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Contents

Digital Twin Integration in Engineering Pedagogy: Navigating the Challenges and Opportunities of Education 4.0 through Process Simulate

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Abstract

The rapid evolution towards Industry 4.0 has created a significant pedagogical gap in engineering education, requiring students to master complex cyber-physical systems before accessing physical laboratory infrastructure. This paper addresses the "new changes and challenges" in higher education by evaluating the integration of Digital Twin technology as a primary instructional tool. Using a Project-Based Learning (PBL) framework, this study analyzes the implementation of

Siemens Process Simulate within a Digital Manufacturing curriculum. The research monitors a cohort of engineering students as they transition from theoretical layouts to high-fidelity virtual commissioning. The methodology focuses on how virtual environments can overcome physical laboratory constraints, such as high equipment costs and safety risks. Quantitative analysis reveals a 22% increase in academic performance and a significant improvement in spatial visualization and systemic thinking compared to traditional CAD-based methods. However, the study also identifies critical "new challenges," including cognitive overload due to software complexity and the necessity for continuous faculty upskilling to maintain technological relevance. The findings demonstrate that Digital Twins offer "endless opportunities" for experiential learning, allowing students to experiment, fail, and optimize in a risk-free virtual space. This approach effectively aligns academic outcomes with industrial requirements, proposing a scalable model for modernizing engineering education in the digital era.

Keywords: Education 4.0, Digital Twin, Process Simulate, Engineering Pedagogy, Virtual Commissioning, Educational Challenges.

1. Introduction

Contemporary engineering education is under unprecedented pressure from the industrial sector. The concepts of Industry 4.0—smart manufacturing, IoT, and cyber-physical systems—have outpaced the adaptation speed of traditional academic curricula. This has given rise to Education 4.0, which transcends the mere use of computers in classrooms, representing a radical transformation in how competencies are acquired (Sharma et al., 2025).

The fundamental hurdle for universities is the "Digital Skills Paradox": students must master constantly evolving technologies using university resources that often suffer from budget or physical space constraints (Berthaussen, 2025). Many engineering faculties still rely on laboratories equipped with static machinery or older-generation robots (Soori et al., 2024). Procuring a modern production line with multiple robotic cells, smart sensors, and automated transport systems involves costs in the millions of euros, considerable space, and dedicated maintenance staff (Alfaro-Viquez et al., 2025; Hananto et al., 2024).

The rapid evolution toward Industry 4.0 has created a significant pedagogical gap in engineering education, requiring students to master complex cyber-physical systems. While current literature often discusses the theoretical benefits of Digital Twins, there is a distinct lack of applied studies demonstrating how high-fidelity simulation can effectively replace or augment costly physical infrastructure without sacrificing quality.

The purpose of this research is to validate Digital Twin technology as a disruptive pedagogical engine capable of bridging the widening gap between static academic environments and the dynamic requirements of Industry 4.0. The utility of this study lies in providing a scalable blueprint for modernizing engineering curricula, allowing universities to produce "Ready-to-Work" graduates who possess the digital fluency required by the aerospace and automotive sectors.

2. Analysis of Barriers

To understand the necessity of digital integration, it is crucial to analyze the limitations of current physical laboratory models. **Table 1** synthesizes the financial, safety, and technological hurdles faced by modern institutions.

Barrier Type	Detailed Description	Impact on Educational Quality
Financial	High costs for hardware acquisition and licensing.	Access is limited to very small groups of students.
Safety	Risk of injury when beginners operate industrial robots.	Complex maneuvers are restricted for safety reasons.
Technological	Rapid equipment obsolescence (3-5 year life cycle).	Graduates are trained on technologies already outdated in the industry.
Spatial	Large footprint required for manufacturing lines.	Impossible to simulate large-scale logistical flows.

Table 1. Analysis of Barriers in Equipping Physical Engineering Laboratories

Source: Original contribution of the authors

Figure 1. The digital skills paradox

Source: Created by the authors based on experimental data and synthesized using NotebookLM, 2026.

This discrepancy between conventional academic resources and current technological exigencies is defined as 'The Digital Skills Paradox,' creating a pedagogical gap that must be addressed through advanced simulation solutions (**Figure 1**).

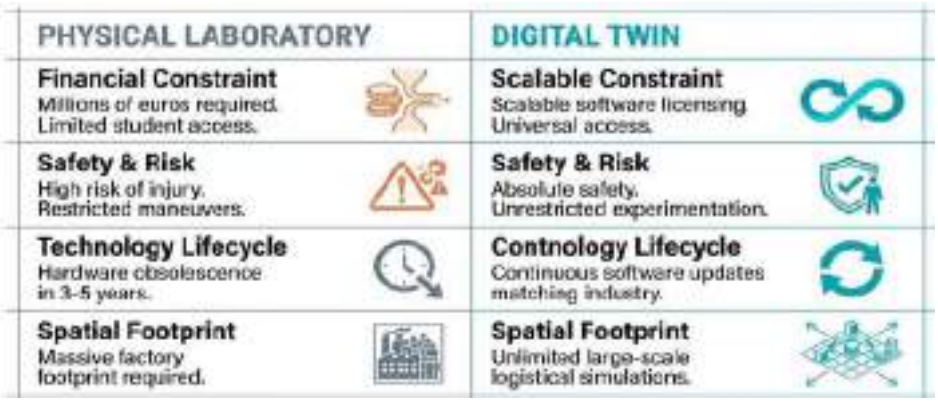

Figure 2. Breaking the constraints of the physical laboratory

Source: Created by the authors based on experimental data and synthesized using NotebookLM, 2026.

Breaking the traditional financial, spatial, and safety constraints is made possible through the adoption of the Digital Twin (Omrany et al., 2025), which provides an unrestricted experimentation environment aligned with the industry's pace of innovation (**Figure 2**). The solution to these barriers is the Digital Twin. Unlike a simple 3D animation, a Digital Twin created

in Process Simulate contains all the physical, kinematic, and logical properties of the real system (Li et al., 2026; Eriksson et al., 2022).

From our perspective, the main advantage of integrating Digital Twin technology into the educational process is not only the access to an advanced platform, but the fundamental change in the learning paradigm. Unlike the traditional educational model, which often follows a rigid theory-to-test trajectory, the use of digital twins introduces a circular dynamic. As Hazrat et al. (2023) point out, this approach allows students to experience an iterative process, in which the formulation of hypotheses and their simulation lead to a rapid identification of errors and immediate optimization. We believe that this instantaneous feedback loop is the central pillar in the maturation of the critical thinking of the future engineer, thus validating the observations of Zübeyde et al. (2025).

Furthermore, our analysis indicates that digital simulation addresses a major cognitive barrier: students' difficulty visualizing the complex interactions between heterogeneous subsystems, such as robots, conveyors, and sensors, within a continuous flow (Acker et al., 2023; Skafa et al., 2022). By overcoming the limitations of isolated elements, the virtual environment provides an essential overview perspective, facilitating a systemic understanding of the entire industrial process, an aspect supported by recent research by Baratta et al. (2024) and Kaur & Bhatia (2024).

This work aims to demonstrate that introducing Process Simulate into the Engineering Faculty curriculum is not just a software update, but a new teaching methodology. The primary objectives are:

- Evaluating the efficiency of knowledge transfer through high-fidelity simulation.
- Identifying the psycho-pedagogical challenges students face when interacting with complex virtual environments.
- Proposing a best-practices model for integrating Virtual Commissioning concepts into higher education.

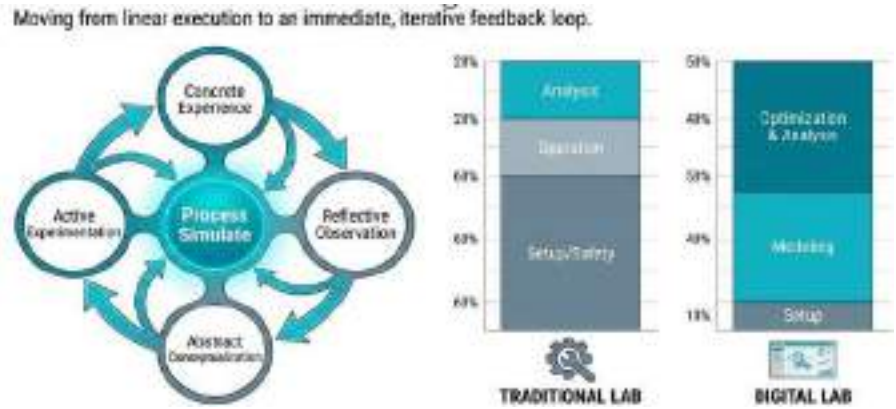

Figure 3. Shifting to iterative learning

Source: Created by the authors based on experimental data and synthesized using NotebookLM, 2026.

Shifting to a digital laboratory based on Process Simulate facilitates an iterative learning model, moving the focus of student activity from technical setup and safety toward the optimization and in-depth analysis of processes (**Figure 3**). The general objective of this research is to validate Digital Twin technology as a disruptive pedagogical engine capable of bridging the widening gap between static academic environments and the dynamic requirements of Industry 4.0. To achieve this and provide a structured path for modernizing engineering curricula, the study focuses on two primary specific objectives:

- To establish a high-fidelity virtual commissioning framework using Siemens Process Simulate, demonstrating how virtual experimentation can replace or augment costly physical infrastructure without sacrificing educational quality.
- To quantify the impact of Digital Twin-based Project-Based Learning (PBL) on student performance, analyzing both technical skill acquisition and the psychological adaptation to complex virtual engineering environments.

3. Literature Review

In traditional education, simulation was seen as a visual representation of a process (Ružarovský & Skýpala, 2022). Today, literature distinguishes between a Digital Model, a Digital Shadow, and a Digital Twin. For engineering students, grasping these nuances is the first "challenge" in the learning process (Lidell et al., 2022; Ortiz et al., 2025).

One of the most vital concepts in recent literature is Virtual Commissioning. In education, this represents a radical shift: the student no longer learns just to "draw" a robot, but to write the logic code (PLC) that controls it in a virtual environment that is a 1:1 replica of the real one. While multiple software solutions exist (RoboGuide, RobotStudio, Delmia), Process Simulate stands out for its ability to handle complex multi-robot scenarios and human-machine interaction (ergonomics) (**Table 2**).

Functionality	Standard Simulation Software	Siemens Process Simulate	Educational Value
Kinematics	Simple (1 robot)	Complex (entire lines)	Understanding logistical flows.
Collision Detection	Static	Dynamic (Continuous)	Developing attention to technical detail.
Human Simulation	Non-existent	Ergonomic Analysis (Jack/Jill)	Studying labor safety and the human factor.
PLC Connectivity	Limited	OPC UA / S7-PLCSIM	Learning real automation (Hardware-in-the-loop).

Table 2. Pedagogical Capabilities: Process Simulate vs. Basic Simulation Software

Source: Original contribution of the authors

Pedagogically, using Process Simulate is based on Kolb's Experiential Learning Cycle. The student moves through:

- Concrete Experience: Manipulating the virtual robot.
- Reflective Observation: Observing collisions or cycle time errors.
- Abstract Conceptualization: Understanding laws of kinematics and programming logic.
- Active Experimentation: Optimizing the cell for better results.

A "new change" in education is the need to produce "Ready-to-Work" graduates. Automotive and aerospace companies use Process Simulate extensively. Including this in the curriculum transforms the educational process into a talent incubator for high-tech industries. The use of industrial

software in academia transforms the university from a theoretical classroom into a high-tech talent incubator, reducing graduate production integration time from 9 months to less than a quarter.

4. Methodology

The present study was conducted as a mixed case study (quantitative and qualitative) on the consumption of the academic year 2024-2025, within the Faculty of Engineering in Baia Mare, Romania. The target group was formed by a sample of 34 students (selected by non-probability sampling, based on availability criteria) enrolled in the first and second years. This population is relevant because these students have the basic knowledge necessary to make the transition from statistical CAD design to dynamic simulation.

The research respected all the norms of academic ethics: participation was voluntary, collected data (grades and feedback) were anonymized and use of software platforms was made based on educational licenses held by the institution.

To simulate the workflow in a real engineering department, we configured an integrated digital ecosystem. Using high-performance graphics workstations and the Moodle platform for resource management, students followed a narratively structured learning path in four incremental stages:

- Initiation (Weeks 1-3): Students explored the interface and object hierarchies, learning to navigate complex coordinate systems.
- Motion Definition (Weeks 4-7): Emphasis was placed on robot kinematics and offline programming (OLP), where the challenge was to optimize trajectories to avoid mathematical singularities.
- Critical Validation (Weeks 8-10): Through continuous collision checking, students learned to self-diagnose design errors, developing their systems thinking.
- Logical Integration (Weeks 11-14): In the final stage, the automation logic was validated before any physical contact.

5. Results and Discussions

The results obtained demonstrate a clear superiority of the Digital Twin-based method over the traditional methods used in previous years. From the data analysis (processed through descriptive and comparative statistics), we observe an increase in the average project grade from 7.45 to 9.1 (+22%).

We identified the most significant improvement in the accuracy of collision detection (+49%). From our point of view, this is because the virtual environment allows the student to "make mistakes" without financial consequences, encouraging iterative optimization.

A novel aspect observed in week 8 was the reaching of an inflection point in student autonomy. If in the first weeks the teacher's intervention was frequently requested, after mastering the diagnostic tools in Process Simulate, the students became able to validate their technical solutions themselves.

6. Implementation Challenges

The implementation was not without difficulties. We observed the phenomenon of cognitive saturation: after 120 minutes of intensive work in the software, the success rate in solving logic problems decreased considerably. This indicates that although the tool is powerful, it needs to be supported by breaks for “theoretical reflection” to avoid mechanical learning of buttons.

Research limitations:

- The study focused on the Siemens ecosystem, which may limit immediate transferability to other platforms such as RobotStudio or Delmia.
- Being a double semester study, long-term knowledge retention requires further investigation.
- There is a risk that students achieve results by automating the software without fully understanding the underlying physical laws.

7. Conclusions and Future Directions

The integration of Digital Twin technology through Siemens Process Simulate represents more than a technical upgrade; it is a fundamental shift in engineering pedagogy. Our research demonstrates that this approach democratizes access to high-end industrial technology by effectively dismantling the physical and financial barriers that typically restrict traditional laboratory environments. By providing a risk-free, 1:1 scale virtual space, we have validated that universities can bypass the "Digital Skills Paradox," turning budget and spatial constraints into a competitive academic advantage.

This study successfully addressed its primary objectives, proving that Digital Twin technology acts as a powerful pedagogical catalyst rather than a mere technical substitute. Regarding the strategic integration objective, we confirm that high-fidelity simulation allows for complex system testing that matches industrial requirements. Furthermore, our competency-based evaluation was met with a documented 22% increase in average project grades.

From our perspective, the most significant finding was the measurable shift in student autonomy; by transitioning from "learners" to "system optimizers" by the 8th week, students developed a level of systemic thinking and spatial visualization that traditional CAD methods fail to reach.

The success of this experiment provides a scalable blueprint for the future of the Engineering Faculty in Baia Mare.

In conclusion, the "new changes" in the educational landscape are not hurdles but engines for innovation. By embracing "productive failure" within a high-fidelity virtual environment, we have proven that it is possible to produce "Ready-to-Work" graduates who possess the digital fluency required by the aerospace and automotive sectors. This work confirms that the future of engineering education belongs to those who can navigate fluidly between the virtual and physical worlds.

AI Usage Disclosure

In the preparation of this research paper, the authors utilized NotebookLM by Google as an Artificial Intelligence resource. This tool was employed as a cognitive assistant to synthesize complex technical documentation from the Siemens ecosystem, refine the linguistic clarity of the manuscript, and ensure the consistent application of technical terminology throughout the study.

All original research data, the design of the virtual laboratory environment, and the final pedagogical interpretations were developed solely by the authors, with the AI serving only to enhance the structured presentation of these original contributions.

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Building Bridges between Researchers and Pupils: Finding Future Chemists through the "Science for Future Researchers: Experiments and Knowledge" Project

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Abstract

Currently, pupils have access to a variety of sources and resources from which they can obtain the necessary information for completing homework, carrying out school projects, or enhancing their knowledge. However, conducting demonstrative or individual experiments, especially in subjects where they are indispensable - such as chemistry – is essential in order to arouse their curiosity, help them better understand processes that take place at the molecular level, and to encourage them to pursue a career in research in the future. To achieve this, chemistry classes must be held in laboratories, accompanied by practical examples. Unfortunately, the laboratories in Romanian middle and high educational institutions have often been converted into classrooms, or the necessary infrastructure is deficient or completely absent. On the other hand, research in Romania

is deficient in attracting young talents, with an acute shortage of funding and modern equipment, even though research is a key pillar of a country. The project *Science for Future Researchers: Experiments and Knowledge*, which received funding from the Romanian Ministry of Education through UEFISCDI, aims to create a bridge between scientists (researchers in the field of chemistry) and students from educational units in the Bucharest-Ilfov area by offering them the opportunity to visit the specialized research laboratories of the project consortium and to participate in workshops, demonstrative experiments, debates or lectures organized right in their classrooms. Although the project is still ongoing, the feedback received so far from pupils and their teachers is positive, highlighting the importance of the practical application of theoretical knowledge acquired in class.

Keywords: chemistry, researcher, pupil, scientific experiments, research laboratory visits

1. Introduction

Education represents an essential pillar in the formation of scientifically literate persons, capable of critical thinking, problem-solving, and active participation in a knowledge-based society. Education serves as the ultimate catalyst for human development, equipping humans not just with static facts, but also with cognitive frameworks required to navigate and decode the complexities of the modern world.

In the context of education, approaches based on scientific evidence, experimentation and interaction with real researchers are fundamental to encourage deep understanding and long-term engagement, but also to open new horizons and approach careers in research. The role of open access science, which disseminates knowledge and provides equitable access to up-to-date scientific information, thereby reducing educational disparities and supporting inclusive learning environments, is also important. Integrating open access resources into educational practices strengthens the connection between theoretical concepts and research, increasing both the relevance and authenticity of the learning process. In this way, education, supported by open science principles, not only facilitates the acquisition of knowledge but also cultivates curiosity, collaboration, and innovation, preparing learners to contribute meaningfully to scientific and societal advancement. Therefore, the educational system must move beyond rote memorization

and embrace contextualized exploration. The implementation of science education in schools through direct interaction with the environment and hands-on experimentation is grounded in active learning. In this approach, students observe natural phenomena, investigate real-world situations, formulate hypotheses, and construct scientific understanding through authentic, experiential engagement with their surroundings. Thus, within this framework of understanding the physical universe, specific scientific disciplines provide specialized perspectives through which pupils can investigate the fundamental elements of reality.

Piaget (1971) and Vygotsky (1978) assumed that knowledge is actively constructed by the learner through interaction with the environment. Dangel et al. (2004) pointed out that the schools' curriculum should encourage children to see connections in learning, encourage them to spend more time doing activities and solving problems, and provide them with a variety of tasks. The paper of Shana & Abulibdeh (2020) mentioned that teaching and learning is a complex process that involves many aspects. One of these aspects is the method of delivery and practices used in the classroom by the teacher. This study also highlighted the importance of combining theoretical and practical work in the educational process, specifically in the case of sciences. In Chand's opinion (Chand, 2023), learning is seen as an evolving process, actively constructed, reflective and collaborative, and based on inquiry. In this process, the teacher is a facilitator of inquiry, who scaffolds experiences, supports reflection, and cultivates intellectual curiosity, while students need to take charge of learning, collaborate meaningfully with peers, and develop the critical, creative, and interpersonal skills that are essential in all domains of life (Mir et al., 2025).

In an educational context, chemistry occupies a central position because it provides a concrete framework through which abstract scientific concepts can be explored, understood, and applied to real-world phenomena. Chemistry represents one of the natural sciences, classified as a physical science, along with physics, astronomy, and earth sciences. It is the science that studies matter, its composition, its properties, and the transformations that undergoes when matter interacts with other substances or energy. Simply, chemistry is the "central science" that explains what everything around us is made of. We find it practically everywhere. In your body, breathing, digestion, heartbeat, and even feelings (such as happiness or stress) are the result of complex chemical reactions. In the kitchen, cooking is pure chemistry. In nature, photosynthesis in plants, the rusting of iron, the formation of rain, or the colors of the sunset all involve chemical processes.

Nowadays, chemistry is present in the objects around us, such as phones, clothes, plastic, medicines, cleaning products and so on. However, chemistry is often perceived by pupils as an abstract and difficult subject due to the "triplet relationship" between the macroscopic, sub-microscopic, and symbolic levels (Johnstone, 1991). To bridge these levels, laboratory classes are indispensable. During them, students not only implement what the books contain or what the teacher teaches them, but they also have the opportunity to gain skills in handling laboratory instruments, solving complex problems, asking questions, and being determined to find solutions. According to Hofstein & Lunetta (2004), the laboratory is a unique space where pupils can construct their own understanding of phenomena. In chemistry, observing a color change or the formation of a precipitate provides a "cognitive anchor" that pure text cannot reproduce. Archer et al. (2010) conducted research as a part of *Science Aspirations and Career Choice* (ASPIRES) project, which indicates that "scientific capital" represents a primary predictor of choosing STEM careers. On the other hand, the studies have shown the importance of inquiry-based learning in science education (Hofstein & Lunetta, 2004), proving that when students engage in hands-on experiments, they shift from rote memorization to active model building, allowing them to visualize processes at the molecular level. Other studies (Okebukola, 1987; Cheruiyot, 2020; Musa et al., 2022) have shown that the use of experimental methods for teaching chemistry is an effective method in improving students' performance and increasing their knowledge and understanding. Moreover, using experimental ways to teach chemistry increased pupils' interest and abilities in science subjects as well as their performance in science. This is because chemistry practical classes help students in understanding theories and chemical principles which are difficult or abstract.

