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ROLE OF SCIENTIFIC STUDENT ASSOCIATIONS IN DEVELOPING COMPETENCIES AMONG BIOLOGY STUDENTS: THE CASE OF THE STUDENT SCIENTIFIC ASSOCIATION OF ANIMAL PHYSIOLOGISTS "*OXYGEN*" (POLAND)

Abstract. *This article explores the educational and developmental role of Student Scientific Associations (SSAs) in biology education, emphasising their potential as supplementary learning environments in higher education. The Student Scientific Association of Animal Physiologists 'Oxygen' at the Pomeranian University in Słupsk (Poland) is used as a case study. Using qualitative data from interviews, observations, and document analysis, the study shows that participating in SSA 'Oxygen' greatly improves a range of competencies, including research methodology, technical laboratory skills, data analysis, critical thinking, communication, teamwork, leadership, and self-efficacy. Notably, the SSA 'Oxygen' offers students the chance to experience the entire research process, from designing experiments to interpreting results and presenting findings in academic settings.*

The interdisciplinary projects undertaken by SSA 'Oxygen', such as investigations into oxidative stress, ecophysiological monitoring of wild bird populations, and the pharmacological evaluation of plant extracts, expose students to real-life scientific challenges, developing their ability to apply theoretical knowledge in practice. These activities are often carried out in cooperation with external institutions, broadening the academic perspective and fostering international collaboration. Students also present their findings at local, national, and international seminars and conferences, strengthening their academic identity and preparing them for future professional roles in research, education, and environmental protection.

The findings emphasise the importance of mentorship, peer learning, autonomy, and organisational involvement as key elements in developing competence. However, the article also identifies several challenges, including limited funding, a lack of infrastructure, time constraints and member turnover, which may hinder continuity and effectiveness. Overcoming these barriers requires stronger institutional support and the strategic integration of SSA activities into university curricula. With effective support, SSAs can play a transformative role in higher education by bridging the gap between theory and practice. Recognising their achievements formally, alongside providing stable resources and mentorship, can maximise their educational impact. This provides students with valuable scientific skills, as well as confidence, resilience, and long-term professional advantages.

Keywords: *Student Scientific Associations; biology education; experiential learning; research competencies; interdisciplinary projects; peer mentoring; academic development.*

Introduction. The rapid evolution of the biological sciences in the 21st century means that, in addition to solid theoretical knowledge, graduates now need a broad set of professional competencies. These include laboratory methodology, analytical thinking, scientific communication, interdisciplinary collaboration, and self-directed learning. As biology becomes increasingly data-driven and integrative, the ability to apply knowledge in practical settings and

collaborate effectively within research teams is paramount. Both employers and academic institutions emphasise the importance of experiential learning and cultivating transferable skills that extend beyond mere textbook mastery [24; 41].

Although formal university curricula provide a solid foundation, they often prioritise content delivery and standardised assessment over exploratory learning. While students acquire essential theoretical frameworks, they may lack opportunities to engage in independent research, design and execute projects, analyse complex datasets, and present their findings professionally. As a result, there is increasing recognition that complementary educational initiatives are necessary to support the holistic development of future biologists [17]. Without these opportunities, students may struggle to develop a scientific identity and may be less prepared for postgraduate study or employment in research-intensive environments. Therefore, additional educational structures are required to encourage deeper engagement and skill acquisition.

Student Scientific Associations (SSAs), also known as Student Scientific Circles (SKNs in Poland), have emerged as vital platforms for bridging this gap. These voluntary, student-led groups provide extracurricular spaces where learners can deepen their subject knowledge, gain hands-on experience, and interact with peers and experts outside the confines of formal coursework. SSAs usually operate within university departments under the supervision of academic staff, but their activities are driven by student initiative and curiosity. They provide a flexible environment for experimentation, interdisciplinary dialogue, and scientific dissemination [6; 26].

Despite their widespread presence in European universities, relatively little systematic research has been conducted on how SSAs specifically contribute to the development of competencies among biology students. Existing literature tends to focus on general student engagement or extracurricular involvement, failing to identify the pedagogical mechanisms that make SSAs effective. Understanding these mechanisms is crucial for optimising the role of SSAs in higher education and for developing effective institutional support strategies. Furthermore, as a discipline spanning molecular, ecological, and physiological domains, biology offers a rich context for exploring how student-led research can enhance learning outcomes [48].

This study examines the Student Scientific Association of Animal Physiologists '*Oxygen*' (Polish: Studenckie Koło Naukowe Fizjologów Zwierząt '*Oxygen*'), which is based at the Institute of Biology at the Pomeranian University in Słupsk (Fig. 1).

Since its establishment in 2006, the association has grown into a vibrant community of undergraduate and postgraduate students engaged in diverse research projects related to animal physiology, biochemistry, toxicology, and environmental monitoring. Supervised by experienced faculty members, the association provides a structured yet flexible framework for scientific exploration and skill development. Importantly, the association's mission aligns with national

strategies for higher education and European frameworks for key competences in lifelong learning [14].

Fig. 1. *Members of the Student Scientific Association of Animal Physiologists 'Oxygen' in May 2024.*

Photo by Natalia Kurhaluk.

The Student Scientific Association of Animal Physiologists, '*Oxygen*', is distinguished by its interdisciplinary approach and intensive international collaborations. Students participate in projects examining oxidative stress in animal tissues, evaluating the pharmacological properties of plant extracts and monitoring the physiological responses of wildlife to environmental pollutants. Such activities require proficiency in laboratory techniques, statistical analysis, and scientific writing – competencies that are frequently overlooked in traditional curricula. Furthermore, the Circle's partnerships with institutions in Ukraine and other countries expose students to global research practices and foster academic mobility [44].

The influence of the SSA '*Oxygen*' is evident in its members' academic achievements. Many have co-authored publications in peer-reviewed journals, received awards at scientific competitions and gone on to pursue postgraduate studies in biology and related subjects. These outcomes suggest that participation in the SSA '*Oxygen*' enriches the university experience and serves as a springboard for professional advancement. By combining research, mentorship and dissemination, SSA '*Oxygen*' demonstrates how SSAs can nurture scientific talent and prepare graduates for the demands of contemporary science [8].

