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Students' knowledge of plant anatomy and physiology as a reflection of interest in the teaching profession

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Not only in Slovakia, there is a debate about the low interest in the teaching profession and the decline in students' knowledge in international tests. The aim of this work was to find out what knowledge in the field of botany high school graduates (ISCED 3 A) have and compare their results with those of first-year biology teaching students at universities (ISCED 5 A). Students from seven high schools/gymnasiums (*n* = 96 respondents) had significantly better knowledge of plant anatomy and physiology than first-year students from three universities (*n* = 95 respondents): however, there was no interest in becoming a teacher among the former group. Some questions yielded a success rate of only a few percent among university students, indicating an insufficient basis for university studies. On the contrary, high school students preferring socially attractive fields of study (medicine or pharmacy) achieved higher scores in our test (up to 14% of the absolute score) but no significant difference was observed between high school students who plan to study abroad (27% of our respondents) and those who want to study at a Slovak university. Despite this partly pessimistic result, the finding that plant biology knowledge improves during university studies was positive, as evidenced by comparison of our students in the beginning and final year (23% increase in absolute score). In addition to the identified botanical shortcomings, we also discuss the socio-economic causes of low interest in the teaching profession and possibilities for improvement.

Keywords Botany, Knowledge, Plant biology, Science process skills, Teacher

Despite a rise in international student enrolment, close to one out of five Slovak learners chooses to undertake higher education abroad, a share second only to Luxembourg in the OECD[28]. One unfavorable observation is that only a minority of these students intend to return to Slovakia after completing their studies[9]and recent data indicate that 45% of students intend to study abroad after graduating from high school, and 31.6% of students would prefer to attend a Slovak university[24]. One reason for studying abroad is the better conditions for scientific and creative activities at foreign universities[10]. This trend may be countered effectively through strategic investment in the development of Slovak universities, as public expenditure on education in Slovakia has been comparatively low for an extended period[29,30].

Interest in botany has been reported to be significantly lower compared to other areas of biology[4], which may hinder the development of adequate botanical knowledge. Lower interest in plants and weaker knowledge in botany compared to zoology have been associated with the concept of plant blindness[42], recently referred to as plant awareness disparity[33]. Plants are perceived by humans as inanimate organisms that create habitats for animals and 30 scientific articles confirmed that pupils or students consider plants to be inferior to animals[37]. Insufficient student interest in plants and limited understanding of plant-related processes represent a serious concern in the context of global challenges, in which plants play a crucial role[11] and the references therein). In this regard, an in-depth narrative literature review indicated that each of the symptoms of plant blindness may prevent the achievement of at least one Sustainable Development Goal[1]. Within this framework, the role of biology teachers becomes particularly important, as they shape not only students' knowledge but also their attitudes toward plants and plant-related issues. However, if teachers themselves possess insufficient botanical knowledge, it is difficult to expect that students will achieve the desired level of understanding or develop sustained interest in this domain. In this context, research by Jose et al.[15], revealed that one of the

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main reasons botanists chose this field was an early interest in plants fostered through personal experiences or inspired by influential teachers and lecturers. It is therefore concerning that, when describing an image of a deer accompanied by various plant species, all pre-service teachers used animal-related terminology, whereas fewer than half referred to plants: moreover, among the participants who referred to plants, almost half described plants exclusively as a food source for animals[35].

Many studies have identified misconceptions and problematic areas within plant biology. However, most articles tend to concentrate on specific topics, such as photosynthesis[2] or plant reproduction[18]. Within individual topics, the corpus of studies addressing the understanding of plant anatomy and the role of phytohormones in plant physiology is limited. In this context, we note that an overview of misconceptions about plants is available in the literature[43]: however, no research was carried out that would identify problematic areas in plant biology in a more complex way. In the past, only a questionnaire for teachers was implemented, in which educators defined specific problem areas encountered by their students, but the students' comprehensive knowledge of botany was not assessed[17]. Misconceptions are characterized by their persistence, and educational efforts may not effectively facilitate their elimination[34]. Consequently, it is not surprising that numerous misconceptions regarding plants were identified among university students[19,44].

As authors who work in biology and botany/plant biology education at Slovak universities, we aimed to assess the knowledge of high school students in botany (plant anatomy and physiology) and compare these results with those of first-year university students in a biology teaching program. We evaluated not only encyclopedic knowledge, but also the ability to draw conclusions from tables and graphs. We compared our results with available foreign data and suggested ways to solve the long-standing problem of educational quality.

