher should not neglect these factors when implementing the EduScrum method.

CONCLUSION

The EduScrum method, as a method of education based on agile working methods, can be used in science education. Survey has shown that students most often cite teamwork as the strongest aspect of this method. Similarly, problems with non-cooperation are most often cited by students as a weakness of the method and a major risk for implementation. Thus, they point to a key aspect of the method that needs attention during implementation. It appears that students perceive the method as beneficial for the development of their knowledge and skills, based on their experience of learning biology, suggesting the possibility of its targeted use in education.

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The impact of activating teaching strategies on the achievement of cognitive and affective goals in plant education at the primary school

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Abstract

The paper focuses on the evaluation of the effectiveness of STEM -oriented teaching activities linking botany education with practical life in primary schools. The data were obtained through an experiment. In the control group, teaching in the regular classroom was conducted using traditional methods (N= 83 pupils), while in the experimental group, teaching mainly involved STEM oriented education (N= 85). The results show that teaching with STEM activation elements has a weak, but statistically demonstrable effect on the acquisition of new knowledge, but above all on increasing the popularity of botanical topics among primary school pupils and on their understanding of the connection between the curriculum and everyday life.

Keywords

Botany; primary schools; activating teaching methods; experiment

INTRODUCTION

The key role of vegetation in the functioning of ecosystems and its impact on human society is undeniable (Pauleit et al., 2011; Chen et al., 2014). Plants are of vital importance in any ecosystem. They are producers of wood, paper, oxygen and a source of energy for animals and humans (Kubiatko et al., 2021). Botanical knowledge of plants plays an important role in solving many global problems (Douglas et al., 2019). Examples include food production limits in different parts of the world, environmental degradation and anthropogenic impacts on climate change (Bonan, 2002; Rötzer et al., 2019). Through ignorance, humans can then make a series of unqualified decisions (e.g. incompetent interventions in vegetation cover) that often affect entire generations to come (Morison & Morecroft, 2006; Ryplová, 2018). For this reason, the general dissemination of plant awareness must take place in the primary school environment. Cognitive and affective goals are strongly shaped by the socio-cultural environment, which includes, in addition to the family, the classroom collective, led by the personality of the teacher, from pre-school and younger school age (Kuwabara & Smith, 2016). There has been a lot of research in the field of science curriculum at different types and levels of schools in the Czech and especially in the world pedagogical community (e.g. Uno, 2009; Patrick & Tunnincliffe, 2011; Balas et al., 2014; Ryplová, 2017). The results show several negative facts that will need to be addressed in the future.

Pupils' interest in science education is declining worldwide, as confirmed by both foreign and national research (e.g. Veselský & Hrubišková, 2009; Sláviková et al., 2012; 2008; Uitto, 2014). Science education consists of many sub-disciplines that show varying degrees of student popularity (Fančovičová & Prokop, 2011). In the following, we will discuss in more detail the teaching of botany, which is generally considered to be one of the less popular components of nature education (Balas & Momsen, 2014; Jeong et al., 2015; Selvi & İslam, 2021).

Plant topics are received rather negatively in the school learning environment (Martín-López et al., 2007; Fančovičová & Prokop, 2010; Jose et al., 2019). In Elster's (2007) research, botany even comes out as the least fun of all science topics. Plants are generally less fun for students than animals (Schussler & Olzak, 2008). The main causes include the fact that plant organisms lack movement (Kinchin, 1999) and botany is seen as difficult and boring (Balas & Momsen, 2014). Another reason is named by Hemingway et al. (2018), who state that the fact that students encounter animal organisms much more frequently during class has an impact on negative attitudes towards botanical topics because a) the curriculum gives more space to animal organisms and b) teachers themselves know animal organisms better and therefore use them to demonstrate generally valid biological phenomena. Plants also show less pronounced visual signals than other elements in the ecosystem (Bonan, 2008). Another limiting factor is the fact that during primary school pupils encounter the plant world mainly in terms of anatomy and morphology and knowledge of basic taxonomic species, topics that require rather memorization and orientation in scientific terminology (Ryplová, 2017). Then plants are easily perceived as abstract, static, hard to understand organisms. Research by Canal (1999) and Carlson (2002) shows that these issues are among the most difficult topics in biology and students often perform poorly (Vidal & Membiel, 2014). In the international literature, the term "plant blindness" has even been used since the 1990s (Wandersee & Schussler, 1999). Plant blindness is explained by Strgar (2007) as a complete disregard for plants, especially their ecological importance to the environment. To reduce prejudice against people with disabilities, the term "plant awareness disparity" is used in more recent publications for plant blindness (Parsley, 2020).

Further research shows that the increase in the attractiveness of botany is mainly influenced by activating interdisciplinary educational approaches (currently e.g. STEM – Science, Technology, Engineering and Mathematics), linking teaching with practical life and greater interaction with concrete organisms in the classroom (Lohr & Pearsoon-Mins, 2005; Balding & Williams, 2016; Robinson et al., 2016). Most of the studies described are situated in lower secondary and secondary schools. Therefore, we attempted to investigate the primary schools, specifically in grade 5.

MAIN GOAL

The main aim of the study was to examine the effect of different teaching strategies on the achievement of cognitive and affective learning goals of primary school students in the area of botany, which appears to be boring and difficult. The authors' sub-goal was to make the topic more attractive and popular for pupils. For this reason, STEM elements were also implied in the experimental group. The lesson entitled How do plants travel? focused on how generative parts of plants spread. The idea was to make plants (parts of plants) move and to make practical connections between humans and the plant kingdom. It is the little action and the abstractness of the teaching in terms of misunderstanding its meaning that pupils mention as the main shortcomings of the botany curriculum (see chapter introduction).

METHODOLOGY

The Research Process

The actual data collection was preceded by a pilot survey in which 38 fifth-grade students participated. Based on the results of the pilot survey, the lessons and proficiency tests were finalised (the lessons and proficiency tests were commented on by ten practising primary school teachers).

Data were collected in a controlled manner using the experimental method. The research was conducted in the fifth grade in three elementary schools, which always had two parallel classrooms (control; experimental) in which an identical teacher taught the classes to filter out one of the limiting factors, i.e., teacher personality. In the research, 85 pupils participated in the experimental group and 83 pupils participated in the control group (N= 168).

Before the experimentation started, the students were given a knowledge test (pre-test) to measure their level of initial knowledge. The pupil could score 0 to 10 points. For operational reasons, it was not possible to create paired samples, i.e. homogeneous classes in which pupils were equally distributed according to their scores on the initial test. This fact can be seen as a limiting factor of the investigation. The difference in pre-test scores was not significantly different between the groups ($t(166) = 0.51$; $p = 0.61$). Thus, the starting position in both groups was at a comparable level. In the experimental group, teaching was conducted using real natural resources in a school garden setting and using elements of STEM (e.g. comparison of distances travelled by individual seeds, time traces of movement, calculation of movement speed and explanation and reasoning). In addition, concrete examples of human inspiration in the plant kingdom were included in the education (e.g. maple seedpod - propeller, dandelion fluff - parachute, anchor seeds - kayak, burdock fruit - velcro ...). The control group was taught in a typical conventional style using a textbook and an interactive whiteboard. The educational unit lasted 90 minutes in both groups. One week after the end of the experimentation, the pupils' output knowledge was verified by a single post-test. The post-test was the same as the pre-test but also included Likert-type questions (e.g., following Reynolds-Keefer et al., 2009) that verified students' achievement of affective goals.

Data analysis

The level of knowledge, assessed through pre-test and post-test scores, underwent analysis via Repeated-measures ANOVA, utilizing group (experimental versus control) as a variable. To compare the variance in subjective enjoyment and perceived real-life applicability between the experimental and control groups, a t-test for independent samples was employed. Despite deviations from normality, parametric tests were selected for analysis due to the robustness of these tests to violated assumptions (Carifio & Perla, 2008; Norman, 2010; Blanca et al., 2023).

RESULTS

The results of the post-tests indicate that there was a significant increase in botanical knowledge in both groups (control; experimental). ANOVA with repeated measures showed a statistically significant difference ($F_{1, 166} = 2061.25$; $p < 10^{-17}$). A significant difference between the groups was also diagnosed, with the experimental group showing a greater improvement than the students in the control group ($F_{1, 166} = 4.92$; $p = 0.03$; with trivial effect size (partial $Eta^2 = 0.03$)). The average score on the post-test was 6.88 points in the control group and 7.2 points in the experimental group (see Figure 1). Achievement of affective goals was determined based on the subjective opinion of the student. A Likert scale was used, with 5 being definitely yes and 1 being definitely no. Figure 2 visualizes the results obtained in response to the statement. Subjective ratings of the enjoyment of the lesson showed significantly higher scores in the experimental group compared to the control group ($t = 5.35$; $df = 166$; $p < 10^{-6}$; with small effect size (partial $Eta^2 = 0.15$)). Thus, the lesson was rated as significantly more enjoyable in the experimental group. In the same way, a subjectively rated measure of the connection between teaching and real life was obtained. In this case, students responded to the statement "The information gained during the class is useful for life" (5=definitely yes; 1=definitely no). The results are shown in Figure 3. It shows that the learning in the experimental group was more connected to practical life and the information is more applicable in the future. The results are again statistically significant ($t = 5.64$; $df = 166$; $p < 10^{-6}$; with small effect size (partial $Eta^2 = 0.16$)).

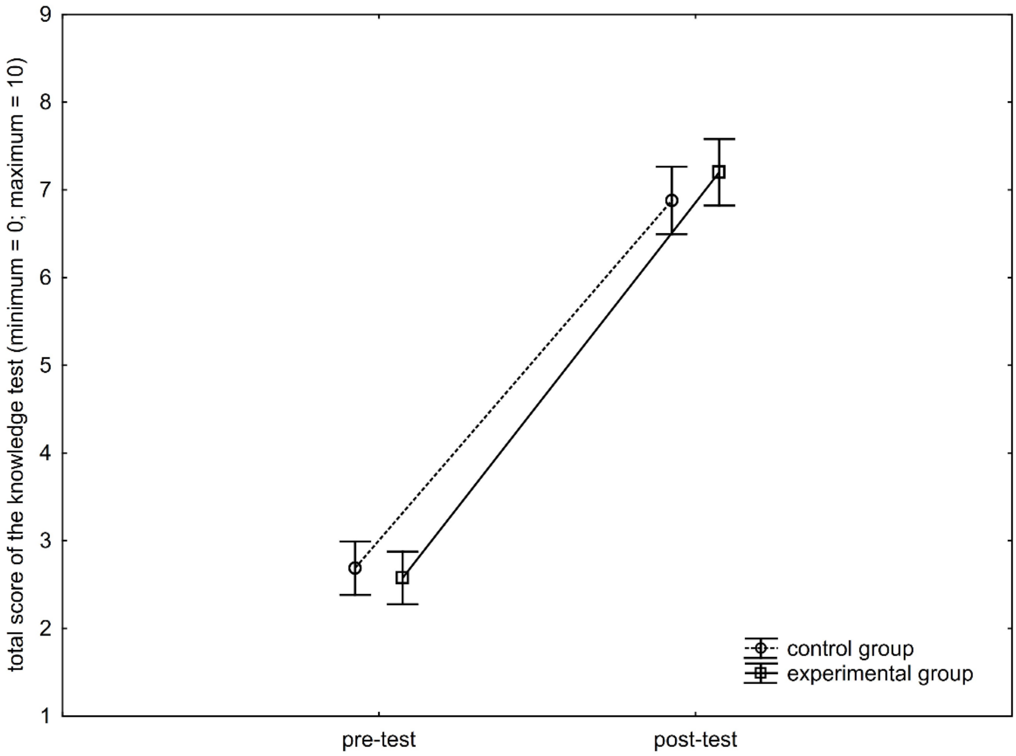

Fig. 1 Total pre-test and post-test scores for experimental and control groups ($F_{1, 166}$ = 4,92; p = 0,03)

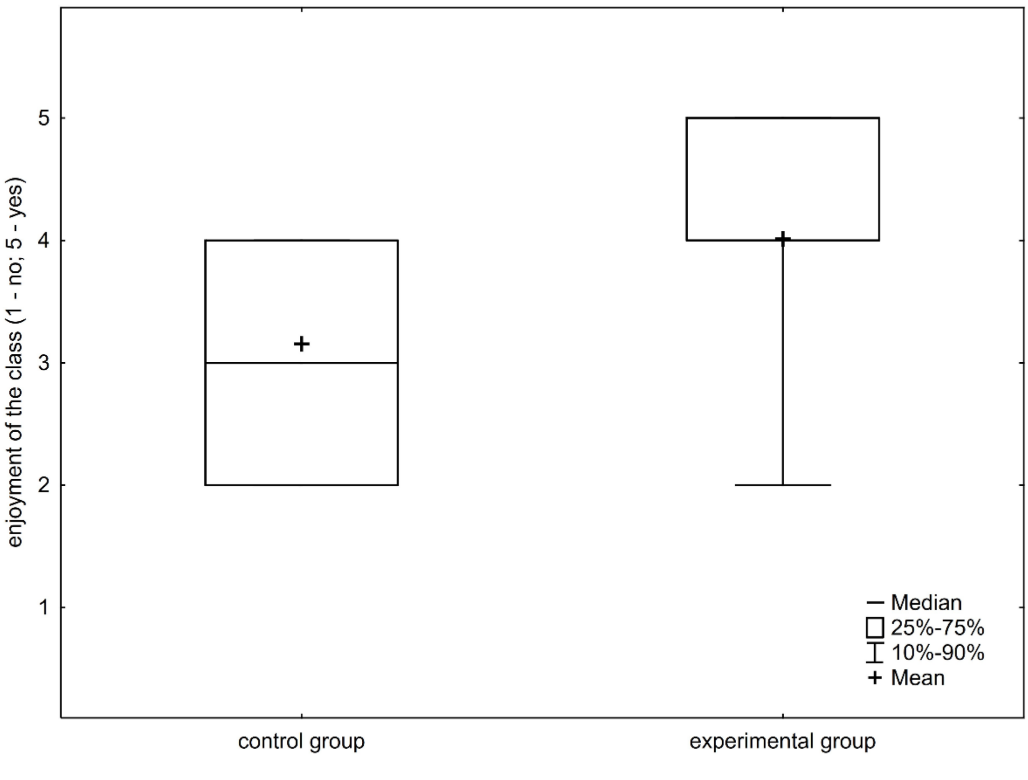

Fig. 2 Subjective measures of enjoyment of teaching in the control and experimental groups (t = 5,35; df = 166; p < 0,01)

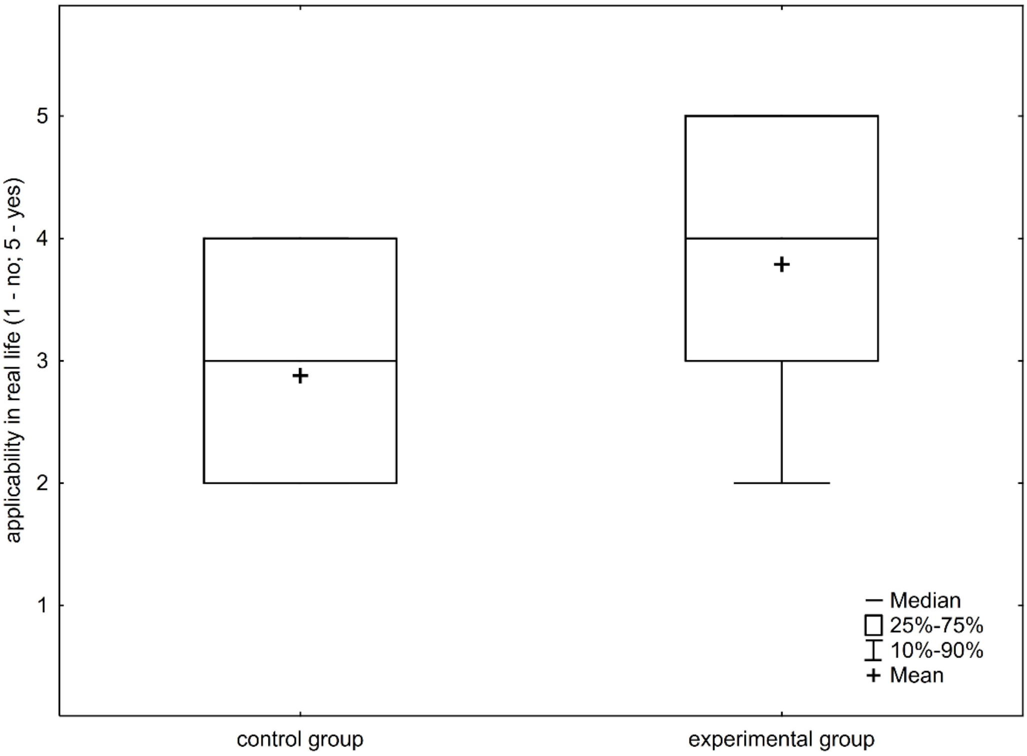

Fig. 3 Applicability of acquired knowledge in real life (t = 5,64; df = 166; p < 0,01)

CONCLUSION

The results show that teaching using activating educational strategies based on STEM principles and real natural environments had a statistically significant effect on the acquisition of new knowledge (low statistical significance and trivial effect size) and increased enjoyment of botany (high statistical significance and small effect size). Even though the resulting effect sizes are relatively small, the authors of the paper believe they are meaningful because even small steps are allowed to lead to a big goal. We can debate whether cognition or fun is the main thing to emphasize in teaching. However, it is indisputable that factual knowledge is one of the fundamental pillars that influence students' interest and attitudes in various topics. Similar conclusions are reached in studies such as Kubiatko et al. (2021) and Nyberg & Sanders (2014). Of course, the reverse phenomenon is also true; if students enjoy learning, they often have better outcomes (Arroyo et al., 2020). The environment in which learning takes place is also crucial in the learning process (Rusek et al., 2016). In this case, the use of school gardens has proven to be a good option, as their potential for botanical topics and STEM education is indisputable, as reported by Klemmer et al. (2005) and Vácha (2015). Direct manipulation of the natural world also plays an important role (Leuven et al., 2018; Kim et al., 2020). In the case of our research, generative plant parts with different dispersal strategies have proven to be useful in the context of plant dispersal. At the same time, the teaching conducted in the outdoor environment and the work with real organisms had a significant impact on the understanding of the connection between the topics discussed and practical life. In conclusion, it can be assumed that the chance to make botanical issues more attractive in the future is to involve different activation strategies in which the student is not only a passive recipient and manipulates real organisms, preferably in their natural environment. Linking learning using real-life science and digital technologies, which are essential for today's youth, also appears to be an effective approach (Ryplová et al., 2023). The reality described will of course require time that is not available to educators in the current primary school curriculum. It will therefore be necessary to rethink and possibly reduce the curriculum and place more emphasis on topics that are more enjoyable for pupils and easier to relate to everyday life. This will have to be the subject of further discussion by the educational community.

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The impact of prior knowledge on the educational effectiveness of simulations for reconciling chemical equations

Małgorzata Nodzyńska-Moroń & Vladimír Sirotek

Abstract

Balancing chemical equations is a difficult element of chemical education. Therefore, the solution is to use PhET simulation, which shows how by making sandwiches you learn to balance chemical reactions. Our previous research has demonstrated the usefulness of this simulation in teaching children aged 9 to 12. Over 50% of them achieved success. The research aimed to investigate whether this simulation is equally useful in teaching older students (respondents were between 14 and 19 years old). A total of 251 students completed a pre-test and then a post-test after working with the simulation. It turned out that the longer students studied chemistry, the more difficult it was for them to understand this analogy. As an explanation for this fact, psychological concepts such as negative transfer, proactive. This means that simulations should be used at the earliest possible stages of learning.

Key words

Balancing chemical equations; chemical reactions; learning by analogy; pro- and retroactive inhibition; computer simulations

INTRODUCTION

Writing and balancing chemical equations is the basis of teaching chemistry at all levels of teaching. This is undoubtedly one of the most difficult elements of chemical education. Research (BouJaoude & Barakat, 2000; Dahsah & Coll, 2008; Dierks et al., 1985; Fach et al., 2007; Schurmeier et al., 2011) explain why this skill is difficult for many students. Over 10 years of research, scientists identified 8 main problems. It follows that the main problem in writing and balancing chemical reactions is the complexity and multi-stage nature of this process. Many scientists have conducted research trying to solve this problem. For example, Bílek et al. (2018) contend that a practical way to teach the balancing of chemical equations would be introduced earlier in the educational curriculum, such as mathematics classes. A qualitative case study conducted by Chandrasegaran et al. (2009) were designed to test students' understanding of the limiting reagent concept and the strategies they used to solve four reaction stoichiometry problems. Students' written problem-solving strategies were examined using a think-aloud protocol during problem-solving and retrospective verbalization after each problem activity. Kern et al. (2010) presented the results of a large-scale (n = 1.337) qualitative descriptive analysis of partial representations of a chemical reaction by US high school students. Student representations were coded into 17 distinct subcategories. Of the 65% of students who successfully balanced the equation, more than half were unable to identify the correct representation of the particles. The ability to represent a chemical reaction at the symbolic level does not guarantee the ability to represent the reaction at the particle level. Naah and Sanger (2012) identify students' misconceptions and difficulties in writing balanced equations at the symbolic level for the dissolution of ionic compounds in water. Cokadar (2013) reported Turkish students' difficulties in writing chemical formulas for reaction products (as many as 56% of respondents had false ideas about balancing chemical reaction equations), and Marias (2014) reported South African students' difficulties in understanding the molecular level of chemical equations. Astudillo and Niaz (1996) examined the reasoning strategies students used to solve stoichiometric problems and examined the relationship between these strategies and prior knowledge. Much of the research involves the use of computer animations of chemical reactions at the particle level. These studies were intended to improve students' conceptual understanding of these chemical processes (Williamson and Abraham, 1995; Sanger et al. 2000; Kelly and Jones, 2008; Gregorius et al. 2010a, b). Some researchers have used animations as part of the assessment process (Sanger et al., 2007; Rosenthal and Sanger, 2011). Nyachwaya et al. (2011) compared students' ability to balance chemical equations at the symbolic level with their ability to produce detailed drawings of these chemical reactions and found that students were proficient in balancing chemical equations but were unable to translate these formulas to the particle level. Research has also shown the effectiveness of using analogies (Arao et al., 2022, 2023; Haglund, 2013; Oliva et al., 2007), simulations (Gorgees & Hilal, 2018; Nja et al., 2022) and especially Phet simulation (Moore et al., 2014; Quahi et al., 2020, 2022) in teaching chemistry. As can be seen from the above literature review, the problem of the ability to write and balance chemical reaction equations has been studied from many sides. Effective methods and tools were sought to solve this problem. It is puzzling that if simulation can be used to teach young children how to balance chemical reaction equations (Bílek et al., 2018) so many science students have problems with it. It was decided to investigate this problem.

RESEARCH & METHODOLOGY

Our previous research (Bílek at al., 2018) used analogies (as García-Carmona, 2021) and PhET simulation to teach children with no prior exposure to chemistry to balance chemical equations. These children did not have incorrect, false ideas about this activity. Now we wanted to examine whether it is possible to help students who, despite several years of study, still cannot agree on the balance of chemical reactions.

