Science Education in Universities – Practical Impacts

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Abstract

The advance science education is crucial for addressing new digital era reality and frame of challenges. It can be implemented via knowledge sharing new learning methods based on research and networking. Education 4.0 is a desired/aspired approach to learning that aligns itself with the emerging fourth industrial revolution [1].
The strategic task of teachers and lecturers is the effective educational motivation for students [2], which will create the bilateral teacher-student contact, assist to practically assimilate the acquired theoretical knowledge. Thus, universities perform double mission - educational institutions in their own right, and a catalyst exporting programs needed for economic prosperity. An impetus on science-based education is a core element in any University research strategy.
Bringing science and formal education closer to the agenda of society, will create a supportive environment for bottom-up initiatives where access and develop knowledge in an agile way, and following personalized learning paths with IPR results.
The science education addresses the following priorities of EC: Stimulation of innovative learning and practices; Promotion of inter-connected education systems; Digital transformation. Science education stimulates critical thinking, research and active participation in the learning process [1].
The article explores innovative teaching methods in science education, while also examining the practical impacts of this approach. It presents lessons learned from Bulgarian practices in science-based higher education, offering insights and potential next steps for improvement as a case study.

Keywords: *science teaching, higher education, knowledge, impact*

1. Introduction

21st-century educational frameworks stress the need for students to develop skills essential for thriving in the evolving workforce. Many normative documents of the European Union concerning education, training, and social cohesion, such as European Qualifications Framework, European Pillar of Social Rights, New Skills Agenda for Europe, Council Recommendation on Key Competences for Lifelong Learning, Strategic Framework for European Cooperation in Education and Training, Youth Guarantee Initiative, Council Directive on Combating Discrimination in Employment and Education, Communication on Achieving the European Education Area by 2025, Digital Education Action Plan (2021–2027), address the issue of ensuring the development of essential competencies. In this context, educators bear the critical responsibility of assessing whether existing teaching methods are effective in fostering these skills and meeting the outlined goals. These include learning skills such as creativity, critical thinking, problem-solving, and collaboration; literacy skills like information, media, and ICT literacy; and life skills, including adaptability, initiative, intercultural awareness, and leadership.

Educational institutions serve as pillars of knowledge and innovation, playing a shared role as centers of learning and catalysts for economic growth by exporting programs essential for prosperity. They also bridge science and society, fostering advancements that address societal challenges and improve quality of life.

A particularly vital skill today is the ability to reason through complexity, requiring professionals to reflect on and adapt to a rapidly changing world, expanding beyond scientific reasoning to embrace systems thinking, critical thinking and creative problem-solving, enabling innovative responses to modern societal challenges. These skills should be integrated into different types of training, but special attention should be paid to vocational education, as it directly influences the competitive environment.

Vocational education is based on the research base as well in order to address the challenges of new industries and technologies. A number of normative documents pose these point - UNESCO - Frame of activity – aim 4, European Skill Agenda. In the Strategic Framework for The Development of Education, Training, and Learning in the Republic of Bulgaria (2021–2030) various activities supporting this aim are included.

Active pedagogies, as outlined by Ramírez-Montoya [1], focus on critical thinking, collaboration, and digital skills, supported by emerging tools like augmented reality and immersive virtual reality, which foster engagement and STEM-related skills. They are essential for advancing AI tools and technologies, as it provides the foundational knowledge and skills required to develop, innovate, and improve these systems. The rise of educational neurotechnology and digital literacy underscores the need for methodological shifts and proactive information cultures [1].

From the perspective of Education 4.0, personalized learning plays a crucial role by tailoring educational experiences to the individual needs, interests, and abilities of each student. In their research Miranda et al. [2] comment on the role of Education 4.0 and that it includes several aspects, such as self-directed learning, encouraging students to reflect on and understand their learning process, collaborative learning through peer-based teaching methods and use of technology and the internet to provide flexible learning experiences that aren't limited by time or place. Elements of Education 4.0 are closely related to innovative teaching methods.

