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The use of image analysis in improving knowledge and skills on the example of teaching the biology of algae and fungi

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Abstract

We investigated the effect of short-term teaching (3 weeks) using image analysis on gymnasium/secondary school students' (ISCED3A) skills (science process skills, SPS) and knowledge using Fiji (ImageJ) software. The theoretical teaching was combined with IT-based education (measurement of the area or signal intensity on photos from scientific papers using algae *Ulva* or *Coccomyxa* and the fungus *Glomerella*) and students formed conclusions from data and answered knowledge questions. Experimental education increased score (post-test/pre-test) in the area of knowledge (by 102%) and SPS (by 44%) and greater impact of IT implementation on the development of girls' SPS and knowledge was found. Besides, the Pearson's correlation analysis showed a more intense improvement of students who had greater deficiencies in pre-test. This experimental gymnasium group ($n = 53$) also retained a higher score in re-test in comparison with control gymnasium students (without the implementation of image analysis, $n = 54$) and detailed analysis of individual questions revealed that there was a development of SPS, especially those that were emphasized in the experimental teaching. Another control group "university students" (ISCED5A, $n = 19$) had a higher score in re-test than the experimental gymnasium group, but the area of knowledge was comparable. These results indicate that the involvement of IT improves SPS and knowledge of gymnasium students at the level comparable with university students. The test and worksheets are attached for free use with the aim of improving the teaching of less interesting topics such as botany.

Keywords Image analysis-based teaching · Information technologies · Lower plants · Science education · Teamwork

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1 Introduction

In the last 100 years, there has been a large increase in scientific information about plants, but, in the same period, there has also been a decline in the level of students' knowledge and interest in botany (Link-Pérez & Schussler, 2013; Randler et al., 2012; Stroud et al., 2022). In order to overcome the challenges of the twenty-first century in the science and technology sector, students need to be equipped with skills to ensure their competitiveness in the globalization era (Turiman et al., 2012). It is estimated that about 65% of children entering primary school will have jobs that do not yet exist (Mišianiková et al., 2022). There is an international consensus that science education should support not only knowledge but also students' SPS (science process skills) development (García-Carmona et al., 2024). Implementation of digital technologies into science education can significantly help in the process of scientific inquiry (Ješková et al., 2011). One way to improve students' knowledge and SPS is the use of information technologies (IT), including image analysis, in education (Haglund & Schönborn, 2019; Helendra et al., 2018; Mišianiková et al., 2022; Wong & Subramaniam, 2022; Yadav & Chakraborty, 2024). One of the main conclusions of a meta-analysis examining the impact of implementing mobile devices in teaching is that these devices improve student learning by integrating it with scientific research (Dong et al., 2024).

One of the consequences of technological development is the common use of image analysis in various biological fields (Gerringer et al., 2023; Mišianiková et al., 2021; Schindelin et al., 2015). Microscopic techniques as well as modern technologies allow biologists to obtain a large amount of data in the form of images that can be analyzed by IT. For example, a 10% decrease in cell size or a twofold decrease in the intensity of a fluorescently labeled protein in an image is undetectable to the human eye, but image analysis using Fiji/ImageJ software can detect such negligible but biologically significant changes (Baviskar, 2011). This software is freely available, user-friendly, and easy to install. Although image analysis is widely used in research, its implementation in the teaching process is rather rare (Petersen, 2021). There are several suggestions for activities using image analysis, e.g. leaf fluorescence and leaf reflectance (Björn & Li, 2013), neurite development (Pemberton et al., 2018), marine biodiversity (Gerringer et al., 2023), protein structure (Gokalp et al., 2018), RNA interference (Palmisano et al., 2022), zebrafish (*Danio rerio*) nerve development (Petersen, 2021) or regenerative ability of planarians (Campillo et al., 2023). The mentioned activities are professionally demanding and applicable only in university education. For example, university students reported that education using image analysis improved their skills in the interpretation of results, they had a better understanding of the research process and learned to work independently (Gerringer et al., 2023). Implementation of image analysis in high school education has only rarely been performed (Mišianiková et al., 2021). To our knowledge, no paper studied the impact of the educational implementation of image analysis on students' knowledge or science process skills in the area of plant biology. Indeed, a recent review focused on learning activities with plants and technology reported that only 1 out of the 9 analyzed studies included a non-vascular plant using “augmented reality” (Leo-Ramírez et al., 2023 and the references therein).

The present study aims to create practical activities with the use of image analysis that can be used at various levels of education and to verify the impact of the worksheets on the student’s knowledge and science process skills (SPS). Learning with the use of digital technologies can be strongly influenced by various factors (Almasri, 2022; Byukusenge et al., 2024) and therefore we investigated whether changes in knowledge and SPS of students (who implemented image analysis) would also be influenced by study program and gender. The worksheets are focused on the so-called lower plants and fungi, as teachers use algae during the lesson less than other groups (Kováčik & Vydra, 2023). The more complex questions in the test and in the subsequent experimental education are intended to highlight the need for more comprehensive teaching in secondary schools (and we personally observe deficiencies in this area even among university students).