Methods

Knowledge test

To identify areas of plant biology problematic for students, we constructed a knowledge test. The whole test with examples of correct and incorrect answers is presented in the supplementary materials. This test containing 17 tasks was divided into two parts: (A) Plant anatomy, morphology and reproduction and (B) Plant physiology and ecology. Knowledge of plant anatomy and physiology is an essential part of botanical literacy, particularly in the area of cognitive outcomes (i.e. understanding the structure, function and basic processes of plants, as well as recognizing the key role of plants in ecosystems, including symbiotic relationships, food webs and soil stabilization), which underlines the relevance of the areas we tested[3]. Each task consisted of several questions with 64 sub-questions in the whole test. The area of Plant anatomy, morphology and reproduction consisted of 9 tasks and 40 sub-questions. The area of Plant physiology and ecology consisted of 8 tasks and 24 sub-questions. Students received 1 point for each correct answer, with a maximum of 64 points (40 points from the first area and 24 points from the second area). The score of each participant was subjected to further statistical analysis. The average success rate of individual tasks and questions was calculated as a percentage. The initial part of the test examined preferences to study attractive study programs (where veterinary/medicine and pharmacy were found to be more popular than other programs) or the preferences for studying abroad. The reliability of the test estimated by the split-half method and the Spearman-Brown formula showed a high internal consistency of the instrument (0.97). The difficulty of the test was consulted with practicing teachers and the almost 100% success rate of selected high school students was verified.

Participants of the study

The research was conducted at gymnasiums, a type of secondary school that provides a general education and prepares students (ages 15–19) for further studies at the university level. There are approximately 230 gymnasiums in Slovakia. We identified schools interested in collaboration through a previous nationwide questionnaire survey of biology teachers at gymnasiums[17]. Some teachers (n = 34) expressed their willingness to participate in further research activities in this questionnaire and were subsequently asked to conduct a knowledge evaluation among graduating biology students (ages 18–19). Teachers from six gymnasiums across Slovakia expressed interest in participating, giving a response rate of ~ 18%. The test was completed by 85 Slovak gymnasium students graduating from biology (in the last year of study, ISCED 3 A) and 11 students of one gymnasium from the Czech Republic (a partner school of the authors). Since the involvement of schools depended mainly on the willingness of the teachers to participate in the research, the resulting sample can be characterized as a voluntary (convenience). Students took the test voluntarily during regular biology classes (6 to 8 months before the final biology exam). The knowledge evaluation was conducted anonymously and solely for research purposes. Although participation was voluntary, none of the students declined to complete the test.

The test was voluntarily completed by 95 first-year students in a bachelor's degree program focused on biology teaching. After five years of study, including a master's degree, they will be qualified to teach K5-K12. The students were from three universities (corresponding to ISCED 5 A): Faculty of Education at the University of Trnava in Trnava, Faculty of Natural Sciences at the Matel Bel University in Banská Bystrica and Faculty of Science at Pavol Jozef Šafárik University in Košice. These universities are the authors' actual or previous affiliations, and the selection of these universities can be characterized as convenience sampling. The test was administered before students took any botany-focused course at university and the results of this test are therefore a reflection of the knowledge that students come with from high school.

For comparison, 15 final-year master's students (ISCED 5 A) also took the test at the University of Trnava. This provides an opportunity to compare the knowledge of first- and fifth-year students, especially with regard to knowledge retention and self-development. Botanical subjects are taught in the first and second years, but there are no special botanical courses thereafter.

Statistical analysis

Normality of results was verified by the Shapiro-Wilk's test. We investigated the impact of the preference for attractive study programs (medicine, pharmacy and veterinary medicine) with the common requirement of passing entrance exams and the preference for studying abroad on the results of the plant biology test. In addition, the test results of individual groups of students were also compared. For comparison between groups we used ANOVA, Student's t-test or Mann-Whitney U test. Also, Pearson's correlations were conducted between students' results from two areas of knowledge test (Plant anatomy, morphology and reproduction vs. Plant physiology and ecology). Statistical analyses were conducted using XLSTAT (Addinsoft, New York, USA) and graphs were created in Graphpad Prism version 9.5.0 (Graphpad Software). Power analysis using G*Power (version 3.1.9.7.) indicated that the sample size would provide requested power at 0.90 to detect a medium effect (Cohen's d = 0.50) at a significance level $\alpha = 0.05$[6].