We hypothesized that the use of simple simulations that help young children understand the process of balancing chemical reactions will also help students who, despite having studied chemistry, still have problems understanding this process regardless of how long they have been learning chemistry. We also concluded that the correctness of answers in the post-test would be strongly correlated with the time the student worked with the simulation.

We concluded that there would be a positive transfer (learning how to make sandwiches would directly translate into learning how to balance chemical reactions) and that the impact of proactive inhibition would be small (García-Carmona, 2021; Vidak et al., 2019).

Over 300 students took part in the research - however, we obtained pre- and post-tests from only 251 of them. The study used a one-group pre-test – post-test design to test the hypothesis. The surveyed students were divided into three groups depending on how long they had been learning chemistry (see Table 1) - those who studied chemistry for the first year, those who studied for 2-3 years and those who studied for more than 3 years. To examine the effectiveness of the test, knowledge growth rate (PW) was used:

$$PW = \frac{Wpost - Wpre}{Wmax - Wpre} x100\%$$

Wpost - the result of measuring knowledge after the didactic process

Wpre - the result of measuring knowledge before the didactic process

Wmax - maximum possible knowledge measurement result

The data were analysed statistically using the Jamovi. The Shapiro-Wilk W 1 test for group 1 is 0.950 and the Shapiro-Wilk p 1 0.006 for groups 2 & 3 is 0.950 and the Shapiro-Wilk p 1 0.006 and for group < 3 (the smallest) 0.887 and < .001.

Tab. 1. Data of research participants (Division made in this way due to the specificity of the division into education levels in the Czech Republic www1).

	1 year of studying chemistry at school (approx. 14 years)	2 or 3 years of studying chemistry at school (approx. 15-16 years)	more than 3 years of studying chemistry at school (over 17 years)
WOMEN	34	65	12
MEN	30	36	18
NO ANSWER	9	33	14

The research had four stages. In the first chemistry lesson - in the first part of the study, students completed the test (Fig. 1) and in the second part, the teacher showed how to learn how to balance chemical reactions using PhET simulation ("Reactants, Products and Leftovers"). This simulation uses an analogy - comparing balancing chemical reactions to making sandwiches (see Fig. 2). The third stage was voluntary, the students had to practice balancing chemical reactions on their own with this simulation. In the fourth stage (on the next chemistry lesson), students took a post-test, which was identical to the pre-test. The test used in this study had been used many times before and the results were valid and reliable. It was used, among others, in the studies of Bílek et al (2018) and Kopek-Putała & Nodzyńska (2015).

The pre- and post-test questionnaire contained 4 open questions:

1. *Assemble 4 water molecules. How many molecules of hydrogen [.A.] and oxygen molecules [.B.] do you need to complete this task?*
2. *If you use 3 hydrogen molecules and 2 oxygen molecules - how many water molecules are formed [.A.]? Since not all molecules participate in the reaction, there will be "leftovers". How much and what kind of "leftovers" will you be left with? hydrogen [.B.], oxygen [.C.].*
3. *Assemble 4 molecules of ammonia. How many molecules of hydrogen [.A.] and nitrogen molecules [.B.] do you need to complete this task?*
4. *If you use 3 nitrogen molecules and 3 hydrogen molecules - how many ammonia molecules are formed [.A.]?*
   Since not all molecules will participate in the reaction, there will be "leftovers". How much and what kind of "leftovers" will you be left with? nitrogen [.B.], hydrogen [.C.].

Fig. 1 Pre- & Post-test

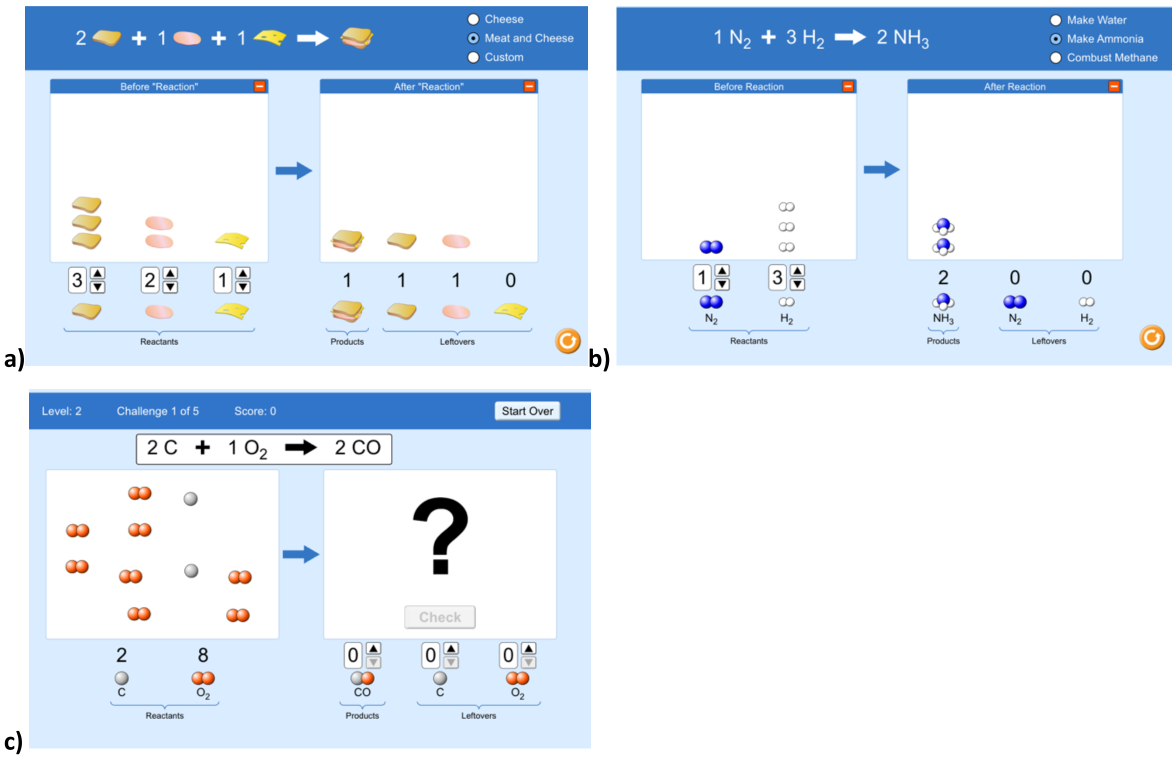

Fig. 2 Possible activities in the PhET simulation ("Reactants, Products and Leftovers"). a) Agreeing on the number of elements needed to create the given sandwiches, b) Balancing chemical reaction equations using simple examples, c) Balancing chemical reaction equations at various levels (also on time)

RESULTS

Individual questions posed various difficulties for the surveyed students (see Table 2). The most difficult task turned out to be the second sentence, where the "limiting factor" appeared. Because the research involved students at various levels of education (see Tab. 3), we used the knowledge growth rate (see Fig. 3).

Tab. 2 Comparison of pre- and post-test results. In table 1A means the answer to the first part of question 1 and 1B means the answer to the second part of question 1. Similarly in the remaining questions.

%	1A	1B	2A	2B	2C	3A	3B	4A	4B	4C
PRE-TEST	59.76	64.94	38.25	35.46	13.55	47.01	54.98	45.02	43.03	51.00
POST-TEST	72.51	68.53	39.04	35.86	17.53	53.39	61.35	60.96	55.78	64.14

Tab. 3 Results obtained by students at various levels of education. The number (1) indicates the group of students learning chemistry for only the first year, (2 & 3) students learning chemistry for two or 3 years, (>3) students learning chemistry for more than 3 years (4, 5, 6).

%	1A	1B	2A	2B	2C	3A	3B	4A	4B	4C
PRE-TEST (1)	42.47	50.68	24.66	20.55	5.48	34.25	42.47	20.55	28.77	34.25
POST-TEST (1)	84.93	78.08	42.47	47.95	19.18	57.53	64.38	73.97	60.27	90.41
PRE-TEST (2&3)	63.38	58.27	31.69	35.78	14.31	42.94	48.05	55.20	44.98	67.47
POST-TEST (2&3)	74.63	69.40	44.03	36.57	22.39	50.75	61.19	56.72	56.72	55.22
PRE-TEST>3	81.82	90.91	65.91	65.91	34.09	79.55	86.36	84.09	72.73	81.82
POST-TEST>3	86.36	88.64	52.27	47.73	22.73	90.91	93.18	90.91	77.27	86.36

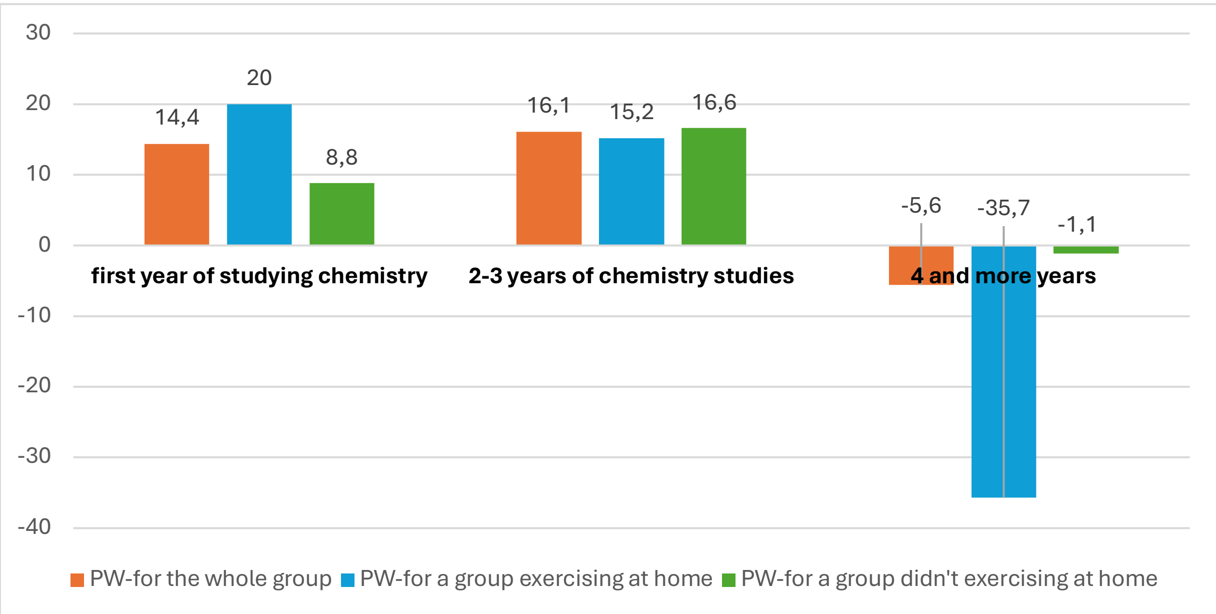

Fig. 3 The increase in knowledge in individual groups, broken down into subgroups that exercised at home and did not exercise.

The results show that when this simulation based on analogy was used, the results of first-grade students increased on average by 14.4%, and in the group that practiced at home by even 20%. In the case of a group of students who had been studying chemistry for 2-3 years, the use of simulation resulted in an average increase in results by approximately 16%. It didn't matter whether they worked at home with simulation or not. The worst results were obtained in the third group, where the use of simulation lowered the post-test results. In the group of students working at home with simulation by as much as 35.7%.

DISCUSSION

Although the effectiveness of PhET simulation is confirmed by numerous studies (Carpenter et al., 2022; Herrington, et a 2022; Moore et al., 2014; Quahi at al., 2020, 2022) it turned out that comparing this research with research conducted on children who have not yet learned chemistry (Bílek et al., 2018), we can notice that with each year of chemistry education, the effectiveness of this simulation is decreasing. It seems that throughout their education, students develop more or less effective ways of balancing chemical equations and trying to teach them a new, correct way confuses their minds.

Similar to the study by Chandrasegaran et al. (2009), students had trouble understanding the concept of limiting reagent. It seems that there would be a positive transfer (learning to make sandwiches would directly translate into learning to balance chemical reactions) and that the impact of proactive inhibition would be small were not confirmed (García-Carmona, 2021; Vidak et al., 2019). Unfortunately, the influence of proactive braking turned out to be very large.

CONCLUSION

The positive transfer (the ability to make sandwiches translates into the ability to balance chemical reaction equations) competes with proactive inhibition (when previously acquired incorrect information or skills make it difficult to learn how to correctly balance chemical reaction equations) (Falkowski & Tyszka, 2009). For children who have not studied chemistry or students who are just starting their chemistry education, the use of this simulation helps them understand this topic. However, for students with longer chemistry experience, this simulation has a negative impact. Here we can quote Comenius (Haraszkiewicz, 1905) who claimed that "Learning is easier than unlearning", citing the ancient Greeks: Themistocles, who claimed that he preferred to acquire the art of forgetting rather than the art of memory, and the musician Timothy, who demanded double payment from students who they had previously acquired bad habits in art. Therefore, it seems that a good solution would be to use simulation at the beginning of chemical education, so as not to create incorrect cognitive paths in the minds of students, which need to be eliminated later.

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Implementation of STEM education in the subject of Technology at Lower Secondary School - case study

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Abstract

The aim of the contribution was to design a teaching model for a technical class for 14-year-old students using the STEM concept and to determine whether by applying the STEM concept in teaching the subject of Technology, students would develop all the objectives set by the national educational program. Qualitative methods were used in the research: evaluative case study, questionnaire, and observation. Through analysis of observations of 17 of 14-year-old students during teaching and data from questionnaires, we confirmed that the set objectives have been proven. Additionally, we confirmed that the proposed teaching model for the subject of Technology motivates students to study, suits them for group work.

Key words

STEM education; micro: bit; project

INTRODUCTION

Many authors currently consider project-based learning as a significant opportunity for implementing the concept of STEM education within lower secondary schools (Sarwi et al, 2021). The acronym STEM originates from the words Science, Technology, Engineering, Economics, and Mathematics. The STEM concept is currently very popular and is used as a general term for any activity, policy, program, or practice that involves one or more of the mentioned STEM disciplines (Reeve, 2013). For example, in the USA, this term is often interpreted to refer more to science or mathematics than to technology or engineering. In many countries, STEM education is defined as an approach that integrates science, engineering, technology, and mathematics with a focus on solving real-world problems, including the development of new processes or products that benefit human life and work. In the teaching process, the STEM concept is understood as the implementation of interdisciplinary relationships with the aim of applying knowledge and skills related to, most commonly, natural sciences and technology (Bybee, 2010). According to Thomasian (2011), the conception of STEM in the realm of educational processes is seen as a mean of enhancing both critical and logical thinking among lower secondary school students. In our contribution, we present the results of implementing STEM education in the subject of Technology at the lower secondary school.

THEORETICAL BACKGROUND

Several studies explore the implementation of the STEM concept in school practice. One such study, *STEM Education in Practice: Case Studies* from three schools, examined STEM education and its implementation in practice at Mater Dei Catholic College, Wagga Wagga in Australia in 2018. An integrated STEM program was introduced for 8th-grade students (14-year-old students), consisting of two tasks. During these tasks, students worked in groups and utilized active methods such as those for developing critical thinking, coding and decoding information, and information processing itself. The results of their work were evaluated qualitatively by both the teacher and through self-assessment. The study results showed that students engaged in the presented study considered the module successful, with positive feedback from the students (Lowrie et al, 2018). Another research study focusing on the STEM education concept was the *STEM Modules: Developing Innovative Approaches to Enhance Student Learning*, conducted in 2014 by the Department of Chemistry and the Department of Materials Science and Engineering at Tuskegee University, titled Storm Chasers and Space Detectives. This module addressed the teaching theme of tornado formation and was implemented with high school students participating in the Math and Science Partnership Program. The research results showed that after the implementation of the Storm Chasers and Space Detectives module, students significantly improved their learning outcomes compared to before the implementation. The mentioned modules demonstrated an improvement result of up to 26%. (Andrews et al, 2014). The aim of the study The *Influence of Project-Based STEM* was to examine the impact of STEM education applications involving the use of waste materials on students' skills. The research sample consisted of a total of 24 students. The research results showed a significant difference between the pre-test and post-test scores. Based on the findings, it can be concluded that education utilizing STEM contributed to the development of students' skills (Baran et al. 2021). The research conducted by Sarwi et al (2021) focused on implementing project-based teaching in the STEM education concept within distance learning for 5th-grade students (11-year-old students) in the subject of Technology in Magelang, Indonesia, in 2019 and 2020. The research results on the application of project-based teaching within the STEM concept showed that 5th-grade students in the subject of Technology were capable of solving problem tasks. The success rate in solving problem tasks was reported as high as 92% (Sarwi et al, 2021). The studies by authors Shidiq et al. (2020) and e.g., Murphy et al. (2019) focus on the time demands of STEM education. They both agree that the preparation and implementation of such education are time-consuming for teachers. As evident from the presented results, the STEM concept is fully utilized in education at primary and secondary schools.

THE PURPOSE AND METHODOLOGY OF THE RESEARCH

The Department of Technology and Information Technologies at the Faculty of Education of Constantine the Philosopher University in Nitra was involved in the international STEMkey project within the Erasmus+ programme. The project aimed to prepare future teachers of science and technical subjects. Project participants from 12 European countries were tasked with creating tasks that required the application of the STEM concept. Our task was to create a STEM-based task focusing on technical materials. In our case, we took a slightly unconventional approach by choosing water as the technical material. The task we compiled focused on creating a water distribution system based on the following problematic situation:

> *Imagine, that you have inherited an old house somewhere in the deep woods. The nature surrounding the house is so nice and you also like the old-fashioned style of the house. It is so nice, like in a fairy tale! You really want to keep it... and to use it... BUT! But there is a problem. The house has no water supply!*

How the problem with water in general and moreover the problem with the drinking water should/could be solved? Solutions to bring by car utility water in jerry cans or canisters, and drinking water (mineral water) to buy in a shop are not acceptable. As there is no water supply and no source of the water, a solution of the stated problem is based on collection of rainwater. – i.e. to collect rainwater from the roof of the wooden house.

So, we must collect rainwater and then to distribute it from the water tank collector to the house. But besides the utility water we also need some water to drink, this means that besides the water distribution problem we have as well a problem to ensure water to be drunk.

So, to solve the introduced problem with water in general, there are two tasks which the students are supposed to solve.

Task 1: How to design water distribution system?

Task 2: How to treat the collected rainwater go gain drinking water from it?

A solution of the second question is to clean the rainwater with a filter.

The research goals

Our goals were:

- Design a model for a technology class lesson applying the STEM concept, with the use of microcontrollers

• Determine how lower secondary school students in the subject of Technology cope with the given problem task using the STEM concept.

In the research, we wanted to answer the following research questions:

- Will students achieve the objectives set by the National Education Program through the designed task?
- Which activities will be the most difficult for students?
- Will students find STEM education interesting?

Research sample

Since STEM education required some specific tools, organizational work, and the presence of a qualified, experienced teacher, the research was conducted on a small, deliberately selected sample of 17 students at a selected lower secondary school among 8th-grade students (14-year-olds).

Research timeline

The research was conducted in February of the school year 2022/2023. The application of the STEM conception included lesson preparation, implementation, and subsequent reflection by the students on learning. The lesson was conducted within the thematic unit of Technical Electronics, focusing on the topic of Cold and Hot Water Distribution. Before engaging the students in the education, related topics in chemistry, physics, computer science, and environmental education were reviewed. These topics included filtration (chemistry), properties of liquids (physics), micro: bit integration and programming (computer science).

One teaching session was defined for the task (45 minutes). In the first teaching session, there were 9 students divided into three groups of three students each, and in the second teaching session, there were 8 students divided into two groups of three students and one group of two students. For the task, students had a worksheet available, which included the assignment, basic parts of the filtration system, and the connection of the micro: bit.

It took us approximately three months to develop the teaching module, worksheet, and material resources for the teaching session. Then we proceeded with the implementation of the teaching session using the STEM concept.

The case study was conducted as an evaluative study, focusing primarily on assessing the achievement of the planned educational process goals (Yin, 1994), which we outline below. An evaluative study provides a complete description of a phenomenon, focusing mainly on evaluating a program or intervention based on pre-established criteria (Hendl, 2016). The data for the case study were obtained from observations of students in individual groups by teachers and questionnaires for students.

During the teaching session, there were two teachers present: one led the class while the other observed its progress. The main observations were recorded by the observer during the teaching or after the completion of the teaching unit. The observation focused on the students' ability to correctly connect the microcontroller with the pump and to assemble the filter correctly.

The used questionnaire was of our own construction. It contained three items. In the first item, students were supposed to express how they liked the teaching hour, in the second item, they were supposed to express how they understood the task from the worksheet. In these items, they were to express their attitude by choosing from the offered options yes/no/cannot decide. The third item determined which attributes of the teaching hour interested the students the most. Students can choose group work, working with various unconventional technical materials, working with worksheets, assembling the water purifier, presenting the water purifier creation, working with technical devices (micro: bit integration), and other options. Students could select multiple answers in this question. The students filled out questionnaires at the end of the teaching session, and it goes without saying that the school principal's consent was obtained for the experimental verification of the teaching. Despite the small sample size of students participating in the study, there is an assumption that the results of the case study can be generalized based on an analytical model, which assumes that generalization is possible based on the existence of any case (Silverman, 2005).For the analysis of the obtained data, we used qualitative description and partially quantitative methods – some methods of descriptive statistics (graphs and tables) were employed.

The limitations of the information obtained in this way lie in the small research sample (1 teacher, 17 students), but this is offset by the detailed description of the educational process and the assessment of the set teaching objectives.

Observed educational objectives

Regarding the cognitive objectives of the teaching process, our focus was on the following:

- The student can express their own idea about the project.
- The student can characterize water filtration while emphasizing the application of interdisciplinary relationships between the subject of Technology and the subjects of Chemistry, Physics, Computer science, and Environmental education.
- The student can characterize ways of water pollution and suggest solutions in their own words.

From the perspective of psychomotor goals in the teaching process, our focus was on the following:

- The student can develop the "Water Purifier" project using given substrates.

• The student enhances fine motor skills and can work with different types of materials used in the "Water Purifier" project.

• The student can adhere to safety, health protection, and hygiene while working.

• The student can handle selected tools (scissors, spatula) and materials (stones, coarse sand, activated charcoal, fine sand).

Regarding affective goals, we focused on the following:

• The student can communicate within the group.

• The student respects the opinions of their classmates.

• The student develops their presenting skills within the group.

THE IMPLEMENTATION OF STEM LEARNING

Students were initially motivated by the introductory story described above. Subsequently, they were given two tasks. The first task was to design a water distribution system in a cottage, and the second task was to create a water purifier (filter). The students worked and progressed according to the worksheet:

Task 1: Based on the design, create a water distribution system in the cottage (Figure 1).

