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Fostering scientific inquiry and STEM skills in higher education: A Ukrainian case study

Dmytro V. Lubko

Dmytro Motornyi Tavria State Agrotechnological University,
66 Universytetska Str., Zaporizhzhia, 69063, Ukraina

Abstract. This paper presents a case study of the scientific activities and STEM education initiatives implemented at the Department of Computer Sciences at Dmytro Motornyi Tavria State Agrotechnological University in Ukraine. The study examines how engaging students in research projects, scientific circles, and STEM-focused curricula can enhance their acquisition of technical skills, problem-solving abilities, and overall academic performance. Findings suggest that participation in these activities fosters a sense of responsibility, creativity, and teamwork among students while preparing them for successful careers in their chosen fields. The paper discusses the key components of the department's approach, including intelligent systems projects, robotics workshops, and industry collaborations, as well as the challenges and opportunities encountered in the implementation process. Recommendations are provided for adapting and scaling similar initiatives in other higher education contexts. The study underscores the importance of integrating scientific inquiry and STEM education into the undergraduate experience to cultivate a new generation of skilled and innovative professionals.

Keywords: higher education, research activities, STEM education, curriculum innovation, skills development

1. Introduction

In an increasingly competitive and globalised higher education landscape, institutions are seeking innovative strategies to enhance student learning outcomes, boost graduate employability, and contribute to societal progress [6, 30]. One promising approach is to integrate scientific research activities and STEM (science, technology, engineering, and mathematics) education into the undergraduate curriculum [9, 13]. By engaging students in authentic inquiry, problem-solving, and hands-on experimentation, these initiatives aim to cultivate not only technical skills but also critical thinking, creativity, and collaboration [2, 36].

However, implementing effective research and STEM programs at the undergraduate level presents various challenges, such as limited resources, competing academic priorities, and student preparedness [8, 35]. Moreover, there is a need for context-specific studies that examine how these initiatives unfold in diverse higher education settings, particularly in developing countries and emerging economies [19, 23].

To address these gaps, this paper presents a case study of the scientific activities and STEM education initiatives implemented at the Department of Computer Sciences at Dmytro Motornyi Tavria State Agrotechnological University (TSATU) in Ukraine. As a leading agricultural university in the region, TSATU has sought to integrate research and innovation into its educational mission, with a focus on preparing students for the demands of the 21st-century workforce [12]. The Department of Computer Sciences has been at the forefront of these efforts, experimenting with various strategies to

0000-0002-2506-4145 (D. V. Lubko)
di75ma@gmail.com (D. V. Lubko)
http://www.tsatu.edu.ua/enf/pro-fakultet/kerivnyctvo/lubko/ (D. V. Lubko)

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engage students in scientific inquiry and STEM learning.

The study aims to:

1. Describe the key components and activities of the department's research and STEM initiatives
2. Examine the impact of these initiatives on student skills, knowledge, and academic performance
3. Identify the challenges and success factors in implementing undergraduate research and STEM programs
4. Provide recommendations for adapting and scaling similar initiatives in other higher education contexts

2. Literature review

The integration of scientific research and STEM education into undergraduate curricula has gained increasing attention in recent years, as higher education institutions seek to prepare students for the complex challenges of the 21st century [9, 13].

Engaging undergraduate students in authentic research experiences has been shown to yield numerous benefits for their academic, personal, and professional development [21, 26]. Participation in research projects can enhance students' understanding of scientific concepts, develop their analytical and problem-solving skills, and foster a sense of ownership and responsibility for their learning [18, 33]. Research experiences also provide opportunities for students to collaborate with faculty mentors and peers, building their communication and teamwork abilities [11, 27].

Moreover, undergraduate research has been linked to increased retention and graduation rates, particularly among underrepresented minority students [3, 32]. Students who engage in research are more likely to pursue graduate studies and careers in STEM fields, contributing to the diversity and talent pipeline in these important areas [20, 28].