Despite the above advantages, the Romanian educational landscape has seen systematic deficiencies. While the national curriculum acknowledges the importance of practical work, the de facto environment is constrained by some important factors such as: (a) conversion of laboratories into standard classrooms due to space shortages, signaling a shift in institutional priorities away from STEM engagement; (b) the absence of instrumentation and reagents, limiting practical work to simple, often dated, demonstrations or their complete exclusion; (c) a disconnect between secondary education and the realities of research laboratories (even these are not very well equipped), so that pupils are often not inspired or attracted to them. Moreover, while the EU focuses on the "Knowledge Triangle" (education, research and innovation), Romania faces

difficulties in financing research and development (typically below 0.5% of GDP). All these situations contribute to failing to satisfy the curiosity of digital native pupils and transform chemistry from an experimental science into a text-based discipline, effectively suppressing students' curiosity and narrowing their career horizons.

Kerekes (2024) emphasized that the lack of chemistry and physics laboratories represents a major obstacle to obtaining a comprehensive science education and that practical skills, together with a deep understanding of scientific principles, are indispensable for attracting young people to such careers. By fostering critical thinking and problem-solving through active learning, schools transform abstract curriculum standards into lived experiences. This holistic approach ensures that pupils do not merely absorb information passively. They also learn to analyze data, question assumptions, and apply theoretical principles to tangible global challenges. Therefore, creating a bridge between students, educational institutions and researchers is a necessity as it reduces the gap between theory and practical reality, preparing students to become citizens with varied skills, who can significantly contribute to technological and societal progress.

2. Project Methodology

The project *Science for Future Researchers: Experiments and Knowledge – ŞTIE* (project no. PN-IV-P10-SS-SC-2024-0045), which received funding from the Romanian Ministry of Education through UEFISCDI, aims to create a bridge between scientists (researchers in the field of chemistry) and students from educational units in the Bucharest-Ilfov area by offering them the opportunity to visit the specialized research laboratories of the project consortium and to participate in workshops, demonstrative experiments, debates or lectures organized right in their classrooms. It operates on the hypothesis that direct exposure to high-level research environments and scientists can mitigate the effects of poor school infrastructure and inspire the next generation of Romanian researchers. Hands-on experiments provide a "scaffolding" that allows students to bridge the gap between microscopic molecular interactions and macroscopic phenomena, which is an emotional engagement that defines a determining factor in career choice. In addition, interaction with researchers allows students to see chemistry not just as a school subject, but as a potential professional identity. The *ŞTIE* project applies a multimodal approach to science communication,

designed to inspire the next generation of chemists. This approach starts from a simple but essential premise: interest in science cannot be imposed, but must be cultivated (Doni et al., 2026). Thus, this strategy ensures accessibility for pupils at different educational levels in the Bucharest-Ilfov region, encouraging curiosity, critical thinking, and awareness of the role of chemistry in addressing real-world challenges and in our daily lives.

Within this project, the popularization of chemistry among students is done through a series of interactive activities. For example:

1. **Workshops and demonstration experiments**: Researchers from the project team visit schools equipped with portable, safe, and engaging experimental kits, adapted to the age and knowledge level of the students. Thus, pupils have interactive discussions during the experiments and spend time conducting experiments themselves. These sessions, lasting 1-2 hours, encourage questions and direct participation, making abstract chemistry tangible and fun.
2. **Lab immersion**: To bridge the gap between classroom learning and cutting-edge research, students take part in guided tours of the consortium's research laboratories. Here, they can see both how researchers carry out their daily work and the infrastructure they use. Under the close supervision of researchers, participants observe live experiments and even manipulate equipment, gaining insight into professional workflows and the excitement of discovery.
3. **Debates and interactive lectures**: Dynamic sessions feature discussions led by experts and PhD students on actual global topics, highlighting chemistry's essential role in innovation and sustainability. Topics include high-performance materials for extreme conditions, green fuels (e.g., hydrogen and biofuels), emerging technologies in biomaterials (e.g., hydrogels for drug delivery), and chemistry's contributions to combating climate change (e.g., carbon capture or renewable energy) as well as any other topic that is launched by the participants. Formats include Q&A sessions, debates, and multimedia visual materials, fostering lively exchanges and enabling students to envision their own contributions to these fields.

In this respect, the project emphasizes a collaborative dialogue. Rather than simply witnessing a demonstration, pupils are encouraged to propose hypotheses, predict outcomes, and discuss

failures. This shifts the classroom dynamic from a "teacher-led" model to a "community-of-inquiry" model, which has been shown to increase student persistence in STEM fields (National Research Council 2011).

3. Preliminary Results and Observations

At the end of the activities, students are asked to anonymously complete questionnaires expressing their opinion about the session they participated in. These questionnaires are completed either in printed format or online. Up to now, over 800 students have participated in the activities offered by the *ŞTIE* project, but not all of them have expressed their willingness to complete the questionnaires associated with these activities. However, we believe we have enough answers to draw some conclusions regarding pupils' perception of a more applicative and interactive way of learning chemistry.

It is worth mentioning that approximately 100 questionnaires have been analyzed for the present paper. Following this analysis, we observe interesting situations. First, it is interesting to note that the number of high school students who reported that participated in such activities is slightly lower than those who did not participate, while, in the case of middle school students, the situation is the opposite, as can be seen from **Figure 1**.

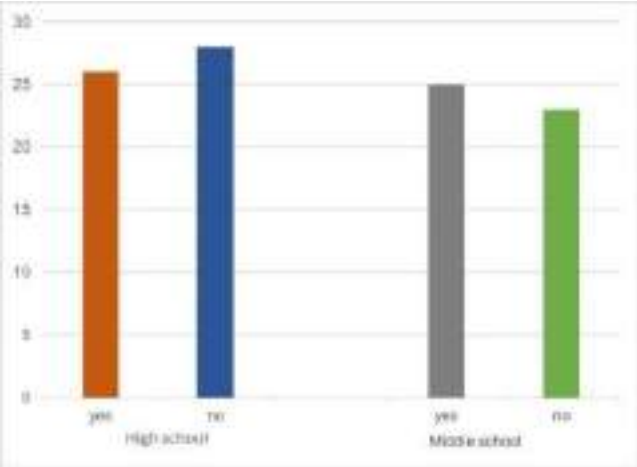

Figure 1. Participation in *ŞTIE* project activities among high school and middle school students

When asked how motivated students are to learn more about science/research/chemistry after following these activities, students considered themselves rather very motivated or motivated to

participate in such activities than less motivated. This indicates not only the need for chemistry classes in which theory is combined with the experimental part, but also the fact that students perceive and assimilate the information more easily in this way. This situation is easily seen from **Figure 2**.

At the end of the activities, all pupils reported that the experiments made chemistry more interesting than standard lessons. At the same time, teachers noted that students who participated in the activities were better able to explain some aspects of chemistry processes.

Even though this project is still ongoing, we can consider that this project is well received among young people, taking into account that, regardless of their level of education, all students considered such an activity useful and responded with humanity that they would follow such an activity in the future or would recommend such an activity to another person. This situation is presented in **Figure 3**.

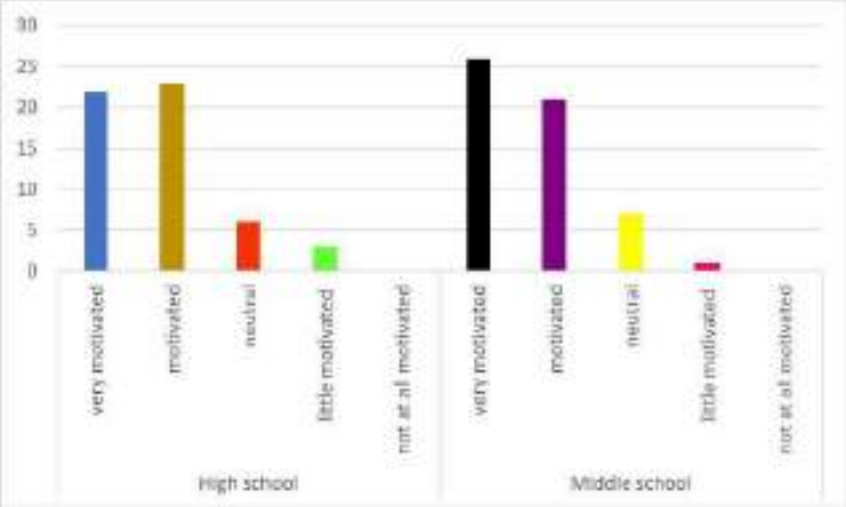

Figure 2. Motivation levels among high school and middle school students

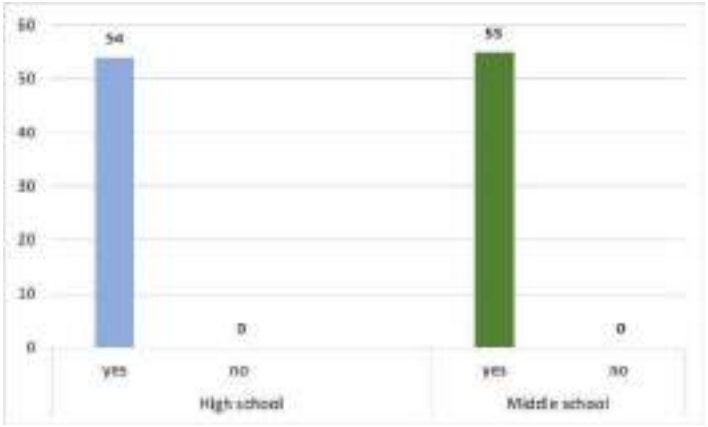

Figure 3. Students' perceptions of the activity's usefulness and their willingness to participate in the future

Following the analysis of the collected data, we can say that the "bridge" created by the *ŞTIE* project has a double scope: it offers students access to equipment that their schools do not have and emphasizes the importance of the researcher, showing that a career in science is accessible and collaborative.

During the activities, the researchers observed that the interest of middle school pupils in such activities and in actively participating in them is higher than among high school students. This may be due primarily to the easy access to technology and information, but also to the fact that high school students begin to have other priorities (e.g., preparing for the baccalaureate exam), chemistry not being among them. It is also possible that this subject, which they have been studying for a few years, is not taught in their understanding and that is why they find it very difficult to learn and uninteresting.

However, in the long term, the impact of such initiatives is profound. They contribute to the formation of a generation that is better informed, more curious and better prepared to understand and address the challenges of the future. At the same time, they create the premises for attracting young people to careers in science and research, in a context where the need for specialists is growing (Doni et al., 2026).

Overall, the practical impact and utility of the *ŞTIE* project are reflected across three distinct educational and societal levels:

- For pupils: it fosters critical thinking through engaging experimental activities, enhances understanding of the role of chemistry in everyday life, and serves as a tool for early career orientation.
- For teachers: It provides tangible support for continuous professional development by offering modern resources and applied teaching strategies that increase classroom engagement.
- For society: It builds bridges of trust and credibility; in an era marked by misinformation, the project provides clear scientific benchmarks validated directly within research laboratories.

4. Conclusions

The transformation of science education requires moving beyond the constraints of the traditional classroom. The *Science for Future Researchers: Experiments and Knowledge* project highlights that students are intrinsically motivated by the "doing" of science. By integrating them into professional research environments, we not only improve the acquisition of their theoretical knowledge but also cultivate the researchers of tomorrow.

The *ŞTIE* project serves as a successful pilot for science outreach in Romania along with the other projects of this kind that have been financed. Preliminary findings confirm that practical application is the most effective tool for arousing curiosity.

As the project continues, data will be collected to see if the trends found so far are maintained or changing. However, the sustainability of such projects remains a challenge. Short-term funding cycles provide “sparks” of interest, but long-term systemic change requires a permanent integration of research-school partnerships into the national curriculum.

Challenges and future implications

To ensure the long-term success of the Romanian scientific research sector, it is crucial that policymakers continue to support such collaborative outreach initiatives, guaranteeing that the "laboratory experience" is a fundamental right of every pupil, not a rare privilege. Therefore, to ensure a constant access to interactive, practical classes as well as laboratory experiments for each

student to better understand chemistry but also to capture their attention during the teaching process, and spark their interest so that they can choose careers in research in the future, it is imperative to: (a) restore school laboratories to their primary function; (b) create permanent specialized programs for future researchers; (c) increase fiscal incentives for private-sector involvement in science education.

Unfortunately, the main challenge remains the implementation of such initiatives as those listed above. Although projects such as the *ŞTIE* project are very successful at the moment, this program must continue if other efforts cannot be made to facilitate students' access to quality education.

In the short term, this can be resolved through institutional partnerships so that the universities and institutes' laboratories become an extension of the school classrooms, thus creating a "virtual" infrastructure that benefits both the schools and the research institutions by fostering a pipeline of future talents.

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Exploring the Role of Virtual Reality in Physical Education for Stress Adaptation Among Adolescents in Socio-Political Crisis Settings

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Abstract

Physical education can serve as more than a motor domain. In unstable social environments, it can also function as a structured context for emotional regulation, controlled challenge, and resilience-oriented learning. The present quantitative experimental study examined cardiovascular stress reactivity during a single-session virtual reality protocol embedded in a secondary-school physical education setting. Fifty high school students aged 15-19 years participated (25 males, 25 females). After a resting baseline assessment, each participant completed a time-pressured virtual fire emergency task followed by a standardized 5-minute AimXr combat-survival challenge. Heart rate was monitored continuously with a Mi Band 6 wearable, and the primary physiological outcomes were resting heart rate, minimum heart rate, average heart rate, maximum heart rate. In addition, a composite performance score was derived from cardiovascular and task-performance indicators. The findings indicated clear cardiovascular activation during virtual exposure, with average heart

rate increasing substantially from pre-exposure baseline to task performance. The primary physiological outcomes were resting heart rate, minimum heart rate, average heart rate, and maximum heart rate. Average heart rate showed a weak-to-moderate positive association with performance score. This finding suggests that greater cardiovascular engagement was modestly related to better task performance, but it should be interpreted cautiously because the study did not formally test a curvilinear model. The result may be discussed conceptually in relation to the Yerkes-Dodson framework, but it does not provide direct evidence of an inverted-U relationship. The results support the educational use of supervised virtual reality in physical education as a safe means of rehearsing decision-making, self-regulation, and stress adaptation in adolescents living under conditions of heightened uncertainty.

Keywords: virtual reality, physical education, cardiovascular response, adolescent resilience, socio-political crisis.
JEL Classification: I.

1. Introduction

Physical education is increasingly understood as a multidimensional school subject with physical, affective, social, and cognitive value rather than as a narrow vehicle for motor training alone. Reviews of school-based physical education and youth physical activity have linked participation to broad developmental benefits, while major policy documents continue to frame quality physical education as an important contributor to health, inclusion, and life-skills education (Biddle et al., 2019; UNESCO, 2015; World Health Organization, 2020).

This broader view becomes especially relevant in socio-political crisis settings. Adolescents exposed to prolonged uncertainty, emergency discourse, forced displacement in their communities, or conflict-related anxiety may not necessarily require direct trauma simulation in school. Rather, they may benefit from structured, developmentally appropriate opportunities to rehearse self-control, situational awareness, and adaptive coping under manageable pressure. Research on war-affected and crisis-affected youth has repeatedly emphasized ecological resilience, school functioning, social support, and protective processes over purely deficit-oriented framings of trauma (Betancourt & Khan, 2008; Betancourt et al., 2013; Masten, 2014; Panter-

Brick & Leckman, 2013; Tol et al., 2011).

Within that perspective, virtual reality is pedagogically attractive because it allows controlled exposure to challenge without exposing learners to real danger. The sense of presence created by immersive environments can heighten emotional engagement and decision urgency, but the school retains control over scenario content, duration, intensity, and debriefing. This makes VR conceptually compatible with resilience-oriented physical education in settings where preparedness, uncertainty tolerance, and emotional composure are educationally salient objectives. At the same time, immersion alone does not guarantee better learning. The educational literature indicates that instructional design, usability, cognitive load, and sequencing strongly shape outcomes (Jensen & Konradsen, 2018; Makransky & Lilleholt, 2018; Makransky & Petersen, 2019, 2021; Merchant et al., 2014; Radianti et al., 2020).

Against this background, the present study investigated whether an acute VR protocol embedded in physical education would elicit measurable cardiovascular activation in adolescents and whether this activation would vary by sex and relate to performance. The study was guided by two The expectations: first, that VR exposure would increase cardiovascular activation relative to rest; and second, that performance would be associated with the magnitude of cardiovascular activation, without assuming that higher activation would always be beneficial.

2. Literature Review

A substantial body of work has established that immersive and semi-immersive virtual environments can increase attention, presence, engagement, and perceived relevance in educational tasks, although effects on knowledge outcomes are mixed and depend on the fit between media, task structure, and learner preparation (Jensen & Konradsen, 2018; Merchant et al., 2014; Parong & Mayer, 2018; Radianti et al., 2020). Studies by Makransky and colleagues further suggest that VR learning processes follow both affective and cognitive pathways, in which presence, positive emotion, usability, cognitive value, and self-efficacy jointly influence outcomes rather than immersion acting as a simple main effect (Makransky & Lilleholt, 2018; Makransky & Petersen, 2019, 2021).

Theoretical work on presence and experiential transformation helps explain why VR is particularly suitable for stress-adaptation pedagogy. Slater and Sanchez-Vives (2016) argued that immersive

VR changes behavior primarily when users respond to virtual events as if they matter, while Riva et al. (2016) emphasized the capacity of immersive systems to reorganize emotionally meaningful experience and support adaptive change. In educational settings, these mechanisms suggest that VR can be used not only for content delivery but also for embodied rehearsal of coping, composure, and action sequencing under time pressure.

The safety-training literature is especially relevant to the present study. Virtual environments have been shown to support procedural learning in safety scenarios and to compare favorably with traditional materials in terms of engagement and, in many cases, retention. Fire and evacuation training has emerged as a prominent domain, and recent meta-analytic evidence indicates that VR safety training generally outperforms conventional approaches in knowledge acquisition and retention, although the literature still suffers from limited theoretical integration and relatively sparse long-term follow-up (Buttussi & Chittaro, 2018, 2021; Pallavicini et al., 2016; Scorgie et al., 2024).

From a psychophysiological standpoint, adolescence is a period of heightened sensitivity to stress-related biological and psychosocial demands. Reviews have documented developmental shifts in stress responsivity during adolescence, while meta-analytic work on heart rate variability has supported the use of cardiovascular indices as pragmatic markers of autonomic regulation under stress. (Kim et al., 2018; Laborde et al., 2017; Romeo, 2013; Shaffer & Ginsberg, 2017). Simulation research in education also indicates that heart rate can capture meaningful stress changes across task phases, although excessive activation may hinder performance rather than help it, in line with the classic Yerkes-Dodson formulation (Nakayama et al., 2018; Yerkes & Dodson, 1908).

Taken together, the literature supports the integration of immersive technologies into school contexts when the aim is not only content transmission but also the development of self-regulation, situational awareness, and adaptive coping. In unstable socio-political environments, this is particularly relevant because education systems require methods that are engaging, ethically acceptable, and capable of simulating challenge without reproducing trauma.

3. Methodology

The study used a quantitative experimental design with one standardized VR session per participant. The protocol was conducted at Laude-Reut Educational Complex, Bucharest, Romania, in a school gymnasium annex temporarily configured as a supervised VR assessment station. Data were collected between September 2025 and January 2026. Each participant completed the same experimental sequence, consisting of a resting baseline assessment, a fire-emergency VR simulation, and a standardized 5-minute AimXr challenge. The crisis frame was educational rather than traumatic: students were not exposed to graphic injury, victimization, or war scenes. Instead, the scenarios were designed to represent emergency preparedness, uncertainty management, rapid response, and cognitive pressure, which are constructs relevant to resilience education in socio-politically unstable environments. The pedagogical aim was to observe physiological adaptation to controlled stress, not to simulate trauma.

Immersive stimuli were delivered using a Meta Quest 2 headset, and the 5-minute combat-survival block was standardized through AimXr in an offline, bot-controlled condition. Cardiovascular data were recorded continuously with a Mi Band 6 wrist-worn monitor. The Quest 2 supports 1832 × 1920 resolution per eye and refresh rates up to 120 Hz, while AimXr provides a repeatable shooter-survival environment for timed decision-making tasks. Recent validation work suggests that smart-band devices can be used cautiously for field-based monitoring, although they should not be treated as equivalent to clinical-grade instruments (Ortiz-Gutiérrez et al., 2025).