Results and discussion

Deficiencies identified in plant anatomy, morphology and reproduction

Results showed both gymnasium (high school) and university students had the biggest problems with the anatomy of plant organs (stem: task no. 1, root: task no. 3 and leaf: task no. 9), basic types of tissues and structures on the epidermis (task no. 2 and task no. 7) and also with reproduction and metagenesis (task no. 8, Fig. 1). Students had low scores in identifying individual tissues in a cross-section of a stem (question no. 1. a.), but the ability to theoretically name meristems providing secondary growth was higher (especially for gymnasium students, question no. 1. c., Tab. S1). The better ability of students (especially from gymnasiums) to name the tissues responsible for secondary growth compared to university students may be due to the fact that high school students who did not study at gymnasium (general high school education) are also admitted to university program focused on biology teaching and therefore had no or minimal knowledge in plant biology. In addition, even high school teachers admit shortcomings in plant anatomy[17]. It was found that students more correctly identified the tissues in the root cross-section (question no. 3. a., Tab. S1) in contrast to the stem cross-section (question no. (1) a., Tab. S1), indicating that root anatomy is less difficult for students, as also confirmed in recent experimental study[39]. However, only a small percentage of students (especially from universities) know the importance of pericycle (question 3. c., Tab. S1). Within leaf anatomy, only up to 13% of students demonstrated the ability to identify xylem and phloem on leaf cross-section (question no. 9. a.) but a higher percentage of students identified this organ (question no. 9. b., Tab. S1). The basic types of tissues pose challenges for students, and only 12% of them were able to state the importance of sclerenchyma as a conductive tissue in addition to its mechanical function (question no. (2) a., Tab. S1). Only a minimum of students identified trichomes and their

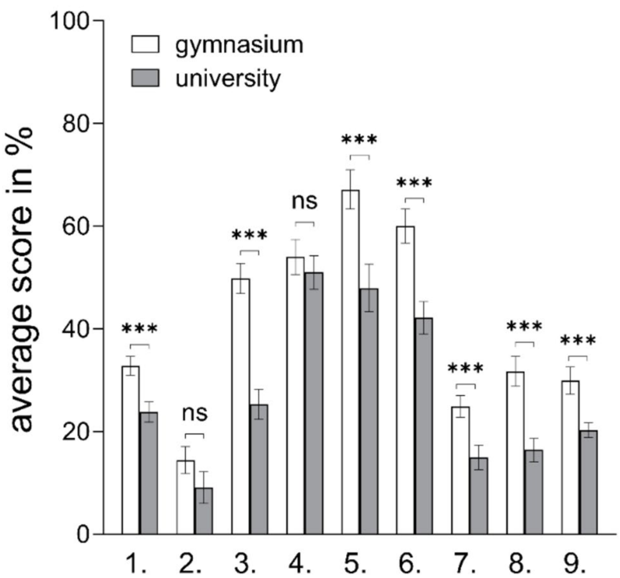


Fig. 1. The average scores of gymnasium students graduating from biology ($n = 96$) and first-year university students in the biology teaching program ($n = 95$) are presented for individual tasks focused on knowledge of *plant anatomy*, *morphology*, *and reproduction* (see the supplementary materials for a complete test, along with the correct and most common incorrect answers): stem anatomy (1), basic tissues (2), root anatomy (3), stomata and chloroplasts (4), structure of monocot and dicot stems (5), flower structure (6), trichomes and tentacles (7), reproduction and metagenesis (8), and leaf anatomy (9). The data show the average success rate of students in each task, expressed as a percentage ± SE. Values above columns with *** indicate significant differences at the 0.001 level according to the Mann-Whitney U test between the two groups (ns indicates a non-significant difference). For the content of the individual tasks, refer to the test and the detailed results in the supplementary materials.

absorptive function (questions no. 7. a., c., Tab. S1) but tentacles and their function were better recognized by students (questions no. 7. b., d., Tab. S1).

Our findings indicate that plant anatomy is a challenging area for students. Despite this, less attention is paid to its research compared to plant physiology. According to university students from Spain, the most complex concepts in plant anatomy are protoderm, procambium and basic meristem (37.6% of students), cambium and phellogen (36.6% of students) or collenchyma and sclerenchyma (26.7% of students[7]). One of the methods to enhance students' understanding of plant anatomy is through more frequent use of visualization of structures on microscopic slides[16,39].