Purpose and Objectives. This study aims to shed light on the role of the Student Scientific Association of Animal Physiologists '*Oxygen*' in developing its members' academic and professional skills. As biology education increasingly emphasises experiential learning and

interdisciplinary collaboration, student-led initiatives such as the SSA '*Oxygen*' association provide an important means of examining how informal structures can complement formal curricula [8; 17]. By analysing the activities, organisational dynamics, and perceived outcomes of participating in the SSA, this study aims to identify features and mechanisms that could inform best practices for similar student associations in the biological sciences.

To achieve this, the study is guided by four specific objectives. First, it seeks to identify the core competencies – namely, research, technical, interpersonal, and communicative – that biology students perceive as being developed through their involvement in SSA '*Oxygen*'. These competencies are critical for success in academic and applied biological contexts, and understanding how they are cultivated in extracurricular settings could inform effective educational strategies [24].

Secondly, the study aims to describe the types of activities that the SSA '*Oxygen*' conducts to contribute to the development of these competencies. These include laboratory-based research projects, field studies, scientific seminars, and conference participation. Examining the structure and content of these activities will highlight the pedagogical value of student-led scientific work in fostering autonomy, critical thinking, and methodological rigour [43].

Thirdly, the study will analyse the challenges the association faces in facilitating competence development. These include funding limitations and access to laboratory resources, time constraints due to academic commitments, and inconsistent levels of student engagement. Understanding these barriers is essential for developing targeted interventions and support mechanisms that can enhance the functioning and impact of SSAs [6; 26].

Finally, the study will make recommendations to strengthen the role of SSAs in biology education. Based on the findings from the SSA '*Oxygen*' case study, these recommendations will address institutional support, mentorship models, integration with academic programmes, and strategies for sustaining student motivation and participation. The aim is to provide a framework that other universities can adopt to enrich their biology curricula through student-led research initiatives [14].

Together, these objectives form a coherent analytical framework that establishes SSA '*Oxygen*' as something greater than just a student club. By combining theory and practice, and individual and collective approaches, the association shows how informal learning environments can play a transformative role in the development of future biologists.

Furthermore, the study contributes to the wider discourse on the importance of student autonomy in higher education. At a time when academic institutions are rethinking their teaching methods to better prepare graduates for the complex scientific and societal challenges they will

encounter, SSAs such as '*Oxygen*' offer a compelling example of how grassroots academic communities can encourage innovation, resilience, and professional development [48].

Research Methods. A qualitative case study design was employed to explore the role of the SSA '*Oxygen*' in developing student competencies. This approach was chosen because it is well-suited to capturing complex, context-dependent phenomena, such as informal learning, peer collaboration, and skill development within student-led scientific communities [51]. The study aimed to develop a comprehensive understanding of the association's educational impact by integrating various data sources, including interviews, observations, and document analysis. This strategy is particularly appropriate for research in higher education, where competence development often depends on experiential and context-specific practices rather than standardised processes [35].

Design. Using the case study methodology, we conducted an in-depth analysis of the functioning of the SSA '*Oxygen*' at the Institute of Biology of the Pomeranian University in Słupsk. By combining qualitative techniques, we were able to capture subjective experiences and observable practices and situate them within the broader institutional and disciplinary context. This triangulated design enhanced the credibility of the findings and helped us to identify recurring patterns related to competence development [13].

Participants. The study included current and former members of the SSA '*Oxygen*', comprising undergraduate and master's level biology students. A purposive sampling strategy was adopted to ensure diversity in levels of involvement and roles within the association [39]. The sample included board members responsible for organising activities, active members who regularly engaged in research and events, and individuals who participated occasionally or in specific projects. Additionally, including alumni enabled the study to capture the longer-term impacts of participation, such as postgraduate career trajectories and continued research engagement. This variation enabled a nuanced exploration of how different levels of engagement influence perceived learning outcomes.

Data collection. Data collection was conducted over a period of several months, employing three complementary methods.

Interviews. Semi-structured interviews were conducted with selected participants to gain insight into their experiences of SSA '*Oxygen*'. Questions focused on perceived gains in research and technical skills, communication abilities, and teamwork and leadership skills. Participants were also invited to reflect on any challenges they had faced and to suggest ways in which the association could improve [28].

Observation. Multiple SSA '*Oxygen*' meetings, workshops and seminars were observed in order to study the dynamics of student interaction and the structure of activities. The informal

learning processes, collaborative behaviours, and integration of scientific content into practical tasks observed were documented in field notes [4].

Document analysis. A variety of internal and publicly accessible documents were examined, including project reports, event programmes, student publications, and information about the association's online presence. These materials provided contextual information about the scope of activities and thematic focus areas, as well as the evolution of the SSA over time. Where available, records of student achievements and participation in conferences were also reviewed [7].

Together, these data sources provided an in-depth overview of SSA '*Oxygen*'s' operations and its contribution to student development. Integrating first-hand accounts, observational data and documentary evidence allowed us to conduct a thorough analysis of individual and collective learning trajectories.

Data Analysis. The collected data were analyzed using thematic coding, guided by a predefined framework of competencies relevant to biology education. These included:

- Research skills (e.g., hypothesis formulation, experimental design, data interpretation);
- Technical laboratory skills (e.g., sample preparation, use of analytical instruments);
- Communication (e.g., scientific writing, oral presentation, peer discussion);
- Teamwork and leadership (e.g., project coordination, conflict resolution, mentoring peers).

Emerging themes were identified inductively and mapped onto this framework to assess the extent and nature of competence development. To enhance the validity of the findings, triangulation across the three data sources was used. Any discrepancies and convergences were examined to ensure that interpretations were grounded in multiple forms of evidence [40]. Member-checking was also conducted, allowing participants to review preliminary interpretations and further strengthening the trustworthiness of the results [31]. Reflexivity was maintained throughout the analysis, with attention to the researcher’s positionality and potential biases.