3.1. Participants

The sample comprised 50 adolescents enrolled in high school, with equal sex distribution: 25 males and 25 females. Participants were between 15 and 19 years of age (M = 16.8, SD = 1.1). Recruitment took place through physical education classes in a public secondary school setting. Inclusion criteria were regular participation in school physical education, absence of known acute cardiovascular or respiratory illness on the day of testing, and ability to tolerate headset use. Students were excluded if they reported severe motion sickness history, a current panic episode, or medical advice against strenuous or stress-inducing activity.

Resting heart rate was collected during seated quiet rest before exposure. The observed baseline range in the present sample was 63-84 bpm, which remained consistent with normative

expectations for adolescents and older teenagers.

All procedures complied with ethical standards for research involving minors. Students younger than 18 years participated only after written parental informed consent and student assent had been obtained, while participants aged 18 or older provided their own written informed consent. Participation was voluntary, and students were informed that they could discontinue at any point without academic consequences. A physical education teacher and school psychologist were present throughout testing, and the scenarios were piloted to avoid excessive psychological distress. The study protocol conformed to the principles of educational beneficence, proportional challenge, and supervised withdrawal.

Figure 1. Two of the participants

3.2. Experimental Procedure

Testing was performed individually. Each session began with a briefing, equipment fitting, and a 5-minute seated adaptation period. During the final 3 minutes of this period, resting heart rate was recorded. Participants then completed a very brief headset familiarization segment to reduce novelty effects unrelated to the experimental tasks.

The first experimental task was a fire emergency simulation designed to create cognitive and

emotional pressure without trauma exposure. Students were required to activate the alarm, identify the fire source, locate the extinguisher, operate it correctly, and extinguish the fire under time pressure. The scenario rewarded rapid but accurate sequencing and penalized ineffective or delayed action. Completion time varied across participants depending on efficiency and errors.

Immediately after the fire task, participants entered the AimXr challenge for a fixed duration of 5 minutes. To improve comparability, the same map, session length, and difficulty setting were used for all students. Participants were instructed to remain active, survive as long as possible, minimize deaths, and defend themselves effectively against virtual opponents. Because the purpose was to elicit controlled cognitive stress rather than violent immersion, the task was framed as a perceptual-motor decision challenge within a gamified environment.

The total active test duration therefore consisted of the individualized fire-simulation time plus the fixed 5-minute AimXr block. Across the full sample, mean total task duration was 7.8 minutes (SD = 0.7), with a mean fire-simulation completion time of 2.8 minutes (SD = 0.6).

3.3. Variables and Measurements

Resting heart rate. Resting HR was defined as the average bpm recorded during the final 3 minutes of quiet seated rest prior to headset exposure.

Minimum, average, and maximum heart rate. During the active VR period, minimum HR reflected the lowest valid value captured, average HR represented the arithmetic mean across the entire test, and maximum HR represented the highest recorded peak. These indices were selected because acute stress reactivity is often expressed through both overall cardiovascular elevation and transient peaks of autonomic mobilization (Kim et al., 2018; Romeo, 2013).

Performance score: task performance was operationalized through a study-specific composite index ranging from 0 to 100 points. The score was constructed to summarize observable behavioral performance across the two virtual reality tasks: the fire-emergency simulation and the AimXr combat-survival challenge. Higher values indicated better overall task performance.

The composite performance score included four components: fire-task time efficiency, fire-procedure accuracy, death avoidance, and combat effectiveness. Each component was first converted to a 0–100 scale so that all indicators had the same direction of interpretation, with higher scores representing better performance.

Fire-task time efficiency reflected how quickly each participant completed the fire-emergency simulation. Because shorter completion times indicated better performance, this variable was reverse-normalized using the following formula:

$$\text{Fire Time Efficiency} = 100 \times [(T_{max} - T_i) / (T_{max} - T_{min})]$$

where Ti represents the fire-task completion time of participant, Tmax represents the longest completion time recorded in the sample, and Tmin represents the shortest completion time recorded in the sample.

Fire-procedure accuracy reflected the correctness of the emergency-response sequence. Five key procedural steps were evaluated: activating the alarm, identifying the fire source, locating the extinguisher, using the extinguisher correctly, and extinguishing the fire. The score was calculated as follows:

Fire Procedure Accuracy = 100 × (Correct Steps / 5)

where Correct Steps represents the number of correctly completed procedural steps for participant.

Death avoidance reflected survival efficiency during the 5-minute AimXr challenge. Because fewer deaths indicated better performance, this variable was reverse-normalized using the following formula:

$$\text{Death Avoidance} = 100 \times [(D_{max} - D_i) / (D_{max} - D_{min})]$$

where Di represents the number of deaths recorded for participant, Dmax represents the highest number of deaths recorded in the sample, and Dmin represents the lowest number of deaths recorded in the sample.

Combat effectiveness reflected the participant's ability to respond effectively to virtual opponents during the AimXr challenge. It was based on the number of opponents eliminated and was normalized using the following formula:

$$\text{Combat Effectiveness} = 100 \times [(K_i - K_{min}) / (K_{max} - K_{min})]$$

where Ki represents the number of opponents eliminated by participant, Kmax represents the highest number of eliminations recorded in the sample, and Kmin represents the lowest number of eliminations recorded in the sample.

The final performance score was calculated using the following weighted formula:

Performance Score = 0.30 × Fire Time Efficiency + 0.25 × Fire Procedure Accuracy + 0.25 × Death Avoidance + 0.20 × Combat Effectiveness

The weighting structure was selected on pedagogical grounds. Greater importance was assigned to emergency-task efficiency, correct action sequencing, and survival-oriented behavior than to opponent elimination alone. This choice was consistent with the educational purpose of the protocol, which was to assess controlled decision-making, situational awareness, and adaptive functioning under pressure rather than gaming ability or aggressive output. Therefore, the performance score should be interpreted as a transparent, study-specific task-performance index, not as a standardized psychological or clinical scale.

Figure 2. Example of HR measured with the wearable device

3.4. Statistical Analysis

Data were analyzed using descriptive and inferential statistics. Means and standard deviations were reported for resting heart rate, minimum heart rate, average heart rate, maximum heart rate, and performance score. The Shapiro-Wilk test was used to assess the normality of the main continuous variables.

To examine cardiovascular activation during the VR protocol, resting heart rate was compared with average heart rate during the active VR tasks using a paired-samples t test. Sex-based comparisons were conducted using independent-samples t tests when distributional assumptions were met. Effect sizes were reported using Cohen's d, with values of approximately 0.20, 0.50,

and 0.80 interpreted as small, moderate, and large effects, respectively.

The association between cardiovascular activation and task performance was examined using Pearson correlation analysis between average heart rate and performance score. Statistical significance was set at $p < .05$. All analyses were interpreted cautiously because of the modest sample size and the exploratory nature of the single-session school-based protocol.

4. Results and Discussions

Shapiro-Wilk testing indicated acceptable normality for resting heart rate, minimum heart rate, average heart rate, maximum heart rate, and performance score (all $p > .05$). Therefore, parametric procedures were used for the main comparisons. **Table 1** presents the descriptive statistics by sex and for the total sample.

Variable	Male (n = 25)	Female (n = 25)	Total (N = 50)
Resting HR (bpm)	71.6 ± 5.5	73.9 ± 5.7	72.8 ± 5.6
Minimum HR (bpm)	70.8 ± 6.0	72.1 ± 6.2	71.5 ± 6.1
Average HR (bpm)	103.9 ± 9.4	100.1 ± 8.7	102.0 ± 9.1
Maximum HR (bpm)	137.4 ± 12.6	132.6 ± 12.1	135.0 ± 12.4
Performance score (0-100)	65.8 ± 11.2	58.9 ± 10.9	62.4 ± 11.5

Table 1. Descriptive statistics

Across the full sample, average heart rate during the VR tasks was markedly higher than resting heart rate. A paired-samples t test indicated that the increase from resting HR ($M = 72.8$, $SD = 5.6$) to average task HR ($M = 102.0$, $SD = 9.1$) was statistically significant and large in magnitude, $t(49) = 20.84$, $p < .001$. This result indicates that the combined VR protocol elicited clear acute cardiovascular activation in the participating adolescents.The sex-based inferential comparisons are summarized in **Table 2**.

Comparison	Test statistic	p	Effect size
Resting HR	t(48) = -1.45	.153	d = 0.41
Minimum HR	t(48) = -0.75	.455	d = 0.21
Average HR	t(48) = 1.48	.145	d = 0.42

Maximum HR	t(48) = 1.37	.177	d = 0.39
Performance score	t(48) = 2.21	.032	d = 0.62

Table 2. Inferential comparisons

Sex-based comparisons showed no statistically significant differences in resting heart rate, minimum heart rate, average heart rate, or maximum heart rate. The only statistically significant sex-based difference was observed for performance score, with males obtaining higher scores than females, $t(48) = 2.21$, $p = .032$, $d = 0.62$. The effect size was moderate, suggesting a meaningful but not extreme difference in task performance.

This finding should be interpreted cautiously. The performance score included fire-task time efficiency, fire-procedure accuracy, death avoidance, and combat effectiveness. Therefore, the observed difference may reflect differences in prior familiarity with game-like visuomotor tasks, speed of interaction with the virtual environment, or tactical adaptation during the AimXr challenge, rather than any general difference in stress adaptation capacity.

Correlation analysis showed a weak-to-moderate positive association between average heart rate during the VR tasks and performance score, Pearson's $r = .29$, $p = .041$. This suggests that students who displayed greater cardiovascular engagement during the VR protocol tended to obtain slightly higher task-performance scores. However, the association was modest and should not be interpreted as evidence that higher physiological activation is always beneficial.

Overall, the results support two main observations: first, the VR protocol elicited meaningful cardiovascular activation, as shown by the increase from resting heart rate to average heart rate during task performance; and second, task performance was moderately higher among males, while the main heart-rate indicators did not differ significantly by sex.

The present study examined whether a brief, supervised virtual reality protocol embedded in physical education could elicit measurable cardiovascular activation and generate observable task-performance differences among adolescents. The main finding was that average heart rate during the VR tasks was substantially higher than resting heart rate. This indicates that the protocol produced clear acute cardiovascular activation, even though the scenarios were educationally framed and did not involve traumatic or unsafe content.

This finding is important because it suggests that VR can be used in physical education as a

controlled pedagogical environment for challenge, attention, and decision-making under pressure. In contrast to real emergency exposure, VR allows students to experience urgency, uncertainty, and task demands while remaining in a safe and supervised school setting. This is consistent with broader views of physical education as a subject that supports not only motor development, but also self-regulation, health education, social responsibility, and life skills (Bailey, 2006; UNESCO, 2015; World Health Organization, 2020).

The results also suggest that VR-enhanced physical education may be relevant for resilience-oriented learning. In socio-politically unstable contexts, schools need educational methods that help adolescents rehearse calm action, situational awareness, and adaptive coping without reproducing traumatic experiences. The present protocol addressed this need by using non-graphic emergency and survival tasks that required rapid perception, decision-making, and behavioral control. This approach is compatible with ecological perspectives on youth resilience, which emphasize protective educational environments, competence, and adaptive functioning rather than deficit-based understandings of stress exposure (Betancourt & Khan, 2008; Betancourt et al., 2013; Masten, 2014; Tol et al., 2011).

A weak-to-moderate positive association was found between average heart rate during the VR tasks and performance score. This suggests that students who showed greater cardiovascular engagement tended to perform slightly better. One possible interpretation is that moderate physiological activation may support attention, readiness, and task involvement. However, this result should be interpreted cautiously. The study did not formally test a curvilinear model, and the correlation does not prove that higher activation always improves performance. Therefore, the finding should be understood as evidence of association, not causation.

The sex-based results showed that males obtained moderately higher performance scores than females, while the main heart-rate indicators did not differ significantly by sex. This pattern does not support the conclusion that one sex experienced greater physiological stress or showed superior stress adaptation. A more cautious interpretation is that the performance difference may reflect task-specific factors, especially prior familiarity with game-like visuomotor environments, speed of interaction with VR controls, or tactical adaptation during the AimXr challenge. Because prior gaming experience was not measured, this explanation remains provisional.

The construction of the performance score was intended to reduce the risk of interpreting the

AimXr component as a simple gaming or combat score. The index included fire-task time efficiency, fire-procedure accuracy, death avoidance, and combat effectiveness. Greater weight was assigned to emergency-task efficiency, correct procedural sequencing, and survival-oriented behavior than to opponent elimination alone. Therefore, the score should be interpreted as a task-specific indicator of adaptive performance under pressure, not as a standardized psychological or clinical measure.

The findings are also consistent with educational VR literature showing that the value of VR depends not only on immersion, but also on task design, usability, emotional engagement, cognitive load, and instructional integration (Jensen & Konradsen, 2018; Makransky & Lilleholt, 2018; Makransky & Petersen, 2019, 2021; Radianti et al., 2020). In this study, the protocol was intentionally brief, structured, supervised, and followed by an educational framing. This may explain why the task produced measurable physiological and behavioral responses without requiring excessive intensity.

From a practical perspective, short VR modules could be integrated into physical education as supplementary activities for emergency preparedness, self-regulation, and decision-making under pressure. A feasible school-based model would include a short physical and psychological briefing, a clearly bounded VR challenge, heart-rate monitoring, and a structured debrief. The debrief could focus on breathing, emotional labeling, tactical reflection, safe decision-making, and the difference between impulsive reaction and controlled response.

Several limitations should be acknowledged. First, the study used a single-session design, so the results refer to acute cardiovascular activation rather than long-term stress adaptation. Second, the sample size was modest and does not allow detailed subgroup analysis. Third, heart rate was recorded with a consumer-grade wearable device under school conditions, so the physiological data should be interpreted as practical field-based indicators rather than clinical measurements. Fourth, prior gaming experience, physical fitness, trait anxiety, and perceived stress were not assessed, which limits the interpretation of individual performance differences. Fifth, the socio-political crisis frame was conceptual and educational; therefore, the results should not be generalized to clinical trauma populations or to adolescents directly exposed to severe crisis without additional safeguards.

Overall, the findings suggest that supervised VR tasks can create a meaningful but controlled state

of cardiovascular engagement in adolescents. When integrated carefully into physical education, VR may support not only motor and perceptual-motor activity, but also preparedness, emotional regulation, decision-making, and resilience-oriented learning.

5. Conclusions

A brief, supervised VR protocol embedded in physical education elicited meaningful cardiovascular activation in adolescents, as reflected by the increase from resting heart rate to average heart rate during task performance. These findings suggest that VR can be used as a controlled pedagogical tool for emergency preparedness, situational awareness, and adaptive functioning under pressure.

The performance score indicated moderate overall task performance, with males obtaining higher scores than females. However, this difference should be interpreted as task-specific and may reflect prior familiarity with game-like visuomotor environments rather than a general difference in stress adaptation. No significant sex differences were observed in the main heart-rate indicators.

Used judiciously, VR may help physical education extend beyond traditional motor practice toward controlled challenge, decision-making, emotional regulation, and resilience-oriented learning. However, several limitations should be acknowledged. First, the study used a single-session design, which means that the findings reflect acute cardiovascular activation rather than long-term stress adaptation. Second, the sample size was modest and drawn from one educational setting, limiting the generalizability of the results. In addition, heart rate was recorded with a consumer-grade wearable device, and variables such as prior gaming experience, physical fitness, perceived stress, and trait anxiety were not assessed.

Future research should address these limitations by using larger and more diverse samples, repeated-session or longitudinal designs, and validated psychological measures alongside more precise physiological monitoring. Further studies should also examine whether repeated exposure to supervised VR tasks in physical education can produce measurable improvements in self-regulation, emergency preparedness, and stress-management skills over time.

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Bullying Awareness and Prevention in a Multicultural University Context: Student Adaptation in Cluj-Napoca

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Abstract

This paper examines bullying awareness and prevention in a multicultural university context, focusing on students' adaptation to a new cultural environment in Cluj-Napoca, Romania. Although bullying has been widely documented in schools, less attention has been paid to how it is perceived and addressed in higher education, where mobility and diversity are strongly present. Babeș-Bolyai University (UBB), as a large academic centre attracting students from different regions of Romania and from abroad, provides a relevant context for exploring how everyday interactions, communication practices and institutional messages shape students' understanding of bullying.

The study aims to investigate how students define and recognize bullying, how they experience or witness it in academic and social settings, and how they evaluate existing prevention and awareness efforts. Particular attention is paid to differences between local students and those who relocate to Cluj-Napoca, often encountering a new cultural, linguistic and social environment. The research also explores how factors such as perceived belonging, openness to diversity and trust in university structures relate to students' willingness to seek help or report bullying situations.

Methodologically, the paper is based on a questionnaire survey conducted among undergraduate and postgraduate students enrolled in several faculties at UBB in Cluj-Napoca. The instrument includes items on perceptions of bullying prevalence, personal or observed experiences, bystander reactions, attitudes towards diversity and inclusion, and perceived accessibility of support services and reporting mechanisms. Descriptive and comparative analyses are used to identify patterns and differences among student groups.

Preliminary insights highlight the role of communication in facilitating or hindering adaptation and in shaping bullying awareness. Students who report a lower sense of belonging and limited social networks appear more vulnerable to subtle forms of exclusion and more hesitant to report negative experiences. At the same time, many respondents indicate a preference for clear, student-

centred communication strategies, peer-led initiatives and online campaigns that address bullying and discrimination in relatable language. The paper discusses implications for designing more inclusive, culturally sensitive prevention and awareness programmes in higher education, with a focus on strengthening institutional communication, student engagement and support structures at UBB.

Keywords: Bullying prevention, Student adaptation, Multicultural university context, Communication strategies, Higher education.

1. Introduction

Bullying represents an increasingly discussed issue within educational environments, particularly in relation to students' well-being, academic integration and social inclusion. While the phenomenon has been extensively examined in primary and secondary education, research focusing on bullying in higher education remains comparatively limited. Recent studies indicate that university students may also experience various forms of exclusion, discrimination and hostile behaviors, especially within multicultural academic contexts characterized by increased mobility and social diversity.

Contemporary universities are increasingly shaped by internationalization, cultural diversity and student mobility, factors that significantly influence interpersonal interactions and adaptation processes. Students who relocate to a new academic environment frequently face challenges associated with communication, integration and the development of social support networks. In such contexts, subtle forms of bullying and exclusion may affect students' ability to adapt successfully to university life and may reduce their sense of belonging within the academic community.

Recent literature highlights that bullying in higher education often differs from traditional school bullying through its indirect and relational nature. Instead of overt physical aggression, university students more commonly encounter behaviors such as social exclusion, repeated mockery, online harassment or marginalization based on cultural, social or regional differences. These forms of behavior may negatively influence students' emotional well-being, academic participation and trust in institutional support mechanisms.

Within multicultural university environments, adaptation and belonging become essential dimensions of the student experience. Research suggests that students who experience lower levels of social integration and acceptance are more vulnerable to isolation and less willing to report bullying or discrimination situations. At the same time, perceptions regarding institutional support and inclusivity significantly influence students' confidence in university structures and their willingness to seek help.

Cluj-Napoca represents a relevant context for investigating these issues due to its status as one of the most important academic centers in Romania and its highly diverse student population. Babeș-Bolyai University attracts students from different regions of the country as well as international students, creating a multicultural academic environment where processes of adaptation, integration and social interaction become particularly significant.

The main objective of this study is to explore how university students in Cluj-Napoca perceive bullying and exclusion within a multicultural academic environment and how adaptation and sense of belonging influence their willingness to report bullying situations.

The research is guided by the following research questions:

RQ1: How do students in Cluj-Napoca perceive and recognize bullying and exclusion behaviors in the university environment?

RQ2: How does adaptation to a new academic and cultural environment influence students' sense of belonging and their willingness to report bullying situations?

The study is based on a quantitative exploratory approach using a questionnaire survey administered to undergraduate, master's and doctoral students studying in Cluj-Napoca. By examining students' perceptions regarding bullying, exclusion, adaptation and reporting behavior, the research aims to contribute to the growing literature addressing inclusion and student well-being in multicultural higher education environments.

2. Literature Review

2.1. Bullying and Exclusion in Higher Education

Recent literature increasingly examines bullying within higher education contexts, not only in pre-university educational environments. Current studies indicate that the university environment may

facilitate subtle forms of aggression and social exclusion, particularly in contexts characterized by cultural diversity, academic competition and complex processes of social adaptation. Although bullying is often associated with school-age students, recent research demonstrates that the phenomenon continues to affect university students as well, influencing social integration, academic performance and overall well-being.

In higher education, bullying manifests differently compared to traditional forms commonly identified in school settings. The literature highlights that direct aggression is less frequent, being replaced by indirect behaviors such as social isolation, exclusion from groups, repeated mockery, marginalization or discrimination based on cultural and social differences. Tight (2023) argues that bullying in higher education remains an insufficiently explored issue, despite the fact that a significant number of students report experiences associated with victimization and social exclusion. At the same time, Edward (2025) emphasizes that university bullying includes various forms, ranging from verbal harassment and cyberbullying to relational exclusion and identity-based discrimination.