Despite the many benefits of undergraduate research, implementing effective programs presents various challenges for higher education institutions [5, 29]. One key issue is the availability of resources, including funding, facilities, and faculty time, to support meaningful research experiences for a large number of students [22, 25]. Institutions must also navigate the competing demands of research and teaching, ensuring that faculty are adequately recognized and rewarded for their mentorship efforts [24, 34].

To address these challenges, the literature highlights several best practices for designing and implementing undergraduate research programs [10, 16]. These include:

- providing structured training and guidance for both students and faculty mentors;
- aligning research projects with students' interests and career goals;
- offering a range of research opportunities, from course-based projects to summer internships;
- fostering a collaborative and inclusive research culture that values diversity and interdisciplinarity;
- integrating research experiences into the broader curriculum and co-curricular activities;
- assessing and evaluating the impact of research programs on student learning and success.

In recent years, STEM education has become a cornerstone for universities striving to prepare students for the tech-driven and scientifically complex workforce of today [13, 37]. Beyond offering research opportunities, institutions are placing greater emphasis on innovative teaching to meet these needs. Yet, keeping students—particularly those from underrepresented groups—engaged and enrolled in STEM fields remains a tough nut to crack [14, 15]. So, what can be done to make STEM more inviting and effective? Researchers suggest a handful of promising approaches. For starters, active and problem-based learning can shake things up by swapping lectures for real-world challenges that get students involved. Hands-on projects, like running experiments, designing prototypes, or coding, bring abstract ideas into focus. Educational tools such as simulations, virtual labs, and online platforms can stretch learning beyond the classroom and clarify tricky concepts. Offering early research experiences and internships gives students a confidence boost and a taste of what STEM careers entail. Inclusive teaching methods, tailored to diverse learners, help break down barriers and make everyone feel welcome. And partnering with industry, government, or community groups ties it all together by connecting coursework to real-world opportunities. By blending these evidence-based strategies into their programs, universities can create STEM experiences that spark curiosity, build skills, and set students up for success in their chosen paths [17, 31]. It's about crafting an environment where learning thrives and every student gets a fair shot.

While the literature on undergraduate research and STEM education is growing, there is a need for more context-specific studies that examine how these initiatives are implemented in diverse higher education settings [19, 23]. Case studies from different countries and regions can provide valuable insights into the challenges, adaptations, and innovations that emerge in response to local needs and constraints.

For example, a study of undergraduate research programs in South Africa highlighted the importance of building institutional capacity and support structures to sustain these initiatives in resource-limited contexts [1]. Another case study from Malaysia described the development of a community-based STEM education model that leveraged local knowledge and partnerships to engage students in authentic problem-solving [7].

These international perspectives underscore the need for contextually sensitive approaches to undergraduate research and STEM education that take into account the unique strengths, challenges, and aspirations of different higher education systems. By learning from these diverse experiences, institutions can adapt and innovate their own programs to better serve their students and communities.

3. Methodology

This case study employs a qualitative research design to examine the scientific activities and STEM education initiatives implemented at the Department of Computer Sciences at Dmytro Motornyi Tavria State Agrotechnological University (TSATU) in Ukraine. The study aims to provide an in-depth and contextualised understanding of how these initiatives are designed, implemented, and experienced by students and faculty members.

3.1. Data collection

Data for the study were collected through multiple methods, including:

- Relevant documents, such as program descriptions, course syllabi, student projects, and university policies, were reviewed to gain insights into the goals, structure, and content of the department's research and STEM initiatives.
- Semi-structured interviews were conducted with a purposive sample of 15 faculty members and 20 students involved in the department's research and STEM programs. The interviews explored participants' experiences, perceptions, and

reflections on the initiatives, as well as the challenges and benefits they encountered.
- The researcher conducted non-participant observations of selected research and STEM activities, such as lab sessions, project presentations, and scientific circle meetings. Field notes were taken to document the interactions, practices, and dynamics observed in these settings.

The data collection process was guided by ethical principles, including informed consent, confidentiality, and respect for participants' rights and well-being. The study received approval from the university's research ethics committee.