This methodological approach provided a robust foundation for understanding how the SSA '*Oxygen*' programme functions as a learning environment, and which specific mechanisms contribute to its educational effectiveness. The subsequent sections present the findings derived from this analysis, offering insights into the strengths and limitations of student scientific associations in biology education.

Results.

Competency Development of Biology Students through Participation in the Student Scientific Association ‘Oxygen’. The activities organised by the Student Scientific Association of Animal Physiologists, '*Oxygen*', have demonstrably contributed to the multidimensional development of its members, particularly in areas crucial for academic and professional success in the biological sciences. Participants have reported significant growth in research skills and scientific

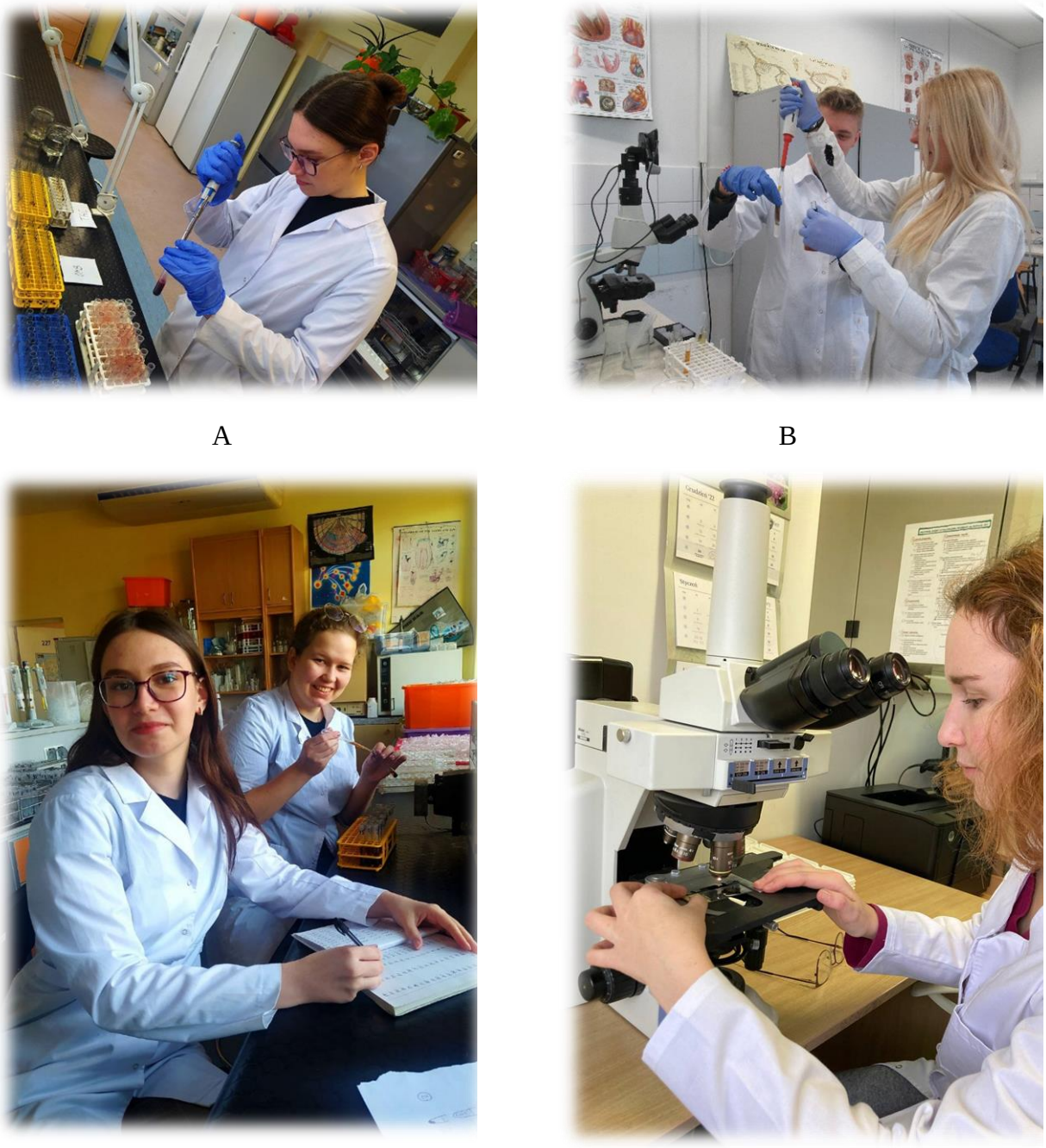
methodology as one of the most notable areas of development. Through supervised projects and laboratory-based tasks, students have become familiar with experimental design and physiological and biochemical measurement techniques, as well as the systematic handling of laboratory equipment. Such engagement in authentic research environments is widely recognised as a key factor in fostering student competencies and scientific literacy [17; 32]. These experiences have enabled students to collect and analyse data with greater autonomy and precision, providing them with a solid foundation for future scientific research (Table 1).

Table 1.

Key competencies and how they can be developed through the activities of the Student Scientific Association of Animal Physiologists 'Oxygen'

Competency	**Description of enhancement within SSA "*Oxygen*"**
Research skills and scientific methodology	Members reported gaining familiarity with experimental design, physiological measurement techniques, handling lab equipment, data collection and analysis. Projects and lab-based tasks under supervision contributed significantly.
Technical laboratory skills	Hands-on training in handling physiological assays, use of microscopes, properly conducting protocols, working with live material (if applicable), preparation and maintenance of lab equipment, etc.
Critical thinking and problem solving	Designing experiments, troubleshooting protocols or data inconsistencies, interpreting results, and connecting theoretical knowledge with observed phenomena.
Communication skills	Preparing presentations and posters for seminars, delivering talks, writing reports, possibly manuscripts; participating in discussions and debates within the group.
Teamwork and leadership	Working in project teams, organizing events, dividing roles, coordinating tasks; some students taking leadership positions (e.g. event coordinators) and mentoring new members.
Self-efficacy and motivation	Increased confidence in conducting research, in scientific discourse; enhanced motivation to pursue further research or academic careers.