2 Methods

2.1 Participants of the study

Three independent groups of Slovak students were involved in this study and the research began before the topics we focus on (algae and fungi) were taught:

A Students of three independent classes from gymnasium were involved in the experimental education (marked as “our experimental gymnasium students”), which was provided by the first author of this paper: two 2nd-grade classes in a 4-year program (2. A and 2. B with 18 and 17 students) and one 6th-grade class in a 8-year program (Sexta, 18 students), ensuring that all students were 16–17 years old. From the point of view of the formal content of curriculum, there is no difference between 4-year and 8-year gymnasium program (students of the 2nd-grade and 6th-grade have the same age), however, in general, 8-year gymnasium programs are considered more excellent, since admission requires successfully pass the test and typically only one class of the 8-year program opens at a given gymnasium (see chapter 3.1. for further explanation and comments on 4-year and 8-year program). A total of 53 students were involved (30 girls and 23 boys). Gymnasium is a type of high school (ISCED3A) that provides general upper secondary education and prepares students for further university education.

B Students of similar age (15–16 years old) served as “control gymnasium students” for comparison with the experimental gymnasium mentioned above. The total number of 54 students included both 4-year and 8-year programs (however, since we did not detect differences between them, the results were evaluated as the sum of all students). The education here was provided by their teacher independently of our research in accordance with the curriculum for gymnasia, but the teacher had a pre-test available and could therefore implement some additional information during the following education in the area of algal and fungal biology (before the re-test).

C The 19 university students of biology in the 2nd year (20–21 years old) at the Faculty of Education served as another control (marked as "university students") for comparison between gymnasium students mentioned above and university students (ISCED5A, bachelor study). Education was provided by the corresponding author of this work within the subject "Diversity and adaptations of lower plants" (including fungi and lichens).

2.2 Research tool

The test used to determine both SPS and students' knowledge (pre-test, post-test and re-test) was designed by the authors of this work and consulted with education experts from gymnasia and universities (see test in supplementary materials).

In all groups, the pre-test was filled by students before the beginning of education in the field of biology of algae and fungi, and any possible knowledge in this area therefore comes only from previous education. We used the pre-test and post-test to measure changes in students' knowledge and science process skills (SPS) in response to experimental education (see test in the supplementary materials). The test contained graphs (Kováčik et al., 2016), table (Coşkun et al., 2023), and microscopic photos (Kováčik et al., 2019) from scientific papers. We monitored "knowledge" with 14 tasks and "science process skills" with 11 tasks. The test contained only open questions and for each correct answer, the student received one point (maximum score of 25 points, see examples of the most common correct and incorrect answers in supplementary Table S1). We evaluated two individual areas, i.e. the knowledge and science process skills, as well as the overall score. For easier interpretation, the results were converted into percentages (25 points = 100%). The reliability of the test was sufficient (0.75). Pre-test and post-test were carried out seven days before and after the experimental education. Re-test in all three groups was implemented 10–12 weeks after education.

2.3 Experimental education and control groups

Experimental education focused on biology of algae and fungi was realized during 3 weeks in the range of 6 h (each 45 min), of which 2/3 were focused on algae and 1/3 on fungi. Of the given 6 h, 3 h were taught theoretically and 3 h practically. Theoretical lessons were taught with presentation focused on the body/thallus structure, ecology, significance and slightly systematics of algae and fungi. Within practical activities, students analyzed photos from randomly selected scientific works using the Fiji (ImageJ) program (see Schindelin et al., 2012 for details about it). Students analyzed photos of the thalli of the cultivated alga *Ulva fenestrata* (Steinhagen et al., 2022), photos from fluorescence microscope of the alga *Coccomyxa subellipsoidea* (Kováčik et al., 2017) and photos showing the effect of salicylic acid (SA) on symptoms caused by the fungal pathogen *Glomerella cingulata* (Zhang et al., 2016). Students worked in groups of four so that each student analyzed at least one photograph using the given software (the selected scientific papers contained 4 or 8 photographs). Students' work in groups also has several advantages, e.g. better motivation (Laal & Ghodsi, 2012). Worksheets focused on image analysis and respective tasks and questions are included in the supplementary materials. We created 3 worksheets:

- Algae as food and a source of nutrients
- Algae, oxidative stress and antioxidant
- Fungal disease and Aspirin-related compound

The main aim of this experimental education was to monitor the impact of IT combined with real scientific data on students' knowledge (understanding the importance of given organisms, the basic principles of oxidative stress and plant defense, and the interaction between organisms) and on the development of science process skills (check variables, formulate assumptions and conclusions, interpret data, formulate relationships between variables, and construct graphs).