3.2. Data analysis

The data were analysed using a thematic approach [4], which involved iterative cycles of coding, categorisation, and interpretation. Interview transcripts, field notes, and documents were first read and re-read to gain familiarity with the data. Initial codes were generated to capture key ideas and patterns, which were then grouped into broader themes and sub-themes based on their similarities and relationships.

The analysis was guided by the research questions and informed by the literature on undergraduate research and STEM education. Themes were refined and elaborated through constant comparison and negative case analysis, seeking to capture the diversity and complexity of participants' experiences and perspectives.

To enhance the trustworthiness of the findings, several strategies were employed, such as triangulation of data sources and methods, member checking with participants, and peer debriefing with colleagues. The researcher also maintained a reflexive journal to document the analytical process and monitor potential biases and assumptions.

4. Findings

The analysis of the data revealed several key themes related to the design, implementation, and impact of the scientific activities and STEM education initiatives at the Department of Computer Sciences at TSATU.

4.1. Program components and activities

The department's research and STEM initiatives comprise a range of curricular and co-curricular components that engage students in scientific inquiry, problem-solving, and hands-on learning. These include:

1. Research projects

Undergraduate students have opportunities to participate in faculty-led research projects in areas such as intelligent systems, robotics, artificial intelligence, and software engineering. These projects typically involve small teams of students working on specific tasks or modules, with guidance and mentorship from faculty members and graduate students. Some projects are integrated into coursework, while others are extracurricular or summer internships.

One example is the "Intelligent Greenhouse" project, where students develop sensors, actuators, and control systems to optimise plant growth and resource efficiency. Another project involves creating educational robotics kits and tutorials for secondary school students, as part of the department's outreach and community engagement efforts.

2. Scientific circles

The department hosts several scientific circles or clubs that bring together students and faculty with shared interests in specific topics or technologies. These circles meet regularly to discuss recent developments, work on group projects, and organise events such as hackathons, workshops, and guest lectures.

The "Intelligent Systems" circle, for instance, focuses on developing applications and expert systems for various domains, using machine learning and natural language processing techniques. The "School of Robotics" circle, on the other hand, engages students in designing, building, and programming robots for tasks such as navigation, manipulation, and interaction.

Participation in scientific circles is voluntary but encouraged, as it provides students with opportunities to deepen their knowledge, skills, and networks in their chosen fields. Faculty members serve as mentors and facilitate the activities, but students take an active role in shaping the agenda and projects of the circles.

3. STEM courses and modules

The department has also integrated STEM content and pedagogy into its regular curriculum, through both standalone courses and embedded modules. For example, the "Introduction to Robotics" course covers the fundamentals of robot design, control, and programming, using hands-on labs and projects. The "Data Structures and Algorithms" course includes modules on computational thinking and problem-solving, using real-world datasets and applications.

Other courses, such as "Software Engineering" and "Database Management Systems", incorporate STEM elements through case studies, design projects, and industry collaborations. Students have opportunities to work on authentic problems and develop solutions using cutting-edge tools and technologies.

4. STEM outreach and engagement

The department also organises various outreach and engagement activities to promote STEM education and careers among secondary school students and the wider community. These include:

- robotics workshops and competitions for secondary school students, where participants learn to build and program robots using Arduino kits and other tools;
- public lectures and demonstrations on topics such as artificial intelligence, cybersecurity, and digital innovation, to raise awareness and interest in STEM fields;
- collaboration with local industry partners to provide internships, mentorship, and career guidance for undergraduate students in STEM majors.

These outreach activities not only serve to attract and inspire future STEM students, but also provide opportunities for current undergraduates to develop their communication, leadership, and mentoring skills.

Figure 1 presents the results of a survey of 50 undergraduate students who participated in the department's research and STEM programs. The survey asked students to rate their level of agreement with statements about the impact of these programs on their technical skills, problem-solving abilities, collaboration and communication, and motivation and engagement in their studies.