Furthermore, the development of digital communication and the expansion of online interactions have contributed to the emergence of new forms of cyberbullying within academic environments. These manifestations include hostile comments in digital spaces, exclusion from online groups or ridiculing behaviors on platforms used for academic activities. Recent studies suggest that such forms of aggression may have an impact similar to or even stronger than direct negative interactions, as they affect both the academic and social dimensions of students' lives.

Specialized literature also underlines that multicultural university environments may generate additional vulnerabilities for certain categories of students. Cultural, regional and linguistic differences may influence the way students are integrated into social and academic groups. In this context, exclusion and marginalization frequently occur through microaggressions, stereotypes or difficulties in integrating into university social networks. Rodríguez-Hidalgo et al. (2025) highlight that bullying based on cultural and identity differences becomes more frequent in communities characterized by high levels of diversity.

The consequences of such behaviors extend beyond social relationships and directly influence students' academic experiences. Recent studies associate bullying and exclusion with adaptation difficulties, reduced academic participation, lower levels of belonging and increased social

isolation. Tay & Zamore (2024) demonstrate that negative perceptions of the university environment are associated with more frequent experiences of victimization and hostile behaviors. Similarly, research on student adaptation indicates that experiences of marginalization and exclusion reduce students' ability to integrate effectively into a new academic environment.

These aspects are particularly relevant in universities characterized by high mobility and cultural diversity, where social and academic adaptation becomes essential for student integration. In this regard, multicultural universities such as Babeș-Bolyai University in Cluj-Napoca represent relevant contexts for investigating the relationship between bullying, adaptation and sense of belonging.

2.2. Multicultural Adaptation, Sense of Belonging and Reporting Behavior

The process of adapting to the university environment represents one of the most important stages in the experiences of students who relocate to a new city for their studies. Adaptation involves not only academic integration, but also social and cultural integration into a new environment. Recent literature indicates that students who leave their family environment and previous social networks may experience difficulties related to communication, integration and the development of a new sense of belonging.

Eryılmaz et al. (2023) highlight that the university adaptation process is influenced by factors such as the social environment, peer support, university activities and the degree of familiarity with the new city. At the same time, research shows that lack of social integration, communication difficulties and negative experiences within the university environment may reduce students' ability to adapt effectively.

In multicultural universities, adaptation is also influenced by the cultural and regional diversity of the academic community. Interactions between students coming from different backgrounds may facilitate inclusion and tolerance, but may also generate difficulties associated with stereotypes, cultural differences or feelings of isolation. Recent studies regarding intercultural sensitivity and inclusion in higher education suggest that academic environments encouraging integration and open communication contribute to reducing social vulnerability and increasing students' sense of safety and acceptance.

A central concept in recent literature is the sense of belonging, defined through students' perceptions that they are accepted, integrated and valued within the university community. Recent studies demonstrate that sense of belonging influences both academic participation and emotional well-being, as well as students' willingness to engage socially. In highly diverse university environments, belonging becomes an important factor in reducing isolation and social vulnerability.

At the same time, literature emphasizes that students who fail to develop a sufficient sense of belonging tend to display higher levels of social anxiety, withdrawal and distrust toward institutional structures. Lack of social integration may contribute to the normalization of negative experiences and to the avoidance of reporting bullying or discrimination situations.

Reporting behavior represents another important dimension in recent studies concerning bullying in higher education. Several studies indicate that many students avoid reporting negative experiences because they fear that the situations will not be treated appropriately or that their reactions will be minimized. Edward (2025) underlines that university bullying is frequently underreported due to stigmatization, lack of trust and the perception that institutional mechanisms are not sufficiently accessible or effective.

Moreover, recent research on university environments indicates that perceptions regarding institutional support significantly influence students' willingness to seek help or report negative behaviors. Universities that promote inclusive climates, clear support mechanisms and accessible communication tend to encourage higher levels of trust and engagement among students.

Although recent literature increasingly addresses bullying in higher education, there is still a limited number of studies investigating the relationship between multicultural adaptation, sense of belonging and reporting behavior within multicultural universities. In this context, the present research aims to explore how students in Cluj-Napoca perceive bullying and social exclusion and how adaptation and integration influence their willingness to report such situations.

3. Methodology

3.1. Research Design

The present study is based on a quantitative exploratory research design aimed at investigating university students' perceptions regarding bullying, exclusion, adaptation and reporting behavior

within a multicultural academic environment. A questionnaire survey was selected as the primary research method due to its suitability for collecting perceptions, attitudes and experiences from a relatively large number of participants within a limited time frame.

The exploratory nature of the study is justified by the limited number of recent studies focusing on the relationship between bullying, multicultural adaptation and sense of belonging within Romanian higher education environments. In this context, the research seeks to identify patterns related to students' perceptions of bullying and social exclusion, as well as the influence of adaptation and belonging on reporting behavior.

The study focuses on students enrolled in universities located in Cluj-Napoca, a major academic center characterized by cultural diversity and high levels of student mobility. The multicultural characteristics of the city and its academic environment provide a relevant context for examining issues related to inclusion, adaptation and vulnerability among university students.

3.2. Participants and Sampling

The research sample consists of 120 students enrolled in undergraduate, master's and doctoral programs within the university environment of Cluj-Napoca. Participants include both students originally from Cluj-Napoca and students who relocated to the city for their studies.

The study employs a convenience sampling approach, as participants were selected based on accessibility and voluntary participation. Although this sampling method does not allow for broad generalization, it is appropriate for exploratory research focused on identifying perceptions and tendencies within a specific academic context.

The inclusion of students from different study cycles and backgrounds contributes to a more comprehensive understanding of how bullying, exclusion and adaptation are perceived within multicultural university environments.

3.3. Research Instrument

Data were collected through a structured questionnaire consisting of 10 closed-ended questions organized into four main sections: respondent profile, perceptions of bullying and exclusion, adaptation and belonging, and reporting behavior.

The questionnaire was designed to address the two research questions of the study by examining students' perceptions regarding the frequency and forms of bullying in the university environment,

as well as the relationship between adaptation difficulties, sense of belonging and willingness to report bullying situations.

The instrument included questions regarding students' perceptions of exclusion behaviors, experiences related to adaptation difficulties, feelings of integration within the university environment and levels of comfort associated with reporting bullying situations to university structures.

Closed-ended questions were selected in order to facilitate the comparative analysis of responses and the identification of patterns across participants. The structure of the questionnaire also allowed for a clear and concise quantitative interpretation of the collected data.

3.4. Data Collection and Ethical Considerations

The questionnaire was distributed online through Google Forms between April 22, 2026 and April 30, 2026. Participation in the study was voluntary, and respondents were informed about the academic purpose of the research before completing the questionnaire.

The study respected principles related to confidentiality, anonymity and informed consent. No personally identifiable information was collected, and participants had the possibility to withdraw from the questionnaire at any point.

The collected data were used exclusively for academic and research purposes. Responses were analyzed descriptively in order to identify tendencies and relationships regarding bullying perceptions, adaptation experiences and reporting behavior among students in Cluj-Napoca.

4. Findings and Discussion

4.1. Perceptions of Bullying and Exclusion in the University Environment

The findings indicate that bullying and exclusion are perceived as present but not dominant phenomena within the university environment in Cluj-Napoca. Most respondents reported that such behaviors occur *occasionally* or *rarely*, while a smaller yet significant proportion identified them as *frequent* or *very frequent*.

This distribution suggests a pattern of moderate normalization, where bullying is neither perceived as an exceptional occurrence nor as a pervasive structural issue. Rather, it appears embedded in everyday social interactions, aligning with recent literature that conceptualizes bullying in higher

education as diffuse and context-dependent rather than overtly aggressive (Tight, 2023; Tay & Zamore, 2024).

A critical dimension of this perception emerges from the types of behaviors identified by respondents. The most frequently selected forms include:

- social exclusion,
- irony or mocking behavior,
- online harassment.

In contrast, direct forms of aggression (e.g., explicit verbal hostility) appear less dominant.

These results reinforce the idea that bullying in higher education operates primarily through relational and symbolic mechanisms, rather than through direct confrontation. This supports existing research emphasizing the role of microaggressions, social marginalization and informal exclusion practices in shaping negative student experiences (Rodríguez-Hidalgo et al., 2025).

Importantly, a considerable proportion of respondents reported having witnessed bullying or exclusion behaviors, even when not directly experiencing them. This distinction between perception and observation suggests that bullying is socially visible and collectively recognized, even when not individually internalized. Such visibility contributes to the normalization of these behaviors, potentially reducing their perceived severity and discouraging intervention.

4.2. Adaptation and Perceived Vulnerability in a Multicultural Context

The data reveal a strong consensus among respondents regarding the vulnerability of students who relocate to Cluj-Napoca for their studies. Most participants agreed that these students are more exposed to exclusion and adaptation difficulties.

This perception reflects a shared understanding of relocation as a critical transition, involving not only academic adjustment but also social and cultural negotiation. It aligns with recent studies highlighting that students entering new academic environments face challenges related to communication, identity positioning and integration into pre-existing social networks (Eryılmaz et al., 2023).

However, when examining self-reported adaptation difficulties linked to bullying, the results become more nuanced. While a majority of respondents indicated that they had *rarely* or *never* experienced such difficulties, a non-negligible proportion reported experiencing them *occasionally* or even *frequently*.

This discrepancy between collective perception (high vulnerability) and individual experience (moderate direct impact) suggests the presence of a perceived vulnerability gap. In other words, students recognize structural or contextual risks affecting others - particularly relocated peers - even when they do not personally identify as victims.

This finding is particularly valuable, as it points to the role of social awareness and collective narratives in shaping perceptions of exclusion. It also suggests that vulnerability in multicultural environments may operate at a symbolic and anticipatory level, not only through direct experience.

4.3. Sense of Belonging and Patterns of Social Integration

The majority of respondents reported feeling **mostly or very much accepted and integrated** within the university environment. This indicates that, at a general level, the academic context in Cluj-Napoca supports a relatively positive integration experience.

However, the data also reveal a smaller but significant segment of students who reported only *moderate*, *low* or *very low* levels of integration. This subgroup represents a zone of latent vulnerability, which is particularly relevant in multicultural settings.

When interpreted alongside responses regarding marginalization, a consistent pattern emerges. While most students reported that they had *never* felt excluded based on cultural, social or regional background, a noticeable proportion indicated experiencing such situations *occasionally* or *rarely*, and in some cases even *frequently*.

These findings suggest that exclusion is not structurally dominant, but selectively experienced, affecting specific individuals or groups rather than the student population as a whole. This aligns with contemporary research on belonging in higher education, which emphasizes that integration is unevenly distributed, often depending on social positioning, cultural proximity and access to peer networks.

From an analytical perspective, the coexistence of high overall belonging with localized experiences of marginalization indicates a dual-layer integration model:

- a general perception of inclusion at the macro level;
- pockets of exclusion at the micro-social level.

This duality is particularly relevant in multicultural academic environments, where diversity can simultaneously foster inclusion and generate fragmentation.

4.4. Reporting Behavior and Institutional Trust

One of the most significant findings of the study concerns students' willingness to report bullying situations. The data show that a substantial proportion of respondents feel either *neutral* or *uncomfortable* when considering reporting such incidents, while fewer participants expressed high levels of comfort.

This pattern indicates a limited level of reporting confidence, suggesting that institutional mechanisms for addressing bullying may not be perceived as fully accessible, effective or trustworthy.

This reluctance to report aligns with recent literature emphasizing that bullying in higher education is often underreported, not necessarily due to its absence, but due to:

- fear of not being taken seriously,
- normalization of exclusion behaviors,
- lack of trust in institutional responses (Edward, 2025).

When considered in relation to the previous findings, reporting behavior appears closely linked to both sense of belonging and perceived vulnerability. Students who feel less integrated or who perceive higher levels of exclusion may also exhibit greater hesitation in engaging with formal support structures.

This suggests that reporting behavior should not be understood solely as an individual decision, but rather as a relational and context-dependent process, influenced by:

- social integration,
- perceived legitimacy of institutional structures,
- and the broader communicational climate within the university.

Synthesis of Findings

Taken together, the results of this study outline a nuanced picture of bullying and adaptation in a multicultural university environment:

1. Bullying is present primarily in subtle, relational forms, rather than through direct aggression.
2. Students perceive relocated peers as more vulnerable, even when personal experiences are less frequent.
3. A generally strong sense of belonging coexists with localized experiences of marginalization.
4. There is a clear hesitation in reporting bullying, indicating potential gaps in institutional trust and communication.

These findings contribute to the growing body of research on higher education by highlighting the importance of examining not only the presence of bullying, but also the interplay between perception, adaptation, belonging and institutional engagement within multicultural academic contexts.

5. Conclusions, Implications and Limitations

5.1. Conclusions

This study set out to examine how university students in Cluj-Napoca perceive bullying and exclusion within a multicultural academic environment, as well as how adaptation and sense of belonging influence their willingness to report such situations.

The findings reveal that bullying in higher education is not perceived as a dominant or structurally pervasive phenomenon. Instead, it is understood as a moderately present and normalized aspect of everyday interaction, primarily manifesting through subtle and relational forms such as social exclusion, irony and online behaviors. This supports the growing body of literature suggesting that bullying in university settings operates through indirect and socially embedded mechanisms, rather than overt aggression.

A key conclusion of the study is the distinction between collective perception and individual experience. While most respondents agree that students who relocate to Cluj-Napoca are more vulnerable to exclusion and adaptation difficulties, fewer report direct personal experiences of such challenges. This indicates the presence of a perceived vulnerability gap, where awareness of risk exists at a social level, even when not strongly internalized individually.

At the same time, the results highlight a generally positive perception of integration, with most students reporting high levels of acceptance within the university environment. However, this overall sense of belonging coexists with localized experiences of marginalization, affecting a smaller but significant segment of respondents. This duality suggests that inclusion in multicultural academic environments is unevenly distributed, rather than uniformly experienced.

Finally, one of the most significant findings concerns students' willingness to report bullying situations. Although a proportion of respondents express comfort in reporting, a substantial number remain neutral or hesitant. This indicates a fragmented level of institutional trust, where reporting behavior is influenced not only by individual attitudes, but also by perceptions of accessibility, effectiveness and legitimacy of university support structures.

5.2. Practical Implications

The findings of this study have several relevant implications for higher education institutions, particularly those operating in multicultural contexts.

First, universities should recognize that bullying in higher education does not typically manifest through explicit forms, but rather through subtle and relational dynamics. As a result, prevention strategies should move beyond traditional anti-bullying frameworks and address issues such as social exclusion, microaggressions and informal group dynamics.

Second, the perceived vulnerability of relocated students suggests the need for more structured and proactive integration mechanisms. Universities should invest in:

- peer mentoring programs,
- orientation activities focused on social inclusion,
- and communication strategies that facilitate early integration into academic and social networks.

Third, the coexistence of high belonging with pockets of marginalization highlights the importance of identifying and supporting at-risk subgroups, rather than relying solely on general indicators of student satisfaction.

Finally, the results related to reporting behavior emphasize the need to strengthen institutional trust and communication clarity. Universities should ensure that:

- reporting mechanisms are visible and accessible,
- procedures are clearly communicated,
- and students perceive responses as effective and supportive.

In this sense, communication plays a central role not only in awareness, but also in shaping students' willingness to engage with institutional structures.

5.3. Limitations and Future Research

Despite its contributions, the study presents several limitations that should be acknowledged.

First, the use of a convenience sample limits the generalizability of the findings. Although the sample includes students from different study levels and backgrounds, it reflects a specific academic context and may not fully represent broader student populations.

Second, the research relies on self-reported data, which may be influenced by subjective perceptions, social desirability or individual interpretation of bullying and exclusion behaviors.

Third, the use of exclusively closed-ended questions, while appropriate for quantitative analysis, does not capture the full complexity of students' experiences and meanings associated with bullying and adaptation.

Future research could address these limitations by:

- incorporating qualitative methods, such as interviews or focus groups;
- expanding the sample to include multiple universities or international contexts;
- and exploring in greater depth the relationship between communication strategies, institutional trust and reporting behavior.

Additionally, further studies could examine how specific categories of students—such as international students or those from minority backgrounds—experience adaptation and exclusion within multicultural academic environments.

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Education as a Tool for Civic Participation in the Danube Region

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Abstract

Education has always played multiple roles for both individuals and society. In today's world, education is no longer limited to the transmission of knowledge, but has also become a fundamental tool for promoting civic participation and engagement, especially in regions marked by cultural diversity and shared challenges, such as the Danube Region.

This paper explores the capacity of educational systems to encourage civic engagement among students, highlighting how universities in the Danube Region actively integrate civic engagement into their curricula or provide platforms and facilitate student involvement in community-based initiatives. The analysis is complemented by a survey conducted among students in the Danube region exploring their perceptions and experiences related to education and civic engagement.

The findings emphasize the potential of civic participation to promote pathways to unity and mutual understanding across multicultural communities in the Danube Region, while also offering strategic recommendations for improving civic engagement through education.

The topic is particularly relevant, given the importance of civic participation for sustainable development in the region, but also at the EU level, as well as the need to involve citizens as much as possible in decision-making processes and to promote intercultural dialogue.

This study is limited by the availability and accessibility of data from the various key stakeholders, particularly universities within Danube region.

Keywords: education, students, civic participation, Danube Region, universities

JEL Classification: I21, D72, P16, R58

1. Introduction

Throughout history, education has served a variety of functions for both individuals and society. In today's world, education is no longer limited to the transmission of knowledge (Niazi, A. 2025), but has also become a fundamental tool for promoting civic participation and democratic engagement. Civic participation refers to the active involvement of individuals in their communities, by contributing to the social, political and civic life of their societies. This involvement can also be through activities such as voting, volunteering, participating in public debates and engaging in community initiatives (Galston, 2007; Qiao et al., 2017).

The Danube Region is characterized by a rich diversity of ethnic, linguistic and religious communities (Simionescu, 2018; Crețan, 2006). Considered one of the most complex regions in Europe (Gál et al., 2013), the Danube Region follows the course of the Danube River (Padło et al., 2021), often regarded as a symbol of Europe (Koller, 2010), from Germany through ten countries to the Black Sea (Sommerwerk et al., 2009). The region encompasses countries with different historical legacies, political systems, cultural traditions and educational structures (Schmid et al., 2023).

This context represents a unique framework for examining the relationship between education and civic participation. In this area with a population of over 80 million inhabitants (Miklós, 2010), promoting active citizenship is particularly relevant due to shared historical experiences, economic disparities and varying levels of democratic development (Ribeiro et al., 2016).

This paper explores how education can function as a tool for increasing civic participation in the Danube Region, focusing on students' perceptions, educational experiences and institutional practices. The research combines a student survey with an exploratory institutional mapping analysis of universities affiliated with the Danube Rectors' Conference network[1].

The study addresses the following research questions:

- How does education influence civic participation among young people in the Danube Region?
- To what extent do universities integrate civic participation within educational and institutional practices?
- What are students' perceptions regarding active citizenship and regional participation?

2. Literature Review

The literature review for this article was structured around four distinct but interconnected parts. The first part focuses on the concept of civic participation and its role in democratic and community life. The second examines the Danube Region from both geographical and political perspectives. The third direction addresses civic participation within the Danube Region at a scalar

[1] https://www.drc-danube.org/

level. Finally, the fourth focuses on education and civic participation among young people and students.

The literature review was based on key theoretical approaches related to civic participation, community development and cultural integration, particularly Putnam's theory of social capital (2000) and the civic voluntarism model proposed by Brady et al. (1995).

Civic participation is generally recognized as a central component of democratic governance and community development (Cnaan & Park, 2016; King & Hustedde, 2001). It may involve both formal and informal actions and activities of engagement, including volunteering, activism, political participation and community involvement.

In the Danube Region, level of engagement reflects the complex socio-political climate and cultural dynamics. At scalar level, Bitusikova (2018) examines civic activism in Slovakia, while Lütgenau (2010) highlights the role of civil society in the European Danube Strategy framework.

Regional and territorial trends in the Danube Region regarding collective involvement and regional identity were also taken into account, as reflected in the study conducted by Mayer and Langer (2015) and in the studies by Römisch et al. (2024).

The literature highlights that bridging the information gap between citizens and authorities is essential for effective participation, as evidenced by civic programs that enhance transparency and communication (Protik et al., 2018). In the context of community planning, participatory approaches add value in terms of legitimacy, local ownership and sustainability (Langton, 1987; Simmons, 1994; Tosun, 1999).

Overall, the literature emphasizes that inclusive, transparent, and collaborative mechanisms are critical for building resilient and empowered communities in the Danube region.

Also, this study integrates official documents that support civic participation and governance. It is normal for the presence of public authorities to play a significant role in participatory governance (Bonini et al., 2015), thus creating the necessary circumstances to represent a state of support or favorability (Foster, 2011).

Previous studies (Bomberg, 2001; Grote & Gbikpi, 2002) emphasize that a democratic institutional framework is needed to develop participatory governance. In this sense, the support given by the European Union, through Decision No. 445/2014/EU of the European Parliament and of the Council, to cultural governance and the European Capitals of Culture programme (Council

conclusions on the participatory governance of cultural heritage) is evident. Within this framework, the official recognition of European cultural heritage was integrated through the European Parliament resolution: "Towards an integrated approach to European cultural heritage". This element of policies, which considers cultural heritage as a common good, reflects the principles of polycentric governance as stated in the study by Stephan et al. (2019). Compared to traditional top-down models, this approach is considered more flexible, resilient and capable of providing more practical solutions.