The reproduction and metagenesis of plants (Fig. 1) were also identified as problematic areas for students and less than 25% of the university students correctly identified the sporophyte and gametophyte of mosses (question no. 8. b., Tab. S1). A survey among university students revealed that only about 30% respondents agree with the statement "*The gametophyte phase is reduced in the development cycle towards angiosperms*"[22] and are probably unaware of this important change in the process of plant evolution. Besides, although 21.6% of gymnasium students knew that a zygote or seed is formed by the fusion of haploid gametes, only 2.45% of the first-year university students had the same knowledge (question no. 8. c., Tab. S1). The investigation of misconceptions and knowledge gaps regarding plant reproduction has received more attention than plant anatomy. Several misconceptions were identified worldwide, e.g. high school students think that after fertilization, the flower's ovule will develop into fruit (18.6 to 36.5% of students), seeds need water during photosynthesis to produce nutrients for germination (22.5 to 58.3% of students), seeds need carbon dioxide during photosynthesis to produce energy for germination (5.6 to 12.2% of students), seeds need sunlight during photosynthesis to produce energy for germination (20.5 to 50.6% of students), organic substances in the soil are used as nutrients for germination (27.3 to 60.9% of students[20]). Other misconceptions have been identified among university students, e.g. 84.3% of students think that all plants arise from seeds and 48.3% of students think that male and female gametes can be identical[19]. Pupils and students exhibited a greater comprehension of the function of seeds in comparison to that of pollen[18]. It is also alarming that almost 25% of secondary school students aged 11–19 think that plants cannot reproduce[32]. Combining topics on anatomy and reproduction with plant physiology and ecology can be a way to better understand the topic, and the use of visual aids/real plants can be highly recommended.

Deficiencies identified in plant physiology and ecology

Generally, students at both the gymnasium and university levels encountered challenges in the domains of plant nutrition (tasks no. 10 and 11), plant hormones (task no. 15), photosynthesis (task no. 16) and regulation of transpiration (task no. 17, Fig. 2). The tasks on plant nutrition were focused on macroelement nitrogen. It is noteworthy that over 40% of the gymnasium students accurately identified the nodule bacteria on the roots of Fabaceae plant (question no. 11. a.) and recognized their significance in assimilating atmospheric nitrogen

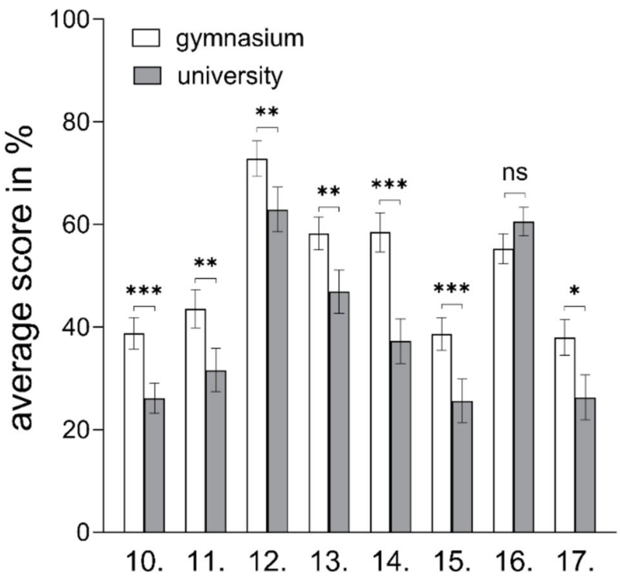


Fig. 2. The average scores of gymnasium students graduating from biology ($n = 96$) and first-year university students in the biology teaching program ($n = 95$) are presented for individual tasks focused on knowledge of *plant physiology and ecology* (see the supplementary materials for a complete test, along with the correct and most common incorrect answers): nutrition of carnivorous plants (10.) root nodules (11.), respiration (12.), lichens (13.), water regime (14.), hormones (15.), photosynthesis (16.) and regulation of transpiration (17.). The data show the average success rate of students in each task, expressed as a percentage ± SE. Values above columns with *, ** and *** indicate significant differences at 0.05, 0.01 and 0.001 levels according to the Mann-Whitney U test between the two groups (ns indicates a non-significant difference). For the content of the individual tasks, refer to the test and the detailed results in the supplementary materials.

and elevating soil nitrogen content (question no. 11. b., Fig. S2). The students were generally unable to draw conclusions from the table about the uptake of zinc (Zn) and copper (Cu) by carnivorous plants from the soil, and not from ants (question no. 10. a., Tab. S2). We strongly recommend placing more emphasis on drawing conclusions from tables and graphs related to ecology and plant nutrition using practical examples.