Developing technical laboratory skills is closely linked to acquiring research competencies. Members of the SSA '*Oxygen*' group received hands-on training in conducting biochemical and physiological assays, operating laboratory equipment, and adhering to standardised protocols. In some cases, students worked directly with live biological material, requiring not only technical proficiency but also ethical awareness and precise execution of procedures (Fig. 2). Preparing and maintaining laboratory instruments further reinforced their understanding of the practical demands of experimental biology. Experiential learning of this kind is particularly effective in bridging the gap between theoretical knowledge and professional practice [25].



A B C D

Fig. 2. *Members of the Student Scientific Association of Animal Physiologists 'Oxygen' carry out biochemical assays in the laboratory.*

Photo by Natalia Kurhaluk.

Participation in the SSA '*Oxygen*' also fostered critical thinking and problem-solving skills. Students were actively involved in designing experiments, resolving methodological issues, and interpreting complex datasets. This required them to apply their theoretical knowledge to empirical observations, deepening their conceptual understanding and improving their ability to navigate scientific uncertainty. The iterative nature of research, characterised by trial and error, provided a

valuable context for cultivating intellectual resilience and analytical flexibility. This reflects broader findings that undergraduate research significantly contributes to the development of higher-order thinking skills [27].

The development of communication skills was equally important. Students regularly prepared presentations and posters for seminars, delivered oral reports, and practised scientific writing (Fig. 3). This included drafting research summaries and, in some cases, manuscripts for publication. Group discussions and debates provided further opportunities to articulate ideas, defend interpretations, and respond constructively to feedback. These communicative practices improved students' ability to convey scientific information and strengthened their confidence in public speaking and academic discourse [1; 6].

Fig. 3. *The members of the Student Scientific Association of Animal Physiologists 'Oxygen' popularise science among children and adolescents.*

Photo by Natalia Kurhaluk.

The collaborative structure of the SSA '*Oxygen*' provided an ideal environment for developing teamwork and leadership skills. Students worked in project teams, organised events and took on various roles. Some took on leadership responsibilities, such as serving as event coordinators or mentoring newer members. These experiences helped them develop essential skills in task delegation, conflict resolution, and group facilitation – skills that are valuable in both research environments and broader professional settings. Research confirms that collaborative, peer-led projects substantially improve students' leadership and social competencies [5; 49].

Ultimately, the cumulative effect of these experiences led to a significant increase in participants' self-efficacy and motivation. Students reported feeling more confident in their ability to conduct research and engage in scientific dialogue. Many also expressed greater enthusiasm for pursuing academic or research-oriented careers, attributing this to the supportive and intellectually stimulating environment fostered by the SSA [6].

In addition to laboratory and research activities, members of the SSA '*Oxygen*' are actively involved in initiatives that promote science, education, and community outreach. These initiatives further reinforce students' competencies:

1. Promotion of the Pomeranian University in Słupsk and scientific awareness. Members represented the university in regional media, such as TV and newspapers, and at student symposia, including “Panorama Regionalna” in Słupsk (2009) and “Teleexpress” in Gdańsk (2009). They also presented research outputs and student mobility initiatives at the 40th Anniversary Student Symposium at the Pomeranian University in Słupsk. There, they presented their research findings and initiatives to promote student mobility [20].

Fig. 4. *The members of the Student Scientific Association of Animal Physiologists 'Oxygen' run educational programmes for the Universities of the Third Age.*

Photo by Natalia Kurhaluk.

2. Science popularisation and educational workshops. Students have been organising and leading numerous workshops at the Bałtycki Science Festival (2010-2025) and the Nights of Biologists (2014-2025). They also ran intergenerational educational programmes for the University of the Third Age (Fig. 4). Topics included physiology, biochemistry, diet and nutrition, health promotion, and sustainable practices [20].

3. Competitions and Recognition. Members of the SSA '*Oxygen*' participated in national and international competitions, achieving awards and distinctions. These include being named finalists in the *'Studencki Nobel*' competition (2022-2023) and receiving recognition from the Provincial Fund for Environmental Protection and Water Management. Several members have been awarded prestigious scholarships, including the Scholarship of the Minister of Science and Higher Education and the Scholarship of the Marshal of the Pomeranian Voivodeship (2009-2023) [20].

Fig. 4. *Members of the Student Scientific Association of Animal Physiologists 'Oxygen' participate in national and international competitions and have won numerous awards and distinctions.*

Photo by Nataniel Stefanowski.

4. Field and Laboratory Research Projects. Students have been actively involved in applied research projects, including spawning ground studies of migratory trout and Atlantic salmon, DNA barcoding of fungi at the 4EU+ Summer School, and pharmacological analysis of plant extracts (e.g. The 'Student Scientific Associations Create Innovations' programme, *'Greater Celandine (Chelidonium majus L.) as a Source of Bioactive Substances for Pharmaceutical Use*' (registration number SKN/SP/571192/2023) and was co-financed by the Ministry of Education and Science for the period 2023-2024), which have been funded through national innovation programmes. These projects have enhanced their practical skills, critical thinking, teamwork and data interpretation capabilities [20].

On 22 September 2023, Tetiana Tiupova, Chair of SSA '*Oxygen*', successfully passed the national exam, obtaining the official qualifications of a mushroom classifier. Between 28 August and 3 September 2023, she participated in the intensive summer school course '*From Fungal Morphology to Genotype*', organised by the 4EU+ Alliance in the Stołowe Mountains National Park (Poland). Coordinated by the University of Warsaw in cooperation with Charles University in Prague and the University of Copenhagen, the programme gathered students from Poland, the Czech Republic, Denmark and Germany. During the course, 680 fungal occurrence records were deposited on the PlutoF platform and several DNA sequences of selected markers were obtained. Participants tested advanced molecular biology techniques in field conditions, including nanopore sequencing with MinION [19-21] (Fig. 5).

Fig. 5. *Members of the Student Scientific Association of Animal Physiologists 'Oxygen' participate in the intensive summer school course 'From Fungal Morphology to Genotype', organised by the 4EU+ Alliance in the Stołowe Mountains National Park (Poland).*
Photo by Tetiana Tiupova.