The control groups B and C were educated in a standard manner as mentioned above (i.e. curriculum for gymnasia or syllabus of the subject "Diversity and adaptations of lower plants" at the Faculty of Education) without the use of software for image analyses.

2.4 Statistical analyses

Normality of distribution was verified with the Shapiro–Wilk test. Considering that not all data were normally distributed (Shapiro–Wilk $P < 0.05$), we used the Wilcoxon signed-rank test (comparison before and after the education) and Kruskal–Wallis test (comparison between groups of students). Correlations were measured by Pearson's correlation analysis due to normal distribution of given dataset. Statistical analyses were performed in XLSTAT software (Addinsof, Paris, France) and graphs were constructed using GraphPad Prism version 10.1.1 for Windows (GraphPad Software, Boston, Massachusetts USA).

3 Results and discussion

3.1 Results of experimental education in individual programs and classes

By comparing the results of students of the experimental group of the 4-year and 8-year program, we found that they achieved similar results in the pre-test (Fig. 1A and B). Experimental teaching (with the use of software and taught by the first author of this work) in the group of students of the 4-year program had no significant effect in the area of science process skills/SPS (Fig. 1A). On the contrary, students of the 8-year program achieved a significantly higher score (by 62%) in the post-test compared to the pre-test (Fig. 1B). The Slovak Ministry of Education itself claimed: "*The current state of 8-year gymnasia has gradually reached a lower than expected quality*" (MESRS-SR, 2014) and limits the number of admitted students