Though the identification of maize and cactus was good (questions no. 17 a., b.), only 15.5% of gymnasium students and 7.8% of first year university students correctly explained the basic difference between C4 and CAM photosynthesis (Tab. S2). Several misconceptions regarding photosynthesis have been identified worldwide, e.g. ca. half of high school students have misconceptions regarding products of photosynthesis and 35% of students about the place where it occurs[2]. Besides, 14% of students agree with the statement: "*Sleeping near plants is dangerous at night because we may run out of oxygen*" and 30% with the statement: "*Plants carry out photosynthesis during the day and breathe instead at night*"[34]. However, Slovak students know the Krebs cycle (question no. 12. a.), can locate the organelle in which it takes place (question no. 12. b.) and know the significance of this process (question no. 12. c., Tab. S2). There are several proposals for hands-on activities designed for high school and university students that can improve their knowledge of plant photosynthesis and cellular respiration[12,14,26].

Plant hormones can be included in a broad topic of the Slovak curriculum, "*The basic stages of ontogenesis and its regulation by exogenous and endogenous factors*" and students have deficiencies in this topic even from the perspective of teachers[17]. Within the tasks focused on plant hormones and the regulation of transpiration, students were required to interpret data presented in graphs (questions no. 15. a., 17. a., b.) and especially university students had difficulties in such interpretation (Tab. S2). The ability to interpret data from graphs is a fundamental science process skill and a recent study revealed the positive impact of short-term experimental teaching using image analysis on the development of this skill[40]. The comprehension of the function of auxins (question no. 15. c.) and abscisic acid (17. c.) was achieved by approximately 20% of gymnasium students, with an even lower percentage observed among university students (Tab. S2).

Factors influencing test scores: teaching profession only as a "back-up plan"

Students from gymnasiums (ISCED 3 A) achieved an absolute score higher by 14% in plant anatomy, morphology, and reproduction (large effect, Table S3); and by 10% in plant physiology and ecology (medium effect, Table S3) than first-year university students of biology teaching (ISCED 5 A; Fig. 3). These findings can be attributed to the limited interest in the biology teaching study programs, which often represents a so-called "back-up plan" when choosing a university study program (and students of biology teaching often combined with chemistry mostly have medical fields as their first choice). It is known that university students of education programs from various countries (Australia, USA or Germany) perceive the teaching career as demanding and realize that teachers do not have a high social status (mainly in Germany), are not sufficiently financially valued (mainly in Australia and USA) and are often discouraged (in all three countries) from choosing a given study program[41]. In line with these findings, a comparison of average annual salaries indicates that teachers' salaries in the EU 25 countries are at least 2 times higher than in Slovakia. Within the V4 (Visegrád Group) countries, Slovak teachers earn less than teachers in the Czech Republic, Hungary and Poland ([31]. Therefore, it is not surprising that Slovak students are more interested in other fields, such as medicine or pharmacy: they only consider a study program focused on biology teaching if they fail the entrance exams for these more attractive programs.

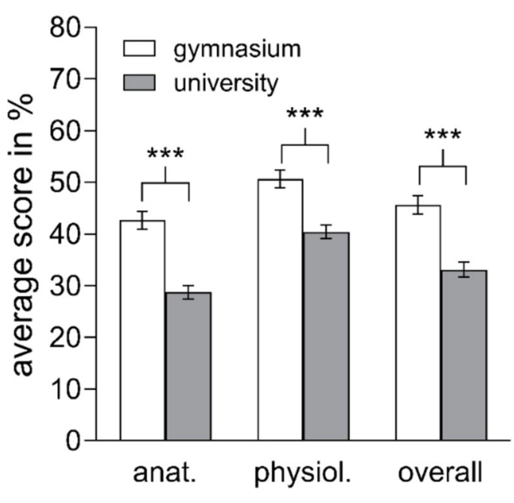


Fig. 3. A comparison of the scores of gymnasium students graduating from biology ($n = 96$) and first-year university students in the biology teaching program ($n = 95$) in the areas of anatomy, morphology, and reproduction (anat.), physiology, and ecology (physiol.), as well as the total score (overall). The data show the average test score expressed as a percentage of success ± SEs. Columns with *** indicate significant differences at the 0.001 level according to Student's t-test between the two groups. Table S3 provides a comprehensive overview of descriptive statistics, statistical test results, and effect sizes. There were not enough boys among the university students for a statistical comparison. In the case of the gymnasium students, no differences in scores depending on gender were found (anat. $p = 0.979$, physiol. $p = 0.169$, overall $p = 0.515$).