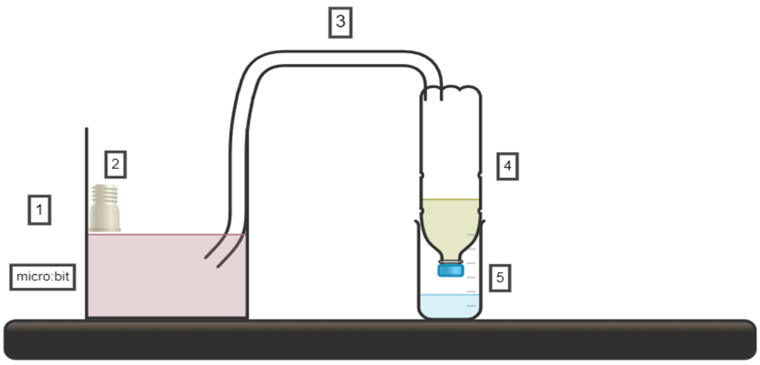

Fig. 1 Water Distribution (Komárová, 2023). Legend: 1. tank - water container, 2. pump, 3. piping, 4. filter, 5. filtrate container

According to figure 1, the students assembled the water distribution system. When connecting the micro: bit, they followed the instructions displayed in figure 2. The students implemented the connection using jumper cables to the micro: bit connector. The program for controlling the pump with the micro: bit was pre-loaded into the microcontroller.

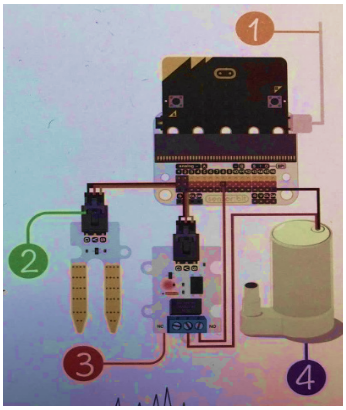

Fig. 2 Micro: bit Wiring (Water Level Alarming, 2022).

Legend: 1 - micro: bit with a USB cable, 2 - a moisture sensor, 3 - a relay, 4 - and a centrifugal pump

Task 2: Construct a water filtration system. The most crucial part of the entire project was the creation of the filter. This was constructed using a plastic bottle that students filled with activated charcoal, pebbles, fine sand, and coarse sand. The filter created by the students was filled with substrates in the following order from the bottom: fine sand, coarse sand, activated charcoal, and pebbles. Students secured a bandage with a rubber band around the neck of the bottle, which also acted as one of the filtration media (Figure 3).

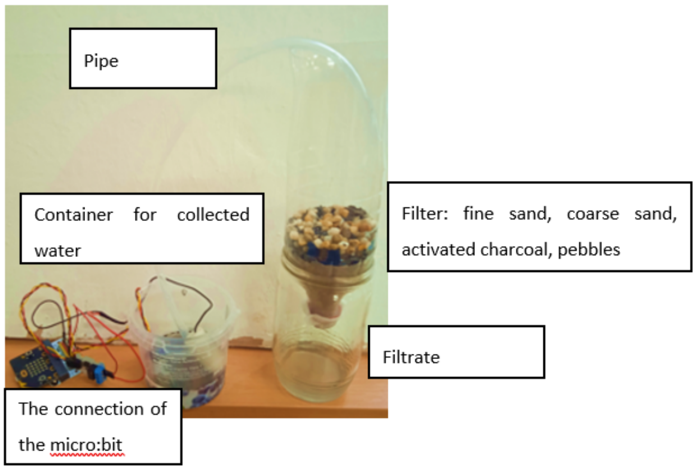

Fig. 3 Water Purifier.

RESULTS OF THE CASE STUDY

All groups managed to create a water purifier with the correct micro: bit integration and the development of a filter. During the first teaching session, students in all groups successfully created the water purifier. The arrangement of filtration components was correct. In the second teaching session, students in the workgroups similarly proceeded correctly in assembling the filter. However, problems mainly occurred during the connection of electronic components of the assignment.

Evaluation of the results of STEM education regarding cognitive objectives:

Students can express their own idea about the project. During the project-solving process, students proposed using various containers to create a sand filter. They had minor concerns about programming the micro: bit. After being informed that the program was already directly uploaded into the microcontrollers, these concerns were unnecessary since the program was already uploaded.

Students can characterize water filtration by applying interdisciplinary relationships between the subject of Technology and the subjects of Chemistry, Physics, and Computer Science. This objective was preceded by preparing students through a review within the individual subjects. Students were not informed that revisited material would be necessary to solve the project. During the actual solution, they could correctly name water filtration itself, name the basic parts of the filter, state what filtrate is, and so on. They were familiar with the basic physical properties of water. They encountered minor issues in connecting the micro: bits, mainly related to correctly connecting the pump and relay to the respective connectors of the microcontroller.

The student can characterize methods of water pollution and propose their solutions in their own words. When identifying the origins of water pollution based on a model situation, they mainly mentioned washed-off mechanical impurities from roofs and chemical substances present in rainwater due to pollution. During the final analysis of the created project, they pointed out that the filter only removes mechanical impurities and that the water should also be chemically treated to be suitable for drinking.

Evaluation of the results of student projects in terms of psychomotor objectives.

The student can develop a 'Water Purifier' project using given substrates. The water purifier made from the provided materials was executed correctly. When asked by the instructor about the sequence in which they should arrange the individual filter components by fraction, the students correctly determined the order of components and could justify their choices.

The student develops fine motor skills and can work with various types of materials used in the 'Water Purifier' project. Fine motor skills were primarily necessary for correctly connecting the connecting wires to the micro: bit. Their size is relatively small, and the contacts are sensitive to bending. Students had minor issues in correctly connecting contacts, attaching the moisture sensor, where using a screw with a nut was necessary. A lower level of fine motor skills was evident in students during work, which, based on our experience, is a persisting issue over time.

The student can pay attention to safety, health protection, and hygiene during work. Safety measures were crucial in this case when working with sharp tools such as scissors or a knife. These were used to modify PET bottles to create the filter. The students managed the task without any injuries.

The student can handle selected tools (scissors, spatula) and materials (stones, coarse sand, activated charcoal, fine sand). This objective primarily focused on assembling the filter. Emphasis needed to be placed on ensuring that individual filter layers were equally thick and that there was no mixing between layers. As indicated by the analysis of the resulting student products – assembled filters, the objective was achieved; students managed working with the tools.

Evaluation of the results of student projects in terms of affective goals.

The student can communicate within a group. The student respects the opinions of their classmates. The communication among students within the groups was spontaneous and aimed at solving the given task. Elements of brainstorming were applied in their interaction as they attempted to find solutions. In case any issues arose during the problem-solving process, the teacher intervened to guide them toward the correct solution, particularly when there were improperly connected electrical circuits in one group.

The student develops their presence within a group. Achieving this goal occurred at the end of the class when each group presented the results of their work. All members of each group participated in the presentation. All students in all groups successfully managed the task. When evaluating the overall project solution by the students, we can state that they were disciplined, answered questions, showed interest in solving the project. The students' motivation for work was sufficient, with one group even making an effort to present the project's results to their parents.

Based on the provided assessment, we can answer the first research question, stating that students achieved the goals set by the State Educational Program through the proposed task.

The second research question pertained to identifying activities that were the most challenging for students. From the observation assessment, it appears that it was manual dexterity in connecting electrical circuits.

As part of the overall class assessment, there was also a brief survey where students answered the teacher's questions regarding their attitudes toward this type of project via three simple questions from the questionnaire. The survey indicated that 16 respondents liked the teaching unit. One student was unsure if he/she found this type of class interesting. None of the students surveyed stated that they found the class uninteresting. 16 students understood the assigned tasks within the project-based learning, and one was unsure if he/she understood the tasks or not. We believe that this one student approached the class more passively.

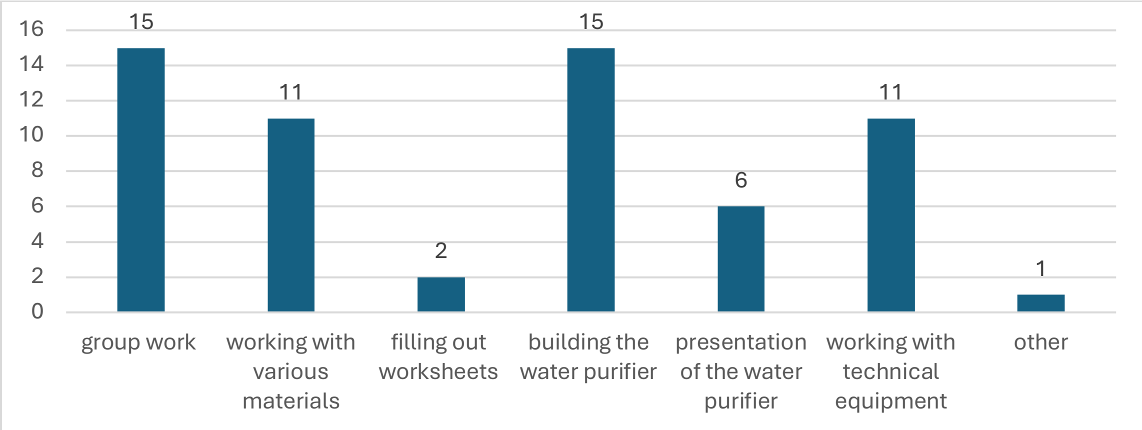

Fig. 5 Responses of respondents to the 3rd question.

The figure 5 indicates that students liked group work the most, which was confirmed by 15 respondents. Building the water purifier received an equal number of responses. 11 respondents selected 'working with various materials' and 'working with technical equipment. Filling out worksheets was the least favoured among students (2 respondents).

The third research question aimed to determine the attitude of students towards STEM education. From the analysis of the questionnaire results, it is evident that students positively evaluated STEM teaching.

DISCUSSION AND CONCLUSION

Education, as one of the areas crucial for shaping a modern and developed society, constantly finds itself amidst rapidly changing conditions and advancements in the progressing world. The ability to master such a segment from the essence of being able to react and comprehend it. One way to enhance the teaching process is by implementing interdisciplinary relationships. The STEM concept provides various approaches to address different situations. In our proposed STEM education, we focused on solving a water purifier issue using various scientific disciplines such as physics, chemistry, and biology. Students were supposed to utilize this knowledge in the technical solution.

The evaluation of the case study revealed that the mentioned method is engaging and stimulating for the students. This is also confirmed by the results of other authors (Lowrie et al, 2018). Our research confirms the findings of Shidiq et al. (2020), who state that STEM education in Chemistry classes, it was possible to reinforce the significance of interdisciplinary relationships between Chemistry and other related subjects such as Technology, Physics, and Mathematics. The lack of time and unpreparedness of educators for the application of STEM teaching in lower secondary schools are confirmed by the works of other authors. They state (e.g., Murphy et al., 2019) that while it's encouraging to see some topics covered in STEM strategies, it's concerning that significant attention isn't given to STEM-related issues in teacher preparation. Because of these shortcomings, educators fail to incorporate strategies essential for improving STEM education for all children at all stages of learning.

We acknowledge that our case study results have limitations due to the size of the research sample. However, we believe they can be beneficial to pedagogical practice, particularly in the areas of teacher motivation, encouraging more use of this concept.

In conclusion, we want to emphasize that the application of STEM education supports, focuses, and significantly enriches the education process, thus contributing to its enhancement and increasing interest in studying technical or natural science disciplines, whose necessity contemporary society continuously emphasizes.

Acknowledgement

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Shift in pre-service teachers' comprehension of ecological role of aquatic plants as impacted by new interactive workbook on photosynthesis in ecological circumstances

Tereza Brčáková & Renata Ryplová

Abstract

This contribution brings the results of a pilot study aimed at the impact of using a new interactive workbook on photosynthesis in pre-service biology teachers' preparation. The study combines elements of STEM education and investigates the shift in pre-service biology teachers' comprehension of the photosynthetic biomass production of aquatic plants and its' ecological role was investigated via pre/post-test and using concept maps. The pre-tests discovered a low level of comprehension of the ecological role of the photosynthetic production of aquatic plants. After intervention supported by the interactive workbook, the post-test results showed improvement in this comprehension.

Key words

Interactive workbook; photosynthesis of aquatic plants; concept map

INTRODUCTION

The phenomenon of plant blindness is a well-known problem that affects all ages (Pany, 2014). Wandersee and Schussler (1999) first defined this problem as the inability to see or notice plants and their role in the human environment. Several studies state that this phenomenon is spread from primary schools (Amprazis & Papadopoulou, 2018) to secondary schools (Pany, 2014), and at the university level (Batke et al., 2020). Besides this problem, teaching botanical topics is also linked to many misconceptions that students acquire not only from their families but also during their education and carry with them into adult life (Jose et al., 2019; Ulfa et al., 2017; Švandová, 2014). International studies show as well that students prefer zoological topics to botanical ones (Jose et al., 2019; Prokop et al., 2010). Students consider botanical topics more difficult than others (Tamir, 2010). All these problems may be due to the huge degree of abstraction in botany and plant physiology (Vágnerová et al., 2019; Ulfa et al., 2017).

One of the most abstract and problematic topics in botany is photosynthesis. This process is often misunderstood not only by students but also by their teachers (Vágnerová et al., 2019). The most common misconception on the topic of photosynthesis is that during photosynthesis plants produce only oxygen (Švandová, 2014). The formation of primary biomass is an often-overlooked aspect (Pavlátová, 2019). However, photosynthetic biomass production is important for all ecosystems.

Therefore, a general understanding of biomass formation is indispensable for sustainable development. One of the sustainable development goals (SDG) is clean water and sanitation. However, this goal cannot be achieved without awareness of the role of aquatic plants in society. Water quality is significantly influenced by photosynthetic biomass production (Pokorný, 2014). Eutrophication and the associated increase of aquatic bloom due to higher photosynthetic biomass production threaten drinking water sources worldwide (Smith & Schindler, 2009).

This research focuses on photosynthesis of aquatic plants. Considering the amount of water bodies on Earth and given increasing eutrophication, the role of aquatic plants in biomass production is not insignificant. Due to the aquatic environment, the photosynthesis of aquatic plants is influenced by different factors, compared to the photosynthesis of terrestrial plants. Photosynthesis in the aquatic environment depends on the amount of light that passes through the water surface, the availability of carbon dioxide, the forms of carbon in the aquatic environment, and the pH of the environment (Pokorný, 2014; Pedersen et al., 2013). The availability of inorganic carbon is often the limiting factor for the photosynthesis of aquatic plants. One of the most important adaptations is the uptake of bicarbonate ions, which are more abundant in water than carbon dioxide. This allows aquatic plants to photosynthesize even at higher pH (Pedersen et al., 2013; Adamec, 2003). Due to the high eutrophication caused by fertilizer runoff from agricultural areas, plants in the water have sufficient nutrients for their growth. In the process of photosynthesis, these nutrients are incorporated into the biomass that accumulates on the water surface, preventing light from penetrating. Algal blooms on the surface of ponds do not allow sufficient light to penetrate and plants living deeper in the water column cannot photosynthesize (Pokorný, 2014).

Forms of carbon in water are dependent on the pH of the water and vice versa. Carbon is found in water as a gas (CO_2), in the form of ions (HCO_3^-, CO_3^{2-}) and carbonic acid (H_2CO_3). All these forms create a well-known carbonate balance. Aquatic plants also need carbon dioxide for photosynthesis. However, this is only present in water at low pH. Carbon dioxide is removed in the photosynthesis process, the pH increases, and the ionic forms of carbon become predominant. The higher the pH, the more of this form is converted into the bicarbonate ion, which only some species of aquatic plants, especially cyanobacteria and algae, can use for photosynthesis (Pedersen et al., 2013). At very high pH values, carbon in water occurs in carbonate form (Pokorný, 2014; NASA, 2011). Light is also needed for photosynthesis. The deeper below the surface the plants are, the less light reaches them through the water surface. Underwater plants are adapted to the shortage and can use even smaller wavelengths for photosynthesis (Pedersen et al., 2013; Adamec, 2003). All these processes are invisible to human eyes because they happen in water. It means the invisibility of photosynthesis and the abstraction of photosynthetic processes and biomass production is even higher in the case of water plants. Modern didactic technologies bring the possibility of visualizations of invisible processes. The positive impact of digital visualizations on cognitive processes was already proved by Teplá et al. (2021).

METHODOLOGY

This contribution brings the results of a survey aimed at the impact of the new digital interactive workbook on pre-service biology teachers' understanding of the photosynthesis of aquatic plants. The teaching block in E-book incorporated elements of STEM (Science, Technology, Engineering, Mathematics) education to enhance learning. The survey aimed to identify the starting knowledge of pre-service biology teachers in photosynthesis in an ecological context and the impact of a newly developed digital workbook on their knowledge. Thus, for this study research question (RQ1) has been formulated:

> **RQ1:** Does this interactive workbook have an impact on students' knowledge of photosynthetic biomass production of aquatic plants?
>
> **H0:** The new interactive workbook has no impact on the level of knowledge of aquatic plant photosynthesis in an ecological context.
>
> **H1:** The new interactive workbook has a positive impact on the level of knowledge about the photosynthesis of aquatic plants in an ecological context.

The new interactive workbook on the photosynthesis of aquatic and terrestrial plants with an emphasis on their ecological role in the ecosystem and landscape sustainability (Ryplova et al., 2023b) was tested in pre-service biology teacher's education at the Faculty of Education, University of South Bohemia in České Budějovice (2nd year of their study). This interactive workbook is available in the Czech language at https://fotosyntezavkrajine.cz/. This research focused on the final chapter of the textbook, which is dedicated to aquatic plant photosynthesis in an ecological context. The Statistica 12 PC Package (Stat Soft Inc.) was used for data processing. Cohen's d, Shapiro-Wilcoxon tests, and T-tests were used for data evaluation. CMapTools was used to create concept maps.

The research was conducted in October 2023. Forty-eight pre-service biology teachers (N = 48) at the beginning of the botany course participated in the research. Shift in their comprehension of the photosynthetic production of water plants was investigated via pre/post-test questionnaire survey extended by the creation of concept maps. These maps served as supplementary information to the collected data bringing the information on how students think about the issues, and whether they understand the principles correctly. The students were faced with the interactive workbook during the botany seminar. After the short introduction the teacher, explained the use of the workbook, and the students worked separately and went through the texts, interactive exercises, and moving animations.

The students completed the pre-test week before the seminar, the post-test was collected one week after the activity. Students worked with the workbook for 90 minutes in the seminar, they could work with it also at home.

The tests for data collection consisted of two parts. The first part focused on knowledge. Students were given seven concepts related to the photosynthesis of aquatic plants. This part contained open-ended questions. Students were asked to explain the concepts presented. The concepts to be explained were algal bloom, biomass, forms of carbon in water, pH in water, eutrophication, oxygen in water, and light in water (in this order). Responses to the questions were coded and scores were assigned based on their answers. In the second part of the test, students were asked to use the concepts from the previous exercise and create a concept map of these. They used lines over which they listed the words that connect the concepts. In addition to the words already given, students could use other words in the map that are related to the target topic (Fig. 4, Fig. 5). The post-test was designed with the same brief. Additionally, the post-test contained space for comments on the new workbook and a five-point Likert scale to assess custom opinions on the interactive workbook (Fig. 1, Fig. 2).

Selected concepts for study

Considering the ecological role of plants, several concepts were selected for the study. All the selected concepts are related to the photosynthesis of aquatic plants. However, photosynthesis itself was not selected as a concept to observe whether the students could reveal that all the concepts given were related to this process.

Here we provide more information on the specified terms. Due to the chosen area of interest, emphasis is placed on the ecological aspects of the issue. Eutrophication (first concept) has become a major environmental issue in recent decades (EEA, 2022). Eutrophication means the enrichment of anthropogenic sources of nutrients, especially nitrogen and phosphorus (Gilbert, 2017; Pokorný, 2014; Withers & Haygarth, 2007). Harmful algae can increase disproportionately with eutrophication (Gilbert, 2017), causing complete shading of the water surface. Eutrophication is closely linked to the water bloom usually caused by algae (Pokorný, 2014). According to Feng (2021), the algal bloom (second concept) is influenced by human activities, especially eutrophication, international interaction, climate change, toxins released by algae, etc. Because of the increasing amount of nutrients (due to eutrophication), plants and algae have plenty of nutrients and can multiply massively. More plants mean increasing in photosynthesis, which leads to an increase in biomass – algae (Pokorný, 2014). According to Vobořil (2017), biomass (third concept) is defined as all organic matter on the planet that participates in nutrient cycling in the biosphere. The primary producers are plants in the photosynthesis process (Odum, 1955). Other selected concepts relate to the conditions of the water environment that affect the process of photosynthesis (pH, the forms of carbon, and the amount of light in the water). These concepts were intended to guide students to the concept of photosynthesis.

RESULTS AND DISCUSSION

The pre-test discovered a low level of comprehension of the ecological role of aquatic plants. Several misconceptions concerning the topic of the ecological role of photosynthesis of aquatic plants were found. Here we list a few of them. The common misconception, which was detected also in this research is, that algal bloom is waterlily. The reason could be the Czech terminology. In Czech translation, the algal bloom is called “water bloom”, hence the word which could hint at algae (algal) is missing. The same misconception was found in our previous research (Ryplová et al., 2023a) in the case of secondary school students. The next detected misconception was that aquatic plants use oxygen for photosynthesis. This is one of the common misconceptions including confusion between the processes of photosynthesis and respiration. This misconception was found also in another research (Brčáková et al., 2023; Švandová, 2014).

Impact of new interactive workbook

In the post-test, the students were asked to evaluate the new interactive workbook. For this purpose, the 5 grade Likert scale was used. The concepts are: I like the new interactive workbook; because of animation I understood this topic better; I enjoyed the work with this workbook; I would like to use this interactive workbook in my future teaching practice. It can be concluded that the students considered the new interactive workbook as a suitable tool for teaching the ecological aspects of photosynthesis, especially because of the animations (Fig. 1; Fig. 2). Most of the students, would use this type of textbook in their practice, none of the students indicated that they would not use the workbook in their practice at all. As follows from the box graph, students enjoyed working with the textbook. They indicated that the moving animations in the workbook were the reason they understood the topic better (Fig. 1; Median 1). Students indicated that they would like to use this digital workbook in their future practice, they enjoyed working with the workbook (Fig. 1; Median 2). Also, Asrowi et al. (2019) reported that students using interactive textbooks achieved better knowledge outcomes in the research than students using traditional paper workbooks. Šarboch et al. (2023) also state that animations have a positive effect on students' interest in the topic and their awareness of its importance. Among other things, they also have a positive effect on knowledge (Šarboch et al., 2023; Xiao, L., 2013).