The knowledge triangle, which is an immanent part of a knowledge-based economy, clearly positions the sustainable relationship between knowledge and science. The triple helix model, which is identified with the knowledge economy as well, places a primary focus on the role of knowledge; the quadruple helix model is associated with the economy of society, where the importance of social well-being (eco-innovation) is the consumer's knowledge, acquired through science-based training. In the last decade, the role of the five-fold helix has been discussed. It could be seen as a framework for analyzing interdisciplinary problems related to sustainable development. In this context, not only a holistic scientific approach is required, but also a transformational approach towards education and training of adequate personnel who will support this sustainable development trend. The present study aims to explore the impact of innovative science education on students and to assess how they perceive such educational approach.

2. Theoretical Background

The Triple Mission of the universities represents a dynamic, multidisciplinary concept closely tied to the broader social and economic responsibilities of higher education institutions. In this light, academia faces critical decisions regarding its approaches to teaching, research, and societal engagement. To remain relevant, universities must break free from traditional isolation and align their efforts with societal challenges and industrial priorities. Bridging the gap between science and society, while integrating these goals into the core functions of teaching and research, is essential for fostering progress and innovation in higher education [3]. International organizations, the EU and many large-scale educational networks for formal and non-formal education pose high on the agenda the issue of science education. An OECD report [4] on innovation policy discusses the quadruple helix approach, which involves collaboration among government, private sector, academia, and civil society to foster innovation and aims to stimulate inclusive and sustainable progress, while driving innovation, economic growth, and social development. The document also emphasizes that innovative approaches in education are a way to achieve the stated goals.

The science education addresses the EC priorities namely: Stimulation of innovative learning and practices; promotion of inter-connected education systems; digital transformation. Additionally, science education stimulates critical thinking, research and active participation in the learning process [2]. In recent years, higher education institutions have sought to equip students with a balanced set of hard and soft skills. Modern teaching methods, rooted in scientific principles, are gaining increasing popularity. These approaches emphasize innovation and evidence-based practices to enhance learning outcomes.

As mentioned, Education 4.0 represents the integration of innovative teaching methods, among other aspects, in higher education. This approach aims to optimize knowledge generation, information transfer, and the development of critical competencies in students [2]. Such types of teaching methods in science education are various. Among the most famous are:

2.1 Inquiry-based Science Education

There is a diverse array of active learning strategies available for educators. Several methods particularly suited for science education include strategies such as problem-based learning, cooperative or collaborative learning (including group work), think-pair-share, peer instruction, and inquiry-based science education, – challenge-based, problem-based learning, learning by doing Project-Based Learning, Flipped Classroom.

Dr. Robyn M. Gillies, a professor in the School of Education at The University of Queensland, Brisbane, defines inquiry-based science as an adoption of an investigative approach to teaching and learning where students are provided with opportunities to investigate a problem, search for possible solutions, make observations, ask questions, test out ideas, and think creatively and use their intuition. In this sense, inquiry-based science involves students doing science where they have opportunities to explore possible solutions, develop explanations for the phenomena under investigation, elaborate on concepts and processes, and evaluate or assess their understandings in the light of available evidence [5].

In an inquiry-based science education-driven teaching and learning environment, students are encouraged to actively engage by solving problems and independently formulating and answering questions, mirroring the processes used by scientists. Researchers emphasize that the inquiry-based approach is among the most effective methods for 21st-century learning, as it helps students develop a broad spectrum of competencies, knowledge, and skills. Furthermore, inquiry-based science education skills can be delineated through various frameworks [6].

The inquiry-based and science education-driven teaching are actively applied in Bulgarian research universities, particularly in Sofia University faculties of Natural Sciences. It needs additional resources and it is supposed to be an element of overall reform in higher educational system.

2.2 Competency-based Learning

In recent years, the significance of the competency-based approach in higher education has been steadily increasing worldwide. This trend is driven by factors such as the rapid development of future professions, the demand for new skills in the labor market, and emerging perspectives on lifelong learning. The key characteristics of competency-based education, include learner-centric approach, outcomes-based assessment, and differentiated learning. Benefits of competency-based education could be outlined as: efficient and cost-effective degree options; better understanding of learning outcomes; better student engagement and motivation; improved retention rate.