Additionally, faculties that prepare future teachers usually accept all applicants into this "unpopular" program. In other words, the only prerequisite for enrollment in the program, which focuses not only on biology teaching, is to apply and pass the high school graduation exam. We hypothesize that admitting all applicants is likely a contributing factor to lower knowledge observed among university-level biology students (Fig. 3) because vocational high schools had a reduced number of biology lessons. Understandably, due to the limited number of biology lessons, these students have a deficiency in knowledge, complicating their transition to university education. In this context, the international large-scale PISA 2022 assessment confirmed that the scientific literacy of 15-year-old Slovak students attending vocational high schools is substantially lower than that of their peers from gymnasiums (mean score 471 vs. 561 as reported by NIVAM[27]).

The dedicated efforts of university teachers are crucial for the academic development of future educators. It was therefore a positive finding that knowledge improves during university studies. The corresponding author of this work verified the plant biology knowledge of his students in the 1 st and 5th year (this was an unexpected test at the University of Trnava). The higher score in the 5th year confirms the retention and development of knowledge from the 1 st and 2nd year: this is despite the absence of direct botanical education in the 3rd and 4th year (Fig. S1). Based on this fact, we feel that in terms of training future teachers, "nothing is lost": a synchronized effort of university teachers in a given field is needed to pay attention to the quality of training and not to "give" an E grade (the lowest possible grade for successfully completing a course) just so that students do not have to repeat a given subject. However, in contrast to the effort of university teachers for quality, state authorities seek to reduce academic failure by penalizing universities for the so-called "drop-out rate" (the percentage of full-time students who left during or after the first year of study, out of all the newly admitted full-time students): We see this as the main challenge in addressing the quality of graduates, which Slovakia must set fairly and pragmatically (and the correctness of this goal is a separate issue that requires discussion and analysis). However, it is important to emphasize that teachers' enthusiasm for teaching a given topic, as well as their subject-matter knowledge, have been shown to enhance student performance[8,21]. This also highlights the importance of pre-service teachers having strong content knowledge and a positive attitude toward plants. Based on our experiences and anonymous evaluations of our plant biology courses, we received predominantly positive reactions from students.

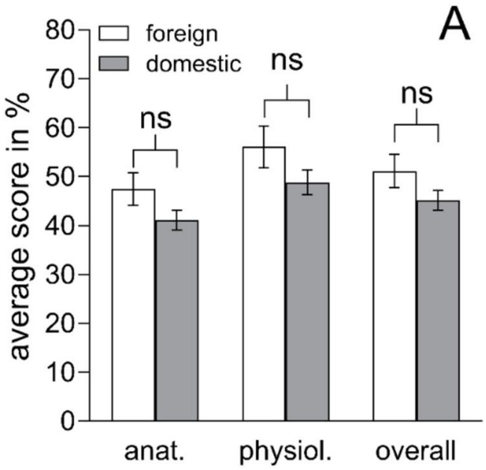
A comparison of students' results from individual gymnasiums revealed considerable differences, which probably indicate the impact of teachers and, perhaps, local conditions at each gymnasium (Fig. S2A). Gymnasiums in Slovakia have various equipment and teachers also admit gaps in their own knowledge[17]. On the contrary, a comparison of students' results at individual universities did not reveal such extensive differences (Fig. S2B). However, the overall knowledge test score in this study was lower for university students, with a large effect size (Fig. 3, Table S3): This confirms the problem of the quality of students entering biology teaching programs at Slovak universities and/or the low interest of the best high school graduates in the teaching profession.

"Brain drain" from Slovakia as a challenge for education and society

A major problem in Slovakia is the so-called "brain drain", when academically more successful students and employees leave for various reasons (e.g. conditions for doing business, taxation, law enforcement, etc. cited in various surveys). Among the OECD member states, Slovakia ranks second in terms of the proportion of students studying at universities abroad, with approximately 15–20%[10,28], and, for example, more than half of the top-performing mathematics graduates studied at universities abroad[23]. In our research even 27% of high school students expressed interest in studying abroad. On the other hand, our research from plant biology knowledge did not reveal that students who prefer studying abroad achieved significantly higher test scores though the absolute value was slightly higher (Fig. 4A).