5. Public engagement and community education. On 16 June 2023, members of the Student Scientific Association of Animal Physiologists '*Oxygen*' took part in the outdoor event *'Empty Classroom Day'* (Polish: *'Dzień Pustej Klasy*'), organised by the Pomeranian Landscape Parks Team – Słupsk Branch in collaboration with the Słupia Valley Landscape Park and its partners: the Municipal Public Library, the Leśny Dwór Forest District, the "Królowa Marysieńka" apiary, and the Wdzydze Landscape Park [20]. As part of the initiative, the students prepared and conducted interactive workshops and demonstrations entitled "*What Was at Hand? – Experiments in a Home Laboratory*", engaging participants in simple yet creative scientific experiments (Fig. 6).

Fig. 6. *Members of the Student Scientific Association of Animal Physiologists 'Oxygen' took part in the outdoor event 'Empty Classroom Day' (Polish: 'Dzień Pustej Klasy'), organised by the Pomeranian Landscape Parks Team – Słupsk Branch in collaboration with the Słupia Valley Landscape Park and its partners.*

Photo by Natalia Kurhaluk.

Taken together, these findings demonstrate how the SSA '*Oxygen*' operates as an all-encompassing developmental platform, equipping biology students with a diverse range of competencies. The integration of practical tasks, collaborative learning and scientific communication within a student-led framework demonstrates the transformative potential of extracurricular scientific societies in higher education.

Mechanisms of student development within the scientific association 'Oxygen'. The Student Scientific Association of Animal Physiologists '*Oxygen*' at the Pomeranian University in Słupsk is a prime example of a dynamic, student-led scientific organisation. Since its establishment in 2006, the association has offered biology students the chance to broaden their academic interests and hone their technical, analytical and communication abilities through organised workshops, research projects and interdisciplinary collaborations. The group currently has 17 active members and operates under the supervision of Prof. Halina Tkaczenko and Prof. Natalia Kurhaluk, who are affiliated with the university's Departments of Zoology and Animal Physiology [20].

A cornerstone of the association's activities is its workshop and training programs, which bridge theoretical knowledge and practical application. These include specialized laboratory sessions on physiological and biochemical techniques (e.g., spectrophotometry and electrophoresis) and workshops on statistical analysis using software such as Statistica. Guest lectures by experts, such as Prof. Piotr Kamiński (Department of Medical Biology and Biochemistry, Division of Ecology and Environmental Protection, Collegium Medicum in Bydgoszcz, Nicolaus Copernicus University in Toruń, Bydgoszcz, Poland) and Prof. Anna Sieroslawska (Department of Animal

Physiology and Toxicology, Faculty of Medicine, The John Paul II Catholic University of Lublin, Lublin, Poland), expose students to cutting-edge methodologies, fostering curiosity and critical thinking [18]. These initiatives align with broader trends in STEM education emphasizing hands-on learning [38] (Table 2).

Members of the Student Scientific Association of Animal Physiologists '*Oxygen*' are involved in a wide range of research projects in biology, physiology and ecotoxicology. These include evaluating the pharmacological properties of tropical and subtropical plants, examining seasonal changes in haematological and biochemical parameters in recreational horses, and investigating the use of mute swan and white stork populations as bioindicators of environmental pollution. They also investigate the effectiveness of new-generation immunomodulators in salmonid fish and examine the relationship between iodine levels and the psychosocial well-being of inhabitants of the Pomeranian region. Additionally, they study oxidative stress markers in people with diabetes. The results of these projects have practical applications in medicine, veterinary science, aquaculture, environmental monitoring and health prevention for humans and animals alike [20].

For example, one ongoing project investigates the pharmacological properties of tropical and subtropical plant extracts in collaboration with botanical institutions in Ukraine, such as the Department of Tropical and Subtropical Plants at the M. M. Hryshko National Botanic Garden of the National Academy of Sciences of Ukraine in Kyiv and the Botanic Garden and Department of Botany at Ivan Franko National University in Lviv [20]. As part of this project, students analyse oxidative stress markers in animal tissues and human blood samples, thereby helping to identify natural antioxidants that could be used in medicine, veterinary science, and aquaculture.

Table 2

Research, training and outreach activities conducted by the Student Scientific Association of Animal Physiologists 'Oxygen'

Type of activity	Example(s)	Competencies developed
Workshops and Training	Laboratory workshops in physiology and biochemistry; sessions on statistics and scientific writing; guest lectures by faculty and invited experts.	Technical laboratory skills, scientific methodology, analytical thinking, academic writing.
Research Projects	Studies on oxidative stress and antioxidant activity; analysis of pharmacological properties of tropical and subtropical plant extracts (collaboration with NAS of Ukraine); monitoring of seasonal haematological and biochemical changes in horses (collaboration with Strzelinko stable).	Research design, data collection and analysis, fieldwork skills, collaboration, and problem-solving.

Type of activity	Example(s)	Competencies developed
Seminars and Conferences	Internal seminars; organization of student conferences; participation in national and international conferences; co-authoring peer-reviewed publications.	Communication, presentation skills, academic discourse, confidence, networking.
Peer Mentoring	Experienced members guide newcomers in laboratory protocols, experimental design, and scientific discussions.	Teamwork, mentoring, knowledge transfer, and leadership.
Organisational Roles	Chair, Vice-Chair, Secretary; coordination of events, resource management, and external collaboration.	Leadership, strategic thinking, project management, and administrative skills.
Outreach and Public Engagement	Field trips, scientific camps, public lectures, and community engagement activities.	Science communication, public engagement, interdisciplinary collaboration, and social responsibility.

Another notable research initiative involves analysing the seasonal changes in the haematological and biochemical parameters of recreational horses. This study is conducted in partnership with the '*Pod Żelazną Podkową*' stable in Strzelinko. Students monitor oxidative stress biomarkers and physical adaptation in horses undergoing training, gaining experience in fieldwork, sample processing, and interpreting physiological data [20]. Such projects enable students to apply their theoretical knowledge to real-world contexts, thereby strengthening their research and technical skills (Fig. 7A).