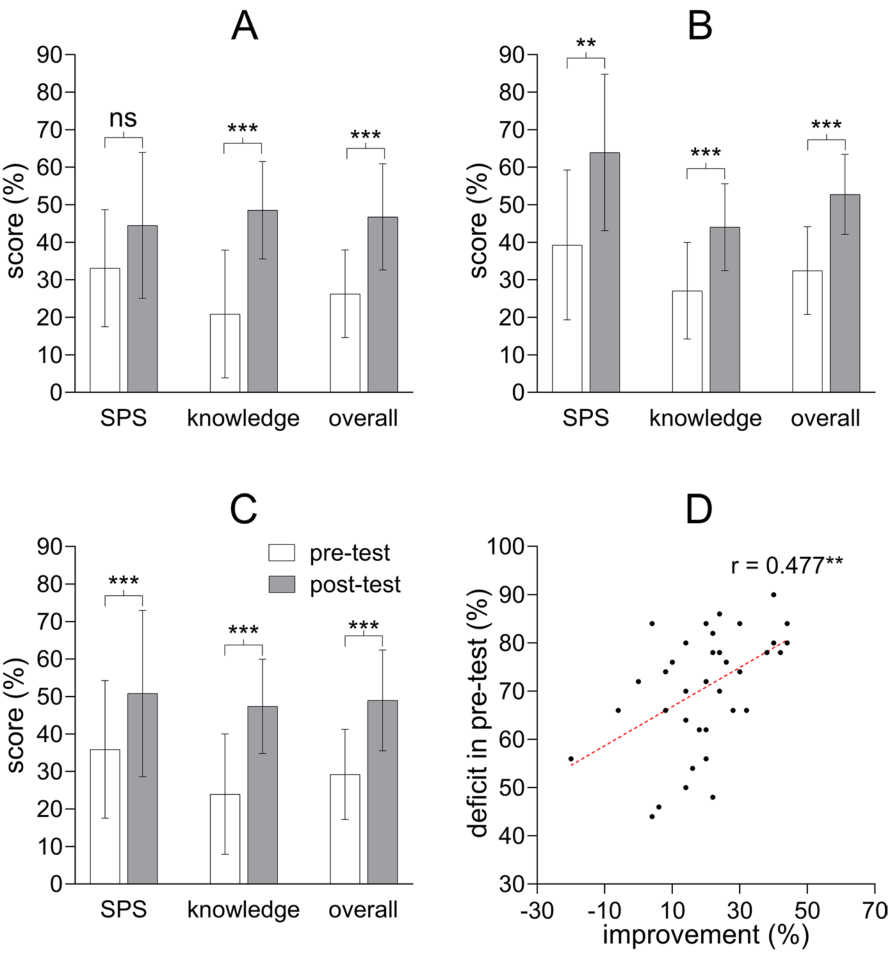

Fig. 1 Comparison of the pre-test and post-test results of students of the experimental gymnasium group of the 4-year program (**A**; $n=35$), the 8-year program (**B**; $n=18$) and the sum of all students from graphs **A** and **B** (**C**; $n=53$). The test monitored either science process skills (SPS) or knowledge (and sum of both parts is shown as columns "overall"). Data are given as a percentage of success out of a maximum score of 100% and bars represent SDs. Values above columns with ** and *** indicate significant differences at 0.01 and 0.001 levels of the Wilcoxon signed-rank test between the pre-test and post-test (and ns means non-significant difference with $P>0.05$). The 4-year program (meaning only gymnasium education, ISCED3A) includes two classes (2.A and 2.B, see supplementary Fig. S1 for details) while the 8-year program (meaning lower secondary followed by gymnasium education, i.e. ISCED2 and 3A) includes class marked as Sexta in Slovakia. Graph **D** shows a Pearson's correlation analysis between the deficit in pre-test (%) and improvement after the experimental education (%). We defined "deficit" as the difference between 100% – the pre-test result (%) and "improvement" as the difference between the post-test and pre-test results. Only a minimum of students had a negative improvement (that is, a worse post-test result than the pre-test), and the positive correlation of most students shows that the worse the pre-test deficit, the greater the improvement (** indicates a significant difference at 0.01 level)

on this program (MESRS-SR, 2018). Besides, 15-years old students of 8-year gymnasia achieved higher score in scientific literacy in the international study PISA 2022 than 15-year students at primary schools and secondary vocational schools, but not than students of a 4-year program at gymnasia (NÚCEM, 2023). The question remains whether these results are due to more effective work with students of 8-year gymnasia, or better abilities of the admitted students already at the beginning of this program (in Slovakia, 8-year gymnasia select the number of students allowed by the state based on the success of the entrance test from the entire population of students in the given year). However, it seems that elite schools (and probably also 8-year gymnasia) have their importance, e. g. it has been proven in Mexico that admission to such type of schools is likely to increase the earnings of students in the future (Estrada & Gignoux, 2017). Also based on personal communication with several teachers, we can say that 8-year gymnasia place more emphasis on knowledge, homework and more scientific work with students and teachers are generally satisfied with these students.

In the area of knowledge, on the other hand, students of the 4-year program improved more between the pre-test and the post-test than the students of the 8-year program (130% vs. 60%). In both groups, this increase was significant and it can be concluded that teaching with the involvement of image analysis had a positive effect on the knowledge (Fig. 1A and B). We also found an increase in the total score of both groups (Fig. 1A and B), which also confirms the increase in the post-test score in SPS (improvement by 44%) and knowledge (improvement by 102%) of all students of the experimental group (Fig. 1C). Improvement was also detected in individual classes pooled as "4-year program" (see supplementary Fig. S1) and only 2 of the 25 questions in the test (see it in supplementary materials) showed no improvement (Table 1). In our opinion, the main benefit of the implemented activities is the emphasis on teamwork. The overall increase in the post-test was mainly caused by a more intense improvement in the scores of students who had greater deficiencies in the pre-test, which implies that the suggested activities and maybe the implementation of teamwork were a stimulus for better results even of students with greater deficiencies before the experimental education as revealed by Pearson's correlation analysis (Fig. 1D). It is group work that has several benefits in teaching, including higher motivation in the classroom, better teaching results, or the development of critical thinking skills (Laal & Ghodsi, 2012). However, teamwork is not implemented enough in teaching, e.g. a questionnaire survey of Finnish teachers educating students aged 7 to 16 found that only 42.7% of respondents use group work weekly (Saloviita, 2018). We can expect that this situation is even worse in other countries (and e.g. Slovakia is under the OECD average in PISA tests; NÚCEM, 2023).

3.2 The effect of gender on the results of experimental education

Both genders achieved similar scores in both areas of the pre-test (Fig. 2A and B). A significant improvement due to experimental teaching in SPS was observed only among girls (by 51%, Fig. 2A). Considering the post-test vs. the pre-test, both genders obtained higher scores in the area of knowledge, however, we found a more intensive improvement

Table 1 Comparison of individual tasks in pre-test, post-test and re-test within our experimental gymnasium students (n = 53), control gymnasium students (teaching without our involvement, n = 54) and university students (second-year bachelor students with a focus on biology and teaching, Faculty of Education, n = 19)