The literature clearly shows that education is closely linked to higher levels of civic engagement. Dee (2020) explains that education increases individuals' understanding of society and strengthens their capacity to engage in the community.

Similarly, Manning & Edwards (2014) explain that civic education, when interactive and encouraging critical thinking, can increase political participation among young people. The education system also plays a key role in shaping civic behaviour. Reichert and Print (2018) show that students who have participated in civic learning activities at school over time are more likely to become active citizens later in life. At the university level, Medne et al. (2024) emphasize that higher education helps the individual develop civic competences and ultimately supports the creation of a more sustainable and responsible society.

Furthermore, in many countries, civic education is considered essential for building inclusive and democratic societies. Borhan (2025) argues that education, and especially civic education, encourages young people to actively participate in social and political life, while Golubeva (2018) emphasizes that education is closely linked to active citizenship and community involvement.

However, social and regional factors are important in the development of civic participation, as noted by Jeleva (2021), who shows that young people are more easily involved in civic life if the opportunities and environment in which they live are favourable.

Recent literature highlights three major trends that are particularly relevant for this study:

First, digital citizenship has become an increasingly important dimension of civic participation, highlighting the role of online platforms and social media in shaping political awareness, civic engagement, and mobilization among young people (Loader et al., 2014).

Second, service-learning and experiential education are widely recognized as effective pedagogical approaches that connect academic learning with community engagement and practical civic experience (Biesta, 2011; Schulz et al., 2018).

Third, the internationalization of higher education is expanding opportunities for cross-border civic learning, particularly within European macro-regions, where universities function as hubs for transnational collaboration, intercultural exchange, and identity formation (Hoskins et al., 2017).

3. Methodology

This paper is part of a comprehensive research study developed within the National Research Program (Program Nucleu) and analyzes, at this stage, how education can serve as a tool for increasing civic participation in the Danube Region. The study focuses on two main research directions: theoretical perspectives and practical applications (Bocsi et al., 2020; Musteață-Pavel & Lixăndroiu, 2024; Rădoi & Lixăndroiu, 2025).

The exploratory approach is based on mixed methods and relies on multiple sources of qualitative and quantitative data in order to ensure a double-layered analysis: bibliographic research, document analysis, civic participation materials, project reports, and survey-based data collection. In this context, the article explores students' experiences and perceptions regarding civic education and civic engagement through an exploratory online survey conducted among students from the Danube Region. In parallel, universities from the Danube Region were contacted in order to gather information highlighting how these institutions integrate civic engagement into their curricula or provide platforms for students to participate in community initiatives.

Sampling and recruitment

The questionnaire was distributed online between April and May 2026 using a purposive sampling strategy targeting youth leadership and higher education networks within the Danube Region. The survey was administered in English, selected as a common language to facilitate participation among respondents from different countries.

A total of 48 contact points across 43 distinct institutions and organizations were directly invited to participate and redistribute the survey link. This network included 18 university student union sand student parliaments, 7 regional pan-European youth networks, 4 specialized Danube regional

initiatives, and 14 youth NGOs and academic administrative bodies. Geographically, the recruitment covered 11 countries, specifically: Austria, Bosnia & Herzegovina, Bulgaria, Croatia, Germany, Hungary, Italy, Moldova, Romania, Serbia, and regional European secretariats.

Because the survey was disseminated through institutional and student networks, it was not possible to determine the exact number of individuals who received the invitation; therefore, a precise response rate could not be calculated. However, a total of 121 valid completed responses were received, forming the final data set used in the analysis.

Survey instrument

A quantitative social research questionnaire was developed in order to investigate young people's perspectives on civic participation and education in the Danube Region (Zahariev & Yordanov, 2024). The structured cross-sectional survey questionnaire consisted of 18 items, using predominantly closed-ended questions, including single-choice and multiple-response formats, along side one open-ended question to provide additional qualitative insights.

The questionnaire was designed to collect opinions, attitudes, and experiences related to civic participation, education, regional awareness concerning the Danube Region, and civic engagement. The aim was to identify trends among students and young people's perspectives on civic participation and the role of education in promoting active citizenship in the Danube Region.

Ethics

Participation was voluntary and anonymous, and no personal or identifiable data were collected. Respondents were informed about the purpose of the study and that the data would be used exclusively for academic research purposes. All data were processed and stored in accordance with applicable data protection regulations.

Institutional mapping methodology

In parallel with the survey research, an institutional mapping exercise was conducted in order to identify whether universities affiliated with the DanubeRectors' Conference network include topics related to civic participation, civic education, democratic engagement, volunteering, sustainability, service-learning, or community development within their curricula, study programmes, or extracurricular activities.

The institutional mapping analysis was conducted using qualitative document analysis combined with structured coding procedures. Data sources included publicly available information: university websites, course catalogues, study programme descriptions and official educational materials. Each university was coded across three dimensions: Civic-related courses/themes; Volunteering / student engagement; Cross-border / Danube-related projects.

A category was coded as "Yes" only when explicitly supported by institutional documentation. Coding was conducted by one primary researcher and verified through secondary cross-checking of all entries. Due to the exploratory nature of the study, no statistical inter-coder reliability coefficient was calculated, but all ambiguous cases were re-checked.

4. Results and Discussions

The survey included 121 respondents from several countries within the Danube Region, providing an exploratory perspective on young people's civic participation and educational experiences. The collected quantitative data were analysed using descriptive statistical methods, while qualitative responses were examined through thematic analysis in order to identify recurring perceptions, motivations and challenges related to civic participation and education.

4.1. Demographic profile of respondents

Regarding age distribution, respondents were relatively evenly distributed across age groups, with 29.8% aged 23-26, 28.9% aged 18-22, 28.1% over 26, and 13.2% under 18, reflecting a diverse mix of adolescents, students, and young adults with varied educational and professional backgrounds."

In terms of educational level, nearly half of the respondents held a Bachelor's degree (47.1%), followed by Master's students (29.8%), while 23.1% reported high school as their highest level of education. The distribution reflects diverse educational backgrounds among respondents, with a predominance of academically engaged young people.

The respondents represented a diverse range of countries from the Danube Region. Romania accounted for the largest share of participants (20.7%), followed by Germany and Austria (10.7% each), and Slovakia (9.9%). Bulgaria, Hungary, and Croatia each represented 8.3% of the sample,

while Moldova, Serbia, and Ukraine each accounted for 7.4%. Montenegro was represented by 0.8% of respondents. Although not geographically balanced, the sample includes respondents from multiple Danube Region countries, supporting the transnational and exploratory dimension of the research.

A significant majority of respondents (91.7%) stated that they live in a region located near the Danube River, while only 8.3% reported living outside the immediate Danube area. This finding highlights the strong geographical relevance of the sample and suggests that most participants are directly connected to the social, cultural, and regional dynamics of the Danube Region.

4.2. Civic awareness and perceptions of participation

Overall, 52.9% of respondents rated civic participation as “important” and 47.1% as “very important”. No responses were recorded in the ”neutral” or ”not important” categories, indicating a uniformly positive perception of civic engagement and highlighting its perceived relevance for democratic and community life in the Danube Region.

Answer options	**Percentage**	**Frequency**
Very important	47.1	57
Important	52.9	64
Neutral	0.0	0
Not important	0.0	0
Total answers	***100***	***121***

Table 1. Perceptions of the importance of civic participation

Source: processed by authors

Respondents identified several forms of civic participation, with voting being the most frequently recognized activity (57%), followed by volunteering (49.6%), community-based projects (44.6%), online activism (43%), and participation in protests (31.4%). These findings suggest that respondents tend to associate civic engagement primarily with institutional and community-

oriented forms of participation, while more direct or less conventional forms of engagement are recognized by a smaller share of participants.

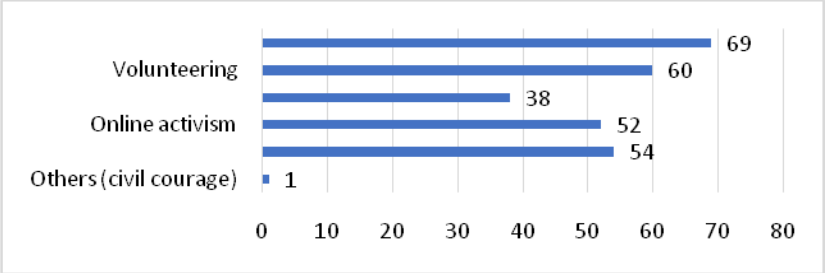

Figure 1. Forms of civic participation identified by respondents

Source: *processed by authors*

Regarding the perceived importance of civic participation in their own countries, 56.2% of respondents considered it "important", while 40.5% rated it as "very important".A small proportion of respondents selected "neutral" (2.5%) and "not important" (0.8%). Overall, these results indicate a strongly positive perception of civic engagement at the national level.

Answer options	Percentage	Frequency
Very important	40.5	49
Important	56.2	68
Neutral	2.5	3
Not important	0.8	1
Total answers	***100***	***121***

Table 2. Perceived importance of civic participation at national level

Source: *processed by authors*

Furthermore, an overwhelming majority of respondents (95.9%) declared that they are aware of civic issues related to the Danube Region, including environmental protection and cross-border cooperation, indicating a very high level of regional awareness among participants and reinforces the relevance of transnational civic education within the Danube macro-regional framework.

Answer options	Percentage	Frequency
Yes	95.9	116
No	4.1	5
Total answers	***100***	***121***

Table 3. Awareness of civic issues related to the Danube Region

Source: *processed by authors*

4.3. Role of education in promoting civic participation

When asked whether their educational experience had prepared them to become active citizens, the majority of respondents (74.4%) answered "yes", while 24% stated "partially" and 1.6% selected "no", suggesting that, for most participants, education plays a significant role in fostering civic readiness, though there is still room for further strengthening of civic education components in formal education systems.

Answer options	Percentage	Frequency
Yes	74.4	90
Partially	24.0	29
No	1.6	2
Total answers	***100***	***121***

Table 4. Respondents' perceptions of education in preparing active citizens

Source: *processed by authors*

Regarding educational methods, debates and project-based learning were each considered most effective for fostering civic participation (28.9%), followed by group work (23.1%) and lectures (18.2%), highlighting the importance of combining interactive and collaborative learning methods in order to effectively support civic engagement among young people.

Answer options	Percentage	Frequency

Lectures	18.1	22
Debates	28.9	35
Projects	28.9	35
Group work	23.1	28
Others	0.8	1
Total answers	***100***	***121***

Table 5. Educational methods perceived as most effective by respondents

Source: *processed by authors*

A significant majority of respondents (93.4%) reported having participated in civic activities organized by their schools or universities, while only 6.6% stated that they had not taken part in such activities. This finding suggests that educational institutions play a very important role in facilitating civic engagement opportunities.

Answer options	**Percentage**	**Frequency**
Yes	93.4	113
No	6.6	8
Total answers	***100***	***121***

Table 6. Participation in civic activities organized by educational institutions

Source: *processed by authors*

Respondents also identified several civic-related themes included in their educational experiences. Environmental protection was the most frequently mentioned topic (48.8%), followed by European cooperation (44.6%) and civic rights and responsibilities (43%). Overall, the findings suggest a relatively balanced exposure to key civic themes, with a slight emphasis on environmental issues, reflecting the growing relevance of sustainability within educational contexts in the Danube Region.

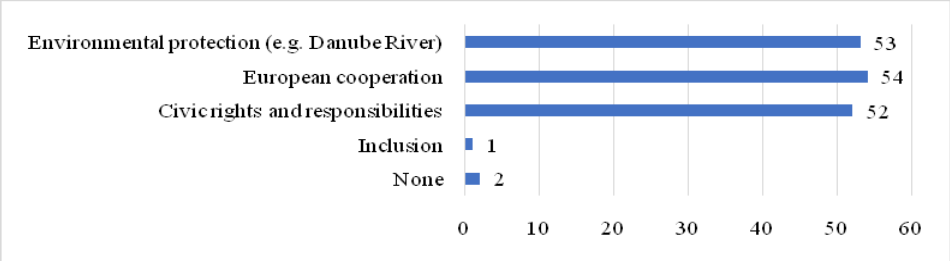

Figure 2. Civic-related topics included in respondents' educational experience

Source: *processed by authors*

Regarding institutional support, most respondents (84.3%) stated that schools and universities encourage civic participation, while 14.9% believed that this support is only partial and 0.8% reported that such encouragement is not present. These findings suggest that civic participation is largely perceived as being supported at the institutional level, although a small proportion of respondents still see room for further integration of civic engagement within educational practices and academic culture.

Answer options	Percentage	Frequency
Yes	84.3	102
Partially	14.9	18
No	0.8	1
Total answers	***100***	***121***

Table 7. Perceptions of educational institutions' role in encouraging civic participation

Source: *processed by authors*

4.4. Regional participation and cross-border engagement

The results suggest a very high level of interest and involvement in regional initiatives related to the Danube Region, as 91.7% of respondents stated that they had previously participated in activities connected to the Danube Region. These findings indicate that the Danube Region is

perceived not only as a geographical area, but also as a space for educational, civic, and transnational interaction.

Answer options	Percentage	Frequency
Yes	91.7	111
No	8.3	10
Total answers	***100***	***121***

Table 8. Participation in activities related to the Danube Region

Source: *processed by authors*

Furthermore, respondents expressed a high level of interest in future cross-border cooperation, with 81.8% interested in participating in cross-border projects with students from other Danube countries, while 11.6% answered "no" and 6.6% responded "maybe". These results indicate a general openness toward transnational collaboration, although a small proportion of respondents remain either uncertain or not interested in engaging in such initiatives.

Answer options	Percentage	Frequency
Yes	81.8	99
No	11.6	14
Maybe	6.6	8
Total answers	***100***	***121***

Table 9. Interest in cross-border student projects

Source: *processed by authors*

4.5 Digital participation and online civic engagement

Most respondents (86%) believe that digital platforms facilitate connections between young people across countries, while 9.9% are uncertain and 4.1% disagree, indicating a strong overall perception of their role in supporting cross-border communication, although a small proportion of respondents remain sceptical or uncertain about their effectiveness.

Answer options	Percentage	Frequency

Yes	86.0	104
Not sure	9.9	12
No	4.1	5
Total answers	***100***	***121***

Table 10. Perception of digital platforms in facilitating cross-country connections among young people

Source: *processed by authors*

A large majority of respondents (82.6%) declared that they use digital platforms for civic engagement activities, including petitions, awareness posts, and online civic initiatives, while 17.4% reported that they do not use such platforms for these purposes. These findings suggest that digital tools are widely integrated into young people's civic practices, although a notable minority remains disengaged from online forms of civic participation.

Answer options	**Percentage**	**Frequency**
Yes	82.6	100
No	17.4	21
Total answers	***100***	***121***

Table 11. Use of digital platforms for civic engagement among respondents

Source: *processed by authors*

The vast majority of respondents (99.2%) considered that social media contributes to increasing civic participation, while only 0.8% disagreed. These findings indicate a near-unanimous perception of social media as an important tool in supporting and amplifying civic engagement among young people.

Answer options	**Percentage**	**Frequency**
Yes	99.2	120
No	0.8	1
Total answers	***100***	***121***

Table 12. Perceived impact of Social Media on civic participation

Source: *processed by authors*

Online participation appears to complement traditional forms of civic engagement and may facilitate transnational communication and cooperation within the Danube Region.

4.6. Students' perspectives on education and civic participation

The qualitative responses indicate that students perceive education as a key driver of civic participation, particularly when it moves beyond theoretical instruction toward practical, experience-based learning. Across responses, a central theme is the need for more hands-on and participatory approaches, such as community projects, volunteering, civic simulations, and field activities that connect students with real social issues and civic institutions. Many respondents emphasized that civic education becomes more meaningful when it is directly linked to local community challenges, environmental initiatives, and real-world problem-solving.

Figure 3. Summary of key terms

Source*: processed by authors (https://www.wordclouds.com/)*

A key idea is the importance of partnerships between schools, universities, and local organizations, including NGOs and public institutions. Respondents highlighted that such cooperation could strengthen youth engagement through environmental campaigns, volunteer programs, and student-

led civic initiatives. Several answers also stressed the need to empower and support youth organizations and NGOs working with young people, particularly in professional or vocational education contexts, as well as to encourage universities to organize more civic forums and awareness campaigns.

Digital competence and media literacy emerged as another important theme. Many respondents underlined the need for education to teach students how to critically evaluate information, recognize misinformation, and engage responsibly online. This includes promoting respectful online communication and understanding both the positive and negative impacts of social media on civic participation.

In addition, respondents frequently pointed to the importance of critical thinking, dialogue, and debate-based learning. Interactive methods such as discussions, group work,and debate activities were seen as effective tools for developing civic awareness, democratic understanding, and communication skills. Early civic education was also emphasized, with several participants arguing that civic responsibility and empathy should be nurtured from a young age to build long-term civic habits.

Overall, the responses consistently suggest that civic education should be practical, interactive, and closely connected to real-life experiences. Education is perceived not only as a space for learning about civic values, but also as a platform for actively practicing citizenship through participation, collaboration, and engagement with both local and broader societal issues

4.7. Preliminary institutional mapping of universities in the Danube Region

The institutional mapping analysis indicates that many universities affiliated with the Danube Rectors' Conference integrate civic participation-related themes within curricula, extracurricular activities and institutional strategies. The analysis identified recurring themes such as: active citizenship, democratic governance, sustainability, volunteering, community engagement, European cooperation and social responsibility. To visualize the geographical distribution of the universities united in this consortium from a spatial, geographical perspective, we used Geographic Information Systems (GIS). The data were collected from the GIS database for the country borders, and the route of the Danube River was extracted from Open Street Map. The member cities were

digitized based on the official membership page of the consortium, and the country labels were applied for clarity.

Figure 4 illustrates the spatial distribution and the formation of clusters by country. For example, a major concentration is noted in Romania, which includes the largest number of institutions in the consortium (18 universities) and features the highest spatial density. This is followed by Germanyand Austria, each with 8 members. Another important concentration is represented by institutions in the middle sector of the Danube, comprising universities from Hungary, Serbia, and Croatia. At the opposite pole, a lower presence is recorded in Italy, with only two universities included, and in the Republic of Moldova, which is represented by a single institution, highlighting the more peripheral areas of the Danube Region network.

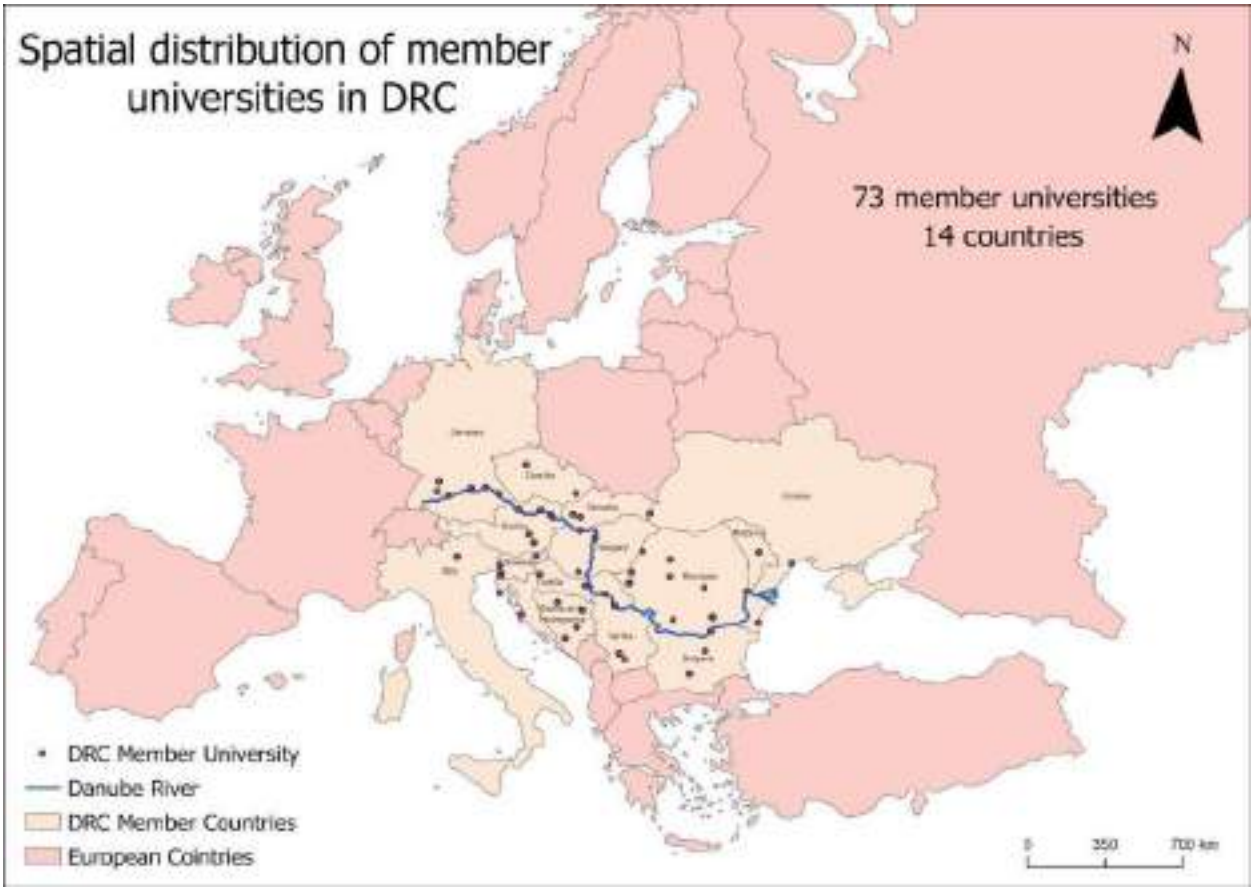

Figure 4. Spatial distribution of university members within the Danube Rectors' Conference (DRC)

Source: *processed by authors*

In order to visualize the preliminary institutional mapping of civic participation and engagement in universities in the Danube Region, a database was created with elements showing how universities in the Danube Region actively integrate civic engagement into their study programs or provide platforms and facilitate student engagement in community initiatives.