Members of the Student Scientific Association of Animal Physiologists '*Oxygen*' studied the populations of mute swans (*Cygnus olor*) and white storks (*Ciconia ciconia*) to evaluate the effects of human-caused pollution in various regions of Poland. The results revealed that the two species exhibited distinct physiological responses to environmental stressors, including heavy metal accumulation and increased levels of oxidative stress markers [20]. These results demonstrate the potential of both species to serve as reliable bioindicators for monitoring ecosystem health (Fig. 7B).

A

B

C

D

Fig. 7. *Members of the Student Scientific Association of Animal Physiologists 'Oxygen' participate in various scientific initiatives.*

Photo by Natalia Kurhaluk.

Members of the Student Scientific Association of Animal Physiologists '*Oxygen*' assessed the correlation between body iodine levels and psychological-emotional state across different age groups in Pomerania (Figs 7C, 7D). The results showed that adequate iodine intake significantly reduces anxiety and depressive symptoms, although the effect varies depending on age and sex. Conversely, iodine deficiency may contribute to thyroid dysfunction and emotional disturbances [20]. These results highlight the importance of monitoring iodine intake to promote mental well-being and cognitive function in children, adolescents, and older adults.

To disseminate research findings and foster scientific dialogue, SSA '*Oxygen*' regularly organises seminars and student conferences (Fig. 8). These events provide a platform for members to present their work, receive feedback, and interact with peers from other academic centres. Participation in national and international conferences is actively encouraged, and students often co-author publications in peer-reviewed journals [20]. This emphasis on communication and dissemination helps students to refine their presentation skills and build confidence in academic discourse.

A key feature of the SSA's '*Oxygen*' programme is its commitment to peer mentoring. Experienced members support newcomers by sharing practical tips, demonstrating laboratory techniques, and guiding them through research protocols. This informal mentorship accelerates skill acquisition and fosters a collaborative culture. It also prepares students for future roles in academia or industry, where teamwork and knowledge transfer are vital [6].

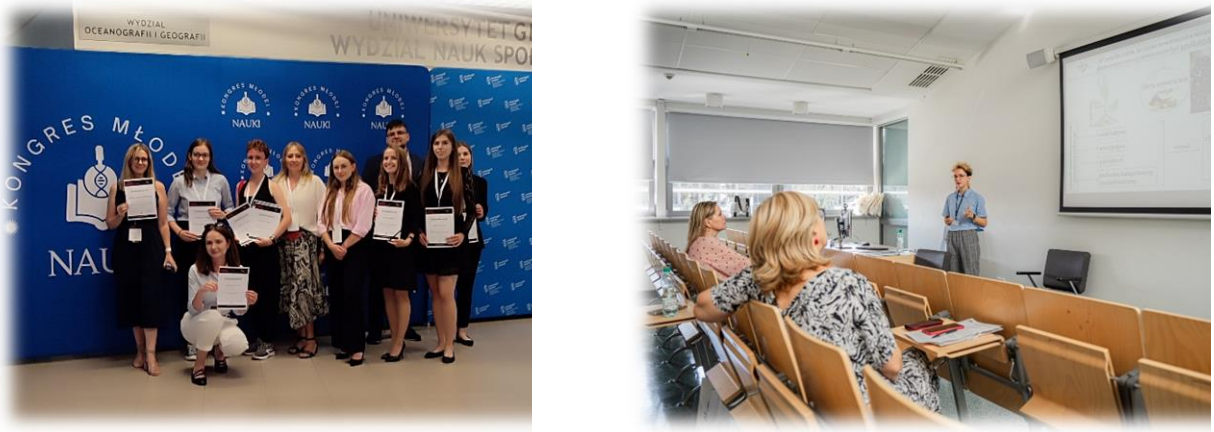


Fig. 8. *Members of the Student Scientific Association of Animal Physiologists 'Oxygen' participate in various scientific conferences.*

Photo by Tetiana Tiupova.

In addition to scientific activities, students are encouraged to take on organisational roles within the association. Responsibilities related to event planning, resource management, and coordination with faculty and external partners are involved in positions such as Chair (currently held by Tetiana Tiupova), Vice-Chair (Anna Litovka), and Secretary [20]. Taking on these roles helps students to develop invaluable leadership, strategic thinking, and administrative competencies in both academic and professional settings [6].

The SSA '*Oxygen*' mission encompasses not only individual development, but also broader objectives such as enhancing the university's visibility, fostering international collaboration, and contributing to public science education. Activities such as field trips, scientific camps, and public lectures disseminate scientific knowledge and engage the wider community [20]. Through these initiatives, the SSA '*Oxygen*' programme nurtures future scientists and strengthens the role of science in society [6].

In summary, the developmental mechanisms embedded in the structure of SSA '*Oxygen*' – including hands-on research, peer mentoring, leadership, and outreach – create a rich, integrative learning environment. The combination of formal supervision and student autonomy enables members to develop both disciplinary expertise and transferable skills, setting them up for success in a variety of careers in biology.

Challenges and limitations in developing the Student Scientific Association 'Oxygen'. Despite its dynamic and interdisciplinary nature, the Student Scientific Association of Animal Physiologists '*Oxygen*', which operates at the Institute of Biology and Natural Sciences at the Pomeranian University in Słupsk, faces several challenges that could restrict its full developmental

potential. These obstacles are not unique to the SSA, but reflect broader structural and organisational issues common to many student scientific associations within higher education institutions [1].

One of the most persistent challenges is limited funding and access to resources, which restricts the scope of experimental work and opportunities for external engagement [37]. While SSA '*Oxygen*' has successfully initiated ambitious research projects, such as evaluating the antioxidant properties of tropical and subtropical plant extracts in collaboration with Ukrainian botanical institutions, the financial burden of laboratory reagents, specialised equipment, and travel to national or international conferences often exceeds the association's budget. This can hinder the continuity of long-term studies and reduce the visibility of student research on broader academic platforms (Table 3). Although the university provides basic infrastructure, there is no dedicated budget line for student research associations, which restricts strategic planning and scalability.

Table 3.