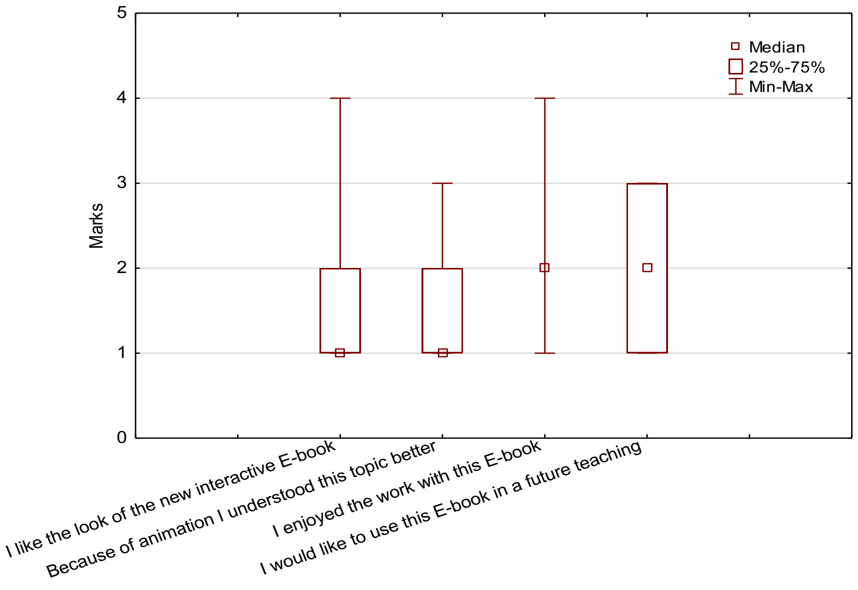

Fig. 1 Analysis of the answer to questions (5 grade Likert scale, 1 = I totally agree, 2 = I rather agree, 3 = I don't know, 4 = I rather disagree, 5 = I totally disagree). Small squares represent median values, boxes quantiles 25 – 75 %, line segments min-max values, N = 48)

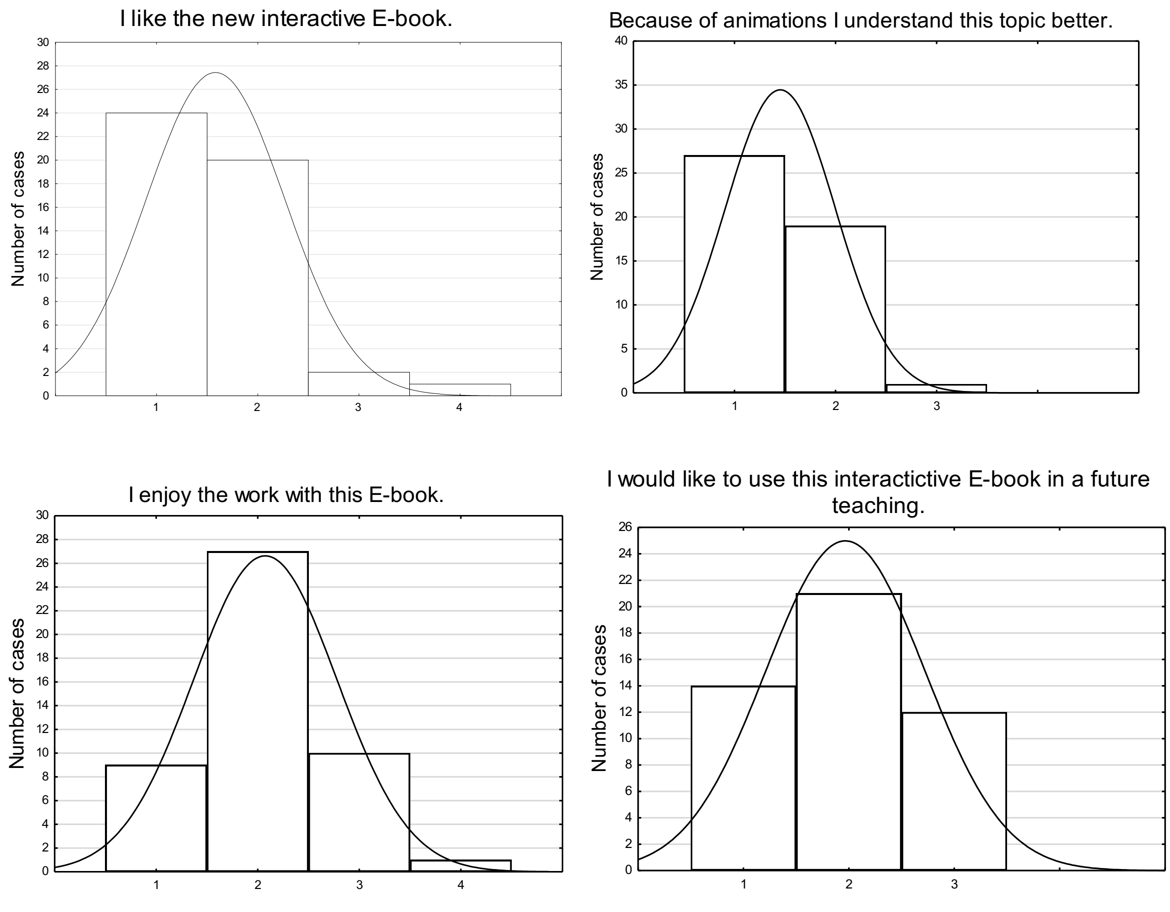

Fig. 2 Histograms showing the results of student rating of interactive workbook (5 grade Likert scale, 1 = I totally agree, 2 = I rather agree, 3 = I don't know, 4 = I rather disagree, 5 = I totally disagree; N = 48).

Based on the comparison of the results of the pre/post-test we can assume, that the new interactive workbook has a significant impact on the improvement of student knowledge of photosynthesis of water plants. According to Cohen's d, we can describe the differences in knowledge between the pre-test and the post-test as large (d = 1.61). 93-98% of students in the post-test exceed their knowledge scores in the pre-test. According to the Shapiro-Wilcoxon test, we can't reject normality. Statistically significant increase of the overall mean score of the pre-test (2,8 ± 1,0 SD) to post-test (4,8 ± 1,7) was proved by Shapiro-Wilcoxon test (pre-test: SW-W = 0,97; p = 0,16; post-test: SW-W = 0,98; p = 0,58) (Fig.3). Also, Hidayatai and Wuryandari (2012) state that animations can help students to understand better difficult topics. At the same time, workbooks and computer-based animations can make learning more interesting for students (Alt, 2018; Taber, 2017). The positive impact of 3D models and animations on students' motivation was found also by Teplá et al. (2021).

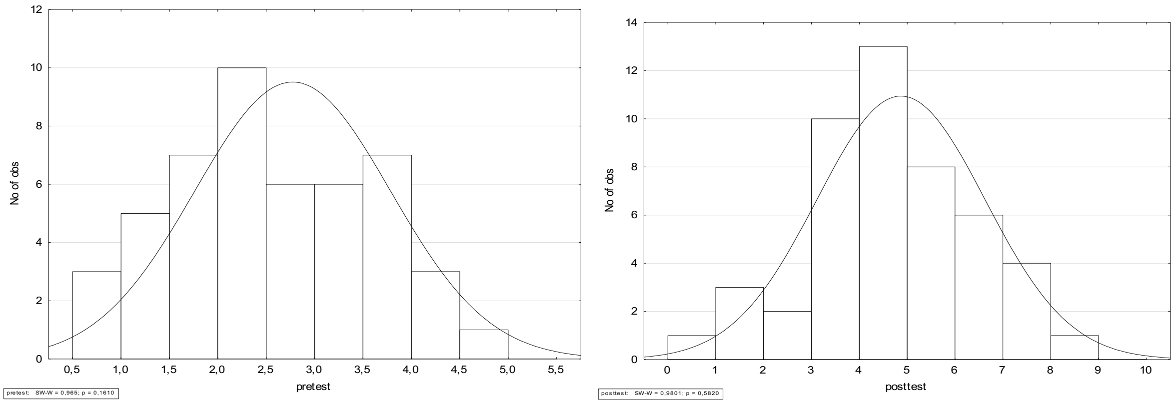

Fig. 3 Histograms showing pre-test (left graph) and post-test (right graph) scores test (pre-test: SW-W = 0,97; p = 0,16; post-test: SW-W = 0,98; p = 0,58).

In the second part of the survey, students created concept maps from the submitted concepts. As follows from the concept maps, in the pre-test (Fig. 4) the students added to the topic 46 other concepts. In the post-test students added 58 other concepts. Concept maps give us a more detailed view of understanding a given topic. Through individual connections, it is possible to detect whether students can also apply the concepts they have learned in practical life and context. Words that were part of the first part of the questionnaire are marked in a darker colour in the concept map. The lighter bubbles then show the added concepts. Solid arrows show correctly linked concepts, and dashed arrows show incorrectly linked concepts. Students listed additional words (most often verbs) above each connection, these are not shown in the concept maps for better readability. Subjective assessment was used to evaluate the concept maps. The correctness of linking the individual concepts was examined. As follows from Figures 4 and 5 in the post-test, students listed more words in the concept map than in the pre-test. On average, students listed one word in the pre-test and two words in the post-test. Correct and incorrect connections of the submitted concepts were also compared by the concept maps. The change in the number of correctly stated and associated concepts was assessed using the student's T-test. In the post-test, the number of incorrect connections was significantly reduced ($t = 2,46$; $p = 0,02$). The number of correct connections also increased. However, this increase was not statistically conclusive ($t = - 1,65$; $p = 0,09$). These concept maps served only as a supplement to the study. Through them, students' thinking about the issue was observed and used to further modify the textbook. Chocholoušková and Müllerová (2020) state that concept maps are a suitable tool for representing and exploring content change in teaching.

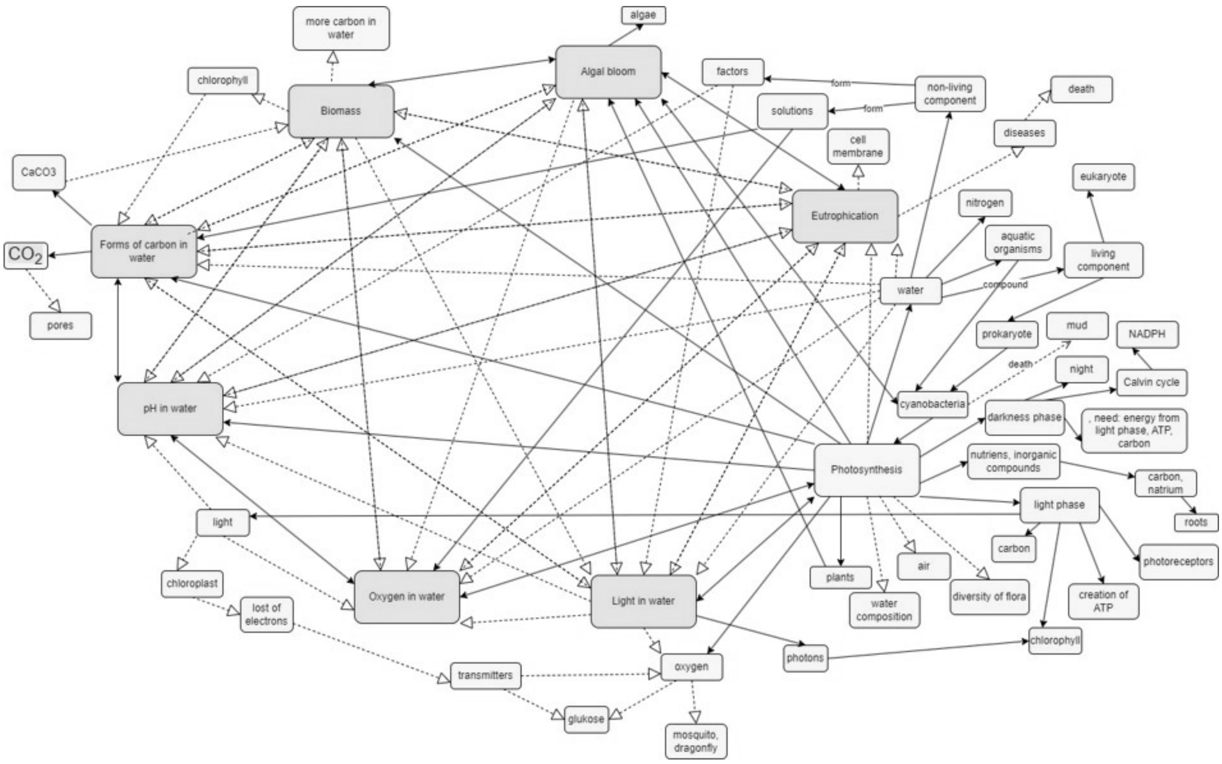

Fig. 4 Collective concept map for pre-test (6 concepts from knowledge part: biomass, algal bloom, eutrophication, light in water, oxygen in water, pH in water, forms of carbon in water and other added concepts from students). Full arrows connect concepts correctly. Dashed arrows for wrong connections or misconceptions.

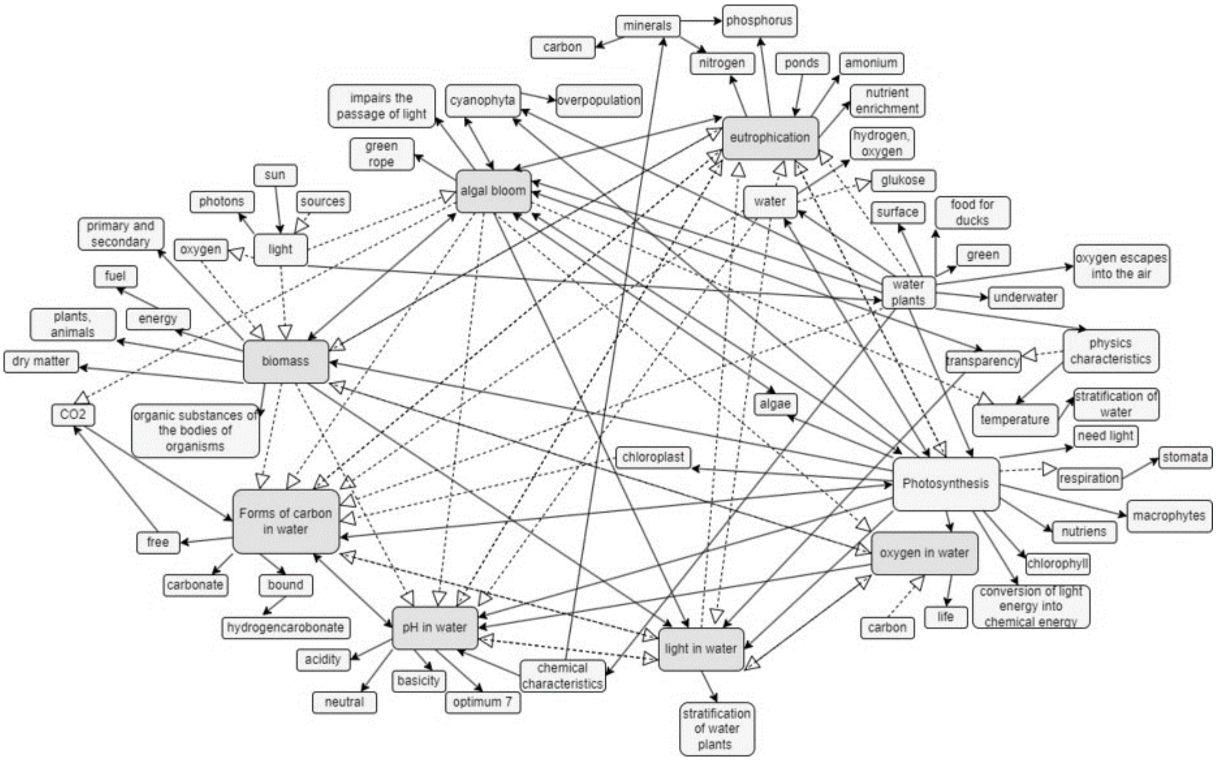

Fig. 4 Collective concept map for post-test (6 concepts from knowledge part: biomass, algal bloom, eutrophication, light in water, oxygen in water, pH in water, forms of carbon in water and other added concepts from students). Full arrows connect concepts correctly. Dashed arrows for wrong connections or misconceptions.

CONCLUSION

Based on the results of this study, we can conclude, that the new interactive workbook on photosynthesis has a positive impact on students' knowledge. By concept maps, not only the ability to explain concepts but also their practical application in context was observed. Students' knowledge of the photosynthesis of aquatic plants was low in the pre-test. Working with the digital textbook had a positive impact on their knowledge. Respondents gave positive feedback on the animations.

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Green chemistry - practical solutions in the chemistry laboratory

Małgorzata Nodzyńska-Moroń

Abstract

Laboratory classes are an important element of chemical education. We explored the possibility of replacing traditional school experiments with other experimentation techniques such as the use of microscale and droplet analysis, microwave oven, microscope, and online laboratories. 44 university students participated in the research. They carried out traditional and modified experiments and assessed them in terms of safety, environmental nuisance, and satisfaction. Students reported enjoying the new techniques, but after 8 years of learning traditional chemistry, they did not perceive the harmful effects of traditional experiences. Therefore, they did not agree with the need to replace traditional experiences with more ecological ones. The obtained results show that chemistry students and future teachers do not recognize the role of green chemistry and do not consider it necessary to redesign chemical experiments to make them more environmentally friendly.

Key words

Green chemistry; ecology; laboratory classes

INTRODUCTION

It's believed that there are many reasons why chemistry is one of the essential subjects in science education:

1. Allows to understand the world - it helps to understand how different substances and processes work within our environment. This allows to understand how different chemical reactions occur and why.

2. Has many practical applications - it is regularly applied in many industrial processes that influence our daily lives; thanks to it, we can create new medicines, building materials, cosmetics, as well as food products; understanding chemistry also allows us to better understand technologies such as solar energy and nanotechnology.

3. Affects our health and safety - knowledge of chemistry is essential to understanding the effects of chemicals on human health and the environment; using this knowledge we can make informed decisions regarding the substances with which we come into contact and minimize the risk of their negative impact.

4. Affect our career and personal development - chemistry can be the basis of many professions, such as chemist, pharmacist, or engineer; having chemical knowledge can open many career opportunities. In addition, learning chemistry develops analytical skills, logical thinking, and problem-solving abilities.

Yet, despite all those aforementioned benefits, chemistry education at all levels can be environmentally disruptive. Therefore, when teaching chemistry, it is essential to use teaching methods and techniques that cause the least amount of harm to the environment.

THEORETICAL BACKGROUND

The application of the green chemistry approach to chemistry education is essential. The concept of "green chemistry", involving both the design and the implementation of technological experiments and processes to limit the use and the production of harmful chemicals, came about at the end of the 20th century. In 1991, Anastas introduced the term "green chemistry" ('Father of green chemistry' Paul Anastas to head EPA research). Together with Warner they defined green chemistry as “the research, development and implementation of products and processes to reduce or eliminate the use and production of dangerous” (Anastas & Warner, 1998). This concept is based on the 12 principles green chemistry and 12 principles of green technology (Winterton, 2001). Although the principles of green chemistry are talked about a lot in the context of industry, the situation is different in the context of school education. There is a lack of theoretical and practical frameworks showing how to apply the ideas of green chemistry to education. However, teachers must put in a lot of work on their own to adapt and translate green chemistry from an industrial or production perspective to a more suitable one for younger students (Nahlik et al., 2023).

Many scientists are conducting research on this topic and articles on introduction of the principles of green chemistry into education have been appearing since 2001. The literature review shows that they can be divided into two trends. Some researchers focus mainly on detailed solutions enabling the transformation of (single) school experiments into experiments consistent with the principles of green chemistry. However, there are also publications whose main goal is to survey current and future chemistry teachers regarding their knowledge and attitudes toward green chemistry. The first type of research will include, for example, the research described in the article by Hempelmann and Caltun (2018) describes two examples: Omega-3 fatty acids from local plants (instead of fish oil) and ionic liquids as recyclable, tenable solvents for dissolving and processing biomass in the form of wood and its ingredients to create alternative processes that are safer and free from waste and additives. Furthermore, the article by Linkwitz, Belova and Eilks (2021) describes a lesson plan about a compound contained in cosmetic products, namely L-carvone. One example the second type research is a study conducted by Basheer et al. (2023), who examined 271 science teachers in Israel. Among the participants, there were teachers who were already in the profession as well as ones preparing for it. As part of their research authors surveyed the participants in terms of their level of awareness about green chemistry and sustainable development, as well as their approach to education as ecological. The results showed that teachers' awareness of sustainability and green chemistry was generally low, although their views on environmental education were generally positive. Furthermore, science teachers, who were already teaching, were found to have more knowledge about green chemistry and sustainability than pre-service science teachers. Teachers with over 10 years of experience had the greatest knowledge. In another research, Karpudewan and Kulandaisamy (2018) designed and examined green chemistry experiments for their applicability to high school chemistry teaching. As a part of this research, 70 secondary school teachers stated that green chemistry experiments were consistent with the current curriculum, feasible to implement, encouraged inquiry, safe, and relevant. These results suggest that green chemistry can be integrated into mainstream chemistry education. In another study, the results obtained by Karpudewan et al. (2012) indicated that the group of students (future teachers) performing "green experiments" was more internally motivated than the group performing traditional experiments. These changes were mainly due to the personal satisfaction participants derived from engaging in pro-environmental behaviours.

Considering the above, it was decided to develop global solutions that will enable the transformation of traditional school chemical experiments into an eco-friendly version. The following assumptions were made. Food reagents and everyday materials (e.g. instead of metal shavings, nails made of various metals were used) were used in place of traditional chemical reagents. Efforts were made to ensure that the reaction products could be used in other experiments or that they were safe for the environment. Classic microscale experiments and droplet analysis were used as typical small-scale chemistry (SSC) experiments, supplemented with microscopy experiments. Although the microscope is commonly associated with research in biology, it also provides great service in teaching chemistry. The basic use of a microscope in chemistry is to observe the shape of crystals of chemical compounds, i.e. its use in crystallography. Nowadays, however, it is increasingly used as one of the microscale methods. In this case, the course of the chemical reaction (and the formation of crystals) is observed directly under a microscope, on a glass slide (with a so-called teardrop). The most common usage of this method is in reactions where the displacement of metals from their salts occurs (Pikuzińska, Cieśla & Nodzyńska, 2014). Nowadays, it is not uncommon to use a microscope that is connected to a computer or a phone with a microscope application.

Since the possibility of using microwaves in experiments was first mentioned in 1986 (Gedye et al., 1986), several thousand articles have been written describing their use in the synthesis of substances (The Web of Science query "microwave" & "chemistry" yields 11,621 publications). It plays an important role due to high efficiency and selectivity, easy separation, purification of products and economy. Direct microwave heating significantly shortens the chemical reaction time and reduces side reactions. A microwave oven was also used. The use of microwaves allows, among other things, the use of diluted reagents (e.g. in the synthesis of esters, we can use dilute sulfuric acid instead of concentrated sulfuric acid) and allows the substances to be heated for a shorter time (e.g. in the dehydration of copper(II)sulphate decahydrate or in the thermal decomposition of ammonium chromate(VII)). The advantages of using microwave ovens in school education in the field of green chemistry have been widely described by Čermák et al. (2010), Kolář, Nodzyńska and Cieśla (2015) or Šulcová and Böhmová (2007a; 2007b). Online labs or simulations have replaced some of the experiments. In place of running water, a refrigerator or ice was used for cooling.

RESEARCH & METHODOLOGY

Students subjected the experiments developed in this way to practical evaluation in the first year of master's studies (future teachers of chemistry and biology). The research aimed to evaluate whether replacing traditional experiments with those that consider the principles of sustainable development (e.g. green chemistry) will affect the students' sense of security and whether they will notice how changing the technique of conducting experiments affects the environment. And whether they will feel safer conducting these modified experiments. It was assumed that after 3 years of laboratory classes in undergraduate studies, students are aware of their users and are aware of the environmental hazards posed by some of the experiments.