Question no.	Experimental gymnasium students			Control gymnasium students			University students		
	Pre-test	Post-test	Re-test	Pre-test	Post-test	Re-test	Pre-test	Post-test	Re-test
1. a.	**20.0%**	**11.1%**	**24.41%**	**16.20%**	**-**	**16.20%**	**47.37%**	**-**	**67.65%**
1. b.	25.6%	41.1%	55.81%	4.23%	-	8.70%	31.58%	-	61.76%
1. c.	7.8%	23.3%	26.74%	19.72%	-	20.65%	44.74%	-	64.71%
1. d.	6.7%	17.8%	15.12%	2.11%	-	1.09%	7.89%	-	17.65%
2. a.	**18.9%**	**25.6%**	**13.95%**	**10.56%**	**-**	**21.74%**	**52.63%**	**-**	**82.35%**
2.b.	92.2%	91.1%	100.00%	84.51%	-	89.13%	86.84%	-	100.00%
2. c.	44.4%	60.0%	82.56%	71.13%	-	65.22%	73.68%	-	91.18%
3. a.	**92.2%**	**75.6%**	**88.37%**	**95.77%**	**-**	**80.43%**	**89.47%**	**-**	**100.00%**
3. b.	**36.7%**	**51.1%**	**60.47%**	**60.56%**	**-**	**71.74%**	**92.11%**	**-**	**100.00%**
3. c.	**28.9%**	**45.5%**	**43.02%**	**26.76%**	**-**	**31.52%**	**39.47%**	**-**	**73.53%**
3. d.	30.0%	46.6%	67.44%	40.14%	-	39.13%	47.37%	-	47.06%
3. e.	22.2%	35.6%	47.67%	14.79%	-	16.20%	18.42%	-	64.71%
4. a.	**53.3%**	**70.0%**	**76.47%**	**57.04%**	**-**	**71.74%**	**89.47%**	**-**	**97.06%**
4. b.	**34.4%**	**51.1%**	**48.84%**	**33.80%**	**-**	**38.04%**	**55.26%**	**-**	**73.53%**
4. c.	15.6%	52.2%	48.84%	10.56%	-	2.17%	15.79%	-	20.59%
5. a.	**26.7%**	**65.6%**	**59.30%**	**34.51%**	**-**	**36.96%**	**78.95%**	**-**	**76.47%**
5. b.	**17.8%**	**33.3%**	**24.42%**	**20.42%**	**-**	**18.48%**	**42.11%**	**-**	**61.76%**
5. c.	**14.4%**	**20.0%**	**17.44%**	**4.23%**	**-**	**11.96%**	**23.68%**	**-**	**61.76%**
5. d.	13.3%	35.6%	34.88%	4.23%	-	6.52%	5.26%	-	11.76%
5. e.	0.0%	33.3%	27.91%	5.63%	-	7.61%	28.95%	-	23.53%
5. f.	37.8%	58.9%	75.58%	21.83%	-	13.04%	73.68%	-	97.06%
5. g.	14.4%	52.2%	66.28%	12.68%	-	19.57%	52.63%	-	88.24%
6. a.	**46.7%**	**68.9%**	**66.28%**	**63.38%**	**-**	**42.39%**	**94.74%**	**-**	**94.12%**
6. b.	2.2%	15.6%	40.70%	2.82%	-	4.35%	7.89%	-	17.65%
6. c.	13.3%	48.9%	56.98%	4.93%	-	2.17%	7.89%	-	32.35%

The data are presented as the average percentage of success of respondents in individual questions. Tasks are marked as **science process skills (in bold)** and knowledge (not in bold). We note the absence of post-test column for control gymnasium students and university students as education with software/IT was not done there. See test and answers in the supplementary materials

among girls compared to boys (157% vs. 71%, Fig. 2A and B). The greater improvement we observed among girls is surprising as boys prefer to use information technologies in biology lessons (Kubiatko & Haláková, 2009). On the other hand, female students may have better SPS than male students, as they are often more enthusiastic and more curious during practical activities. A higher level of critical thinking and partial SPS of girls was identified in Indonesia through descriptive research using observation sheet (measurement of SPS) and a test (measurement of critical thinking; Darmaji et al., 2022). In addition, questionnaire research of primary and high school students found that girls had