Universities such as Babes-Bolyai University, the National School of Political Science and Public Administration Bucharest, the University of Vienna, Corvinus University of Budapest, the University of Belgrade and the University of Novi Sad demonstrate visible engagement in civic education, regional cooperation and student participation initiatives.

The analysis also indicates that civic participation is frequently integrated through non-formal educational activities, volunteering programmes and international cooperation projects rather than exclusively through dedicated academic courses.

Although the integration of civic participation differs significantly between institutions and countries, the preliminary findings suggest that universities increasingly function as facilitators of democratic participation and regional cooperation within the Danube Region.

Nr.crt.	University	Country	Civic-related courses/themes	Volunteering / Student Engagement	Cross-border / Danube projects	Observations
1.	Babes-Bolyai University	Romania	Civic education, European studies, governance, sustainability	Yes	Erasmus+, Service-learning projects	Active involvement in civic and regional initiatives
2.	National School of Political Science and Public Administration	Romania	Public participation, governance, citizenship, democracy	Yes	European cooperation projects	Strong focus on democratic governance and public administration
3.	West University of Timisoara	Romania	Civic engagement, inclusion, sustainability	Yes	Danube and EUSDR initiatives	Active regional cooperation profile
4.	University of Bucharest	Romania	Political participation, European citizenship, civic rights	Yes	Erasmus and NGO partnerships	Civic-related themes mainly in social sciences

Nr.crt.	University	Country	Civic-related courses/themes	Volunteering / Student Engagement	Cross-border / Danube projects	Observations
5.	University of Vienna	Austria	Democracy studies, civic education, European governance	Yes	International and Danube cooperation	Strong interdisciplinary civic education environment
6.	University of Graz	Austria	Sustainability, social responsibility, democratic participation	Yes	Regional cooperation projects	Civic participation linked with sustainability agendas
7.	Corvinus University of Budapest	Hungary	Governance, European studies, public participation	Yes	International student projects	Focus on public policy and civic governance
8.	University of Pécs	Hungary	Community engagement, social inclusion	Yes	Cross-border cooperation	Regional academic cooperation visible
9.	University of Belgrade	Serbia	Democracy, public policy, civic studies	Yes	DRC and international partnerships	Strong institutional international engagement
10.	University of Novi Sad	Serbia	Civic responsibility, sustainability, European cooperation	Yes	Danube regional projects	Important actor in Danube academic cooperation
11.	University of Zagreb	Croatia	Citizenship education, inclusion, social participation	Yes	Erasmus and regional initiatives	Civic themes integrated mainly in humanities and social sciences
12.	University of Maribor	Slovenia	Sustainability and civic engagement	Yes	Cross-border educational cooperation	Active participant in regional academic networks
13.	University of Primorska	Slovenia	Intercultural dialogue, European cooperation	Yes	International partnerships	Strong transnational orientation
14.	University of Ruse	Bulgaria	Environmental protection, European cooperation	Yes	Danube-related activities	Civic themes linked to regional sustainability

Nr.crt.	University	Country	Civic-related courses/themes	Volunteering / Student Engagement	Cross-border / Danube projects	Observations
15.	Constantine the Philosopher University	Slovakia	Citizenship education, social responsibility	Yes	Service-learning initiatives	Participated in civic engagement educational projects
16.	Catholic University of Eichstätt-Ingolstadt	Germany	Service learning, civic engagement	Yes	Erasmus+ Service-learning projects	Direct involvement in civic engagement programmes

Table 13. Preliminary institutional mapping of civic participation and engagement in Danube Region Universities

Source: *Authors' own elaboration based on institutional websites, Erasmus+ project databases, Danube Rectors' Conference documentation, publicly available curricula, and institutional reports. The categories reflect themes identified in publicly accessible documentation and are not intended as exhaustive institutional evaluations.*

In order to visualize the preliminary institutional mapping of civic participation and engagement in universities in the Danube Region, database was created using Geographic Information Systems (GIS). This database highlights how these universities actively integrate civic engagement into their study programs, provide platforms, and facilitate student engagement in community initiatives. The data for countries was downloaded from diva-gis and the universities layer was digitized manually, later added the attributes. This map is created in a choropleth method by the distinct colour of the countries and overlay symbols by the 2 types of data that the universities have. The map features a legend and a list of all member universities.

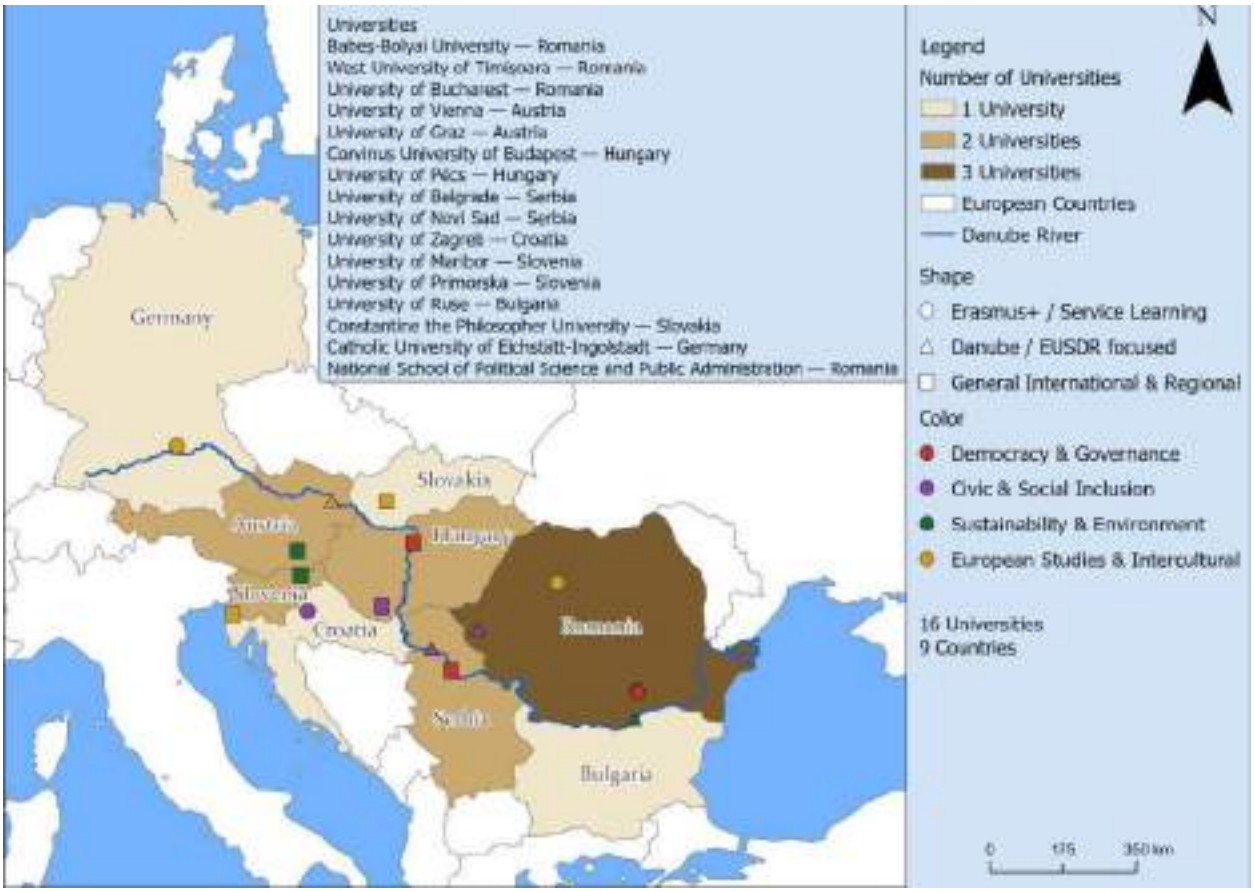

Figure 5. Institutional mapping of civic participation and engagement in Danube Region Universities

Source: *processed by authors*

This map shows that civic engagement is not uniform. What we have found is that higher education institutions are transforming their status from isolated "ivory towers" to active civic actors. We can visualize how universities in the Danube region are moving beyond traditional academia to act as anchors for civic society. By mapping these 16 institutions, we can see a clear regional ecosystem where civic education, democratic governance and cross-border collaboration intersect to address common European challenges.

5. Conclusions

This study contributes to the understanding of civic participation in a macro-regional context, with a focus on the Danube Region as a transnational space of educational and civic interaction.

The findings show that civic participation is highly valued among respondents and is primarily expressed through voting, volunteering, and community engagement. These results confirm a pattern consistent with a mixed model of civic engagement, where traditional forms and emerging digital practices of participation coexist. At the same time, the high level of perceived importance attributed to civic participation suggests a sustained normative commitment to democratic values among young people in the Danube Region.

The findings also underline the central role of education in shaping civic attitudes and competences. While most respondents reported that their education has prepared them for active citizenship, they also emphasized the need for more experiential, practice-based and participatory learning approaches, suggesting a gap between formal civic education and lived civic experience.

A particularly relevant contribution of this study is the strong evidence of regional and transnational civic awareness. The Danube Region emerges not merely as a geographical space, but as a socio-educational and civic framework in which young people develop shared concerns and collaborative practices. This supports macro-regional approaches to identity formation and civic learning, as highlighted in European Union policy frameworks on regional cooperation and youth engagement.

Digital engagement further represents a key dimension of contemporary civic participation. While respondents widely recognize the role of social media and digital platforms in facilitating civic mobilization and cross-border interaction, the difference between perceived usefulness and actual civic use suggests the persistence of a “participation gap” in digital environments.

The preliminary institutional mapping suggests that universities in the Danube Region increasingly integrate civic participation through both formal curricula and non-formal educational practices, including volunteering programmes, service learning, sustainability initiatives, and cross-border cooperation projects. This confirms the role of higher education institutions as facilitators of democratic participation, civic responsibility, and regional cooperation within European educational frameworks.

Furthermore, the visible engagement of universities affiliated with the Danube Rectors’ Conference indicates that civic education is becoming progressively connected to internationalization strategies, European cooperation, and community engagement initiatives,

reinforcing the role of universities as important actors in the development of active citizenship and transnational civic networks in the Danube Region.

In conclusion, the study reinforces the idea that civic education is most effective when it is embedded in participatory, practice-based, and digitally informed learning environments. Strengthening collaboration between schools, universities, civil society organizations, and regional institutions may significantly enhance young people's capacity for active citizenship and democratic participation in an increasingly interconnected European context.

Overall, the study highlights that civic education in the Danube Regionis evolving at the intersection of three major contemporary trends: digital citizenship, service-learning, and internationalized higher education.

The transnational nature of the Danube Region provides a distinctive frame work where thesetrends converge, creating new opportunities for civic learning and participation across borders.

The novelty of this study lies in its macro-regional perspective, as it examines civic participation not only within individual national systems, but also through the shared educational and social dynamics of the Danube Region. In this sense, the paper positions education as a strategic instrument for fostering active citizenship, regional cohesion, and democratic participation across diverse cultural and institutional environments.

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Supporting School Readiness through Intensive Summer Programs: Evidence from an Emergent Literacy Intervention

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Abstract

This study examines the effectiveness of an intensive summer program designed to support school readiness through the development of emergent literacy in preschool children. Using a pre-experimental pre-test/post-test design, 16 preschoolers participated in a two-week intervention including structured daily activities such as guided reading, phonological awareness tasks, and graphomotor exercises.

Emergent literacy was assessed through a multidimensional instrument covering vocabulary, print knowledge, letter recognition, phonemic awareness, early writing, and story comprehension, alongside measures of visual attention and instruction comprehension.

Results indicate significant improvements in emergent literacy and visual attention following the intervention. However, substantial individual variability was observed. Gains in literacy were not consistently associated with improvements in visual attention, suggesting that executive functions – operationalized through instruction comprehension – may play a more important role in mediating learning outcomes.

These findings support a multidimensional perspective on emergent literacy and highlight the importance of integrating cognitive factors into intensive summer programs aimed at enhancing school readiness. The study provides preliminary empirical evidence for the effectiveness of short, structured interventions in early childhood education.

Keywords: school readiness, emergent literacy, intensive summer programs, executive functions, early childhood education

JEL Classification: I21, I24

1. Introduction

The fundamental importance of emergent literacy (pre-literacy) is well documented in the scientific literature, this dimension being considered an essential predictor of school success during the first years of formal education and of subsequent educational trajectories (Cabell, Justice, Logan, & Konold, 2013; Lonigan & Phillips, 2016; Koželuhová & Koželuh, 2024). Longitudinal studies indicate that the level of emergent literacy skills during the preschool years predicts both later reading and writing acquisition and long-term academic outcomes (Cabell, Justice, Konold, & McGinty, 2011; McClelland, Acock, Piccinin, Rhea, & Stallings, 2013; Balea, Kovacs, &

Pogăcean, 2024). In this context, well-structured early interventions become crucial for consolidating a solid foundation of precursor skills, especially among children from socio-economically vulnerable backgrounds (Law et al., 2017; Moonsamy & Carolus, 2019; Xu & Liu, 2021).

Building on these premises, the present study aims to investigate the effectiveness of a two-week intensive programme conducted during the summer holiday for the development of emergent literacy skills among older preschoolers transitioning to the preparatory grade, as well as the role of visual attention and instruction comprehension in explaining the observed progress.

2. Literature Review

Recent research highlights that educational programmes explicitly oriented toward literacy during the preschool years – either through language- and literacy-centered curricula or through complementary programmes – can generate consistent gains in vocabulary, phonological awareness, knowledge of print conventions, and letter recognition, particularly among children at educational risk (Lonigan et al., 2013; Nancollis, Lawrie, & Dodd, 2005; Thomas, Colin, & Leybaert, 2020). Meta-analyses of family literacy programmes and targeted interventions confirm that investments made during the preschool stage present a particularly favorable cost-benefit ratio and contribute to reducing developmental gaps before school entry (Fikrat-Wevers, van Steensel, & Arends, 2021; Hannon, Nutbrown, & Morgan, 2020; Fikrat-Wevers et al., 2021). In Romania, findings from preparatory grade studies and remedial programmes likewise emphasize the need for systematic approaches to emergent literacy, adapted to local contexts and to children's initial developmental levels (Balea, Kovacs, & Temple, 2023; Hurjui, 2024).

A critical moment for such interventions is represented by the transition from kindergarten to the beginning of formal schooling. Intensive summer programmes implemented over short periods but with high frequency have proven effective in accelerating literacy development and strengthening school readiness, including among children with developmental or reading difficulties (Pears, Kim, Fisher, & Yoerger, 2016; Donnelly, Huber, & Yeatman, 2019; Christodoulou et al., 2017). Such interventions aim to maximize exposure to literacy activities within a limited time frame while maintaining a high level of engagement and a playful character, which makes them particularly suitable for preschool-aged children (Lennox, Westerveld, & Trembath, 2018; Yen &

Lee, 2019).

From a theoretical perspective, emergent literacy is a complex construct that includes multiple interrelated subcomponents: expressive vocabulary, knowledge of print conventions, recognition of letters and words, phonemic awareness, early writing skills (e.g., name writing), and story comprehension (Cabell et al., 2013; Cabell et al., 2011; Casani, 2024). Assessments of emergent literacy profiles indicate that these indicators organize into distinct patterns, with direct implications for the design of educational interventions (Cabell et al., 2011; Cabell et al., 2013; Cabell et al., 2011 – profiles). Consequently, programmes targeting multiple subskills simultaneously are more likely to support a smooth transition toward the reading and writing demands of primary education (Lonigan & Phillips, 2016; Koželuhová & Koželuh, 2024; Balea et al., 2024).

In addition to these linguistic and print-related dimensions, the literature also highlights the role of cognitive factors such as visual attention and executive functions in literacy acquisition. Experimental and longitudinal studies show that visuospatial attention supports rapid letter and word recognition, line tracking, and efficient text scanning, thereby influencing the pace of reading acquisition (Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Plaza & Cohen, 2007; Valdois, 2019; Justice et al., 2008; McClelland et al., 2013). At the same time, executive functions – particularly inhibitory control, working memory, and cognitive flexibility – are significantly associated with literacy performance, especially reading comprehension, beyond the contribution of purely linguistic components (Gandolfi, Viterbori, Traverso, & Usai, 2021; Follmer, 2017; Nouwens, Groen, Verhoeven, & Segers, 2021; Williams, 2022). The ability to understand and follow instructions may therefore be viewed as an applied manifestation of executive functions in structured learning situations.

3. Methodology

3.1. Context and participants

The research was conducted within the framework of an intensive summer “school readiness” programme designed as a short-term intervention implemented prior to children’s entry into the preparatory grade. Such programmes, focused on literacy and self-regulation during the summer period, have been shown to significantly improve school readiness, particularly among children at

educational risk (Pears, Kim, Fisher, & Yoerger, 2016; Donnelly, Huber, & Yeatman, 2019; Christodoulou et al., 2017).

The programme described in the present study consisted of 10 consecutive working days, including daily focused activities lasting 60-90 minutes. This structure followed the rationale of short but frequent interventions recommended in the literature on intensive summer programmes: concentrated exposure to literacy tasks within a limited time frame in order to prevent skill erosion and accelerate progress before school entry (Donnelly et al., 2019). The format was designed to maximize children's exposure to emergent literacy stimuli (letter activities, word games, stories, and phonological awareness tasks), while simultaneously maintaining a high level of engagement and reducing the risk of fatigue during the preschool years.

The intervention target group consisted of 16 older preschoolers transitioning to the preparatory grade. The relatively small sample size is typical of pilot studies aimed at testing the feasibility and potential effectiveness of intensive intervention formats prior to implementation on larger samples (Donnelly et al., 2019; Christodoulou et al., 2017).

From an ethical perspective, the study complied with educational research standards. Informed consent for children's participation was obtained from parents or legal guardians, who were informed about the purpose of the intervention, the nature of the activities, and the procedures for data use. All data were processed and reported exclusively in aggregated and anonymized form, ensuring participant confidentiality throughout the research process.

3.2. Intervention design

The present study employed a pre-experimental one-group pre-test/post-test design aimed at evaluating the impact of an intensive educational intervention on the development of emergent literacy. The main dependent variable was the level of emergent literacy skills, analyzed both globally and across specific subcomponents, while the independent variables included participation in the intervention programme and, at a more detailed level, systematic exposure to different types of activities (guided reading, phonological tasks, and graphomotor activities). At the same time, the design allowed for the exploration of the role of moderating variables, such as visual attention and the ability to understand instructions, in explaining the observed progress.

The intervention was implemented over two consecutive weeks in an intensive "school readiness"

format, including structured daily activities. The choice of this format aimed to increase the intervention dose (intensity of exposure), a factor considered essential in the literature for obtaining visible effects within a relatively short period of time. In this respect, the design targeted not only the presence of the intervention itself, but also the frequency and consistency of exposure as operationalized dimensions of the independent variable.

In order to ensure implementation fidelity, each day followed a relatively constant structure, with clearly defined and repeatable sequences. This standardization was intended to reduce contextual variation and increase the comparability of learning experiences among participants, while still preserving the flexibility necessary for adapting to the rhythm of the group. The educational environment was organized to support this coherence: daily routines, the predictable sequence of activities, and the alternation between cognitively demanding tasks and regulation moments (movement activities and guided play) contributed to maintaining an optimal level of engagement and controlling situational variables.

The daily intervention structure followed a predictable routine, starting with emotional regulation and functional routines to facilitate the transition toward subsequent cognitive tasks.

The central component of the design was the “story time” session, which functioned both as the main instructional stimulus and as an element of internal coherence within the intervention. From a methodological perspective, this component may be considered the core mechanism through which language exposure was operationalized, generating the content for subsequent activities. Guided reading, conducted daily in an interactive manner, aimed to simultaneously activate multiple processes: comprehension, anticipation, vocabulary development, and familiarization with print conventions.

Building on this core component, pre-literacy activities were organized as structured tasks oriented toward operationalized objectives targeting the development of phonological awareness, vocabulary, and the relationship between oral and written language. These activities were complemented by graphomotor exercises, which functioned as behavioral indicators of writing readiness, and by practical workshops that facilitated the transfer and application of knowledge in concrete contexts.