The research involved 44 students from master's studies in the field of Teaching Biology and Chemistry. These students had a bachelor's degree in biology or chemistry where they previously had traditional laboratory classes in general, analytical, inorganic, and organic chemistry. As part of the "Designing Chemical Experiments" course, they got acquainted with various techniques for conducting chemical experiments so that they would be more aware of the ecological impacts of experiments and consider the principles of sustainable development (e.g. green chemistry). Students independently designed and performed experiments using a microscale (including droplet analysis), a microwave oven, a microscope and online laboratories or simulations.

The research aimed to check whether there is a real possibility of replacing school chemical experiments with more ecological alternatives. That is, whether new versions of experiments are safer, less burdensome to the environment and whether their performance brings greater satisfaction to students. And what students - future chemistry teachers - think about it.

A questionnaire was used for the research. The main measurement strategy used in this survey questionnaire was the Likert scale. It allows us to obtain knowledge about the degree of acceptance of views and is often used to measure attitudes towards specific events, objects or problems. In total, students were asked 35 questions in the study. 33 of them were closed questions, where a 5-point Likert scale was used, as well as one closed question with YES/NO answer, and one open-ended question.

Because during scientific research, the question always arises whether the results obtained are statistically significant. The obtained results were processed in the Jamovi statistical program.

RESULTS

For many of the variables, the distribution was not normal (see Tab. 1). But it is difficult to expect a normal distribution, e.g. in questions about age (when these are students of the same age), gender (in Poland, there is a clear predominance of women at university). It is also difficult to expect diverse answers (consistent with a normal distribution) in questions regarding their everyday laboratory practice (answers to questions: 1-8, 11-12, 21, 26-29, 31-34). But in a situation where the question concerned new problems that did not appear in chemistry classes in which they had previously participated (questions 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 30) the distribution of answers was consistent with the normal distribution. It can therefore be assumed that the obtained results are statistically significant.

The first part of the research concerned traditional laboratories. The first two questions concerned the students' belief in the need to perform experiments in chemistry classes and their sense of safety in such classes (Tab.2). Most students believe that experiments are an essential element of chemical education (74.1%) and feel safe during this type of classes (79.6%).

Furthermore, the answers to questions about self-conducting experiments, using a burner or using concentrated solutions show quite a high self-confidence in students (Tab. 1.). 56.8% of students are not afraid of using the burner on their own and 54.5% are not afraid of experimenting and using concentrated solutions on their own. It can be assumed that students are confident users of the laboratory. The following questions checked whether students were aware of the negative impact of the chemistry laboratory classes on the environment and the environmental hazards of some of the experiments (Tab. 2). It turns out that most of the surveyed students disagreed with the statements that too many reagents are used, too much water is used, too much electricity is used and too much harmful waste is generated in laboratory classes. This highlights a very poor understanding of ecological issues by the students.

Tab.1. Results of the Shapiro-Wilk W and Shapiro-Wilk p test for individual questions.

	W	P
Sex	0.496	<.001
Age	0.799	<.001
Field of study	0.892	<.001
Level of study	0.759	<.001
1. I believe that doing traditional laboratory experiments in chemistry classes is necessary.	0.629	<.001
2. I feel safe during chemistry lab classes.	0.791	<.001
3. During chemistry laboratory classes, I am afraid to perform chemical experiments on my own.	0.859	<.001
4. During chemistry laboratory classes, I am afraid of heating substances with a burner on my own.	0.837	<.001
5. During chemistry laboratory classes, I am afraid to use concentrated substances myself.	0.858	<.001
6. I believe that too many chemical reagents are used in chemistry laboratory classes.	0.790	<.001
7. I think that too much water is used in chemistry labs.	0.879	<.001
8. I believe that too much electricity is used during chemistry lab classes.	0.807	<.001
9. I believe that chemistry laboratory classes produce too much harmful waste.	**0.923**	0.006
10. I believe that the use of MICROSCALE (DROP ANALYSIS) in chemistry laboratory classes is essential.	**0.915**	0.003
11. I believe that the use of MICROSCALE (DRIP ANALYSIS) in chemistry laboratory classes results in less reagent use.	0.876	<.001
12. I believe that using MICROSCALE (DROP ANALYSIS) in chemistry laboratory classes results in less waste.	0.859	<.001
13. I believe that the use of MICROSCALE (DRIP ANALYSIS) in chemistry laboratory classes will increase my sense of safety during classes.	**0.934**	0.014
14. I believe that the use of MICROSCALE (DROP ANALYSIS) in chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.925**	0.007
15. I believe that the use of a MICROWAVE OVEN in chemistry laboratory classes is essential.	**0.918**	0.004
16. I believe that the use of a MICROWAVE OVEN in chemistry laboratory classes results in less reagent use.	**0.899**	0.001
17. I believe that using a MICROWAVE OVEN in a chemistry laboratory class results in less waste.	**0.923**	0.006
18. I believe that using a MICROWAVE OVEN during chemistry laboratory classes will increase my sense of safety during classes.	**0.934**	0.015
19. I believe that using a MICROWAVE OVEN in chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.924**	0.007
20. I believe that using a MICROWAVE OVEN in chemistry laboratory classes will result in lower energy consumption.	**0.928**	0.009
21. I believe that the use of MICROSCOPE in chemistry laboratory classes is essential.	0.878	<.001
22. I believe that the use of a MICROSCOPE in chemistry laboratory classes results in less reagent use.	**0.924**	0.006
23. I believe that using a MICROSCOPE in a chemistry laboratory class results in less waste.	**0.929**	0.009
24. I believe that using the MICROSCOPE during chemistry laboratory classes will increase my sense of safety during classes.	**0.916**	0.003
25. I believe that using the MICROSCOPE during chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.911**	0.002
26. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes is essential.	0.898	<.001
27. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes results in less reagent use.	0.785	<.001
28. I believe that using ONLINE LABORATORIES in chemistry laboratory classes results in less waste.	0.784	<.001
29. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes will increase my sense of safety during classes.	0.864	<.001
30. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.900**	0.001
31. I believe that ON-LINE LABORATORIES should replace ALL chemistry laboratory classes.	0.621	<.001
32. Have you heard the term GREEN CHEMISTRY?	0.587	<.001
33. I believe that the principles of green chemistry must be applied during laboratory classes.	0.833	<.001
34. If you were to choose a field of study again, would you pay attention to whether the field has a "green chemistry" certificate?	0.868	<.001

The second part of the research concerned the use of microscale techniques and droplet analysis during laboratory classes. SSC is a technique to support experimental chemistry teaching. It involves working with small amounts of chemicals, which increases the safety of the experiment, reduces the time it takes to conduct it, allows for a more detailed discussion, and is also less harmful to the environment. SSC also includes droplet analysis, which is one of the methods of qualitative microanalysis (Orliński, 2013; Tananaev, 1956). The essence of the method lies in the fact that droplets of the test solution and reagent are used for the analysis. During the lectures, students learned about the principles of this technique and then designed and performed experiments using it themselves. It was examined whether, according to students, the use of microscale techniques and droplet analysis during laboratory classes is necessary, whether it causes less consumption of chemical reagents and waste, whether it increases their sense of security, and whether it will make them more willing to perform experiments on their own - compared to "classic" laboratory classes. (Tab. 3.). As our results shows, slightly more than half (59.1%) of students believe using microscale techniques and droplet analysis in laboratory classes results in less consumption of chemical reagents and less waste. 36.4% believe that it increases their sense of safety and is necessary. However, only 25% believe using microscale techniques and droplet analysis in laboratory classes will make them more willing to conduct experiments on their own - compared to "classic" laboratory classes.

Tab. 2 Students' answers to questions 1 – 9.

	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
Performing traditional laboratory experiments in chemistry classes is necessary.	63.6%	20.5%	9.1%	0.0%	4.6%	2.3%	0.0%
I feel safe during chemistry lab classes.	29.6%	50.0%	13.6%	2.3%	4.6%	0.0%	0.0%
I'm afraid to do my own chemical experiments.	2.3%	6.8%	22.7%	6.8%	6.8%	27.3%	27.3%
I'm afraid of heating the substance myself with a burner.	4.6%	6.8%	20.5%	0.0%	11.4%	25.0%	31.8%
I'm afraid to use concentrated substances myself.	6.8%	4.6%	18.2%	4.6%	11.4%	27.3%	27.3%
In chemistry lab, too many reagents are used.	9.1%	4.6%	11.4%	4.6%	4.6%	29.6%	36.4%
In chemistry lab, too much water is used.	0.0%	6.8%	13.6%	13.6%	11.4%	31.8%	22.7%
In chemistry lab, too much electricity is used.	2.3%	2.3%	2.3%	15.9%	6.8%	34.1%	36.4%
In chemistry lab, too much harmful waste is generated.	6.8%	6.8%	13.6%	15.9%	18.2%	25.0%	13.6%

Tab. 3. Students' answers to questions 10 - 14 concerning the use of microscale techniques and droplet analysis during laboratory classes.

Use of microscale techniques and droplet analysis during laboratory classes …	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	13.6%	20.5%	34.1%	27.3%	2.3%	2.3%	0.0%
... results in less consumption of chemical reagents.	27.3%	31.8%	13.6%	22.7%	2.3%	2.3%	0.0%
... creates less waste.	25.0%	34.1%	9.1%	27.3%	4.6%	0.0%	0.0%
... increases my sense of security.	13.6%	22.7%	13.6%	25.0%	11.4%	9.1%	4.6%
... will make me more willing to do my own experiments.	11.4%	13.6%	15.9%	31.8%	4.6%	11.4%	11.4%

The third part of the research concerned the use of a microwave oven during laboratory classes. For example, in Czech publications, we find experiments with the use of microwaves in chemistry lessons (e.g. heating of metals, synthesis of aspirin, synthesis of soap, synthesis of fluorescent dyes) (Šulcová & Nývltová 2004a; 2004b; Šulcová & Böhmová 2007a; 2007b). The answers to our questions about the use of microwave ovens in chemistry laboratories are shown in Table 4.

Tab. 4. Students' answers to questions 15 - 20 concerning the use of microwave ovens during laboratory classes.

I believe that the use of a microwave oven in chemistry lab classes...	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	6.82%	11.36%	25%	27.27%	9.09%	20.45%	0%
... results in less consumption of chemical reagents.	-	4.55%	25%	40.91%	6.82%	15.91%	0%
... creates less waste.	4.55%	9.09%	13.64%	38.64%	9.09%	22.73%	2.27%
... increases my sense of security.	6.82%	2.27%	18.18%	27.27%	13.64%	20.45%	11.36%
... will make me more willing to do my own experiments.	4.55%	13.64%	11.36%	27.27%	6.82%	22.73%	13.64%

43.18% believe using a microwave oven during laboratory classes is necessary, and 27.27% believe that it increases their sense of safety. 36.37% believe that it results in less use of chemical reagents and 27.28% that it causes less waste. 25.01% believe it will result in lower energy consumption. Only 30% believe using a microwave oven in laboratory classes will increase their willingness to conduct experiments independently.

The next question concerned the use of a microscope. The results of answers to questions about the use of a microscope in chemical laboratories are presented in Table 5. 70.43% believe using a microscope during laboratory classes is necessary, and 29.55% believe that it increases their sense of security. 52.27% believe that it results in less use of chemical reagents and 47.72% that it causes less waste. 43.18% believe using a microscope during laboratory classes will increase their willingness to conduct experiments on their own.

Other techniques used during classes were online laboratories and simulations (Krebs, 2023; Teplá & Distler, 2023). 40.9% believe using online laboratories or simulations in laboratory classes is necessary, and 59.1% believe that it increases their sense of safety. 77.3% believe that it results in less use of chemical reagents and 72.7% that it causes less waste. 31.8% believe using online labs or simulations in lab classes will increase their willingness to conduct experiments on their own (Tab. 6). However, most respondents (81.1%) believe that online laboratories and simulations should not replace all existing exercises in chemistry laboratories.

The last part of the research concerned students' attitudes towards green chemistry. During their bachelor studies, most students (68.2%) did not come across the term "green chemistry" either during chemistry classes or during classes on environmental protection or sustainable development. But people who answered question 32 (Have you heard the term green chemistry?) stated that they knew this term and in answer to question 33 (Define the term green chemistry) gave the correct definition of this term. Even more surprising are the students' answers to question 34: If you had to choose your field of study again, would you pay attention to whether this field has a "green chemistry" certificate?' For more than half of the students (52.3%), it does not matter whether the studies they participate in are environmentally friendly. Only one-third of respondents (34.1%) agreed with that statement (Fig.1).

Tab. 5. Students' answers to questions 21 - 25 concerning using a microscope during laboratory classes.

I believe that the use of a microscope in chemistry lab classes...	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	20.45%	25%	25%	0%	15.91%	11.36%	2.27%
... results in less consumption of chemical reagents.	13.64%	27.27%	11.36%	27.27%	9.09%	9.09%	2.27%
... creates less waste.	11.36%	25%	11.36%	29.55%	9.09%	11.36%	2.27%
... increases my sense of security.	9.09%	15.91%	4.55%	43.18%	9.09%	13.64%	4.55%
... will make me more willing to do my own experiments.	11.36%	25%	6.82%	29.55%	6.82%	9.09%	11.36%

Tab. 6. Students' answers to questions 26 - 30 concerning using online laboratories or simulations in laboratory classes.

I believe that the use of online lab & simulations in chemistry lab classes...	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	6.8%	11.4%	22.7%	6.8%	13.6%	15.9%	22.7%
... results in less consumption of chemical reagents.	43.2%	22.7%	11.4%	15.9%	0.0%	2.3%	4.6%
... creates less waste.	43.2%	25.0%	4.6%	18.2%	2.3%	2.3%	4.6%
... increases my sense of security.	27.3%	18.2%	13.6%	18.2%	2.3%	6.8%	13.6%
... will make me more willing to do my own experiments.	11.4%	11.4%	9.1%	15.9%	13.6%	15.9%	22.7%

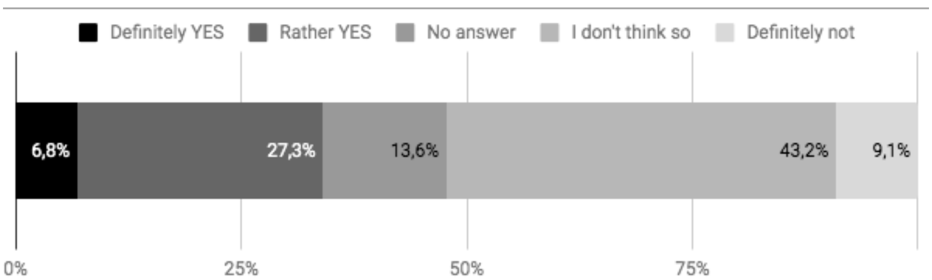

Fig. 1. Students' answers to question 34: If you had to choose a field of study again, would you pay attention to whether the field has a "green chemistry" certificate?

Considering that we are talking about students - future chemistry teachers, the results of the answers to the last question are very disturbing: I believe that the principles of green chemistry should be applied during laboratory classes. More than half of the students (52.3%) have no opinion on whether the rules of green chemistry should be applied during laboratory classes. Only 43.2% of respondents agree with this thesis (including only 11.4% who definitely agree) (see Fig. 2.).

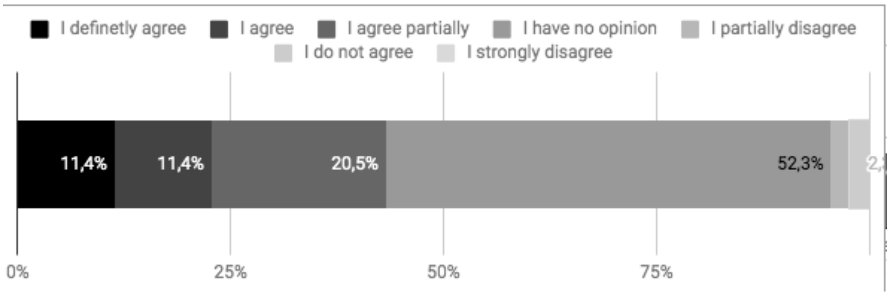

Fig. 2. Students' answers to question 35: I believe that the principles of green chemistry must be applied during laboratory classes

DISSCUSION

Although the principles of green chemistry are popular, teachers must do a lot of work to adapt and translate the principles of green chemistry, regarding industry, into appropriate school experiments (Nahlik et al., 2023). There are no guides for teachers on how to do this, and there are no classes on this subject at universities. Therefore, the research was undertaken to check whether there is a real possibility of replacing school chemical experiments with a more ecological version and what students - future chemistry teachers - think about it. Research on teachers and future chemistry teachers in terms of their knowledge and attitudes toward green chemistry was conducted, among others, by Basheer et al. (2023). Their results showed that teachers' awareness of sustainable development and green chemistry was generally low and depended on years of experience. This means that students do not acquire this knowledge from their studies - this conclusion was also confirmed by our research.

Also, like Karpudewan and Kulandaisamy (2018) we designed and tested green chemistry experiments for their application in teaching chemistry at schools - in this case the results were also confirmed. Respondents found that the green chemistry experiments were consistent with the current curriculum, feasible to implement, encouraged inquiry, were safe, and relevant. However, we were unable to confirm the results obtained by Karpudewan et al. (2012) where the group of students (future teachers) conducting "green experiments" were more internally motivated than the group conducting traditional experiments. We can therefore conclude that our research results are consistent with the research of other, before mentioned scientist’s work.

By analysing in detail, the students' answers to individual questions, we can conclude that the answers of the surveyed students to questions 1 & 2 show that after completing compulsory chemistry classes in bachelor's studies, students believe that chemistry laboratory classes are necessary, and they feel safe during them. Most of them are not afraid to experiment on their own and use a burner and concentrated solutions (compare answers to questions 3, 4 & 5). However, when we compare the students' answers to question 2 with the answers to questions 3, 4, and 5, we see a clear decrease in the number of positive answers (93.2% feel safe in chemistry laboratories vs. 60-70% feel safe performing experiments on their own, using a burner or concentrated solutions). This means that despite the declarative general sense of security (answer to question 2) when we ask about specific laboratory activities, the level of students' safety decreases. Moreover, students do not agree with the statement that typical laboratory classes use too many reagents, too much water, too much electricity, and produce too much harmful waste (see answers 6, 7, 8, 9). This is probably because during the 3 years of chemical education during their bachelor's studies, none of the academic teachers brought this problem to their attention. However, they believe that the use of new techniques: microscale and drop analysis, microscope, microwave oven, simulations, and online laboratories reduce the consumption of reagents and generate less waste compared to traditional laboratories. Since most students feel safe during typical laboratory classes, they do not believe that the use of these techniques will affect their level of safety. A similar situation occurs with the "willingness to perform experiments" - although they consider new techniques interesting, they claim that it does not affect their level of motivation to perform tasks. Therefore, it can be concluded that students positively evaluate the new green methods of conducting classes and believe that laboratory classes conducted in this way will be less burdensome for the environment.

CONCLUSION

The results show that it is possible to replace traditional laboratory classes with more environmentally friendly ones, but after 8 years of traditional chemistry learning, students did not notice the harmfulness of traditional teaching experiences (consumption of large amounts of reagents, water, and electricity, or generation of harmful waste). Therefore, they do not perceive that it is necessary to replace traditional experiences more widely with more ecological versions. It seems that it is necessary to first show academic teachers the burden of traditional laboratory classes on the environment so that they can then properly shape students' attitudes. At the Pedagogical University in Krakow, this topic was dealt with by Justyna Mikołajczyk, MA in her bachelor's thesis (2021): Sustainability in STEM education - insights in the biology teachers' curricula and master's thesis (2023): Sustainable development in the eyes of students and academic teachers of the Institute of Biology and Earth Sciences UP and in publication Mikołajczyk & Nodzyńska (2024).

Particularly shocking are the answers to questions about the course having a "green chemistry certificate" and the need to apply the principles of green chemistry during laboratory classes. Only ⅓ of students would pay attention to the certificate, and more than half of the students (52.3%) have no opinion on whether the rules of green chemistry should be applied during laboratory classes. Therefore, it seems that when it comes to the education of future chemistry teachers, starting from the first laboratory classes, special attention should be paid to the ecological aspect of said education. Elements of green chemistry should also be introduced in primary and secondary school education. The results of this study suggest that green chemistry can and should be integrated into mainstream chemistry education.

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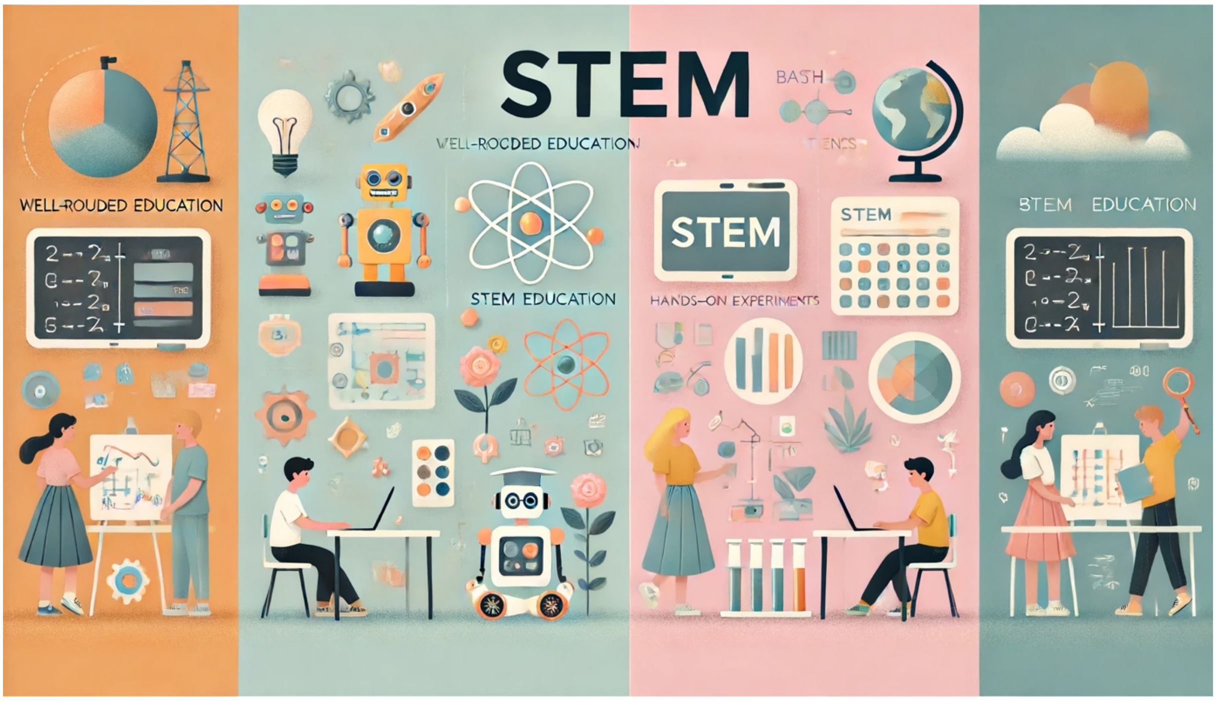

II. OTHER ISSUES IN SCIENCE EDUCATION

Characteristics of Effective Teacher Professional Development Programs

Rıdvan Elmas, Merve Adıgüzel Ulutaş & Mehmet Yılmaz

Abstract

This study elucidates the preferences of 151 science teachers in Turkish Public Schools regarding teacher training programs. Through a survey, the researchers found a strong inclination for shorter, face-to-face, or hybrid sessions over online formats. Teachers preferred training programs focusing on 21st-century skills, laboratory experiments, and real-life problems with an interdisciplinary approach. While overall satisfaction was high, some teachers noted concerns about specific programs being too theoretical. This research underscores the importance of tailoring training programs to meet teachers' preferences for effective professional development.