As the figure shows, a large majority of students (70-85%) strongly agreed or agreed that participating in research and STEM activities enhanced their skills and experiences in all four areas. Particularly high levels of agreement were found for the

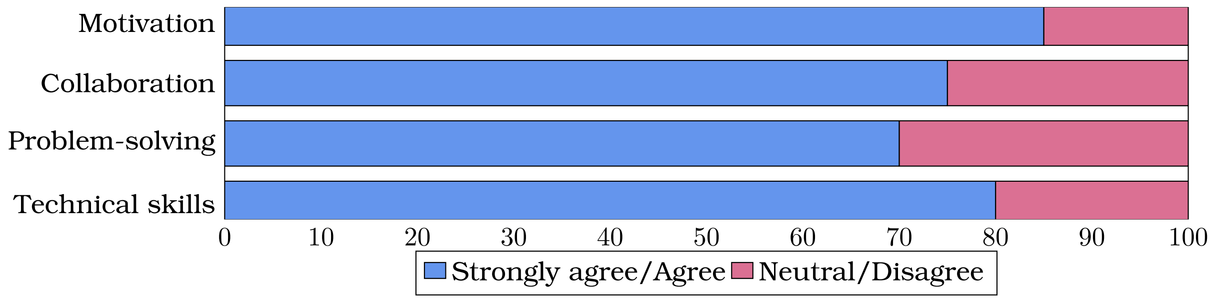

Figure 1: Student perceptions of the impact of research and STEM programs on their skills and experiences (*n*=50).

impact on technical skills (80%) and motivation (85%), suggesting that these programs are effective in developing students' expertise and confidence in their fields.

However, the figure also reveals some variation in students' perceptions, with a minority of students (15-30%) expressing neutral or negative views about the impact of the programs. This suggests that there may be opportunities to further improve and tailor the programs to meet the needs and interests of all students.

Overall, the survey results provide strong evidence of the positive impact of the department's research and STEM initiatives on student learning and development, while also highlighting the importance of continuous evaluation and improvement based on student feedback and outcomes.

4.2. Student outcomes and experiences

The study explored the impact of the department's research and STEM initiatives on student learning, skills, and experiences. Participants reported several positive outcomes, such as:

1. Enhanced technical skills

Students who participated in research projects and scientific circles described gaining hands-on experience with a range of tools, technologies, and techniques relevant to their fields. For example, one student shared:

> Working on the intelligent greenhouse project, I learned how to use sensors, microcontrollers, and data analytics to monitor and control environmental parameters. It was challenging but also rewarding to see our system work in real-time.

Another student highlighted the value of learning programming languages and frameworks through project-based work:

> In the robotics circle, we used Python and ROS [Robot Operating System] to program the robots for different tasks. I had some experience with Python before, but ROS was new to me. It was great to learn it in a hands-on way, with the support of my peers and mentors.

These experiences suggest that the department's initiatives provide students with authentic opportunities to develop and apply technical skills in real-world contexts.

2. Improved problem-solving and critical thinking

Participants also reported that engaging in research and STEM activities helped them develop their problem-solving and critical thinking abilities. For instance, one student described how working on a software development project taught them to break down complex problems into manageable parts:

> At first, the project seemed overwhelming, as we had to create a web application from scratch. But our mentor taught us to divide the work into smaller modules and tasks, and to test and debug our code regularly. Over time, I learned to approach problems more systematically and to think critically about different solutions.

Another student shared how participating in a scientific circle exposed them to different perspectives and ideas:

> In our discussions and projects, we often had to consider multiple viewpoints and evaluate the strengths and weaknesses of different approaches. It helped me develop my critical thinking skills and be more open to feedback and suggestions from others.

These examples highlight the role of research and STEM activities in fostering students' higher-order thinking skills, which are essential for success in both academic and professional settings.

3. Enhanced collaboration and communication

Participants also highlighted the benefits of the department's initiatives for their collaboration and communication skills. Many of the research projects and scientific circles involved teamwork and group discussions, which provided opportunities for students to learn from and with each other. As one student noted:

> Working in a team on the robotics project was challenging at first, as we had different backgrounds and ideas. But over time, we learned to communicate better, divide tasks based on our strengths, and give constructive feedback. It was a valuable experience that prepared me for working with others in my future career.