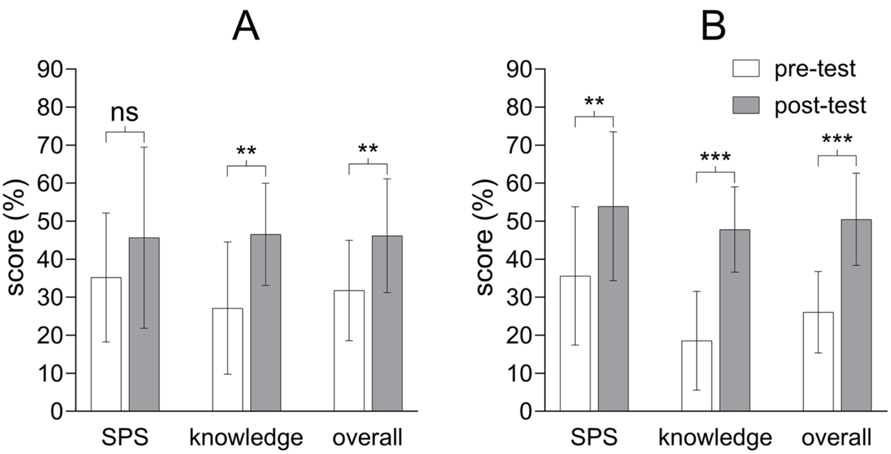

Fig. 2 Comparison of the pre-test and post-test results of boys (**A**; $n=30$) and girls (**B**; $n=23$) of the experimental gymnasium group (based on the sum of all "experimental students" in Fig. 1C). The test monitored either science process skills (SPS) or knowledge (and sum of both parts is shown as columns "overall"). Data are given as a percentage of success out of a maximum score of 100% and bars represent SDs. Values above columns with ** and *** indicate significant differences at 0.01 and 0.001 levels of the Wilcoxon signed-rank test between the pre-test and post-test (and ns means non-significant difference with $P>0.05$). We note that the "overall" post-test score of boys and girls did not differ significantly according to the Mann–Whitney U test ($P>0.05$), although the absolute value was higher for girls

significantly higher scores in all the components of science motivation than boys (Daher et al., 2021). A questionnaire for students at agricultural high school in Mexico revealed the relationship between gender and motivation in two of the five areas of motivation, namely motivation in class and self-efficiency (Chumbley et al., 2015), indicating that gender is also a factor influencing motivation. Considering the differences between the genders, it is important to diversify science teaching methods to fit both male and female students (Daher et al., 2021). It is therefore a positive finding that experimental teaching using image analysis had a stimulating effect on the overall test scores of students of both genders (Fig. 2). A statistical comparison of the "overall" post-test score of boys and girls did not differ significantly according to the Mann–Whitney U test ($P>0.05$, Fig. 2), although the absolute value was higher for girls. Based on these results, we recommend a wider application of the suggested activities at least at the high school/gymnasium level of education, with the aim of improving science process skills/SPS and knowledge, which are essential prerequisites for subsequent studies at the university.

3.3 Science process skills: gymnasium students versus university students

Science is not only about encyclopedic information, but it is a way of systematically understanding the environment (Turiman et al., 2012). For this reason, we focused not only on the development of knowledge but also on the improvement of science process skills (SPS). Among the tasks focused on SPS, university students had higher score than gymnasium students of control or experimental group in almost all questions (Table 1),

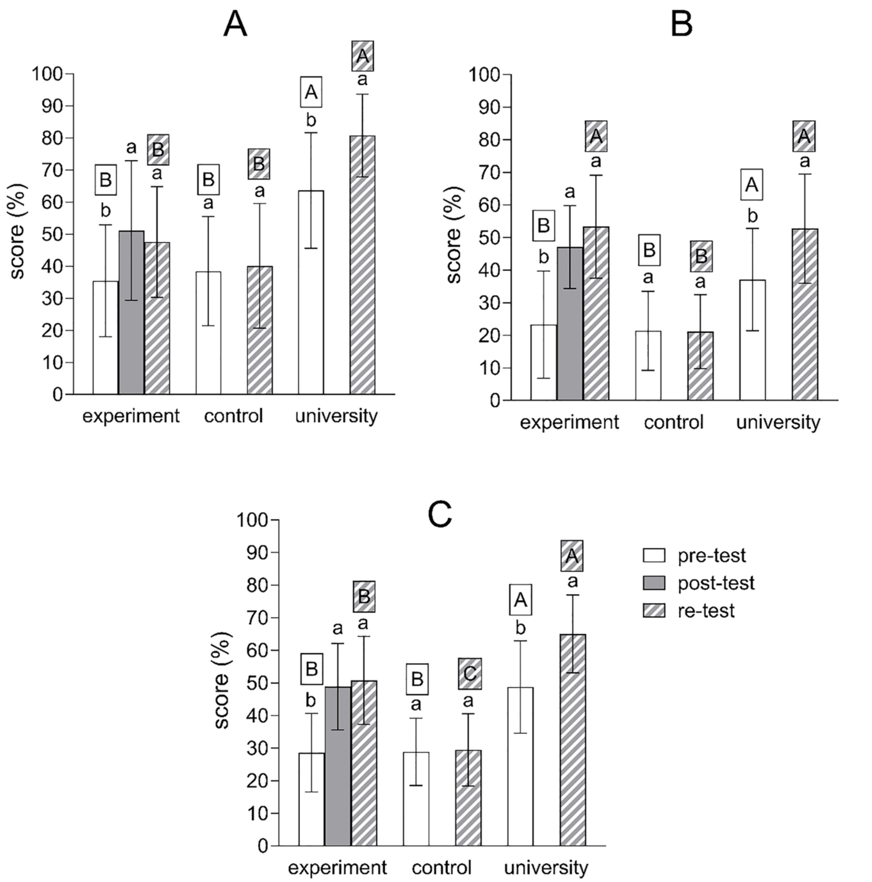

Fig. 3 Comparison of the results of the experimental gymnasium students (experiment; $n=53$), control gymnasium students (control; $n=54$) and university students (university; $n=19$) from questions focused on science process skills (graph **A**), knowledge (graph **B**) and the sum of both parts (graph **C**). Data are given as a percentage of success out of a maximum score of 100% and bars represent SDs. We note that data for pre-test and post-test in experimental group are the same as in the Fig. 1C. We also note the absence of post-test column for control gymnasium students and university students as education with software/IT was not done there. Small letters show differences between pre-test, post-test and/or re-test in individual groups according to the Wilcoxon signed-rank test ($P<0.05$). Capital letters show differences between individual groups according to the Kruskal–Wallis test ($P<0.05$, pre-test in the white box and re-test in the hatched box)