Keywords:

Teacher professional development; teacher training programs; teacher training program characteristics

INTRODUCTION

Teachers are vital in obtaining educational quality and producing well-trained students (Bauer & Prenzel, 2012). Teachers are also responsible for guaranteeing that practical educational innovations and reforms are effective (Biesta & Tedder, 2016). Therefore, teacher education is critical to adapting to the globalizing world (Siddiqui et al., 2021). Eli (2021) emphasized that teachers must be taught with innovative and participatory teaching techniques. Through teacher training, teachers are supposed to obtain new knowledge and abilities. As a result, they are supposed to be lifelong learners who grow themselves and embrace new ideas. At the same time, teacher training is expected to motivate teachers towards education (Sim, 2011). A teacher's competence is not only related to her knowledge and skills but also the teacher's attitude and motivation (Zlatić et al., 2014). However, teachers think they are not supported enough to keep up with new developments and changes and integrate them into the classroom (Nwachukwu & Charity, 2019). In particular, public-school teachers are supported by training programs through seminars or one-session workshops. Nevertheless, these training programs do not provide opportunities for instructors to practice, and teachers may be unable to effectively incorporate the needed information and abilities into the classrooms (Kirkpatrick et al., 2019).

Although teachers, school administrators, and policymakers agree on the necessity of teacher training programs (Hargreaves & Fullan, 2015), there is no consensus on how to implement these programs (Friedman & Phillips, 2001). The general characteristics of teacher training programs are mentioned below (Darling-Hammond, 2012):

- Learning-centred
- Skill-oriented
- Have implementation
- More than a single set of activities
- Encouraging a growth mindset
- Ongoing professional development

Teachers should be supported by training programs that have innovative and effective training schedules. However, there may be more training to meet the needs of teachers, and teachers may need more time and opportunity to follow all this training content (Kirschner & Wopereis, 2003). For this reason, before the training is designed, it is essential to get the teachers' opinions about the current needs of the teachers and how the training will be organized. This study sought teachers' opinions on how to prepare a training module for them in the context of their needs. Teachers will receive training through a training program that provides knowledge, skills, and experience. At the end of the training, the results of applying this training program to the students in their classes. This study significantly discloses teachers' desires and perspectives about teacher training programs.

METHODOLOGY

In line with the purpose of the research, descriptive research design, one of the qualitative research designs, was used. A descriptive research design is a research design that tries to acquire and characterize information about a situation or phenomenon systematically (Willis et al., 2016). This study is part of an extensive research project to develop effective teacher training programs.

Sample

The study research group consists of 151 science teachers working in Turkey. Tab. 1 shows demographic information about science teachers.

Data collection tools

A questionnaire created by the researchers and finalized with experts' feedback was used to collect data in the study. Two experts are professors in teacher training, and the other expert works as a teacher. The five questions asked within the scope of the research are presented below.

1. When you evaluate the training modules in terms of applicability, how many hours should the training programs take?
2. When you evaluate the training modules in terms of applicability, what type of training is better (online, face to face or hybrid)?
3. Which of the listed features should training programs contain?
4. Are you satisfied or unsatisfied with the teacher training programs you have received so far?
5. Why are you satisfied or unsatisfied with the teacher training programs?

Tab. 1 Demographic information about science teachers

TEACHERS		N
GENDER	MALE	53
	FEMALE	98
EXPERIENCE (YEAR):	BETWEEN 1-5 YEARS	23
	BETWEEN 6-10 YEARS	33
	BETWEEN 11-15 YEARS	55
	16 YEARS AND ABOVE	40
SCHOOL TYPE	STATE SECONDARY SCHOOL	107
	SCIENCE AND ART SCHOOL (SPECIAL FOR GIFTED SCHOOL)	25
	PRIVATE SECONDARY SCHOOL	19
EDUCATIONAL ATTAINMENT	BACHELOR	85
	MASTER	58
	PHD	8

Data analysis

The data were analyzed through descriptive analysis by coding the phrases as a unit of analysis. Both researchers analyzed the data to ensure reliability in the data evaluation process. Then, the formula (Reliability=Consensus/All opinions) by Miles and Huberman (2015) was applied. According to the formula, the reliability of the scores is .85 for the study. The coders reviewed mismatched data and made a consensus decision.

RESULTS

In the research, the opinions of the teachers about the training programs were analyzed. The results are shown in the tables below.

Tab. 2 Training time preferred by teachers.

TRAINING TIME	f	%
BETWEEN 1-5 HOURS	78	51,7
BETWEEN 5-10 HOURS	45	29,8
11 HOURS AND ABOVE	30	19,9

When you examine Tab 2, most teachers (f = 78) prefer that a training program between 1-5 hours is more appropriate. Tab 3 shows the training type preferred by teachers.

Tab. 3 Training type preferred by teachers.

TRAINING TYPE	f	%
FACE TO FACE	75	49,7
HYBRID (ONLINE AND FACE TO FACE)	69	45,7
ONLINE	7	4,6

When you examine Tab 3, most teachers emphasized that face-to-face (f = 75) and hybrid (f = 69) training programs are more effective. Tab 3 shows training program features preferred by teachers.

Tab. 4 Training program features preferred by teachers.

TRAINING FEATURES	f	%
It supports the development of 21st-century skills	119	78,8
It should include laboratory experiment	116	76,8
Based on real-life problems	115	76,2
It should include an interdisciplinary approach	114	75,5
It should be sustainable	102	67,5
It should be included misconceptions	102	67,5
It should be leaner-centred approach	100	66,2
Supports individual development	89	58,9
It should develop multiple perspectives	92	60,9
Supports group work	89	58,9
It should be process-oriented approach	87	57,6
It should be skill-oriented approach	76	50,3
It should allow for solution in more than one way	84	55,6
It should support peer learning	79	52,3
It should be constructive feedback loops	68	45
It should be problems-based	68	45
It should be project -based	67	44,7
It should provide effective and meaningful learning with an emphasis on causality	43	28,3
It should contain patterns	38	25,2
It should contain interdependent phases	32	21,2
It should provide an understanding of complex system behaviour	31	20,5
It should allow system mapping	29	19,2
It conceptual teaching should be at the forefront	23	15,2
Focus and in-depth study on a single discipline	11	7,3
It should be product-oriented approach	10	6,6
It should be trainer-centred approach	6	4

When you examine Tab 4, the majority of teachers emphasize that training programs should support the development of 21st-century skills (f = 119), include laboratory experiments (f = 116) based on real-life problems (f = 115), and include an interdisciplinary approach (f = 114). Tab 5 shows teachers' satisfaction with the education they have received so far.

Tab. 5 Teachers' satisfaction with the education they have received so far.

TEACHERS' SATISFACTION	Reasons	f	%
YES	Contributing to Professional Development	56	53,8
	Include Up-to-Date Educational Approaches	37	35,6
	Allowing Implementation	11	10,6
NO	Focus on Theoretical Knowledge	27	57,5
	Inadequate Preparation of Training Content	16	34
	Consisting Of a Single Stage	4	8,5

When you examine Tab 5, Most teachers are satisfied with the training they have received so far. Teachers mostly stated that they were satisfied with the training they received because it contributed to their professional development. In addition, the majority of teachers indicated that they were not satisfied with the training programs they received in terms of focusing only on theoretical knowledge.

DISCUSSION AND CONCLUSION

As a result of the research, it was revealed that teachers preferred short training periods and face-to-face or hybrid training programs. It has been determined that teachers find face-to-face and online training programs useful in these studies (Frantsz, 2017; Marsicano et al., 2015). Furthermore, active study and development of new teaching methods, as well as an emphasis on practicality, are underlined as critical qualities of teacher training programs (Zhao & Liu, 2022). Besides, the training must have some features such as supporting the development of 21st century skills, including laboratory experiments based on real-life problems, and an interdisciplinary approach. According to Gulhan (2022), there is a need for interdisciplinary and implemented studies. Elmas et al. (2023) mentioned that teachers prefer learning environments based on interdisciplinary and real-life problems. Canosa et al. (2020) underline the necessity of contextualized and adaptable education that reacts to real-world and changing events in schools and communities. The majority of the teachers stated that they were satisfied with the education they received in terms of contributing to their professional development. However, some teachers indicated that they were not satisfied with the fact that the education they received focused only on theoretical knowledge. According to Kurniawati et al. (2014), most training programs prioritized attitudes, knowledge, and skills. The training programs also focused on what could be considered short-term practices, which were augmented by field experiences. Tafazoni (2021) stated that teachers' views on teacher education include expectations regarding their professional development. This highlights the importance of addressing these expectations to ensure effective and relevant teacher training programs.

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Content analysis of publications about sustainable education in science classes on a selected publishing platform

Radka Matoušková & Lukáš Rokos

Abstract

Teaching for sustainability in science classes is something relatively new in the world of education. We have always been concerned with environmental issues, but the topic of sustainability as such has only 'recently' come to the fore and into our awareness. This paper is focused on the results of content analysis of publications available particularly on the Web of Science. The analysis was based on the use of several particular keywords and the findings were sorted according to various criteria. The main goal of this paper is then to find out to what extent the phenomenon of sustainability in relation to science education is being dealt with by scientists and research around the world.

Keywords

Sustainability; STEM education; science education; content analysis

INTRODUCTION

Global warming, deforestation of rainforests, plastic waste, floods, droughts, illegal trade in animals and plants, poaching, and many other issues. All these serious phenomena have been in our consciousness for a very long time. Students learn about them at school, we can hear about them on television or radio, or we might read about them in the newspapers. In this paper, we would like to focus more on one particular phenomenon that is both very close to them and equally important – sustainability. This phenomenon, however, does not directly represent a problem or an issue as the previous ones, but rather an essential need. Brundtland's definition of sustainability, as the most frequently quoted one, defines it as meeting the present needs without compromising the ability of the future generations to meet their own needs (Brundtland, 1987). Though, there may be several pitfalls associated with this term. The first of these may be the fact that, unfortunately, not everyone can fully understand the word 'sustainability' itself. Some may think of it as simply 'waste disposal', i.e. using more environmentally friendly products (less plastic, less toxic, or otherwise hazardous waste, etc.), while others may think of it as reducing deforestation and the cutting down of trees in tropical rainforests or using public transport or electric cars instead of petrol or diesel ones. In the field of ecology, the term 'sustainability' refers to efforts to preserve natural resources for present and future generations, as well as to protect global ecosystems that contribute to our well-being and health

(Sphera's Editorial Team, 2020). It is therefore a kind of effort to preserve and maintain stable productivity, diversity, and stability of biological systems and processes. Similarly, for instance, Explicative Dictionary (Cambridge Dictionary, 2023) describes sustainability as the characteristic of an activity that can be carried out over a long period of time, or the use and development of natural resources without leading to their depletion or degradation of the environment.

This lack of clarity about what sustainability represents may in turn lead to the reluctance of individuals or social communities to participate in actions or activities related to environmental protection or sustainability itself, and thus transfer their responsibility to other actors. For instance, Jang (2013, p. 27–36) in his study pointed out to such lack of responsibility as some individuals feel that their own social group is less responsible for the issue of climate change than an outer group. Other studies show that individuals perceive, for example, specifically government more responsible than themselves (Chang et al., 2016, p. 566–584; Lorenzoni, 2006, p. 73–95).

Such an attitude is, apart from the aforementioned issued, also mainly related to their attitudes, values, prejudices or various constraints (Tolppanen & Kärkkäinen, 2021, p. 1-24).

To explore the topic of sustainability from different perspectives, we can combine it with another relatively young phenomenon in the world of education – integrated STEM education. It represents "an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (Moore & Stohlmann, 2014, p. 38). Likewise, Kelley and Knowles (2016, p. 1-11) described it as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning". Based on these definitions, it may be said that STEM education represents a modern way of education that integrates the four fundamental disciplines of science, technology, engineering, and mathematics, and can also be noted that the name STEM itself is made up of abbreviations of these disciplines to which the letters refer.

As STEM education represents a transdisciplinary discipline, it is then more feasible for us to look at sustainability more broadly and from multiple perspectives. Sustainability, on the other hand, requires knowledge from many disciplines that overlap and complement each other, and since STEM offers a transdisciplinary approach, it is than an ideal way for presenting sustainability-related topics. Furthermore, as the topic of sustainability relates to actual problems or phenomena (and thus there is a focus on searching for solutions to those real-world problems), the whole learning process may be then considered to be representative of properly integrated STEM education (Roehrig et al., 2021, p. 5). Sustainability, as a term, can refer to multiple distinct areas of our world - to business, economics, architecture, or even to fashion (Tang, 2018). However, this research will focus on sustainability in the environmental field, and therefore in the field of natural sciences.

NAE & NRC (2014, p. 143-152) came with suggestions to make STEM education of high quality and to put it into practise, for instance: the design and the goals of STEM education should be explicitly stated; the educators, STEM professionals, or research should work together with their colleagues; to create an appropriate assessment for measuring and evaluating the outcomes of the integration. Johnson et al. (2020) also emphasize that STEM lessons and STEM activities should be realistic, authentic, and the therefore it should focus on real-world problems. Once this approach is achieved, it could be then easier for the learners to understand the complexity of real-world issues. Moreover, real-world, and authentic integrated activities are considered by some scholars a tool to develop STEM literacy 21st century skills, such as curiosity, creativity, collaboration, or critical thinking (Moore et al., 2020; NAE & NRC, 2014).

Sustainability, STEM Education and Czech educational system

Even though in Czech educational system the STEM approach theoretically relates to many school subjects, in practise such subjects are taught separately which can cause problems in understanding the broader context and interconnectedness of the acquired knowledge (Janoušková et al., 2019). Nonetheless, this is not the only problem associated with the integrated education. Another problem might be that within Czech educational system, there is a strong tradition for teachers to specialize in only two subjects, i.e. in two majors only. This approach represents an obstacle for integration, which STEM education certainly is. Therefore, the solution for this issue might be either that teachers cooperate together or the modification of the system of their training and their education (Rusek et al., 2022).

Regarding the topic of sustainability and the Czech educational system, in the Czech Framework Education Programme for Basic Education it can be found in the educational area of Humans and Society (Civil Education), Humans and Nature (Natural Sciences), Humans and Their World (Humans and Their World – Diversity of Nature), and in the cross-curricular subject of Environmental Education (MŠMT, 2023). In the Framework Education Programme for Secondary General Education the topic of sustainability might be found in the educational area of Man and Nature (Biology) and in the cross-curricular subject of Environmental Education (MŠMT, 2023). As it can be noticed, the names as well as the content of the educational areas differ in the Framework Education Programmes between primary and lower secondary schools. However, they both have in common that in the Czech educational system, the separate educational field or cross-curricular subject called 'sustainability' is not there yet.

METHODOLOGY

Content analysis

The publications from Web of Science (webofscience.com, searched 2024-01-31) were searched by using several groups consisting of specially selected particular keywords in order to search only for documents focusing on the particular topics (in each group, there was a certain combination of keywords – set 1 to set 7) and then the found data were sorted according to specific criteria. The used keywords were – sustainability, teaching, science education, STEM education, science, STEM education, and sustainable. The applied criteria were – all documents found; documents published in 2023 (including 2023); documents published in the Czech Republic; and documents published in English language only. The reason for choosing these particular criteria was to show the distribution and quantity of documents published in that very year and the difference between the number of publications published in the Czech Republic (including documents either written in Czech language or by Czech authors in another language) and publications written in English language (which, undoubtedly, covers more countries and nations). Summary can be seen in Table 2. Lastly, the results were subsequently described and commented.

Tab. 1 Table with the sets of the particular keywords.

Set	Sustainability	Teaching	Science education	STEM education	Science	Sustainable
1	Yes	Yes	Yes	Yes	No	No
2	Yes	Yes	Yes	No	No	No
3	Yes	Yes	No	Yes	No	No
4	Yes	No	Yes	No	No	No
5	Yes	No	No	No	Yes	No
6	No	No	No	Yes	No	No
7	No	No	No	No	No	Yes

Tab. 2 Table with the number of publications found (based on sorting by individual criteria and on the use of certain keywords).

Criteria	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7
All documents found	80	970	124	3481	20516	16569	556561
Documents published in 2023	7	125	14	399	2344	1701	74426
Documents published in the Czech Republic	1	9	1	30	143	111	4486
Documents published in English language	80	900	124	3260	19699	15895	536055

Legend: Keywords – Set 1 (sustainability; teaching; science education; STEM education); Set 2 (sustainability; teaching; science education); Set 3 (sustainability; teaching; STEM education); Set 4 (sustainability; science education); Set 5 (sustainability; science); Set 6 (STEM education); Set 7 (sustainable).

During each research specific set (Set1 – Set 7) of keywords was first used to ensure that only articles related to these topics (i.e. related to the keywords used) were found. These keywords were used as equally significant (applied as coordinating ones with commas between each of them). The articles found then followed the same aforementioned certain criteria. After this step, articles that met all the requirements were displayed. In the following section, there is a more detailed description of what was found out in each research.

The results of the first search, focusing on **sustainability**, **teaching**, **science education**, and **STEM education**, show us that all publications were written in English language, of which only one article was written in the Czech Republic. Based on the data found, it might be said that the keywords used represent relatively new phenomena, the content of which researchers are only gradually beginning to focus on, and that in the Czech Republic has been very minimal focus on this topic.

The results of the second search, using the next set of keywords, including **sustainability**, **teaching**, and **science education**, show us that considerably more articles have been written than in the previous search. The main reason for this could be the omission of the word STEM education, as the topic of STEM education and sustainability together represent something new and something which has not been much described yet (such presumption can be seen in the following research results). On the contrary, the number of publications published in the Czech Republic has slightly increased.

In the results of the following research, we can see that once we included the **STEM education** phenomenon to the keywords **sustainability** and **teaching**, the number of publications in the Czech Republic reduced to one publication only (as it was in the first research). The number of all publications published, on the other hand, increased. . Finally, we can note that again all published articles were written in English language. The reason is, clearly, that the concept of STEM education represents something not yet fully explored. Therefore, if we omit this keyword, the number of publications will increase (as it did in the previous search). Conversely, if we include this term among the keywords, the number of publications will decrease.

In the fourth research, in which the keywords **sustainability** and **science education** were used, the number of all articles relatively increased compared to the previous results. The reason could be that these keywords no longer represent something completely new or “young” in the field of education, and therefore more attention has been paid to these topics.

The fifth research, however, shows us even higher numbers in terms of the total number of publications found. Both the terms **sustainability** and **science** are very broad and therefore include many other subgroups and sub-subgroups, which corresponds to the high number of publications found. Yet, the number of publications published in the Czech Republic is still relatively low (only 0.7% of the total number of publications found).

Although only one single keyword – **STEM education** – was used in the penultimate survey, the number of all documents found relating to this topic slightly decreased again. The reason is that this single keyword represents a relatively "new" concept and unambiguous term.

The assumption of this can be verified in the last research in which only one single keyword was used once again, but in this case, however, the word was not so "new", but rather a broad one - **sustainable**. This is clearly the main reason why most articles were found in this research.

CONCLUSION AND IMPLICATIONS

The main objective of this paper was to find out to what extent scientists from all over the world (including the Czech Republic) deal with the topic of sustainability as the subject of research and if the term is somehow connected to STEM education in their works.

Firstly, based on the results of the publications analysis, a great number of articles have been written about the topic of sustainable (as it represents diverse and a very broad concept) in comparison to the amount of publications focusing on the concept of STEM education (as it is considered a relatively new phenomenon in the field of school education). Nonetheless, we still assume that the connection between sustainability and STEM education has a certain potential for both science and education as such.

Secondly, most of the published documents have been written in another language (other than Czech) or in another country than the Czech Republic (including both the authors affiliated to the Czech Republic and Czech authors themselves). From these results we may conclude that compared to other countries, the Czech Republic has not yet focused on the aforementioned topics as on the subject of research much.

A follow-up study could also consider different variations and combinations of both keywords and criteria that were used and applied during the research. One of these variations could be a combination of keywords that specifically relate to other areas of STEM (i.e. areas other than science), such as technology, engineering, and mathematics, in relation to the topic of sustainability, or sustainability education. It is generally presumed that the topic of sustainability is in most cases associated with the topic of biology or science in general, the remaining aforementioned topics may therefore be slightly, and unintentionally omitted or may receive less attention (Roehrig et al., 2022). Therefore, the assumption of mine is that such research would yield quite different results.

Similarly, the study could focus on sustainability from one exact point of view, other than the scientific one and also other than STEM education, e.g. ethics. Although it may seem like an unusual connection, I and some of my colleagues believe that ethics is quite close to the topic of sustainability. Whether it is waste sorting, plant and animal protection, or water conservation, an ethical attitude and ethical sensibility should be found in all of these. However, further research would be necessary to give us concrete answers and more detailed information on this issue and on this very point of view.

Finally, if the exact same research was made retroactive to publications issued in 2024, the results might be different. As these are contemporary topics, it is to be expected that even if it was the same research, the results would vary. This would imply that the concepts of sustainability, STEM education, and science education are both very contemporary and vital.

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How to construct inquiry tasks: A methodological framework and task piloting

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Abstract

Scientific skills are one of the essential factors for the development of a person's scientific literacy. Inquiry-based tasks are an essential tool for developing scientific skills in inquiry-based science education. The research aim was to develop a design framework of inquiry-based tasks targeting the development of scientific skills and to find out students' views on the tasks constructed according to the proposed design framework. The tasks were solved by 59 Czech students at lower secondary school who completed the questionnaire consisting of the domains interest, effort, value, pressure, clarity, difficulty after the tasks, focusing on their opinions about the tasks. It was found that they considered the presented tasks quite understandable, important, not difficult, did not feel pressured in solving them and were quite interested in solving them. The verified design framework can be used in practice and the students' opinions show positive features of such design tasks for educational practice.

Key words

science education; lower-secondary school; inquiry-based tasks; student opinions

INTRODUCTION

A good level of scientific skills is a key prerequisite for increasing the scientific literacy of students/citizens. Moving towards developed scientific literacy in the broad sense is then an important factor for a person's full participation in society (see OECD, 2007).

This is also reflected in the EU's political commitments, which influence curriculum documents at the national level. This creates specific requirements for the education of students, particularly in science education (see National Research Council, 2023). Partial findings on the acquisition of scientific thinking and scientific skills by students at the lower secondary school show, according to the results of PISA testing (e.g. Meislová et al., 2018) and other researches (e.g. Nejedlý & Vojíř, 2022; 2023), that it is not of very good quality. It is, therefore, essential to focus on innovation in this area.