Another student shared how presenting their research at a conference helped them develop their public speaking and networking skills:

> I was nervous about presenting my work to a large audience, but my mentor helped me prepare and practice. At the conference, I got to meet other researchers and learn about their projects. It was a great opportunity to build my confidence and make connections in my field.

These experiences suggest that the department's initiatives foster a collaborative and supportive learning environment that helps students develop important interpersonal and communication skills.

4. Increased motivation and engagement

Many participants also reported that participating in research and STEM activities increased their motivation and engagement in their studies. For example, one student shared:

> Before joining the intelligent systems circle, I was struggling with some of my courses and wasn't sure if I wanted to continue in computer science. But working on real projects and seeing the applications of what I was learning made me more interested and motivated. It gave me a sense of purpose and direction.

Another student described how conducting research with a faculty mentor inspired them to pursue graduate studies:

> My research experience showed me the excitement and challenges of working on cutting-edge problems. It also gave me a closer relationship with my mentor, who encouraged me to apply for graduate programs. I'm now planning to pursue a master's degree and possibly a PhD in the future.

These examples highlight the potential of research and STEM initiatives to ignite students' passion for their fields and encourage them to persist and excel in their studies.

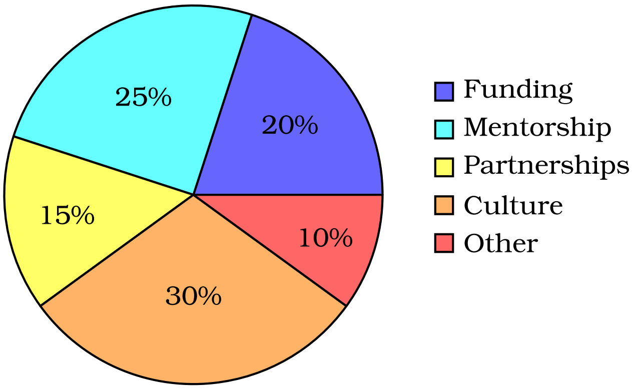

Figure 2: Key success factors for undergraduate research and STEM programs identified by faculty members (*n*=20).

Figure 2 presents the results of interviews with 20 faculty members involved in the department's research and STEM programs. The interviews asked faculty to identify the key factors that contribute to the success and sustainability of these initiatives.

As the pie chart shows, faculty identified several critical success factors, with the most frequently mentioned being a supportive and collaborative culture (30%), effective mentorship and training (25%), and strategic partnerships and resources (15%). Other factors, such as adequate funding (20%) and other elements (10%), were also mentioned but less frequently.

These findings suggest that building a successful undergraduate research and STEM program requires a holistic and multi-faceted approach that attends to both the structural and cultural dimensions of the initiative. While funding and resources are certainly important, faculty emphasized the crucial role of creating a shared vision and values, fostering strong relationships and networks, and providing guidance and support for students and colleagues.

The figure also highlights the diversity of perspectives and priorities among faculty members, underscoring the need for inclusive and participatory approaches to designing and implementing research and STEM programs. By engaging all stakeholders and leveraging their unique strengths and insights, institutions can create more robust and sustainable initiatives that benefit everyone involved.

4.3. Challenges and success factors

While the department's initiatives have yielded many positive outcomes, participants also identified several challenges and success factors in implementing and sustaining these programs. Some of the key challenges included:

- limited resources and funding to support student research and projects;

- balancing the demands of research and teaching for faculty members;
- ensuring equal access and participation for all students, particularly those from underrepresented groups;
- navigating the logistical and administrative requirements of partnerships and outreach activities.

Despite these challenges, participants also highlighted several factors that contributed to the success and sustainability of the initiatives, such as:

- strong leadership and vision from the department head and senior faculty members;
- a culture of collaboration and mentorship among faculty and students;
- flexibility and adaptability in designing and implementing programs to meet students' needs and interests;
- leveraging external partnerships and resources, such as industry collaborations and grant funding;
- regular evaluation and improvement of programs based on feedback and outcomes.

These factors suggest that building a supportive and innovative ecosystem for undergraduate research and STEM education requires a holistic and strategic approach that engages all stakeholders and adapts to changing needs and opportunities.