Each day concluded with a recap stage, functioning as a form of formative assessment and consolidation of learning acquisitions through verbalization and guided reflection.

3.3. Data analysis

The data analysis aimed to quantify the impact of the 10-day intensive programme on the three variables assessed: overall emergent literacy level, visual attention, and instruction comprehension. Descriptive statistics and paired-samples t-tests were employed, a procedure commonly recommended in pre–post design studies to capture changes within the same group of participants (Cohen, 1988; Lakens, 2013). Inferential analyses were conducted only on participants with complete pre-test and post-test datasets. The practical significance of the observed differences was estimated using effect size measures (Cohen's d), in accordance with standard recommendations from the psychological and educational research literature (Cohen, 1988).

4. Results

The comparative pre-test/post-test analysis revealed a statistically significant increase in the total emergent literacy score, $t(7) = 3.59$, $p = .009$, with a very large effect size (Cohen's $d = 1.27$). The statistical indicators for each dimension are systematized in **Table 1**.

Dimension	t	p (t-test)	p (Wilcoxon)	Cohen's d	Interpretation
Expressive vocabulary	1.87	0.104	0.125	0.66	moderate, non-significant effect
Print concepts	1.26	0.250	0.313	0.44	small-to-moderate effect
Letter recognition	3.33	0.013	0.016	1.18	large, significant effect
Word awareness	1.00	0.351	0.317	0.35	non-significant
Phonemic awareness	2.81	0.026	0.042	0.99	large, significant effect
Name writing	2.37	0.050	0.066	0.84	at the threshold of significance
Story comprehension	-0.70	0.504	0.396	-0.25	no progress
Total score	3.59	0.009	0.016	1.27	very large effect

Table 1. Comparison of pre-test and post-test scores for emergent literacy competencies

4.1. Progress in psychological variables (Visual attention)

The results indicate an improvement in visual attention test scores (maximum score = 18) following the intensive summer programme. The initial mean score was 12.50 (SD = 2.51), while the final mean score increased to 13.88 (SD = 2.17), corresponding to an average gain of +1.38 points (SD = 1.41). A paired-samples t-test showed that this increase was statistically significant, t(7) = -2.76, p = .028, while the effect size (Cohen's\ d = 0.98) indicated a large effect. The 95% confidence interval for the mean difference is [0.20; 2.55].

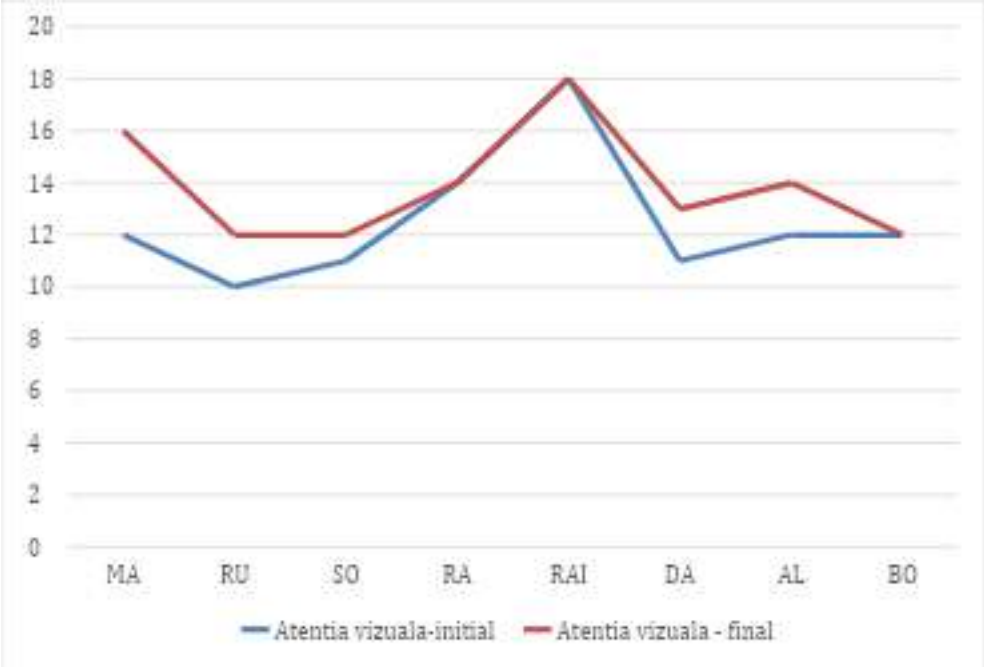

Figure 1. Evolution of Individual Performance on the Visual Attention Test

The individual analysis of the scores revealed differentiated responses:

- Participant MA showed the largest improvement (+4 points).
- Participants RU, DA, and AL each improved by +2 points.
- Participants RA, RAI, and BO showed no changes in visual attention scores. Notably, participant RAI achieved the maximum score (18/18) at both points of assessment.

4.2. Overall progress in emergent literacy

The assessment of emergent literacy skills (maximum score = 74 points) showed that the initial mean score was 26.31 points, while the final mean score increased to 32.31 points, corresponding to an average gain of +6.00 points per child (a relative increase of approximately 23%). Inferential analysis confirmed the statistical significance of this difference ($t(7) = 3.59$, $p = .009$; Wilcoxon signed-rank test: $p = .016$, Cohen's\ $d = 1.27$).

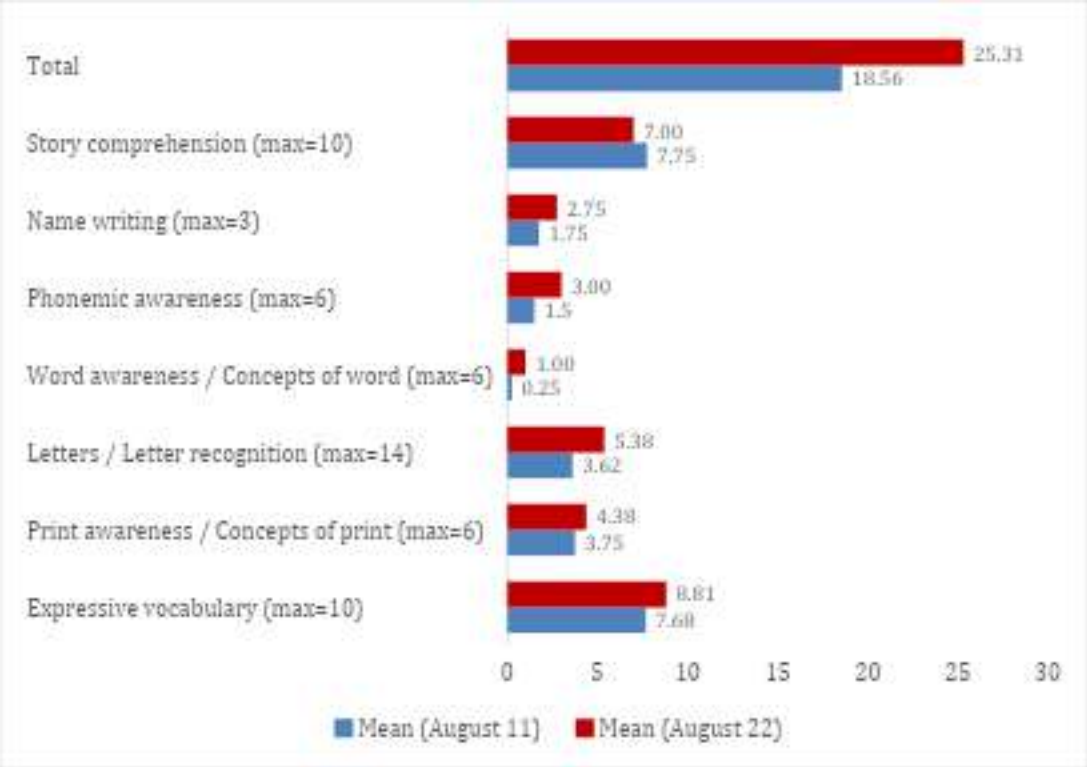

Figure 2. Dynamics of mean scores on emergent literacy subscale

The subscale analysis indicated that the gains were distributed as follows:

- Letter recognition: from 3.62 to 5.38 ($p = .013, d = 1.18$)
- Phonemic awareness: from 1.50 to 3.00 ($p = .026, d = 0.99$)
- Expressive vocabulary: from 7.68 to 8.81
- Print text knowledge: from 3.75 to 4.38

Story comprehension scores remained relatively stable across assessments, showing no

statistically significant progress.

4.3. Interaction between variables

Individual data comparison revealed cross-over patterns between literacy gains and psychological variables:

- Participants RA, RAI, and BO did not show increases in visual attention scores ($\Delta = 0$), yet they achieved substantial gains in emergent literacy ($\Delta = +11$ points, $\Delta = +13.5$ points, and $\Delta = +4$ points, respectively). Participant RA presented a high score on instruction comprehension (14/16).
- Children such as RU and DA, who demonstrated improvements in visual attention (+2 points), showed only moderate literacy gains (+6 and +4 points).

5. Discussions

The findings of this study support the hypothesis that an intensive and structured two-week summer programme can generate meaningful educational gains in both emergent literacy and visual attention. The average increase of approximately 23% in the overall literacy score, together with the large effect identified for visual attention (Cohen's\ d \approx 0.98), is consistent with the literature on intensive summer interventions aimed at developing pre-reading skills and school readiness, which reports moderate to large effects even within relatively short periods of time (Pears et al., 2016; Donnelly, Huber, & Yeatman, 2019; Christodoulou et al., 2017; Balea, 2023; Balea, Kovacs, & Pogăcean, 2024). These findings suggest that school readiness programmes implemented during the transition from kindergarten to formal schooling may represent a realistic and effective strategy for supporting adaptation to preparatory grade, particularly for children in situations of educational vulnerability.

The subscale results suggest that the intervention particularly influenced the foundational components of emergent literacy associated with the development of decoding mechanisms and phonological processing (letter recognition and phonemic awareness).

An important aspect of the study concerns the relationship between literacy progress and the assessed cognitive factors. The literature highlights that visual-spatial attention contributes to rapid

letter recognition, sequential tracking of text lines, and efficient scanning of printed material (Franceschini et al., 2012; Plaza & Cohen, 2007; Valdois, 2019; Justice et al., 2008). The present findings confirm that the intervention facilitated improvements in this cognitive dimension; however, they also suggest that visual attention represents more of a facilitating condition than a sufficient predictor of rapid literacy progress. The individual variation showing that some children with no changes in visual attention achieved substantial literacy gains indicates the involvement of additional cognitive mechanisms.

In this context, the data suggest a particularly important role of executive functions. The profiles of participants who achieved the greatest literacy gains – especially the case of RA, who displayed high performance on the instruction comprehension task (14/16) despite zero growth in visual attention – indicate that the ability to understand, maintain, and apply sequences of instructions may function as a genuine "learning amplifier."

These observations are consistent with contemporary models and longitudinal research highlighting the contribution of executive functions – particularly inhibitory control, working memory, and cognitive flexibility – to the development of emergent literacy and reading comprehension, beyond strictly linguistic or perceptual abilities (Follmer, 2017; Gandolfi et al., 2021; Nouwens, Groen, Verhoeven, & Segers, 2021; Williams, 2022; Balea et al., 2024).

The results also highlight considerable individual heterogeneity in response to the intervention, which aligns with previous findings on distinct developmental profiles (Cabell et al., 2011; Hurjui, 2024). For instance, in the case of participant RAI, the absence of further progress in visual attention is easily explained by a ceiling effect, a phenomenon frequently reported in cognitive assessments of young children when the instrument no longer discriminates very high levels of performance (Clausén Gull et al., 2024).

Limitations and future directions

This study presents several limitations that must be noted:

- Sample and control: The small sample size (N=16, with complete data for 8 participants in the inferential analysis) and the absence of a control group limit the generalizability of the conclusions and the possibility of rigorously separating the intervention effect from maturation or external variables (Donnelly et al., 2019).

- Long-term Tracking: The relatively short duration of the programme and the absence of follow-up assessments do not allow conclusions regarding the long-term stability of the observed gains (Hannon, Nutbrown, & Morgan, 2020).
- Operationalization: Executive functions were operationalized through a single measure - instruction comprehension - which provides only a partial perspective on a complex construct.

Future research should include broader executive function assessment batteries, larger samples, experimental designs with control groups, and longitudinal evaluations.

6. Conclusions

The findings of this study suggest that an intensive and rigorously structured two-week summer programme can contribute to the development of emergent literacy skills in preschool children transitioning to school. The average increase of approximately +6 points in the overall literacy score, together with the statistically significant improvement in visual attention (Cohen's\ d=0.98), indicate that short but intensive interventions represent a promising educational strategy for supporting school readiness and reducing initial learning gaps before entry into the preparatory grade.

Secondly, the study highlights that the relationship between literacy and cognitive factors is multidetermined. Executive functions – operationalized through the instruction comprehension task – play a critical role in how children capitalize on literacy activities. The ability to follow rules, maintain task sequences, and use feedback effectively functions as a learning amplifier, facilitating successful engagement in structured educational activities even when visual attention metrics remain flat.

Furthermore, the individual variability and the recorded ceiling effects emphasize the need for personalized early educational interventions. Task difficulty, work pace, and the type of educational support provided must be adjusted according to each child's baseline cognitive profile.

From an applied perspective, this study provides clear arguments for the systematic integration of integrated activities (linguistic, cognitive, and motor) within school-transition programmes. A short, intensive, and playful programme grounded in meaningful child experiences can successfully facilitate active engagement and accelerate progress before the onset of formal

schooling within the local educational context.

Declaration of AI use

During the preparation of this work, the authors used Gemini to translate the text into English and to verify its coherence, structure, and grammatical correctness. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Feedback in Technical Higher Education

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Abstract

Feedback is an important tool in all activities, used to improve communication, relationships, and performance. In educational environments, its role is to facilitate interaction between students and teachers, helping clarify expectations, correct misunderstandings, and guide learning processes. Its effectiveness depends not only on its presence but also on how it is perceived by students in terms of clarity, relevance, and usefulness. This paper investigates student perspective of feedback based on a custom-designed questionnaire applied among 125 students from different domains of a technical faculty, focusing on the aforementioned aspects. The results indicate that feedback is relatively clear, but less effective in supporting learning, and it is not provided frequently. Despite this, students express a relatively strong desire for more feedback. We also made a cluster analysis, which reveals three distinct student profiles. The largest group consists of engaged students who receive frequent, clear, and effective feedback. A second group includes students who receive limited and low-quality feedback but express a strong desire for improvement. The third group is characterized by disengaged students who perceive feedback as ineffective and show little interest in receiving more.

Keywords: cluster analyses, feedback, higher education, student perspective, technical faculty

1. Introduction

In professional, social, and educational environments, feedback is important because it helps people to identify strengths and weaknesses, adjust their behaviors, and improve their relations or performances. Using effective feedback, the actors who are involved in different activities have more positive experiences because collaboration is facilitated, and thus the innovative side can be increased (Lee et al., 2021). In educational contexts, feedback represents an essential element influencing both the teaching and the learning processes, contributing to academic development, motivation, and student engagement (Williams, 2024). In higher education, it helps students better understand both their strong points and the aspects that require improvement. Through constructive feedback, teachers can guide students toward enhanced academic achievement (Simonsmeier et al., 2020), supporting also the development of knowledge, skills, and critical thinking abilities. Practically, it is an important component of the educational process (Ilie, 2024). Ideally, feedback should encourage reflection, motivation, and continuous progress, helping students improve the quality of their work and learning strategies (Sanchez-Gil-Machín et al., 2025).

Unfortunately, in some situations, feedback is not perceived positively by students, and in this case, they might not use the received information (Jonsson, 2013). Since feedback often focuses on mistakes, weaknesses, or areas that need correction, it may sometimes be interpreted as criticism rather than support, and it can affect their self-esteem (Nemt-allah et al., 2026). This perception can generate anxiety, discomfort, or resistance, particularly when feedback is delivered in a vague or excessively evaluative manner.

In educational environments, another significant factor is the relationship between teachers and students (Wongvorachan et al., 2022), where instructors are frequently associated with authority and evaluation. As a result, some students may perceive feedback more as a judgment process than as a constructive learning opportunity, or they ignore it and look only to the grades (Paterson et

al., 2020). These aspects highlight the importance of understanding how students perceive feedback and what factors influence their effectiveness within the educational process. Modern educational approaches increasingly view feedback as an interactive process in which students actively use and apply feedback to improve future learning, rather than simply receiving information (Winstone & Boud, 2022).

The effectiveness of feedback does not depend only on its frequency. The quality, clarity, relevance, and applicability of feedback are equally important (Haughney et al., 2020) in determining its educational impact. Students may receive feedback frequently, but if it is too general or unclear, its influence on learning may remain limited. On the other hand, well-structured and meaningful feedback can significantly improve student understanding, confidence, and academic performance. Therefore, it is important to analyze not only how often feedback is provided, but also how students perceive its usefulness and contribution to their learning process.

In higher education, particularly in engineering and technical programs, feedback is also crucial due to the complexity of the learning tasks and the practical nature of many activities. Students are required not only to assimilate theoretical concepts, but also to develop problem-solving abilities, analytical thinking, and practical skills. In this context, feedback can help students identify misunderstandings, correct errors, and improve their learning strategies.

The rapid development of digital and blended learning environments has also transformed the way feedback is delivered in higher education. Besides traditional oral feedback provided during face-to-face interactions, students increasingly receive written or online feedback through educational platforms, e-learning systems, and digital communication tools. These modern approaches offer flexibility and accessibility, but they also raise important questions regarding the effectiveness of different feedback forms and the way students perceive them (Kerman et al., 2024).

Starting from these considerations, the present paper investigates students' perspectives on feedback in technical higher education. The research is based on a custom-designed questionnaire applied to 125 students from different programs and years of study and analyzes several dimensions related to feedback, including frequency, perceived clarity, impact on learning, and students' desire to receive further feedback. In addition, we made a cluster analysis to identify distinct student profiles based on their feedback-related perceptions and attitudes.

2. Feedback Types

Feedback is widely recognized as one of the most important elements of the learning process, particularly in writing instruction and formative assessment. Feedback is no longer understood only as correction or evaluation, but increasingly as a dialogic and developmental process that supports students' learning, motivation, and self-regulation (Svanes et al., 2023). In contemporary educational literature, feedback can be classified according to both its function and its mode of delivery, and the most common categories include evaluative, descriptive, and prescriptive feedback, as well as oral, written, and online feedback.

Evaluative feedback can be defined as information that includes evaluations, comments, and recommendations for improvement delivered by a teacher, peer, oneself, or automated feedback systems (Quinlan & Pitt, 2025). It can be argued that higher education research has traditionally concentrated heavily on evaluative feedback and on how students interpret and use such comments. Although evaluative feedback can help students understand performance standards, it also has its limitations (Quinlan & Pitt, 2025). Evaluative feedback alone is often insufficient because it may focus more on judgment than on helping students understand the practical consequences of their actions and decisions.

Descriptive feedback provides students with information about what they did well, what problems exist in their work, and how specific aspects of performance can be improved. Unlike evaluative feedback, descriptive feedback focuses less on judgment and more on information and explanation. Positive reinforcement acknowledges successful aspects of a student's writing, while problem statements summarize the main issues that need improvement (Yoon et al., 2023). Explicit examples are particularly valuable because they identify concrete problematic sections in the text and illustrate them directly for students.

Prescriptive feedback, sometimes referred to as direct feedback, provides explicit suggestions or instructions about how students should improve their work. Rather than merely identifying strengths or weaknesses, prescriptive feedback tells learners what actions to take next. It can also

be described as feedback that provides explicit instructions for revising the text, while indirect feedback encourages students to identify and correct mistakes themselves, and it may include questioning, informative comments, or concrete recommendations for revision (Baz & Aksoy, n.d.). Recent research therefore suggests that prescriptive feedback is most effective when it combines clear direction with specific examples and practical guidance that students can immediately apply during revision.

Oral feedback refers to spoken interactions between teachers and students during classroom activities, discussions, conferences, or collaborative work. Written and online feedback have become increasingly important due to the expansion of digital learning environments, automated writing evaluation systems, and AI-based educational tools. Because of the transition to online learning, it has significantly transformed feedback practices; written feedback became less formalized because communication increasingly occurred through chats, text messages, and digital platforms (Svanes et al., 2023). The distinction between oral and written feedback also became less clear, as digital communication often combined features of both immediacy and textual interaction. Research further shows that online feedback can support flexibility and rapid communication, but it may also create challenges related to clarity, emotional connection, and student engagement (Svanes et al., 2023). Digital feedback practices are also increasing teachers' workload and requiring them to adapt quickly to new technological environments.

3. Methodology

We used a quantitative descriptive research design to investigate students' perspectives on feedback in technical higher education. This explored several dimensions related to feedback, including its frequency, perceived clarity and usefulness, impact on learning and improvement, preferred forms of feedback, and students' desire to receive further feedback. By analyzing these aspects, the purpose was to identify patterns in feedback-related attitudes and to highlight possible differences between student profiles.