When comparing competency-based education to traditional education, one of the key differences lies in the approach to learning outcomes. Competency-based education prioritizes the development of deep understanding and the practical application of knowledge and skills. Unlike traditional education, which often focuses on rote memorization and comprehension for the purpose of passing tests, competency-based education aims to equip students with the critical thinking and problem-solving skills necessary for real-world challenges.

Bulgarian higher education institutions to effectively implement competency-based approaches in teaching, it is essential for academic staff to embrace the role of course designers. They must be able to align the relationship between the execution of a learning activity and the mastery of numerous competencies and sub-competencies, which encompass specific theoretical knowledge, practical skills, and attitudes. High technologies are key to the effective development of higher education and the modernization of the economy. Training educators to implement and utilize these technologies in teaching is of critical importance for society. This includes the development and validation of a scientific and practical guides for high-tech integration of competencies in teaching, learning, and assessment in higher education, as well as the creation of an e-learning course aimed at high-tech implementation, application, evaluation, and certification of competencies and competency systems in higher education [7]. This approach is partially allied in Bulgarian high schools and in a very rare cases in secondary schools.

2.3 Problem-based Approach

Problem-based learning is perceived as a more advanced method than traditional ones and is geared toward activating students' thinking and actions, as knowledge is applied in practice. It is specifically suitable for the specifics of computer knowledge and skills. Contemporary educational technologies are focused on activating thinking, creatively applying existing knowledge, and encouraging students to seek information. Problem-based learning is one such example.

The starting point of the thought process is typically a problem situation. This is a cognitive task characterized by a contradiction between existing knowledge, skills, attitudes, and the need to solve the problem. Thinking begins when there is a need for it, and it usually starts with a problem or question. Problem-based learning is a system of methods and tools that ensure active participation of learners in the process of acquiring new knowledge, fostering creative thinking, and developing the individual’s cognitive interests. It refers to an organization of the educational process where the instructor creates a problem situation. Under their guidance, learners solve the task independently or with minimal help and creative effort. This approach requires the creative application of knowledge and active engagement from learners. In doing so, cognitive skills and thinking abilities are developed. It is crucial to activate and develop thinking and to creatively apply knowledge.

Problem-based learning contributes to achieving several key goals:

- Developing a system of knowledge, skills, and competencies in learners.
- Achieving a higher level of ability for self-directed learning and creative application of existing knowledge and information.
- Cultivating a specific style of mental activity, including exploration, investigation, and independence in students.

The specifics of problem-based learning highlight its capacity to develop critical and creative thinking, foster autonomy, and align educational processes with the practical application of knowledge. The essence of problem-based learning lies in fundamentally altering the structure of students' cognitive activity. At the lowest level, the teacher presents a question, creates a problem situation, formulates a hypothesis, and demonstrates its solution. At the next level, the teacher presents the problem situation, but the solution is left to the students under the teacher’s guidance. This is referred to as the intermediate level of problem complexity and can be implemented and organized through discussion and dialogue. At the highest level, students independently formulate the problem and solve it themselves. This approach is utilized for research and scientific work. A problem situation is one that provokes a psychological state in the learner, where they identify and become aware of the problem [8]. This approach is applied in part of higher education institutions, more often in entrepreneur high schools.

Another applicable approach is project-based learning one. PjBL serves as a dynamic component of science-based education by integrating elements of other teaching methods, such as inquiry-based learning, experiential learning, and problem-based learning, and emphasizes the creation of tangible outcomes and real-world applications that deepen students' understanding of scientific concepts. While project-based and problem-based learning share similarities, project-based learning focuses more on knowledge construction, fostering innovation and autonomy in students. Therefore, PjBL should be more widely implemented in higher education, to help students build essential skills for the future workforce [9].

2.4 Project-based Learning Approach

Project-Based Learning (PjBL) is an instructional approach that focuses on inquiry and active engagement, encouraging learners to build knowledge through meaningful projects and create practical, real-world outcomes. It is an educational approach designed to prepare students for the challenges of the 21st century by promoting critical thinking, problem-solving, and creativity. It uses projects as the central medium for learning, enabling students to investigate, assess, and synthesize information while creating meaningful outputs. This method encourages active participation, real-world applications, and collaborative problem-solving. By prioritizing engagement and hands-on activities, PjBL shifts the focus from rote memorization to dynamic exploration, fostering an environment where students independently tackle realistic tasks and develop their cognitive and practical abilities.