Scientific skills cannot be effectively developed through teacher-focused methods (Tosun & Taskesenligil, 2013). As a result, inquiry-based and model problem-solving instructional approaches that lead students to think and reason independently come to the fore. It is also essential that students can use scientific thinking and reasoning not only in a theoretical context but directly in solving a real-world problem (Saad et al., 2017). The development of scientific skills in conjunction with practical problem solving is targeted by inquiry-based learning (see Bybee, 2013; National Research Council, 2000; Osborne & Dillon, 2008). The current Czech curriculum requires the development of specific skills, including scientific skills such as using various empirical methods to investigate scientific facts, asking questions, making conjectures, and verifying their validity (MŠMT, 2023). In 2024, a new Czech curriculum is being developed that will focus even more on scientific skills (MŠMT, 2024). Czech teachers mainly use textbooks to inspire their teaching (e.g. Vojíř & Rusek, 2021). Similarly, the tasks included in current science textbooks typically do not support the development of complex scientific skills (Vojíř, 2021; Vojíř & Rusek, 2021). Other sources of lab tasks are available, but often these tasks do not meet the basic principles of inquiry-based learning (see Petr, 2014). Even if teachers are familiar with the concept of inquiry-based learning, they find it complicated to solve and use these tasks in their teaching and need specific support (Janštová & Pavlasová, 2019; Pavlasová, Janštová & Lindner, 2018). Thus, their usefulness for meeting scientific skills-related learning objectives is limited. For the practical use of inquiry-based tasks, it is essential that functional tasks adapted to the Czech environment are available.

Research aims and questions

Inquiry-based tasks, in order to successfully target the development of scientific skills, must meet important aspects of the inquiry cycle (e.g. Pedaste et al., 2015; Riga et al. 2017). At the same time, they should be interesting for students and motivate them to solve tasks. It is very time-consuming and difficult for practising teachers to create such tasks. At the same time, when students encounter laboratory activities, they do not target scientific skills, for example only just over 10% of Czech students plan their inquiry in lessons (see Meislová et al., 2018). However, it also shows that frequent inquiry-based learning leads to lower student performance on measures of scientific literacy (see Meislová et al., 2018). Since the main aim of this method is to contribute to the development of students' scientific literacy, the inferior results indicate the poor quality of its implementation. There is, therefore, a need for more inquiry-based tasks aimed at the development of literacy, especially its procedural aspects, which cannot be developed by non-active methods, and to provide more support for teachers. For these reasons, the aim was 1) to develop a general design framework of inquiry-oriented tasks targeting scientific skills development and 2) to find out students' opinions on tasks designed according to the proposed design framework. The second aim was concretized through the following research question: How do students rate the designed tasks in terms of interest, effort, usefulness, pressure, clarity, and difficulty?

THEORETIC BACKGROUND OF INQUIRY TASKS DESIGN

To be regarded as inquiry-based tasks, they should meet the basic principles of inquiry-based education. The National Research Council (2000, p. 25) outlines the basic principles of inquiry, which states that students in tasks are inquiring when they address inquiry-based questions, give priority to evidence, formulate explanations based on evidence, compare, and evaluate the validity of explanations, and communicate and justify explanations (National Research Council, 2000). These principles of inquiry are reflected in the different phases of inquiry-based learning, which can be summarized in the so-called inquiry cycle (see Pedaste et al., 2015). The numerous sub-steps are often summarised into larger parts in order to make the inquiry cycle more effective and easier to integrate into teaching. This is the case, for example, with the phases of the 5E cycle (Bybee et al., 2006). Pedaste et al. (2015) dealt with the phases of the inquiry cycle in more detail and conducted a meta-analysis to summarize different authors' concretizations of the phases of inquiry to describe a coherent and cohesive inquiry cycle. This cycle consists of 34 inquiry activities that are divided into five main phases - orientation, conceptualization, investigation, conclusion and discussion:

1. Orientation - at this stage, the topic is determined by the teacher, the student, or the environment. Furthermore, the student should be motivated, and his curiosity stimulated. Through orientation to the topic, the problem or problem question should be identified.
2. Understanding - in this stage, the process of understanding the concepts of the issue takes place. It is divided into two sub-phases of questioning and hypothesis formation. Through these sub-phases, the inquiry questions, or hypotheses to be explored are established. If the inquiry question is first established, hypotheses are formulated based on it.
3. Investigation - characteristic of this phase is the active resolution of the inquiry questions and hypotheses. There are three sub-phases, namely exploring, experimenting, and interpreting data. Students investigate, design different experiments or solutions according to changing conditions, make predictions and interpret the results.
4. Conclusions - students summarize and present results in this stage and test inquiry questions or validity of hypotheses.
5. Discussion - this phase is divided into communication and reflection sub-phases. Communication is implemented as an external process where students present and share their findings with others. Feedback and comments from other students to the presenter are an integral part of this. Reflection is a thought process taking place in the learner' s mind that reflects on the success of the inquiry or suggests improvements in their cycle of inquiry. For example, the learner asks questions such as "What did I do?", "Did I do it right?", "Were there other ways to do it?", etc. (Pedaste et al., 2015).

To fulfil the principles of inquiry-based learning, it is necessary to create specific tasks. Volkmann and Abell (2003) formulated principles for adapting classical laboratory tasks to inquiry-based tasks. The goal should be to engage students in inquiry through questions, evidence finding, explanation and communication: questions - changing the purpose of the activity to a question; engaging students in activities; where they generate inquiry-based questions; the teacher asks relevant questions.

a) Evidence - students define variables; develop procedures; tabulate and record data; make assumptions.
b) Explanations – a teacher moves the explanation of the problem after the problem is solved; a teacher expects students' main step in the problem to be developing evidence-based explanations; a teacher provides opportunities for students to work and learn together; a teacher engages students in analysing data and finding patterns, use, evidence, and logic to support evidence-based explanations.
c) Communication – a teacher provides opportunities for students to present explanations to other listeners through discussion, writing, and drawing; a teacher guides students in evaluating the logic of their explanations in terms of evidence (Volkmann & Abell, 2003, p. 43).

METHODOLOGICAL FRAMEWORK OF CONSTRUCT INQUIRY-BASED TASKS

The construction of inquiry tasks targeting scientific skill development consisted of multiple phases involving the construction and validation of a general design framework and the subsequent task concretisation. The sequence of construction is illustrated in Figure 1.

In the preparatory phase, key theoretical backgrounds were selected based on a search of expert references. Based on these, the inquiry cycle according to Pedaste et al. (2015) was chosen for the task construction. The principles for creating inquiry-based tasks by Volkmann and Abell (2003) were considered in the planned student and teacher activity. The tasks are built practically and use natural materials for solving (cf. Petr, 2014). Specific scientific skills that should be developed through the tasks were chosen (cf. Nejedlý & Vojíř, 2022). Namely, the development of tasks focused on defining the inquiry question and formulating an answer, designing a solution procedure, recording and processing data, and drawing conclusions. According to Hejnová and Hejna (2016), these skills are key to the development of scientific thinking in the educational process (Hejnová & Hejna, 2016). Based on these factors, a draft of general design framework was made and commented on by an expert panel consisting of three science didactics, three science experts and three biology teachers working at the lower secondary school. Comments on the general design framework were incorporated in a multi-round process until all expert panel members were in full agreement.

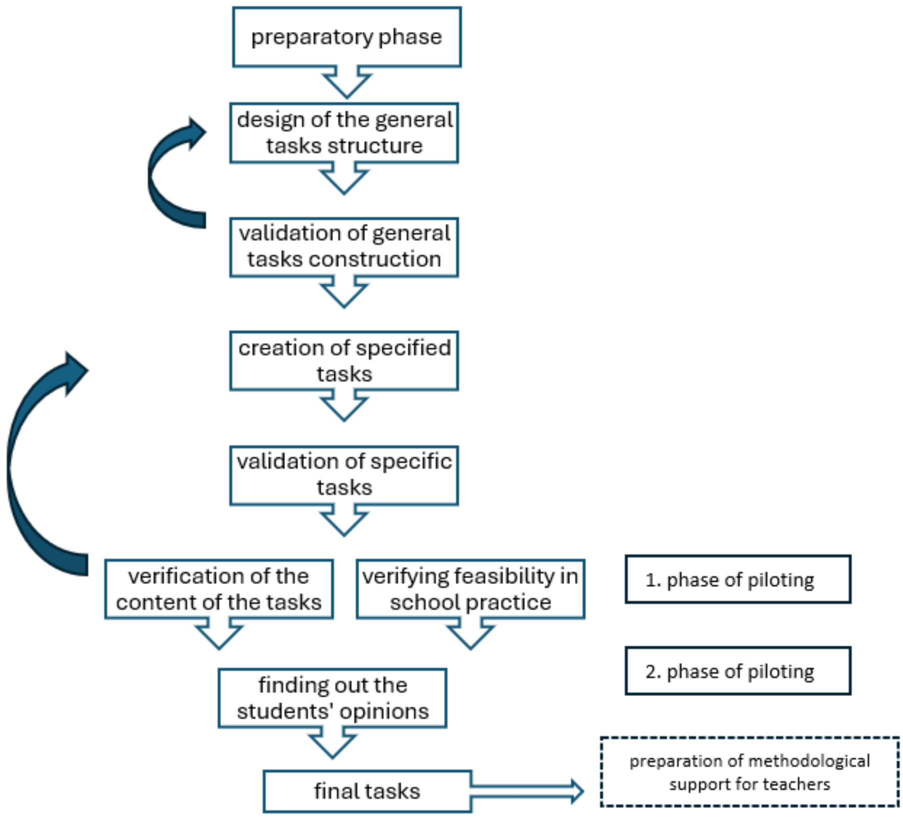

Fig. 1 Diagram of the general design framework of inquiry–based tasks (authors).

The resulting framework for the complex inquiry tasks consists of five subtasks:

1. The first sub-task consists of a short motivational text the students read. The text focuses on a problem situation in everyday life. There is an inquiry phase of the inquiry cycle - an orientation phase in which students are drawn into the topic and motivated to solve the problem.
2. The second subtask focuses on developing the formulation of the inquiry question. It consists of (a) a stated inquiry procedure and tools, (b) a space for students to formulate an inquiry question based on reading the stated procedure and tools, and (c) a space for students to state an expert inquiry question posed by the teacher.
3. The third subtask focuses on data recording and processing development. It consists of part where students record specific data and classify it based on their inquiry.
4. The fourth subtask focuses on the students' formulation of an answer to an inquiry question. It consists of part where students formulate answers to an inquiry question given by the teacher.
5. The fifth subtask focuses on drawing conclusions and discussion. It consisted of part where students write down the conclusions of their inquiry. This is followed by a short discussion between the students and the teacher.

6. The sixth subtask targets the skill of designing a procedure and tools based on the given inquiry question. It consisted of a) a stated inquiry question, which students read and based on the question, design the tools needed for the inquiry and write down the design of the expected inquiry procedure.

The general design framework was used as a basis for the construction of the specific tasks. Each of the problems was constructed to be solved in one class period i.e. 45 minutes. For the specific tasks, the educational content was selected to meet the didactic principles and to be relevant to the target group of students. Care was taken to ensure that the content was not burdensome in solving the tasks and could be varied in the tasks without affecting the focus of the tasks on the development of specific scientific skills.

The first phase of the validation consisted of three parts:

A. To assess validity in the context of task targeting, an expert panel was assembled, consisting of three biology teachers at the lower secondary school level, three biology didactics, an expert biologist to assess the content component, and a Czech language expert to validate the language component.
B. To validate the content aspect, the tasks were repeatedly tested in the laboratory regarding setting up an appropriate laboratory procedure. Specifically, the relationships between the variables, the solution procedure in the tasks, the use of appropriate aids, the time required to perform the laboratory part, the illustrativeness of the processes, and the necessary and appropriate amount of material were verified.
C. To assess the feasibility and technical aspects in school reality, the tasks were piloted on available samples of students.

If deficiencies or problematic aspects were found at any stage, they were modified, and the verification procedure was repeated. In total, 30 students were involved in the validation in three cycles. After two conditions were met (a) agreement in the expert panel on the tasks created and (b) no new problematic aspects were found in the task verification. Subsequently, the second phase of the pilot validation was initiated, in which students' opinions on the proposed inquiry-based tasks were elicited.

EVALUTION OF THE FRAMEWORK BASED ON STUDENTS' OPINIONS ON TASKS

To find out how students evaluate the tasks, a validation of the tasks in the classroom was conducted with a follow-up electronic questionnaire survey. The research was conducted at the beginning of the 2023/2024 school year. Two tasks were chosen for this purpose, with the first task being observational and the second task being experimental.

The research was carried out on a sample of 59 Czech students from the lower secondary school. The students solved the tasks 1) Yeast (experimental nature of the task) and 2) Shells (observational nature of the task).

Methodology

The first task focuses on the lift of yeast activity as a function of the amount of saccharose in solution. Students formulate an inquiry question on their own based on reading the solution procedure and the provided aids. The formulated questions are discussed with the teacher and then the teacher determines the inquiry question they will answer. Inquiry questions can be both causal (e.g. Is yeast activity in an environment with sugar higher than yeast activity in an environment without sugar?) and relational (e. g. Is there a relationship between yeast activity and the presence of sugar in the environment?). The procedure in the problem guides the student step by step in the solution. Students independently record the data from the experiment in a table. Students describe the yeast activity based on the formation of carbon dioxide bubbles. Students formulate an answer to the inquiry question based on the procedure performed and the data recorded. In the last subtask of the task, the inquiry question is chosen to develop the skill of designing a procedure. Students are asked to design an inquiry procedure and the necessary tools and materials based on the given inquiry question: What effect does the environmental temperature have on yeast activity?

The second task focuses on observing the shells of molluscs and describing the characteristics (size, colour, and shape) of a shell of one species based on observations of at least three shells of one mollusc species (e.g. swan mussel, white-lipped snail, etc.). Students formulate an inquiry question on their own based on reading the solution procedure and the provided aids (e. g. What is the size, colour, and shape of the shells of the species presented?). The procedure given in the problem guides the student step by step in the solution. The students independently record the data from the observation in a table. Students formulate an answer to the inquiry question based on the procedure performed and the data recorded. In the additional subtask, students are asked to design an inquiry procedure and the necessary tools and materials based on the given inquiry question: What is the length, colour, and texture of the body surface of the garden snail?

Immediately after solving both tasks, students independently completed the questionnaire electronically on tablets and mobile phones. For the research, a questionnaire was designed to focus on students' opinions about the inquiry-based tasks. The questionnaire was based on the Intrinsic Motivation Inventory (cf. McAuley et al., 1989; Ryan, 1982). The questionnaire consisted of 12 statements rated on a five-point scale (1 - definitely false, 5 - definitely true). Two of the statements always belonged to the same domain. IMI domains interest, efforts, value and pressure were used.

These domains were supplemented with two authors' domains: difficulty (e. g.: I understood what I had to do in the tasks.) and clarity (e. g.: The tasks were difficult for me to solve). The questionnaire was content validated by an expert panel consisting of 3 experts in biology didactics.

Findings

Cronbach' s alpha was calculated for each scale to assess reliability, see Table 1. The values found for all scales (0.85-0.96) can be considered acceptable (see Tavakol & Dennick, 2011). Therefore, the data were considered reliable and were descriptively evaluated.

It was found that in the four evaluated areas (interest, efforts, value and clarity) the students expressed their opinion in the middle of the scale, with the median value reaching 3, see Table 1. In the area of being under pressure, it was found that students do not feel under pressure when solving the inquiry-based tasks presented. This is illustrated by the median reaching a value of 1. Students rather do not perceive the tasks as difficult as illustrated by the median value found of 2.

Tab. 1 Cronbach' s alpha values for scales and medians of students' opinions.

Scale	Cronbach' s alpha	Medians of students' opinions
INTEREST	0,91	3
EFFORTS	0,86	3
VALUE	0,93	3
PRESSAURE	0,90	1
CLARITY	0,90	3
DIFFICULTY	0,82	2

DISCUSSION AND CONCLUSION

A general design framework for constructing of inquiry-based tasks was constructed and validated in multiple steps. Based on this framework, specific inquiry-based tasks were constructed. An important starting point for the development of scientific skills through solving inquiry-based tasks is how students perceive these tasks. The findings from the opinion analysis conducted suggest that students find solving inquiry-based tasks important and find the tasks interesting. Furtak et al. (2012) support the finding that properly implemented inquiry-based instruction through inquiry-oriented tasks has a positive effect on the procedural, epistemic and social domains of students' inquiry (see Furtak et al., 2012). The observed positive perceived value of the tasks for students can be explained by a) the thematic closeness of the tasks to real life and b) students' active solving of practical tasks (see Kwan, 2000). The analysis of the views shows that the tasks are comprehensible for students. The comprehensibility of the tasks for the students is one of the key aspects for successful problem solving (see Kalhous et al., 2002). The findings also show that the students do not find the tasks too difficult and do not feel pressured when solving them. This appears to be an essential factor for ensuring that tasks of too much difficulty do not discourage students from attempting to solve them. At the same time, the stress induced by making the tasks too difficult would be a limiting factor for their cognitive performance (see Kim et al., 2017).

Both the general design framework for the construction of inquiry-based tasks and the tasks constructed according to this framework proved to be functional. For this reason, they appear to be well applicable in educational practice.

However, these findings are limited by the low number of tasks proposed and the limited number of students who solved the tasks. Although the general design framework and the tasks designed according to it were based on available theoretical foundations, it is necessary to systematically address whether these tasks actually lead to the development of scientific skills and whether they are suitable for all students.

It is necessary to focus further attention on the creation of specific inquiry-based tasks that could be used in educational practice. It is also necessary to verify the effectiveness of these tasks for the development of scientific skills. Further research will be undertaken in this direction.

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The Unyielding Evergreen: A Delphi Study Insights into Chemistry Teachers' Views on Nomenclature, Balancing Equations, and Calculations

Martin Rusek & Michal Blaško

Abstract

This study explores chemistry teachers' opinions about critical topics of chemistry education instruction: chemical nomenclature, calculations, and balancing equation. The study employed a Delphi method to refine understanding and consensus among 13 active chemistry teachers, identified through social media platforms, about the evolving educational framework. Our findings suggest a significant variation in teacher perspectives on the necessary instructional scope of the three topics and considerable discrepancies between teacher-perceived goals and subject matter serving ther purpose. This reflects broader uncertainties about the ongoing curriculum reform.

Key words

Chemistry nomenclature; chemistry calculations; chemical equations; perceived curriculum; chemistry education; Delphi study

INTRODUCTION

The basic school curriculum in the Czech Republic has recently undergone a significant reform. This revitalization officially began in 2021 when, after fifteen years, substantial changes were made to the national curriculum for basic education. The changes in what is called the "major revision" were primarily aimed at: creating a competency-based curriculum, reducing the amount of educational content, and placing greater emphasis on basic literacies (reading, writing, and mathematics).

Another major change was a step further strengthening the autonomy of schools in the form of an increase in the available teaching hours. Although at the time of writing this text the proposal had not yet been approved, the brief for the working groups creating the new curriculum was based on a certain provisional time allocation. While these details will not be offered in the new curriculum, the working groups across various subjects within the educational area of Man and Nature operated with the time allocation granted in internal guidelines for the curriculum-making teams by the National Pedagogical Institute of the Czech Republic specified in Table 1.

Table 1 Overview of the ne curriculum's lesson distribution

FIELD	PLANNED LESSONS*	NUMBER OF EXPECTED OUTCOMES
BIOLOGY AND GEOLOGY	8	20
CHEMISTRY	6	15
PHYSICS	6	14

*The sum of lessons in weeks. Six lessons for Chemistry suggest there will be two weekly lessons from 7th to 9th grade (or any other distribution).

The field of chemistry education has been presented with an opportunity to shift its relatively traditional curriculum (Vojíř & Rusek, 2020) towards the directions suggested by the implications of dozens of scholarly texts (see Johnstone, 2010). Given the requirement to reduce educational content and place a greater emphasis on developing competencies and basic literacy, it is essential to make adjustments that, on the one hand, omit selected, albeit traditional topics and present to students the field of chemistry in its current form.

Such a significant revision needs proper argumentational support. For this reason, this study was conducted to serve as a basis for anticipated discussions. For this debate, it is necessary to gather arguments, which will help to constructively direct the curriculum-reforming steps. General arguments for a change include general attitudes towards school, attitudes towards individual school subjects (educational fields), and the effect of existing curricula, i.e., the achieved curriculum. On these grounds, key topics of curriculum are examined in this paper.

Students' attitudes

The sense of belonging to the school (How much I like going to school.) has been the lowest among Czech students in all of Europe. The attitudes are likely reflected in the popularity of school subjects. Only 34% of students favour natural sciences. Conversely, 22% of students stated that they do not like learning natural sciences (Tomášek et al., 2020).

The general attitudes to school probably influence students' attitudes toward chemistry as well. Czech students' attitudes towards chemistry, the popularity of chemistry, or interest in chemistry consistently indicate neutral to negative values (Kubiatko, 2016; Švandová & Kubiatko, 2012). From an international perspective, Osborne et al. (2003b) provided an extensive overview of approaches to measuring students' attitudes towards natural sciences (including chemistry) and emphasize the need to improve the persisting value of attitudes. Osborne et al. (2003b) highlighted the risks of this persisting state for the quality of education and further development of scientific disciplines. The negative attitude towards chemistry (and physics) is attributed to its relevance being hard to identify for students (Osborne & Collins, 2000). Other factors as summarized by Osborne et al. (2003a) are: anxiety towards science, the value of science, self-esteem regarding science, motivation for science, enjoyment of science.

Acquired chemistry curriculum

Viewing curriculum revision as a change, it is necessary to evaluate the effectiveness of the current state. The passage above indicated that the Czech school system has gaps in influencing students' attitudes. Another crucial argument for more significant curriculum revisions is brought by the results of the PISA tests, which since the first year Czech students participated (2006) have consistently shown a discrepancy between relatively good student knowledge but their below-average ability to apply it (Blažek & Příhodová, 2016; Boudová et al., 2023; Palečková, 2007).

Another argument for the necessary change in the curriculum is the actual effectiveness in achieving expected outcomes, i.e., measurable, mandatory curriculum goals. The thematic report of the Czech School Inspectorate from 2023 (Novosák et al., 2023) followed the results of Czech students in six educational fields, including chemistry. Students' results in chemistry were among the worst, with 29% achieving insufficient results (students were unable to solve even the simplest test items). Insufficient results were found in 16% of schools overall. Compared to testing in 2016, there was a decline in results in chemistry (and history), while improvements were noted in other tested fields.

This critical situation is given by the results of basic school students, of whom only 5% (33% at multi-year grammar school) were able to solve tasks at the highest level, while 35% were classified at the lowest level (4% of grammar schools). A more detailed picture is provided by the evaluation of results according to the nature of test items. Only in items grouped under *applied chemistry* did students achieve 51% success, while in all other categories, success was lower than 50%. Considering the passage on attitudes, it is necessary to note that compared with other tested subjects, students rated chemistry and physics as the least interesting and beneficial content. More than half of the students stated that they think the subject is difficult, they experience failure during lessons, and more than 40% stated that they are afraid of making mistakes in chemistry classes.

These findings can be interpreted not only in terms of the nature of the field itself but also through the concept of teaching. 60% identified predominantly teacher-centred approach, and in more than 45% of cases, chemistry teachers do not present the material in the context of real life.