which led to their significantly higher score in the pre-test (Fig. 3A). A detailed analysis of individual tasks showed that gymnasium students had problems (less than a quarter of students answered correctly) with task focused on the ability to control variables and experimental teaching did not improve students' ability to control variables (1. a., Table 1). In line with our data, curricular research revealed that students aged 13 – 18 years had problems with selecting the appropriate experimental setup and handling more than two variables (Tairab, 2016). Another task problematic for gymnasium students (only max. 20–25% of the students answered correctly even in re-test) was focused on the ability to formulate a hypothesis, which points to the need to pay more attention to this area in gymnasia (task 2. a., but university students scored more than 80%, Table 1). In order to develop this ability, students must become active in class, and this is a task not only for the teacher, but also for the student himself (e.g. to understand the benefit of this activity for his skills and future studies or job). For example, it was found that teaching focused on science process skills and Mendel's discoveries had a positive impact on the students' ability to formulate hypotheses in genetics (Kim et al., 2011). In the pre-test, gymnasium students of both groups had a problem with data interpretation (5. b.) and argumentation (5. c., Table 1): lower score achieved in these tasks may have been due to the use of fluorescence microscopy images that the students had probably not seen before. When constructing arguments, students often selectively choose information that is consistent with their own beliefs and ignore information that contradicts their opinion (Zeidler, 1997). The higher success of students in the experimental group compared to the control in these questions (re-test, questions no. 5. a. – c., Table 1) indicates a positive impact of teaching with IT, since the analysis of the intensity of the fluorescence signal was included (see worksheet *Algae, oxidative stress and antioxidant* in supplementary materials). Conversely, gymnasium students had fewer problems (approximately 50% of students) with graph construction (task 6. a., Table 1), although they relatively often forgot to mark individual axes/variables (Table 1). They also had fewer problems when interpreting data from graphs (tasks 3. a. – c.) or tables (tasks 4. a. and b., Table 1) where both groups of gymnasium students achieved a success rate higher than 25% (with some even more than 90%) but university students were the best in all these tasks. In the re-test, the students of the experimental group achieved a higher success rate than control group in questions about the interpretation of data from graphs (questions no. 3. a. and c., Table 1). Some tasks in the worksheets were focused on data interpretation, and it was the discussion and argumentation within the groups that could be a stimulating factor for the development of the given ability. Students of the experimental group did not achieve a higher score in the post-test than in the pre-test only in two SPS tasks (Table 1), resulting in a positive effect of experimental teaching on students' SPS (Fig. 3A). However, re-test did not show statistically significant difference in the area of SPS as a sum between control and experimental gymnasium group (Fig. 3A), which could evoke seemingly a negligible impact of teaching with the help of IT. However, based on the detailed analysis of some tasks presented above (see all data in Table 1), it can be concluded that there has been a development of SPS, especially those that were emphasized during the experimental education (due to the length of the education/6 lessons, the complete development of all skills cannot be expected). In addition to gymnasium experimental group, university students also achieved higher scores in the re-test of SPS (by 27% compared to the pre-test, Fig. 3A), which can be explained by the routine emphasis of the lecturer (corresponding author of this work) on the formulation of conclusions and the development of SPS during teaching (lectures on given groups of algae and fungi realized using data from scientific works, which also included graphs, microscopic and fluorescent photos). In a similar study, it was found that the use of information technology in "science education" had a positive impact on science process skills compared to conventional teaching methods (though score 81.36 versus 74.17 was rather a low increase; Vebrianto & Osman, 2011).