The advantages of PjBL include enhancing student motivation, improving problem-solving skills, and fostering the production of tangible, real-world outputs. It emphasizes deep learning through in-depth investigations, decision-making, and research on significant issues, providing students with meaningful experiences. PjBL also nurtures critical and creative thinking skills, making learning more engaging and relevant to future challenges. By enabling students to work collaboratively or independently on complex tasks, this approach helps build competencies that are crucial for navigating the complexities of modern life and preparing for future careers [10].

According to Krajcik and Shin [11] PjBL has six main characteristics: driving question; focus on learning goals; participation in scientific practices; engagement in collaborative activities; support by learning technologies; creation of a set of tangible products. The authors highlight the importance of selecting meaningful driving questions aligned with learning goals, blending core ideas with scientific practices, and integrating technology effectively. It stresses the need to support teachers with well-developed materials and strategies to engage students in scientific investigations and promote collaboration. They believe that while focused on science, these principles can enhance PjBL across subjects like social studies, arts, and English, improving educational effectiveness by applying learning science principles.

PjBL has shown its positive impact on student learning, including knowledge, skills, and motivation. Various tools, such as questionnaires, interviews, and self-reflection journals, have been used to measure learning outcomes. PjBL has been shown to benefit students' content knowledge, learning strategies, skills, motivation, and product quality [9]. The implementation of the PBL approach among university students is emphasized by Almulla [12] and discussed to collectively foster student engagement in learning. It is commonly practiced in majority of Bulgarian high schools.

2.5 Challenge-based Learning

Challenge-based learning is an emerging approach in higher education that integrates disciplinary knowledge with the development of transversal skills by tackling real-world sociotechnical problems. Challenge-based learning framework could modify and improve open educational resources and engage students in community-based problem solving. Among specific elements of the challenge-based approach are: engage; investigate and act.

This flexible method involves multidisciplinary collaboration, technology-enhanced learning, and engagement with multiple stakeholders to address authentic challenges. Challenge-based learning is frequently used interchangeably with other similar teaching methods like project-based learning and problem-based learning, but according to Gallagher and Savage [13] it has its distinct frameworks, definitions, and approaches. According to the authors while challenge-based learning shares similarities with problem and project-based learning, such as using problems or challenges and projects, its emphasis on the process and sustainability makes it a distinct approach. It does not have predefined content or challenges, involving multiple stakeholders as co-researchers and designers, and focusing on sustainability issues that require urgent solutions.

Fig. 1. Framework of Challenge-based characteristics [13]

Taking into account innovative teaching methods Guo et al. [9] claim that further experimental research is recommended to determine PjBL's impact on diverse learning outcomes. The purpose of this article is to study and assess the effectiveness of science-based education, with a particular focus on PjBL, in addressing socio-economic issues, including an analysis of students' perceptions of these issues. The choice of PiBL derives from the fact that Bulgarian universities and high schools actively participate in a number of national and international projects and have a well-structured project culture. These approaches are widely recognized and implemented in institutions such as the Technical University of Sofia, Sofia University, the Medical Universities of Sofia and Plovdiv, and the American University. Additionally, as a component of informal education, they are particularly popular in short-term training courses offered at Sofia Tech Park, Bulgaria's biggest science and technology park.

3. Methods

This research delves into the students' perceptions of the benefits and challenges associated with PjBL, focusing on their personal opinions and self-reflections. The methodology involves a comprehensive combination of quantitative and qualitative approaches to ensure a well-rounded analysis. This includes a detailed examination of targeted scientific publications to extract relevant insights, the design and implementation of semi-structured interviews to gather in-depth perspectives, and the thorough processing and interpretation of the collected data. Additionally, observation is utilized as a research method to capture real-world behaviors, interactions, and contexts, providing further depth and context to the study. The latter is also used as key instruments in the study as one of the most common instruments for analysis of students' perceptions of PjBL [9]. In order to accumulate necessary data 19 students were interviewed and 20 university representative provided feedback on the topic. Academic staff was included in the feedback process as it is recommended that the perspectives of teachers on using the PjBL approach in academic settings is incorporated [12].