Key challenges faced by the Student Scientific Association of Animal Physiologists 'Oxygen' and potential solutions

Challenge	Description	Potential solutions
Limited funding and resources	Insufficient budget for reagents, specialised equipment, and conference participation; limits long-term projects.	Dedicated university funding streams, external grants, and partnerships with research institutions.
Time management	Students must balance coursework, lab duties, and SSA commitments, which leads to uneven participation and project delays.	Flexible scheduling, integration of SSA work into curricula, and recognition of participation with credits.
Diverse skill levels	The group includes both novice and experienced students; disparities in competence may affect project cohesion.	Structured onboarding programmes, peer mentoring, and stepwise training modules.
Organisational continuity	Frequent turnover due to graduation or mobility; risk of losing institutional memory and delaying ongoing research.	Documentation of projects, succession planning, and faculty-supported archiving of association activities.
Ambitious scope of projects	Complex, interdisciplinary research (e.g., ecophysiology, immunomodulation) requires high expertise and coordination.	Stronger faculty mentorship, cross-departmental collaborations, and phased project planning.

Another significant issue is time management, as students must balance their demanding coursework and laboratory obligations with their voluntary participation in the association's activities [2; 15]. Although being involved in SSA '*Oxygen*' is highly enriching, it requires a significant time and energy commitment. Students often find it challenging to maintain consistent engagement, particularly during exam periods or when undertaking intensive academic modules.

The tension between formal academic responsibilities and extracurricular scientific work can result in inconsistent participation and delayed project execution [9; 29; 30].

The diversity of students' backgrounds and skill levels also poses a pedagogical challenge. The SSA '*Oxygen*' includes both undergraduate and master's students, some of whom have prior laboratory experience, while others are encountering scientific research for the first time. This variability means that some students progress rapidly, while others require more guidance and support. While the association fosters peer mentoring, where experienced members assist newcomers in mastering techniques and understanding protocols, there is still a need for structured scaffolding. Without adequate onboarding and training, disparities in competence development may emerge, which could affect group cohesion and project outcomes [12; 42].

Another concern relates to organisational continuity and institutional memory. As a student-led association, SSA '*Oxygen*' experiences regular turnover of members due to graduation, academic mobility, or changes in personal priorities. Although the current leadership has maintained a stable and proactive structure, the departure of key members can disrupt ongoing research, delay administrative processes, and result in the loss of accumulated knowledge [11; 23].

These challenges are further compounded by the ambitious scope of SSA '*Oxygen*'s' scientific agenda. Projects such as the seasonal analysis of oxidative stress markers in recreational horses, the ecophysiological monitoring of mute swans and white storks in polluted environments and immunomodulation studies in aquaculture require technical expertise, logistical coordination and interdisciplinary collaboration. Managing this level of complexity within a student framework requires substantial support from faculty supervisors and institutional structures [50; 52].

Nevertheless, the resilience and adaptability of SSA '*Oxygen*' members have enabled the association to overcome these challenges with creativity and determination. Through strategic partnerships, mentorship programmes, and a strong sense of community, the SSA '*Oxygen*' continues to fulfil its mission of expanding biological knowledge and empowering student researchers. Providing targeted institutional support, such as dedicated funding streams, formalised training modules, and knowledge transfer mechanisms, could significantly enhance the sustainability and effectiveness of student scientific associations like SSA '*Oxygen*'.

Discussion. The findings of this study confirm that Student Scientific Associations, such as the SSA of Animal Physiologists ‘*Oxygen*’ at the Pomeranian University in Słupsk, play a vital supplementary role in helping biology students develop a broad range of competencies alongside formal coursework. While traditional academic programmes provide the necessary theoretical foundations, they often lack the flexibility and depth required to cultivate practical skills, scientific autonomy, and interdisciplinary thinking [36]. In this context, SSA '*Oxygen*' provides a dynamic educational environment where students can engage in active research, collaborate with peers, and

interact with academic mentors. This model reflects the principles of experiential learning and constructivist pedagogy, which are increasingly recognised as essential in STEM education [3].

One of the most impactful aspects of SSA '*Oxygen*'s' activities is the hands-on nature of its laboratory work. Students participate in real experimental setups, such as *in vitro* studies on oxidative stress markers using extracts from tropical and subtropical plants. These projects are conducted in collaboration with botanical institutions in Ukraine, including the M. M. Hryshko National Botanic Garden and Ivan Franko National University in Lviv. Such international partnerships not only enhance scientific quality but also expose students to cross-cultural research environments (National Academy of Sciences of Ukraine). These projects enable students to master physiological measurement techniques, biochemical assays, and data analysis procedures – skills which are often only superficially covered in lecture-based formats. Working with live biological material and advanced laboratory equipment significantly enhances students' technical proficiency and confidence [10; 33].

These features closely align with existing literature on biology education, which emphasises the importance of experiential learning, collaborative environments, and student agency [22; 52]. The SSA's interdisciplinary projects, which range from the ecophysiological monitoring of mute swans and white storks to immunomodulation studies in aquaculture, demonstrate how SSAs can serve as incubators for innovative, socially relevant research. Furthermore, the association's outreach activities, such as workshops, field trips, and public lectures, promote science communication and community engagement. These initiatives reflect the "third mission" of universities – engaging with society and disseminating knowledge beyond academia [34; 45].

However, to sustain and amplify these benefits, several challenges must be addressed. Limited funding remains a significant barrier, restricting access to advanced equipment and limiting participation in external conferences [37]. Time constraints, arising from the need to balance coursework with voluntary SSA involvement, can result in inconsistent engagement and project delays [2; 15]. Additionally, variability in student backgrounds necessitates structured onboarding and training to ensure equitable skill development [12; 42]. Regular membership turnover also poses risks to institutional memory and long-term project sustainability [11; 23].

To mitigate these challenges, it is crucial to integrate SSA-type activities into academic curricula formally. Recognising student participation through academic credit or certification would validate their efforts and encourage broader involvement [1]. Institutional support in the form of dedicated funding, administrative assistance, and faculty engagement could stabilise resources further and enhance the association's impact. Embedding SSA activities into the formal educational framework would also align with global trends in higher education, which advocate for sustainability, innovation, and student-centred learning [1].