3.4 Knowledge and total test scores of gymnasium students and university students

In the pre-test, gymnasium students achieved an average success rate higher than 30% in only three (control group) or four (experimental group) questions focused on knowledge (Table 1), but non-significant difference between groups was observed (Fig. 3B). University students scored higher than 30% in half of the knowledge questions (Table 1), leading to significantly higher score of the pre-test (Fig. 3B). A detailed analysis revealed that students were able to give examples of fruits and plants that contain a lot of vitamin C (task 2. b.) and were aware of the importance of this molecule in human food (task 2. c.) with the most common answer as "improves immunity". Also, about a third of the students in the pre-test knew that cadmium and nickel are (heavy) metals (task 3. d., Table 1) and a third of the students in the experimental group knew to define lichens (task 5. f., Table 1). However, students of both groups are less aware of the importance of these organisms for the environment and humans (task 5. g., Table 1). A positive finding was that experimental teaching improved students' knowledge in almost all questions of this area (Table 1), resulting in an increase in the total knowledge score (Fig. 3B). The knowledge of students of the experimental group was better even after 10 weeks from the implementation of the experimental teaching (score similar to university students in the re-test), but the students of the control group did not obtain a higher score in this area in the re-test (Fig. 3B). Consistent with these changes, detailed analysis revealed that students in the experimental group scored higher on the re-test in all knowledge-focused questions than students in the control group (Table 1). It can therefore be concluded that experimental teaching using image analysis improved students' knowledge at least indirectly. Consistent with our outcomes, research investigating the effect of ICT-based evolutionary university textbooks found a positive impact of these textbooks on students' conceptual knowledge (Helendra et al., 2018). Also, a 6 week-long experimental teaching using mobile phones designed for data collection during field trips improved students' knowledge about plants (structure of flower, pollinations and pollinators, fertilization and interaction between animals and plants) more intensively compared to the group that did not use smartphones (students in the experimental group had 66% higher post-test score; Zacharia et al., 2016). The use of IT in today's digital age represents a motivational and educational prerequisite for increasing the effectiveness of teaching: based on the positive results presented in this study, we recommend wider testing and possibly incorporation into the Slovak curriculum. In line with this assumption, curricular research in the United Arab Emirates in the field of "science" showed that the need to better prepare students for future scientific inquiry requires new curricula and teaching approaches that respond and focus not only on basic scientific content but also on the acquisition of advanced transferable skills (Tairab, 2016). The implementation of IT in teaching is also positively evaluated by students, e.g. after using mixed reality focused on learning about plants students (aged 11 – 12 years) mention that such teaching was useful and interesting (97.7%) and that enjoyed this education (90.9% of students, Liu et al., 2007). The university students also reached a higher score (compared to the control gymnasium) in the knowledge re-test (Fig. 3B), which points to the influence of the teacher and the self-education of university students (the result may also be influenced by the length of teaching the subject "Diversity and adaptations of lower plants", which lasts 12 weeks).

In the control gymnasium group (taught by a teacher at the given gymnasium), the total score did not increase (pre-test vs. re-test), but the students of the experimental group achieved a higher score both in the post-test and re-test, leading to a significantly higher score in re-test between groups (Fig. 3C). However, the university students had even higher scores in the re-test (Fig. 3C), which may be due to the 12-week education as mentioned above plus the botanical subject in the previous year (Plant anatomy and physiology). The worksheets we have prepared (see supplementary materials) may therefore stimulate group work, discussion between students and the need to argue their opinion/result within the work team: this can represent a good basis for the use of IT tools even for topics less interesting to students, such as botany and especially non-vascular plants/algae or fungi. Indeed, a recent review focused on learning activities with plants and technology reported that only 1 out of the 9 analyzed studies involved a non-vascular plant (Leo-Ramírez et al., 2023).

4 Conclusions

By applying short-term activities combining a less interesting area of biology (algae and fungi) with the use of IT, we found that experimental teaching had a positive effect on knowledge (score 102% higher in the post-test) and SPS (score 44% higher in the post-test). A comparison of the impact of teaching with respect to gender revealed a greater impact of IT implementation on the development of girls' SPS and knowledge. Within the study programs, there was an increase in the score in the SPS area only in the 8-year gymnasium program, but in the knowledge area, both groups achieved higher scores in the post-test compared to the pre-test. Despite the improvement in the SPS scores of the experimental gymnasium students in the post-/re-test compared to the pre-test, the re-tests did not differ between the experimental and control groups. However, a detailed analysis of individual questions revealed that there was a development of SPS, especially those that were emphasized in experimental teaching. The development of SPS also occurred among university students, which is a good prerequisite for supporting the development of SPS of their students in future pedagogical practice. In the area of knowledge, there was a clear improvement in the experimental gymnasium group due to the implementation of IT and these students achieved a similar score in the re-test as the university students. Linking biological topics with chemical and environmental themes represents a challenge for future research with the aim of a complex and more scientific education linking topics, as is also the aim of the "science" curriculum in Slovakia.

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Data availability Supporting data are presented in the supplementary materials. Pre-tests, post-tests and re-tests of students, in Slovak language, are available from the corresponding author upon reasonable request.

Declarations

Ethical statement Students were informed about the aims and verbally agreed to participate. Practical teaching was performed, and knowledge tests were evaluated anonymously.

Conflict of interest The authors declare that there are no conflicts of interest.

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