Multiple factors contribute to students' decision to continue in education at foreign universities. The most detailed questionnaire survey on this matter in Slovakia found the following: (i) Students perceive Slovak universities as lower quality; (ii) foreign universities have a better reputation (85.4% of students), better conditions for scientific and creative activity (47.2% of students), and better social security, such as scholarships and dormitories (35.6% of students); (iii) only 31.1% of Slovak university students reported that all their teachers are experts in their field, while 50.1% of students studying abroad expressed this opinion[10]. In line, the quality and popularity of education given by universities is one of the main factors that determines the selection of university in Turkey[13]. Adequate funding is essential for the enhancement of scientific and creative activity conditions. However, Slovakia's investment in education falls below the average of the European Union and OECD countries[29,30]. An issue of concern is that merely approximately 15% of Slovak students studying abroad contemplate returning to Slovakia[9]. One factor contributing to the "brain drain" may be financial: Slovakia is one of the ten countries with the lowest median annual net income (€11,752) for people who have achieved a tertiary education qualification. In contrast, the Czech Republic has the highest median income in the V4 group (€19,724[5]). This difference may also be reflected in student mobility, as Czech universities attract more Slovak high school graduates than any other destination. That this departure is probably not only about the financial aspect (but also about the quality of studies or service for students) is confirmed by the current analysis of the effectiveness of the scholarship scheme "*I study at home, Slovakia will reward me*", which did not significantly affect the interest of the best high school graduates to study in the Slovak Republic, and those who were motivated by the scholarship did not choose fields of study where there is a shortage of experts, including a shortage of teachers[36]. Similarly, a 2025 analysis states that, of the 2012–2015 high school graduates who completed their entire university education outside of Slovakia, only about 40% had returned by 2022[25].

Our research also examined the impact of the university programs preferred by gymnasium students on their knowledge of plant biology. Data indicates that approximately half (52%) of Slovak high school biology graduates prefer to study programs that are perceived as more attractive by society, such as medicine, pharmacy, and veterinary medicine. Interest in these programs had a medium significant effect on the knowledge of plant



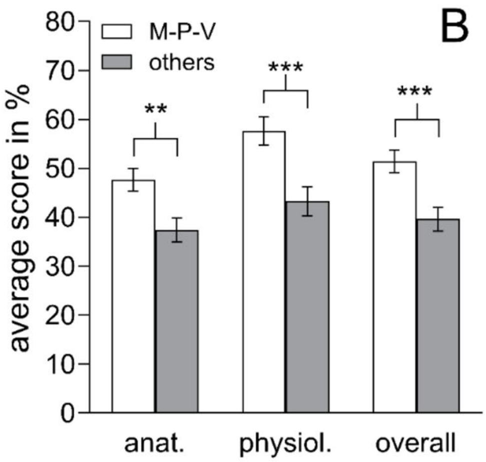


Fig. 4. A comparison of the scores from the anatomy, morphology, and reproduction (anat.), the physiology and ecology (physiol.), and the overall score in the knowledge test of gymnasium students graduating from biology, with respect to their preferences for studying abroad (**A**) or their interest in studying socially attractive programs (M-P-V = medicine, pharmacy, and veterinary medicine) or other programs (**B**). The data show the average test score, expressed as a percentage of success ± SEs (n = 86 respondents in total, from that foreign = 23, domestic = 63, M-P-V = 45 and others = 41). The values above columns with ** and *** indicate significant differences at the 0.01 and 0.001 levels, respectively, according to Student's t-test, between groups (ns indicates non-significant difference). A comprehensive overview of descriptive statistics, statistical test results, and effect sizes is provided in Table S3.

biology among students (Fig. 4B, Table S3). These more attractive programs are also associated with higher average earnings of their graduates. The financial evaluation of the chosen career is an important predictor that has a significant impact on the selection of the study program[38]. As shown in Fig. 4B, students who preferred attractive programs achieved higher absolute scores in plant anatomy, morphology, and reproduction (+ 10.3%) and in plant physiology and ecology (+ 14.3%). These scores correspond to those of all gymnasium students, as stated at the beginning of this chapter. It seems likely that these students contributed to the high school students' better overall results compared to those of university students. One possible explanation is that admission to these attractive programs requires successful completion of an entrance exam. Students are forced to prepare systematically for the exam, which is also reflected in their better botany knowledge (Fig. 4B). High school students had also higher correlation between two monitored areas in the knowledge test compared to university students (Fig. 5A vs. B). Based on these findings, we suggest a discussion on the reintroduction of university entrance exams, including teacher education programs, since this was a common practice in the past. As a form of admissions test, we could consider "General Study Prerequisites" (known as Scio tests), which programs with high interest in studying but with a limited number of possible students admitted already implement.