4.4. Recommendations for practice

Based on the findings of this case study, several recommendations can be offered for higher education institutions seeking to develop or enhance their undergraduate research and STEM programs:

1. Integrate research and STEM experiences into the curriculum, through course-based projects, modules, and internships that align with students' interests and career goals.
2. Provide structured training and mentorship for both faculty and students involved in research and STEM activities, to ensure quality and consistency of experiences.
3. Foster a collaborative and inclusive culture that values diversity, creativity, and experimentation, and provides opportunities for students to learn from and with each other.
4. Leverage partnerships and resources from industry, government, and community organizations to provide authentic and relevant research and STEM experiences for students.
5. Regularly evaluate and assess the impact and effectiveness of research and STEM programs, using multiple measures and sources of data, and use the findings to inform continuous improvement.

5. Discussion

The findings of this case study provide valuable insights into the design, implementation, and impact of undergraduate research and STEM education initiatives in the context of a Ukrainian university. The Department of Computer Sciences at TSATU has developed a range of curricular and co-curricular programs that engage students in authentic scientific inquiry, problem-solving, and hands-on learning experiences. These initiatives have been shown to enhance students' technical skills, critical thinking, collaboration, and motivation, preparing them for successful careers in STEM fields.

However, the study also highlights the challenges and complexities of implementing such programs in a resource-constrained environment, where competing demands and priorities can limit the scope and sustainability of initiatives. The success of the department's programs can be attributed to several key factors, including strong leadership, a collaborative culture, flexibility and adaptability, strategic partnerships, and continuous evaluation and improvement.

These findings resonate with the broader literature on undergraduate research and STEM education, which emphasizes the importance of providing students with authentic, meaningful, and supportive learning experiences that foster their intellectual and personal growth [21, 26]. The study also underscores the value of integrating research and STEM experiences into the curriculum, rather than treating them as separate or optional activities [16, 29].

At the same time, the case study raises important questions and challenges for further research and practice. For example, how can higher education institutions ensure equal access and participation in research and STEM programs for all students, particularly those from underrepresented or disadvantaged backgrounds? How can faculty be supported and rewarded for their mentorship and teaching efforts, while also meeting the demands of research and service? And how can the impact and value of undergraduate research and STEM education be effectively measured and communicated to stakeholders and society at large?

Addressing these questions will require continued research and innovation in higher education, as well as collaboration and partnership among institutions, disciplines, and sectors. The TSATU case study offers a promising example of how one institution is navigating these challenges and opportunities, and provides valuable lessons and insights for others seeking to enhance undergraduate research and STEM education in their own contexts.

6. Conclusion

This case study has examined the scientific activities and STEM education initiatives implemented at the Department of Computer Sciences at Dmytro Motornyi Tavria State Agrotechnological University in Ukraine. Through a qualitative research design involving document analysis, interviews, and observations, the study has provided an in-depth and contextualised understanding of how these initiatives are designed, implemented, and experienced by students and faculty members.

The findings suggest that the department's programs, which include research projects, scientific circles, STEM courses and modules, and outreach activities, have yielded many positive outcomes for students, such as enhanced technical skills, improved problem-solving and critical thinking, increased collaboration and communication, and greater motivation and engagement in their studies. However, the study also identifies several challenges and success factors in implementing and sustaining these initiatives, such as limited resources, competing demands, ensuring equal access and participation, and leveraging partnerships and resources.

Based on these findings, the study offers several recommendations for higher education institutions seeking to develop or enhance their undergraduate research and STEM programs, such as integrating research and STEM experiences into the curriculum, providing structured training and mentorship, fostering a collaborative and inclusive culture, leveraging partnerships and resources, and regularly evaluating and assessing the impact and effectiveness of programs.

In conclusion, the TSATU case study demonstrates the potential of undergraduate research and STEM education to transform students' learning, skills, and aspirations, and to contribute to the social and economic development of communities and societies. It also underscores the critical role of higher education institutions in fostering a culture of scientific inquiry, innovation, and collaboration, and in providing opportunities for all students to participate and excel in STEM fields.

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