In conclusion, the case of SSA 'Oxygen' demonstrates the transformative potential of student scientific associations in higher education. By fostering autonomy, collaboration, and scientific enquiry, SSAs enrich the academic experience and empower students to become active contributors to the scientific community [16; 47]. The continued development and integration of SSAs into institutional structures represents a promising direction for biology education in the 21st century [46; 47].

Conclusion. The Student Scientific Association of Animal Physiologists 'Oxygen', which operates within the Institute of Biology at the Pomeranian University in Słupsk, is a prime example of how student-led initiatives can enhance academic training. Founded in 2006, the association has consistently fulfilled its mission of expanding biological knowledge and engaging students in research. Under the supervision of Prof. Halina Tkaczenko and Prof. Natalia Kurhaluk, the association has become a dynamic community that effectively links theory with practice. Importantly, its activities are embedded in the university's strategy to develop students' research competencies.

Participation in SSA 'Oxygen' significantly broadens students' competencies. Members gain hands-on experience in experimental design, physiological and biochemical analysis, and data interpretation. For instance, projects investigating oxidative stress markers using tropical and subtropical plant extracts, carried out in partnership with Ukrainian botanical institutions, provide technical training alongside exposure to international standards and interdisciplinary approaches. This demonstrates how the association promotes cross-border research cooperation and laboratory skills.

Equally valuable are projects such as the seasonal haematological profiling of recreational horses and the ecophysiological monitoring of mute swans and white storks in polluted habitats. Such studies encourage critical thinking, hypothesis formulation, and problem-solving, while teaching students to link theoretical knowledge with empirical results. Such work fosters intellectual independence and resilience in research practice.

Beyond scientific skills, SSA 'Oxygen' also develops communication, teamwork, and leadership skills. Students present their findings at university seminars, national conferences, and international conferences, and the association's structure enables them to get involved in organising events and peer mentoring. This integration of scientific, social, and organisational competencies prepares members for professional roles in research, education, and environmental management.

To maximise the impact of SSAs such as 'Oxygen', universities should provide stable institutional support, including funding, access to facilities, and consistent faculty mentorship. Formal recognition of SSA activities, such as academic credit or certificates, would validate student achievements, while structured mentorship systems could ease the transition for newcomers.

Encouraging participation from the earliest stages of study strengthens long-term engagement and the gradual development of competence.

Future research could compare SSAs across institutions to identify factors contributing to success and challenges encountered. Using validated tools to measure competence gains and conducting longitudinal studies on graduates' careers would provide evidence of the broader educational and professional benefits of SSAs.

In conclusion, 'Oxygen' exemplifies the transformative role of SSAs in higher education. By integrating research, mentorship, and dissemination within a student-centered framework, such associations prepare young scientists to contribute to academic and social progress actively. The continued development of SSAs and their stronger integration into academic structures represent a promising way to enhance the quality and relevance of biology education.

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РОЛЬ СТУДЕНТСЬКИХ НАУКОВИХ ГУРТКІВ У ФОРМУВАННІ КОМПЕТЕНТНОСТЕЙ СЕРЕД СТУДЕНТІВ-БІОЛОГІВ: НА ПРИКЛАДІ СТУДЕНТСЬКОГО НАУКОВОГО ГУРТКА ФІЗІОЛОГІВ ТВАРИН «*OXYGEN*» (ПОЛЬЩА)

Анотація. *В статті представлено освітню та розвиваючу роль студентських наукових гуртків (СНГ) у біологічній освіті, підкреслюючи їхній потенціал як додаткового середовища навчання у закладах вищої освіти. Як приклад розглядається Студентський науковий гурток фізіологів тварин «Oxygen», яке функціонує в Інституті Біології при Поморському університеті в Слупську (Польща). На основі якісних даних, отриманих з інтерв'ю, спостережень та аналізу документів, дослідження показує, що участь у СНГ «Oxygen» значно покращує різноманітні компетентності, зокрема методологію досліджень, технічні лабораторні навички, аналіз даних, критичне мислення, комунікацію, командну роботу, лідерство та впевненість у власних силах. Особливо важливо, що СНГ «Oxygen» надає студентам можливість пройти весь дослідницький процес – від розробки експериментів до інтерпретації результатів і презентації висновків у академічному середовищі.*

Міждисциплінарні проєкти, які реалізує СНГ «Oxygen», такі як дослідження оксидативного стресу, екофізіологічний моніторинг популяцій диких птахів та фармакологічна оцінка рослинних екстрактів, знайомлять студентів із реальними науковими викликами, розвиваючи їхню здатність застосовувати теоретичні знання на практиці. Ці активності часто здійснюються у співпраці з зовнішніми установами, що розширює академічну перспективу та сприяє міжнародній співпраці. Студенти також презентують свої результати на місцевих, національних та міжнародних семінарах і конференціях, зміцнюючи свою академічну ідентичність і готуючись до майбутніх професійних ролей у сфері досліджень, освіти та охорони довкілля.

Результати підкреслюють важливість наставництва, навчання серед однолітків, автономії та організаційної участі як ключових елементів розвитку компетентності. Водночас у статті окреслено низку викликів, зокрема обмежене фінансування, нестачу інфраструктури, часові обмеження та зміну складу учасників, що може перешкоджати безперервності та ефективності діяльності. Подолання цих бар'єрів потребує посиленого інституційного супроводу та стратегічної

інтеграції діяльності СНГ у навчальні програми університетів. За умови належної підтримки СНГ можуть відігравати трансформаційну роль у вищій освіті, долаючи розрив між теорією і практикою. Формальне визнання їхніх досягнень, разом із забезпеченням стабільних ресурсів і наставництва, здатне максимізувати їхній освітній вплив. Це надає студентам цінні наукові навички, а також впевненість, стійкість і довгострокові професійні переваги.

Ключові слова: *студентські наукові гуртки; біологічна освіта; навчання через досвід; дослідницькі компетентності; міждисциплінарні проєкти; наставництво; академічний розвиток*

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