The research involved students and lecturers from Sofia University, Bulgaria, during the period from 2022 to 2024. Participants were engaged in an international project, where they collaborated in teams to develop and present a personal project. Two competition calls were announced within an academic year, with an independent jury of habilitated experts evaluating the project proposals. A university representative acted as the team leader or couching person, during the project performance. The final presentations were made in two steps: before students of the course's class and contributors from four different countries - which were project partners. The project process encompassed problem identification, solution development, case study analysis, the consideration and implementation of alternative teaching methods, and the preparation of a course. Partners' courses are available on a dedicated e-platform, in full compliance with applicable regulations.

4. Results and Discussion

4.1 General Findings Based On Students' Project Participation

By bringing learning and formal education closer to the agenda of competitive economy and wellbeing society, bottom-up initiatives were announced where teachers and students access and develop knowledge in an agile way. Research is a key element in the process, and learners follow personalized learning paths with ownership of the results and achievements. All small-scale projects facilitated educational process in their programs of study, in the context of the ongoing transformations and the rising demands placed on education by the new digital technologies.

The short-term student's initiatives and/or projects empower universities to engage through innovative research and teaching approaches, building digital capabilities and supporting inclusive, future-oriented education. Students design their own learning pathways through flexible combinations of research-based studies. Students and researchers improve their skills and capacity and co-design course materials. In doing so challenge-based pedagogy is promoted.

Figure 2 presents model for problem assessment and prioritization based on the observation on the students work.

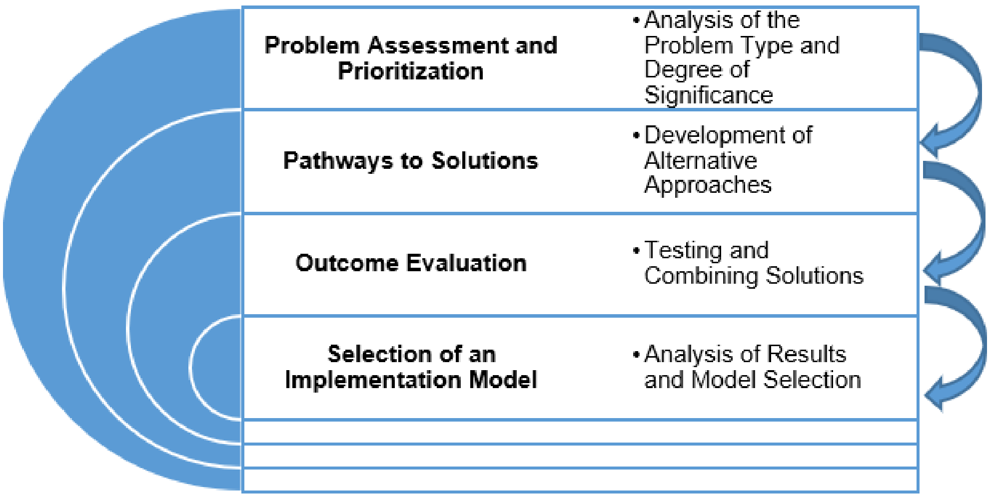

Fig. 2. Model for problem assessment and prioritization

The process begins with problem assessment and prioritization, involving the analysis of the problem type and its significance. Next, alternative pathways are developed to propose multiple solutions. These solutions are then tested and evaluated, with some alternatives combined if necessary, during the outcome evaluation phase. Finally, the results are analyzed to select the most effective implementation model, ensuring an optimal approach to address the problem.

More than 20 students' science-based educational projects have been reviewed by Sofia University. The approach is bottom up and relies on students' creativity and initiatives. The project results contribute to the modernization and therefore competitiveness of higher education. The students' project outputs contribute to development of a high-performing digital education ecosystem, connecting staff, students and infrastructure as well as academic community.