Drawing on experiences from previous debates about curriculum changes, the authors of this text focused on a areas of the chemistry subject-matter which are known to cause students' problems as shown also in the aforementioned thematic study (Novosák et al., 2023). This area refers to topics identified as critical (Rychtera et al., 2018, 2019) and deemed by students as overly difficult and unimportant. Despite indications that these topics are being sidelined in the curriculum in favour of clearly articulated goals—both curriculum itself and the needs of individuals in the 21st century, guided by visions of effective (chemistry) education (see Johnstone, 2010)—the subject still sparks vigorous reactions, often lacking in substance. This study was therefore aimed at supporting reform efforts and enhancing the quality of general discussions by uncovering teachers' arguments for including controversial topics identified as *key* but also *critical* (Rychtera et al., 2019): chemical nomenclature, calculations, and the balancing of chemical equations in the chemistry curriculum for lower-secondary education.

RESEARCH GOAL AND METHODOLOGY

In this study, Delphi methodology (Murry Jr & Hammons, 1995) was used to gather teachers' arguments regarding the inclusion of the specific topic within the lower-secondary school chemistry curriculum, including the rationale for its relevance. The method has been found suitable for such purposes (Blanco-Lopez et al., 2015; Green, 2014; Osborne et al., 2003b).

Further, the analysis encompassed the allocation of lesson hours dedicated to the topic, as well as the breadth of subject-matter covered within this thematic area. For this purpose, a three-round Delphi study among chemistry teachers was conducted.

Participants' selection

In this study, participants were recruited from a Facebook group called 'Teachers of Scientific Subjects'. A question about the arguments for chemistry calculations' relevance for lower-secondary chemistry curriculum was posed. Teachers who provided a more elaborate opinion, those who were identified as *active* within the group—categorized by the Facebook algorithm, as other active discussants and frequent post authors—were selected. They were informed about the study's objectives and were asked for their consent prior to participation. Altogether 13 teachers (7 women) agreed to participate in the study.

One teacher had less than two years of experience, five had 3-6 years, four had 7-12 years, and three had more than 20 years of experience. Eight teachers taught chemistry at lower-secondary level, two taught only at upper-secondary level, and three worked at grammar schools where they taught both lower- and upper-secondary students. Nine teachers had studied chemistry education, three specialized in professional chemistry, and five indicated that they had studied another field focused on other science subjects or their education (the sum here does not match the sample size, as some teachers had degrees in both fields).

Research design and data treatment

The study was conducted over three phases (results of the two are presented in this paper) using an online Google Form. In the initial phase, the form was divided into two sections:

1. respondents' identification: traditional items such as the educators' qualifications, their respective schools, and the subjects they taught,
2. inquiries concerning the chemistry topics: open-ended questions aimed at ascertaining the teachers' perceived ideal scope of the topics: nomenclature, chemical calculations, and balancing chemical equations along with the rationale for this scope.

The participants provided their ideal number of lessons for each of the three topics' instruction as well as their arguments for the topics' position in the national chemistry curriculum.

In subsequent Delphi rounds, participants were presented with a compilation of statements derived from the initial phase of the study. The statements of similar nature were phrased to include all the arguments their authors provided. Unique statements were presented in an unchanged form. The participants' tasks included expressing their agreement with the statements attributing relevance levels from 1 to 4 (1 – *I disagree with the argument*, 4 – *I agree, completed with an option indicating indecision*). Also, they were asked to either agree on the median value of lessons per topic or provide theirs again. Additionally, they were encouraged to propose new statements. They were also tasked with determining the teaching scope for each topic by identifying specific substances, equation types, or calculations from a provided selection or by suggesting additional elements.

Through this iterative process, the consensus was refined for the third phase. In line with previous Delphi studies (Osborne et al., 2003a; Rusek et al., 2022), a consensus threshold of 75% was established for the inclusion of arguments in the final round.

Concrete groups of chemical compounds, types of formulas, and chemistry calculation types were provided based on the authors' experience with the content of lower-secondary chemistry textbooks and what is considered the "typical chemistry curriculum" (see the results). For nomenclature and chemistry calculations, the selection was precise, while the chemistry formulas provided for balancing were chosen based on several criteria: the number of reactants and products, the required value of stoichiometric coefficients (difficulty of balancing the equation), and the practical use of the formula.

RESULTS AND IMPLICATIONS

Since the state curriculum does not specify subject-matter (not teaching the topics is in agreement with the curriculum), their perceived importance at lower-secondary schools shows teachers' persistent conception of chemistry teaching guided by the former curriculum (Vojíř & Rusek, 2020).

Ideal number of lessons on individual topics

The selected topics' instruction hourly scope according to the study participants is shown in Figure 1. The absolute number of hours proposed by respondents in the 1st round of the Delphi study shows a large dispersion, reflecting the non-unified approach of teachers and their differing perceptions of the given topics' importance. For chemical nomenclature, teachers cited an ideal range from 1.5 to 20 lessons (Median = 7). One respondent suggested an ideal amount of 20 hours for teaching chemical calculations, while other teachers suggested values ranging from 2 to 10 (Median = 5). In the case of balancing chemical equations, teachers were more unified. One teacher would not include the topic at all, one would allocate five hours, and the rest suggested values 1-4 hours (Median = 2.5). The numbers are in accordance with teachers' statements in interviews (see Rychtera et al., 2019).

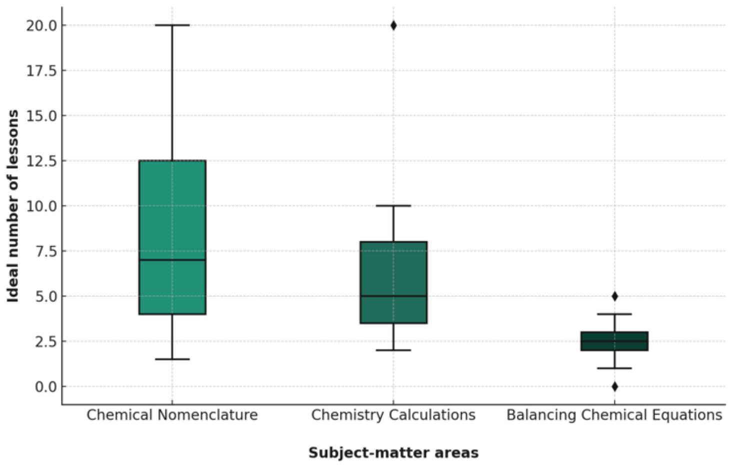

Figure 2 Ideal number of the topics' instruction (lessons)

The specific examples of compounds to name, types of examples, and equations to balance for evaluation probably led to changes in teachers' responses on the ideal number of lessons, which was reflected in their expressions about the medians from the first round as the first consensus.

The ideal number of chemical nomenclature lessons was not determined in the second round of the study either. Although four teachers (31%) agree with allocating seven lessons, six would use fewer, while three opt for a greater number. In case of the other two topics, the consensus was better. Eight teachers (62 %) agreed with the median, three would use fewer and to, on the contrary, more lessons. A good consensus was reached on the topic of balancing chemical equations. Eleven teachers (85%) agreed on a median of 2.5 instructional hours, with only one teacher preferring fewer and another more. Further details will be provided by the results of the third round, complemented by specific content related to the required number of instructional hours as presented by the teachers.

The scope of chemistry topics' instruction

The results of this passage clarify the differences in the number of hours reported by teachers in the first round. They show that teachers do not agree on a minimum, hence many of them indicate that the form and depth of teaching these topics vary not only among individual students but also among classes. This finding is somewhat surprising given that these topics are not anchored in the current curriculum. This disunity among teachers reflects the concept of an open curriculum, which does not specify the scope as did the previous educational standards (Vojíř & Rusek, 2020). The result opens the question whether teachers with longer experience, who used to teach according to the previous curriculum, are following the trend, even though it is now possible to target other topics. Moreover, it remains a question as to what causes similar attitudes among teachers with significantly less teaching experience, specifically those who have not experienced the original curriculum at all or only as lower-secondary school students.

Chemical nomenclature

As the basis for nomenclature, teachers chose five groups of compounds: oxides (100%), hydroxides (92%), halides (92%), including monoatomic anions (77%) and monoatomic cations including ammonium (77%) Except for oxides with the oxidation state (-II), the rest represent compounds where the anions in the oxidation state (-I) are easy to name. Inorganic oxoacids (61%) and diatomic cations, sulphides, and salts (54%) were also considered extended curriculum by the respondents. On the other hand, 12 respondents (92%) considered coordination complexes, and 7 respondents (54%) di- and polyatomic cations unsuitable for the lower-secondary curriculum.

Chemistry calculations

All the teachers agreed that mass fraction calculations belong among the fundamentals. 11 teachers (85%) identified the amount of substance and molar mass calculations as foundational topics. Seven teachers also consider molar concentration to be basic, whereas five view it as an enriching topic. Volume fractions (77%), mixing solutions (69%), and calculations from chemical equations (69%) were mostly considered enriching topics. Conversely, pH calculations (100%) and the ideal gas law (92%) were marked as unsuitable for the lower-secondary curriculum.

Balancing chemical equations

As a basis for equation balancing, teachers mentioned four reactions: the combustion of hydrogen in oxygen, the combustion of carbon in an excess of oxygen, the reaction of zinc with hydrochloric acid, and the decomposition of hydrogen peroxide. More than 60% of the surveyed teachers also identified the reaction of copper with dilute nitric acid, the synthesis of ammonia, and the reduction of ferric oxide as foundational. It is evident that while equations with higher consensus do not require the mastery of more sophisticated balancing techniques, less agreement exists over equations that involve more complex balancing. The equation for the reaction of copper with nitric acid is surprising due to the higher number of products and the magnitude of stoichiometric coefficients.

For types of equations that no longer belong in the curriculum, teachers in very good agreement identified the reaction of hydrogen peroxide with potassium permanganate in a sulfuric acid environment (85%) and the equation for the neutralization of sulfuric acid with sodium hydroxide presented in ionic form (92%).

As equations suitable for further enhancement of equations balancing skills, teachers mentioned the equation for the rusting of steel (54%), the sodium chloride electrolysis (54%), and the equation for the neutralization of sulfuric acid with sodium hydroxide (46%). These values are not considered a consensus by the surveyed group of teachers, yet they indicate a certain trend in the difficulty of the included equations.

Arguments for including the topic in curriculum

Chemical nomenclature

The results are shown in Fig. 2. Three arguments stand out. Most teachers agree that the purpose of chemical nomenclature in the lower-secondary chemistry curriculum is to develop students' understanding and application of principles and procedures. This type of task is known to be one of the few that chemistry textbooks target for higher-order thinking (Vojíř & Rusek, 2022). However, considering the compounds that teachers mentioned students should name in chemistry lessons, there is little to develop students' procedural thinking. Given the number of compounds students learn about, it remains questionable whether these seven lessons are time well spent considering the possible, meaningful tasks for developing the application of procedures (see Hamerská et al., 2024).

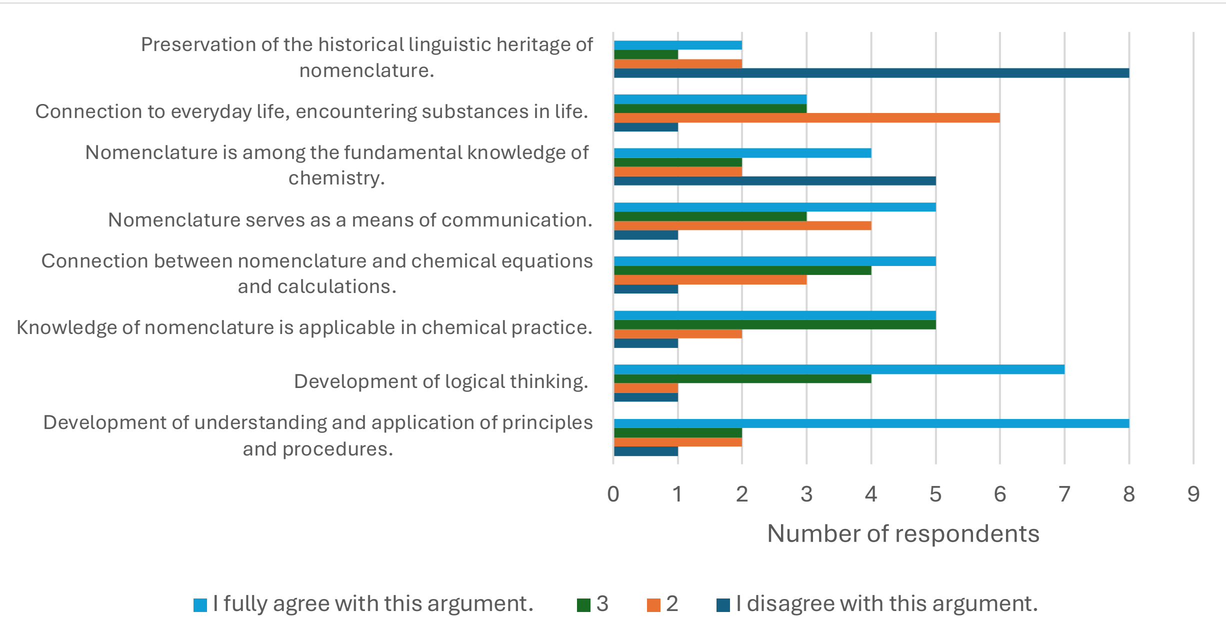

Figure 3 The teachers' assessment of arguments concerning the topic of chemical nomenclature

Consequently, according to these teachers, nomenclature develops logical thinking. The question remains whether it is appropriate to introduce the artificial language of chemistry for this reason, while the investigative component of teaching, in which logic is a natural part, is absent. This interpretation is confirmed by the fact four teachers disagreed with this argument of their colleagues.

The third argument, on which there was consensus is that teaching chemical nomenclature is done for the purpose of preserving the historical linguistic heritage of nomenclature. Only two teachers agree with this argument, while eight disagree.

The rest of the arguments did not polarize the respondents' group as much. For this reason, for the sake of interpretation, both the two agreeable and two disagreeable responses were combined to clarify the respondents' stance (Tab. 2).

Apart from the mentioned, teachers also pointed out the applicability of nomenclature in chemical practice, thus emphasizing one of the purposes of chemistry teaching. Another two arguments received majority agreement (see Tab. 3). The first points to the field itself, therefore creating a vicious circle: chemical nomenclature should be taught to teach chemical equations and balance them. In this regard, the idea arises whether, in the relative time constraint, it makes sense to introduce a goal in the form of an artificial principle that serves exclusively further disciplinary goals. In the same spirit, another argument shared by eight surveyed teachers can be considered: nomenclature serves as a means of communication. This argument reflects different understandings of the phenomenon of chemical nomenclature. On one hand, it might be simply using names and formulas similarly as in biology; on the other hand, there is the necessity of mastering the nomenclature principle for the purpose of communication. Again, the question arises whether it is necessary to practice the principle of naming compounds in the case of lower-secondary chemistry content when the teaching can suffice with a smaller number of them.

Table 2 Merged responses to the chemical nomenclature-related arguments

Arguments	**Disagree**	**Agree**
Development of logical thinking.	15%	85%
Development of understanding and application of principles and procedures.	23%	77%
Knowledge of nomenclature is applicable in chemical practice.	23%	77%
Connection between nomenclature and chemical equations and calculations.	31%	69%
Nomenclature serves as a means of communication.	38%	62%
Connection to everyday life, encountering substances in life.	54%	46%
Nomenclature is among the fundamental knowledge of chemistry.	54%	46%
Preservation of the historical linguistic heritage of nomenclature.	77%	23%

Simultaneously, a contradiction with other arguments can be seen here. If it makes sense to teach students the principle of naming compounds so that teaching is not so heavily based on memorization, it does not make sense that students learn to name only a few groups of substances, while sulphides and salts are already considered an extension, even though their practical use is at least as significant as, for example, hydroxides. This finding points to the lingering echo of the technocratic paradigm (to which the studied three topics belong), while teachers are evidently aware that the relevance of these topics in the curriculum in the current teaching approach requires changes. However, their responses clearly indicate that merely reducing the curriculum content does not lead to achieving the goals that teachers pursue.

Chemical calculations

The teachers' perspectives on chemical calculations are more uniform than in the previous case. Again, the textbook-like type of higher order thinking (Vojíř & Rusek, 2022) predominates, followed by an interesting example of the natural inclusion of mathematical literacy in chemistry. Nine teachers also presented their view of chemical calculations as a field-specific problem (complex tasks). The introduction of the rule of three, is debatable as it does not relate to any of the goals of chemical education. The teachers also emphasized the role of calculations as necessary in practical (lab) tasks. An argument, supported by 10 teachers, was the application of chemical calculations in real life (three teachers disagreed). Considering the issues with calculations, the overall students' success, and the question of the effect of context, this argument appears as an attempt by teachers to modernize the original goals.

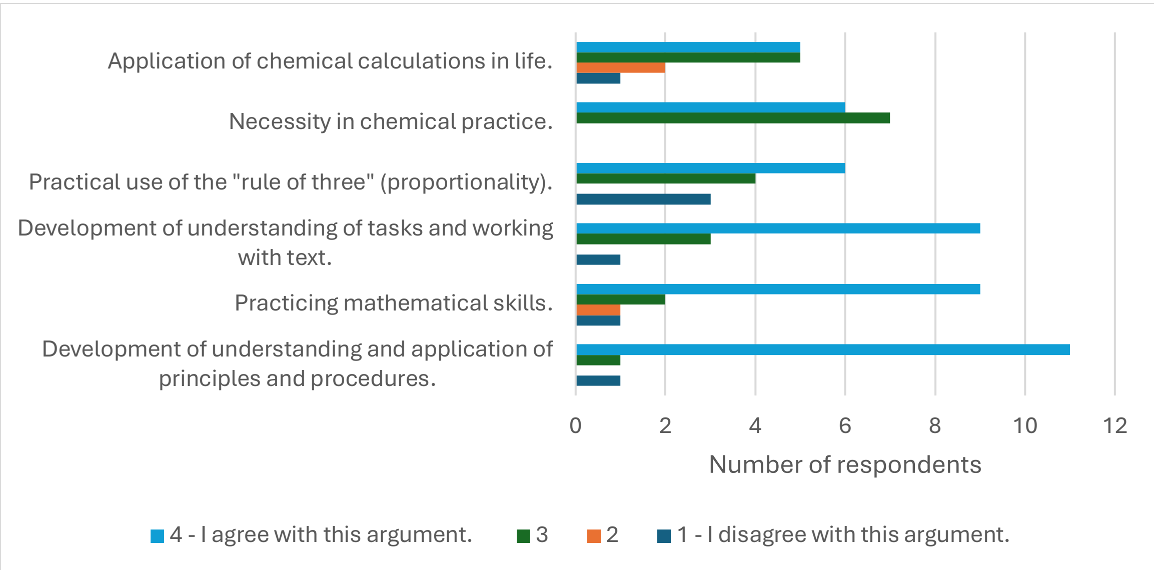

Figure 4 The teachers' assessment of arguments concerning the topic of chemical calculations

Balancing chemical equations

For including the topic of balancing chemical equations, respondents agreed on five arguments (see Fig. 4). This topic uniquely featured responses of "I cannot decide." 11 respondents stated that balancing equations is an application of the law of mass conservation. There is also very good agreement on the role of balancing chemical equations as a means of developing logical thinking.

Respondents (N = 11) also agreed or mostly agreed with the argument for quantifying chemical reactions, which are represented by chemical equations. 10 teachers mostly agreed or agreed that it is important to represent the very meaning of the principle of balancing equations (three respondents disagreed). Slightly less agreement exists on the goal of practice in writing chemical equations, which four respondents disagreed with.

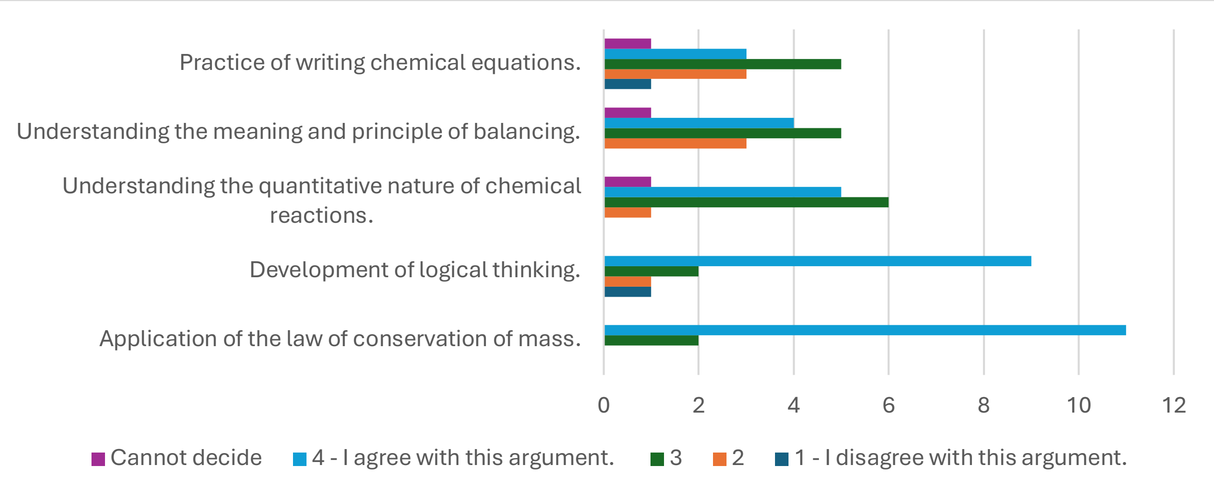

Figure 5 The teachers' assessment of arguments concerning the topic of balancing chemical equations

In this regard, an interesting finding is the discrepancy between the ideal number of lessons devoted to the topic of chemical equations. If one of the most fundamental arguments is the development of logical thinking and the connection to disciplinary concepts – in the case of the law of mass conservation even stronger than with calculations or nomenclature – the half to one-third lesson allocation is a surprising finding. This result likely reflects the problematic nature of the topic (Rychtera et al., 2019). On the other hand, the selection of typical equations for balancing, apart from the reaction of copper with nitric acid, does not require an understanding of the principles of balancing equations and is mostly about filling in a few stoichiometric coefficients. This contradiction calls for further explanation, which would be appropriately obtained through interviews with teachers.

LIMITATIONS

This study's results were affected by several limitations. Though the Delphi study offers enough space for each participant, the depth of their response varies according to the amount of attention they dedicated to their answers. For this reason, follow up interviews are needed to fully cover each participant's thinking. Also, the conclusions need to be read with discretion as there were only 13 participants to this study.

CONCLUSION

The study provided interesting insights into the issue of perceived curriculum. Active chemistry teachers exhibited quite different opinions on three critical areas of chemistry education, thus highlighting the problem of potential curriculum time-lag as well as the transformation of the state curriculum into the school curriculum. Their arguments for including these issues in the curriculum also demonstrate the extent of their alignment with the new curriculum rationale. Although their arguments aim at higher order thinking, the selection of groups of chemical substances for practicing chemical nomenclature, and especially the nature of chemical equations for balancing, do not suggest that they would achieve the goals mentioned in the arguments presented.

Further research will delve into the specifics of each of the studied topics' instruction, the reasons behind the teachers' responses and argumentation, as well as its alignment with curriculum goals and, last but not least, the curriculum attained by students. Additionally, more concrete examples of the particular tasks teachers give to their students should be disclosed to fully evaluate their effect on (chemistry) education research goals' achievement.

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