Conclusions

A plant biology knowledge test revealed deficiencies among high school (biology graduates) and university students (study program focused on biology teaching), especially in the areas of vegetative plant organ anatomy,

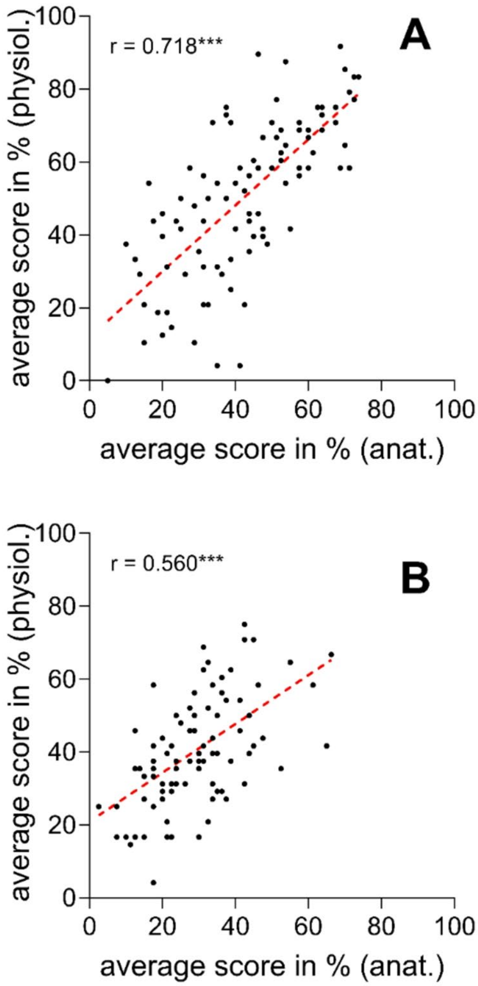


Fig. 5. Pearson's correlation analysis of scores from anatomy, morphology, and reproduction (anat.), physiology and ecology (physiol.) in the knowledge test of high school students graduating from biology (**A**, $n=96$) or first-year university students in the biology teaching program (**B**, $n=95$). The individual points show the scores achieved by each student. *** indicates a significant correlation at the 0.001 level. As shown in Fig. 3, the higher knowledge scores of high school students compared to university students are also reflected in the higher correlation between the two monitored areas of the knowledge test (graph A).

basic tissue types, plant hormones, and drawing conclusions from tables. We hope that identified problem areas will encourage teachers to make plant biology more attractive to students. A comparison of high school and university students (with an age difference of less than a year) showed that university students in the biology teaching program achieved lower scores. It can be concluded that this program is not attractive to high school students with better knowledge. In other words, the best high school students prefer other fields of study, not teaching (and those who want to study medicine or pharmacy also achieved higher scores on our test). These findings aim to stimulate state authorities' interest in the teaching profession and improve the conditions of lifelong education and financial remuneration to a level comparable to other professions requiring a university-level education.

Data availability

Supporting data are presented in the supplementary materials. The datasets generated during and/or analyzed in this study are available from the corresponding author on reasonable request.

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Author contributions

- Jozef Kováčik: Conceptualization, Methodology, Investigation, Supervision, Writing –Review & Editing.
- Marek Vydra: Methodology, Formal analysis, Data Curation, Writing – Original Draft.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

The Committee for Ethics and Research Integrity of the Faculty of Education of the University of Trnava does not require researchers to apply for ethical approval for studies with adults on a voluntary basis and without the collection of personal data. All studies complied with the 1975 Declaration of Helsinki and its derivatives. Confirmation of this compliance was later reaffirmed by the Chairman of the Committee for Ethics and Research Integrity of the Faculty of Education of the University of Trnava on May 26, 2025.

Informed consent

The survey in secondary schools/gymnasiums was approved by the principal of the respective school and consulted with biology teachers and the survey at universities was conducted by approaching random volunteers. Informed consent was obtained from participants in the quantitative phase of the study via personal/oral form: students were informed about the objectives and verbally agreed to participate (implemented between April 2023 and September 2024). Answering the questionnaires by students and their statistical evaluation took place completely anonymously.

Additional information

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