Participation in practice-targeted and knowledge-based trainings, contributing to different curricula, encouraging activities to uptake and scale-up of promising research and practical solutions offered by the students/researchers were among the main achievements of the overall project.

4.2 Review and Analysis on Number of Student Projects Linked to Project Based

After closing the target call and evaluation, 19 students' applications have been approved and supported. The selection was conducted on the base of priority areas, respecting complex and challenging social issues as well. For instance, one of the projects was devoted to sign language interpretation for students with such challenges. The majority of applications were in the area of ICT, knowledge management and smart communication. Projects results have been inbuilt in several current courses at Sofia University after official approval and contribute to course's actualization. The upgraded courses are elective or obligatory and uploaded on the university website and YouTube as well. The interests towards these courses have been tracked and increasing interest has been recognized. The courses were disseminated among other universities via different communication channels and were highly appreciated.

The IPR are associated to the project performance. This enables creators to expand, propose and implement their ideas, and make them applicable, thus addressing the basic postulates of open science and contributing to its establishment.

Student satisfaction with the educational process and the project work is largely positive. This was recognized based on a specialized survey conducted among them. The majority of students highly appreciate the quality of the courses and collaborative work in teams, emphasizing the usefulness of the knowledge imparted and its applicability in practice. This demonstrates that efforts to improve the educational process and introduce innovative teaching methods are yielding positive results.

Despite these positive aspects, one of the main challenges that is still faced is the insufficient adoption of inclusive approaches in the academia work. The lack of inclusivity hinders the full participation of all students. The rigidity of the traditional teaching system and resistance to co-working with students hinder the full implementation of this approach. There is opposition among the academic staff to adopting such practices, as the quality of the learning materials may not meet the required standards. This reluctance persists despite the fact that, in most cases, the outcomes of project-based learning are engaging and appealing to the audience. All these factors highlight the need for systemic changes and modernization of educational methods to meet contemporary demands for innovation, inclusivity, and efficiency.

Addressing this issue requires additional efforts from educators as well as institutional support for creating an inclusive learning environment. The introduction of new technologies, personalized approaches, and active feedback from students can contribute to overcoming these challenges and achieving higher satisfaction and engagement among all learners.

5. Conclusion

The effectiveness of project-based learning in addressing social and economic issues is evident, particularly through student project proposals. These students' projects not only support science-based education but also provide an opportunity to apply modern learning methods that emphasize innovation and engagement. Organizing competitions where the best proposals are implemented encourages students to actively contribute to solving pressing social issues and advancing digital transformation. Successfully implemented ideas and outcomes from student projects are integrated into the university's curriculum, making the educational process more flexible and relevant.

Through semi-structured interviews with 19 students and 20 instructors, several key conclusions were drawn. First, there is a growing interest in science-based education that incorporates student participation. This inclusion provides valuable feedback not only from the direct participants in the projects but also from a broader student audience, contributing to the optimization of courses. Students express a high level of satisfaction with this approach, with a significant number providing positive evaluations of the courses. Furthermore, there is an increased interest in developing new courses based on similar project-based approaches, underscoring their applicability and effectiveness.

However, challenges remain, particularly in expanding the inclusivity framework for students in collaborating with the university. With continued efforts to enhance project-based learning, universities can play an even more active role in addressing socio-economic challenges while preparing students for the real-world demands of the future job market.

What is evident from the experience is that science-based and in particular project-based learning have direct non-traditional and effective results. The collaboration between academic staff and students further contributes to this.
Science-based education improves the attractiveness of the learning process, bettering student's inclusion and their responsibility towards educational process and respectively the quality of the training as well. Such training would engage students more effectively by providing them with the opportunity to express their opinions, expectations and engage with the learning material in a different way. This is one of the paths to achieving appropriate preparation for students in response to the new conditions of the labor market, through the application of innovative teaching methods.

This type of training significantly increases the opportunity for students and scholars to participate as regular project's team members in a number of scientific and educational projects. Through them they could joint to develop new science-based courses, upgrade university capacity building and/ or create scientific results in favor of society or business structures.

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