The research instrument was a structured questionnaire designed for students from four technical higher education programs: electronics, telecommunications and information technologies (named IETTI), electrical engineering (named IE), electrical engineering and computers (IEC), and systems engineering (AIA), from Faculty of Automation, Computers Science, Electrical and

Electronics Engineering, at "Dunarea de Jos" University of Galati, Romania. Participants were distributed across three years: I, II, and III. The questionnaire included both demographic questions and feedback-related items, combining Likert-scale and single-choice questions. Its structure has two main sections:

- Section 1 – Demographics: included questions regarding gender, year of study, and field of specialization/program.
- Section 2 – Feedback in the educational process: investigated several dimensions associated with feedback, including: frequency of feedback received from teachers; perceived clarity and usefulness of feedback; the extent to which feedback helps students understand mistakes and improve; students' desire to receive further feedback; preferred forms of feedback (oral, written/online); preferred feedback types (evaluative, prescriptive, descriptive).

For the questions regarding feedback frequency, responses ranged from "Never" to "Very frequently," while agreement-based items ranged from "Strongly disagree" to "Strongly agree." The Likert-type items were coded using ordinal scales ranging from 1 to 5, where higher values reflected more positive perceptions regarding feedback. The question regarding students' desire to receive further feedback was coded on a 3-point ordinal scale. The questions related to preferred feedback forms were transformed into binary variables (0 = not selected, 1 = selected) for each feedback format.

The questionnaire was administered online using Google Forms in November 2025. Participation was completely voluntary, and all responses were anonymous. No personal data allowing participant identification was collected. A total of 125 valid responses were obtained and prepared for statistical analysis using IBM SPSS Statistics software.

The hypotheses formulated for this study are:

H1. Students who perceive feedback as more useful are more likely to express a stronger desire for further feedback.

H2. Feedback frequency is not significantly associated with the perceived impact of feedback on learning outcomes.

H3. Students can be grouped into distinct profiles based on their feedback-related perceptions and attitudes.

H4. Different student profiles exhibit different preferences regarding feedback forms and feedback types.

4. Results

This section presents the statistical analysis of the data collected through the applied questionnaire, used for testing the hypotheses formulated in the previous paragraph. This was realized with IBM SPSS Statistics. Descriptive statistics were first used to evaluate the overall distribution of responses and the average levels of feedback frequency, perceived usefulness, and learning impact. Spearman correlation analysis was applied to investigate relationships between the analyzed variables. K-means cluster analysis identifies distinct student profiles related to feedback perception and usefulness. The clustering process can group students according to similarities in their responses and to reveal potential differences in feedback-related attitudes and expectations. In addition, ANOVA analysis was used to evaluate the statistical significance of the differences between clusters. First, we present basic demographic information collected, such as gender, year of study, and field of specialization. Their distributions are represented in **Figure 1**.

Figure 1. Participants' distributions

4.1. Descriptive analysis

Descriptive statistics were used to evaluate the general distribution of students responses regarding feedback frequency, perceived usefulness, learning impact, and students desire to receive further feedback. The results are summarized in **Table 1**. The analysis indicates that feedback is not provided very frequently within the educational process, with an average value of 2.88 on a 5-

point scale. Students generally perceive feedback as relatively clear and useful, with an average value of 3.92. In addition, the statement regarding the contribution of feedback to understanding mistakes and improving learning obtained a mean value of 3.76, suggesting a moderately positive perception of feedback effectiveness. For the rest of the paper, we coded the items with V1, V2, V3, and V4, as can be seen in **Table 1**.

	N	Min.	Max.	Mean	Std. Deviation
How often do you receive feedback from teachers? (V1)	125	1	5	2,88	,885
The feedback received is clear and useful. (V2)	125	1	5	3,92	,714
Feedback helps me understand what I did wrong and evolve. (V3)	125	1	5	3,76	1,167
Would you like to receive feedback more often? (V4)	125	1	3	2,70	,571
Valid N (listwise)	125				

Table 1. Descriptive Statistics

At the same time, students expressed a relatively strong desire to receive further feedback, with an average value of 2.70 on a 3-point scale. These results suggest that, although feedback is generally appreciated by students, there is still a perceived need for more frequent and more effective feedback within technical higher education.

An interesting aspect revealed by the descriptive analysis is the difference between the perceived clarity of feedback and its actual contribution to learning improvement. Although students tend to perceive feedback as relatively clear, its educational impact appears to be slightly lower. This observation suggests that clear feedback does not always guarantee meaningful learning outcomes or improved academic performance.

4.2. Correlation analysis

Spearman correlation analysis was performed to investigate the relationships between feedback frequency, perceived usefulness, learning impact, and students' desire to receive additional feedback. The results are presented in **Table 2**.

			V1	V2	V3	V4
Spearman's rho	V1	Correlation Coefficient	1,000	,274**	,142	,088
		Sig. (2-tailed)	.	,002	,115	,328
		N	125	125	125	125
	V2	Correlation Coefficient	,274**	1,000	,210*	,070

		Sig. (2-tailed)	,002	.	,019	,441
		N	125	125	125	125
	V3	Correlation Coefficient	,142	,210*	1,000	,294**
		Sig. (2-tailed)	,115	,019	.	,001
		N	125	125	125	125
	V4	Correlation Coefficient	,088	,070	,294**	1,000
		Sig. (2-tailed)	,328	,441	,001	.
		N	125	125	125	125
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Table 2. Spearman correlations

The analysis revealed a statistically significant positive correlation between perceived usefulness and the impact of feedback on learning ($\rho = 0.210$, $p < 0.05$). In addition, the strongest relationship was observed between the perceived learning impact of feedback and students' desire to receive further feedback ($\rho = 0.294$, $p < 0.01$). This indicates that students are more likely to request additional feedback when they perceive it as genuinely helpful for their academic development. In this case, H1 was confirmed.

A weak but statistically significant positive correlation was identified between feedback frequency and perceived clarity and usefulness ($\rho = 0.274$, $p < 0.01$). At the same time, feedback frequency was not significantly associated with the perceived impact of feedback on learning and improvement ($\rho = 0.142$, $p > 0.05$). This result suggests that receiving feedback more often does not necessarily guarantee a stronger educational impact. Therefore, H2 was confirmed. Overall, the correlation analysis highlights that the effectiveness of feedback depends more on its perceived quality and usefulness than on its frequency alone.

4.3. Cluster analysis

In order to identify distinct student profiles based on feedback-related perceptions and attitudes, a K-means cluster analysis was performed using standardized variables associated with feedback frequency, usefulness, learning impact, and demand for additional feedback. Three clusters were

selected to obtain an interpretable classification of participants. The students' distributions on these are represented in **Figure 2**.

The first one has students characterized by relatively low feedback frequency and low perceived usefulness, but who nevertheless expressed a strong desire to receive additional feedback. This category may be interpreted as a group of students who feel insufficiently supported within the educational process, despite being motivated to receive more guidance and feedback. This cluster included 41 participants.

Figure 2. Clusters distribution

The second cluster is the largest group of participants, including 58 students. These reported frequent, clear, and useful feedback, together with a positive perception of its contribution to learning and improvement. Students belonging to this cluster also expressed interest in receiving further feedback, suggesting a generally positive and engaged attitude toward feedback processes.

The third cluster includes 26 students characterized by low perceived learning impact and a very limited interest in receiving additional feedback. This group may reflect disengaged students who perceive feedback as less effective or less relevant for their educational development.

The distances between final cluster centers indicate a good separation between the identified groups, suggesting that the clustering procedure successfully distinguished different student profiles. Furthermore, ANOVA analysis revealed statistically significant differences between clusters for all analyzed variables ($p < 0.001$). Therefore, H3 was confirmed, demonstrating that students can indeed be grouped into distinct categories according to their feedback-related perceptions and attitudes.

These are illustrated in **Table 3** through the standardized values associated with the identified student clusters. Positive values indicate above-average perceptions regarding the analyzed feedback dimensions, while negative values reflect below-average evaluations. The heatmap highlights significant differences between the identified student profiles. Cluster 2 is characterized by positive values across all analyzed variables, suggesting that these students receive relatively frequent, clear, and useful feedback and perceive feedback as beneficial for learning improvement. In contrast, Cluster 1 presents negative values for feedback frequency and usefulness, but a positive value regarding the desire to receive further feedback, indicating a group of students who feel insufficiently supported but remain motivated to receive additional guidance. Cluster 3 is characterized by strongly negative values regarding learning impact and demand for additional feedback, suggesting a more disengaged student profile.

Variable	Cluster 1	Cluster 2	Cluster 3
V1	-0,61	0,54	-0,26
V2	-0,81	0,66	-0,21
V3	-0,05	0,37	-0,75
V4	0,49	0,41	-1,69

Table 3. Heatmap representation of the standardized cluster centers for the analyzed feedback-related variables

A correspondence analysis was performed to explore the relationship between the identified student clusters and the preferred feedback types. The obtained representation is illustrated in **Figure 3**. The graphical representation suggests that different student profiles are associated with different feedback preferences. Cluster 1 appears to be more closely associated with descriptive feedback, indicating that these students prefer detailed and explanatory forms of feedback. Cluster 2 is positioned closer to evaluative feedback, suggesting a preference for general assessments regarding performance. In contrast, Cluster 3 is more strongly associated with prescriptive feedback, indicating a preference for guidance-oriented feedback focused on improvement recommendations.

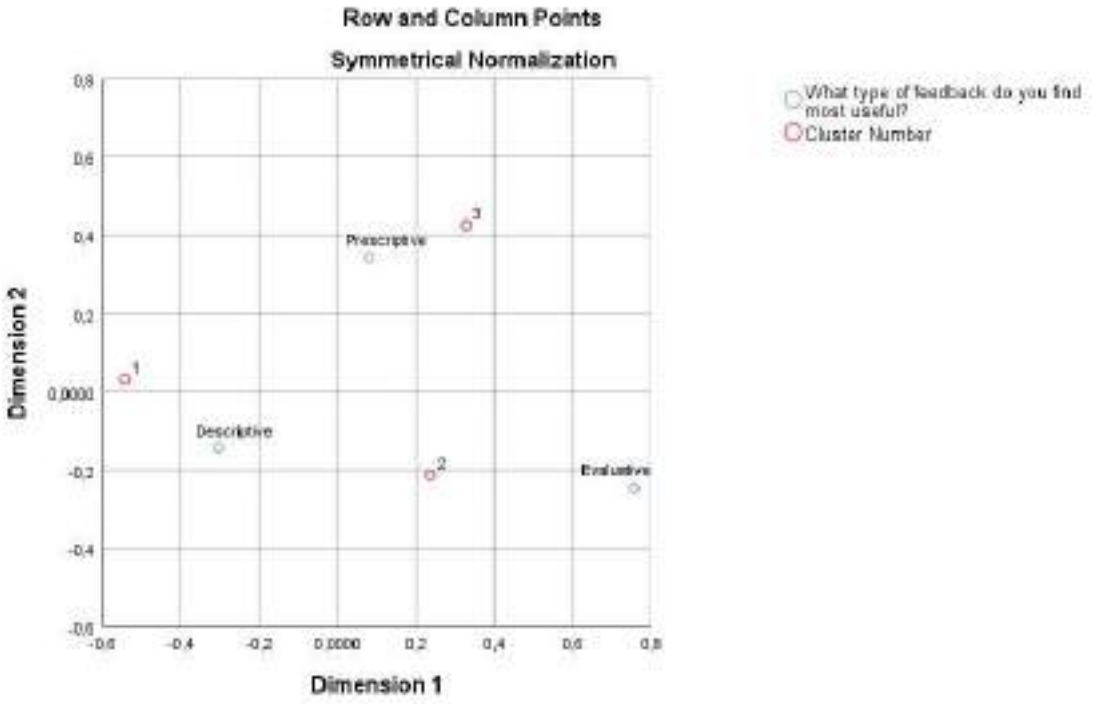

Figure 3. Correspondence analysis of student clusters and preferred feedback types

These results highlight that feedback preferences differ across student profiles, highlighting the importance of adapting feedback strategies according to students' expectations and learning needs. Therefore, H4 was confirmed.

The distribution of preferred feedback forms across the identified student clusters is illustrated in **Figure 4**. The results indicate that oral feedback is generally preferred over written feedback across all student profiles. The highest preference for oral feedback was observed within Cluster 2, which also corresponds to the group characterized by higher perceived usefulness and learning impact of feedback.

In contrast, written feedback was selected less frequently across all clusters, although it remained relatively relevant for students belonging to Cluster 1 and Cluster 3. These findings suggest that students in technical higher education tend to value direct and immediate interaction during feedback processes, particularly when feedback is perceived as meaningful and supportive for learning improvement. The observed differences between clusters further support H4, indicating that student profiles are associated with different preferences regarding feedback forms.

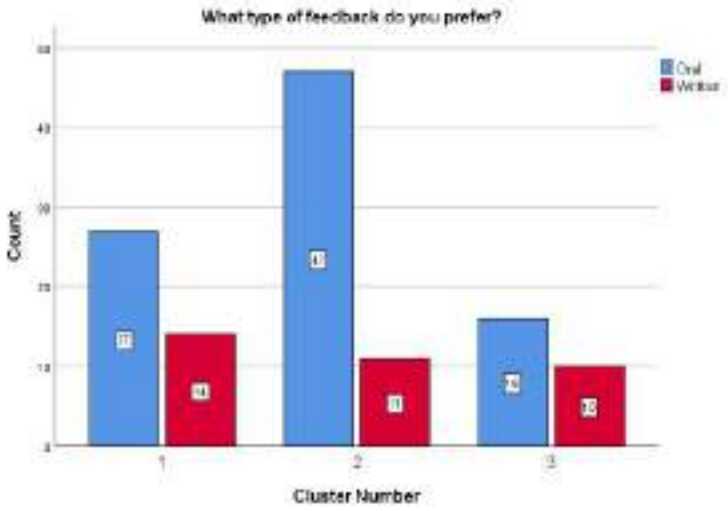

Figure 4. Distribution of preferred feedback forms across the identified student clusters

5. Conclusions

This paper investigated students' perspectives on feedback in technical higher education, focusing on several dimensions associated with feedback frequency, perceived usefulness, learning impact, and preferred feedback forms and types. The descriptive analysis revealed that, although students generally perceive feedback as relatively clear and useful, feedback is not received very frequently during the educational process.

Correlation analysis demonstrated that feedback frequency is not significantly associated with the perceived impact of feedback on learning outcomes. In contrast, the perceived usefulness of feedback was positively associated with students' desire to receive additional feedback.

The cluster analysis identified three distinct student profiles characterized by different attitudes and expectations regarding feedback. While one cluster included engaged students who perceived feedback positively, another group is characterized by low perceived usefulness but a strong desire for additional feedback, suggesting the existence of students who feel insufficiently supported despite remaining motivated to improve. A third cluster reflected more disengaged students with low perceived learning impact and limited interest in receiving further feedback.

The correspondence analysis and the analysis of preferred feedback forms further revealed differences between clusters regarding feedback preferences. Oral feedback was generally

preferred across all student groups, highlighting the importance of direct interaction and immediate clarification within the educational process.

Overall, the results highlight the need for more adaptive and student-centered feedback strategies in technical higher education. Rather than focusing exclusively on increasing feedback frequency, educational practices should prioritize meaningful, clear, and actionable feedback tailored to different student profiles and learning needs.

The present study has several limitations. First, the research was conducted on a relatively small sample consisting of 125 students enrolled in technical higher education programs within a single educational context. Consequently, the results may not fully reflect the perspectives of students from other universities, academic fields, or cultural environments.

Another limitation is related to the use of self-reported questionnaire data. Students' responses may be influenced by subjective perceptions, temporary emotional states, or social desirability bias. In addition, the study focused mainly on students' perspectives regarding feedback and did not include the viewpoints of teachers or objective indicators of academic performance.

Future research could extend the present study to comparisons between technical and non-technical faculties. Additional research directions may include the investigation of teachers' perspectives or the relationship between feedback and academic performance.

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Open-Source Technologies for Industrial Robotics Education in Industry 4.0

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Abstract

This paper addresses a gap in the current literature, namely the absence of a systematic, educationally oriented comparative framework for open-source robotics simulation platforms in the context of Industry 4.0 curricula. While platforms including Gazebo, Webots, and CoppeliaSim are widely used in academic settings, no consolidated study has evaluated them simultaneously against criteria specific to educational environments, such as ease of use, hardware accessibility, pedagogical resource availability, and alignment with ROS 2. Using a multi-criteria evaluation framework applied across four dimensions, specifically ROS 2 integration, ease of use, hardware accessibility, and availability of pedagogical resources, this paper systematically compares Gazebo, Webots, and CoppeliaSim as primary simulation platforms, with contextual references to emerging tools including NVIDIA Isaac Sim and MuJoCo (Multi-Joint dynamics with Contact). The evaluation is grounded in the specific requirements of engineering education programmes targeting Industry 4.0 competencies, where students must acquire practical robotics skills without direct access to industrial hardware. The results indicate that no single platform is optimal across all educational contexts. Webots offers the lowest barrier to entry and is most suitable for introductory courses, while Gazebo, being tightly coupled with ROS 2, is recommended for advanced undergraduate and graduate-level instruction. CoppeliaSim, through its educational license and modular scripting architecture, provides unique advantages for teaching control systems concepts. The paper concludes with a proposed learning pathway for progressive integration of open-source tools across an academic robotics curriculum, along with practical recommendations for laboratory setup and course design.

Keywords: engineering education, simulation-based learning, active learning, competency-based education, virtual laboratory, curriculum design, open-source tools, robotics pedagogy, Industry 4.0 education.

1. Introduction

The fourth industrial revolution, called Industry 4.0, has fundamentally redefined the skills profile required of engineering graduates in the field of automation and robotics. Industrial robotic systems are no longer isolated machines that perform repetitive tasks, but function as nodes integrated into cyber-physical systems, communicating in real time with digital twins, cloud analytics platforms, and distributed sensor networks. This transformation requires technical education programs to train graduates proficient not only in robot programming, but also in middleware communication architectures, simulation validation, motion planning, and sensor integration (Schwab, 2016).

A critical challenge for academic institutions is to provide students with meaningful practical experience in this field, without access to expensive industrial equipment. Open-source simulation platforms, especially Gazebo, Webots and CoppeliaSim, have emerged as a pedagogically and economically viable answer, allowing students to develop, test and validate robotic applications in realistic virtual environments at almost zero cost. Their increasing adoption in engineering curricula in Europe and North America reflects their recognized educational value (Audonnet et al., 2022; Faller & Feldmüller, 2015).

However, the diversification of these tools has created a new problem: the absence of a clear, educationally grounded framework for selecting the right platform according to the instructional context, level of study or learning objective. Most existing comparisons evaluate these tools on purely technical criteria, without addressing the decisive pedagogical dimension for curriculum designers (Macenski et al., 2022). This paper directly addresses this gap, analysing platforms as learning tools and proposing a structured learning path, grounded in education theory.

2. Theoretical Framework

The selection and sequencing of simulation tools in an engineering curriculum is not a purely technical decision, but a pedagogical one. This chapter presents the theoretical foundations that underpin the evaluation framework applied in the paper, starting from the learning theories relevant to the simulation and reaching the competency-based education models used in the accreditation of engineering programs.

2.1. Simulation-based learning in engineering

The use of simulation in engineering education is based on Kolb's (1984) Theory of Experiential Learning, which identifies four stages of effective learning: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Process simulation environments engage all four stages in a single controlled activity: students interact with virtual robotic processes (concrete experience), observe the system's responses to their programming decisions (reflective observation), develop an understanding of control logic and system dynamics (abstract conceptualization), and iteratively refine their programs (active experimentation) (Kolb, 1984).

Simulation-based learning directly supports Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001). While traditional lecture-based instruction predominantly addresses the lower cognitive levels of memory and comprehension, well-designed simulation exercises engage the higher levels: application (implementing control algorithms on a virtual robot), analysis (diagnosing unexpected system behavior), evaluation (comparing platform responses), and creation (designing autonomous robotic solutions for new scenarios) (Anderson & Krathwohl, 2001).

2.2. Competency-based education for Industry 4.0

Competency-based education frameworks, including EUR-ACE and ABET, define learning outcomes in terms of demonstrable skills. For Industry 4.0-oriented robotics education, the relevant set of competencies includes: competence in ROS 2 middleware, simulation system validation, implementation of motion planning, integration of sensor data and cyber-physical systems design. The assessment framework applied in this paper is explicitly calibrated on these competencies, ensuring that the platform selection criteria reflect real educational requirements (EUR-ACE, 2021). Essentially, these skills cannot be developed exclusively through theoretical instruction. They require experimentation in environments that closely approximate real industrial

systems, a requirement that simulation platforms are uniquely positioned to meet at the scale and cost that academic institutions can sustain (Faller & Feldmüller, 2015).

3. Open-Source Platforms as Pedagogical Tools

Five tools were selected for analysis: Gazebo, Webots and CoppeliaSim as primary simulation platforms, ROS 2 as the reference middleware infrastructure and two emerging platforms, NVIDIA Isaac Sim and MuJoCo, as contextual reference. The selection is based on their current adoption in academic robotics programs and compatibility with the ROS 2 ecosystem, the dominant standard after the end of the ROS 1 lifecycle in May 2025. Each tool is examined below from a pedagogical perspective, highlighting the instructional value, the recommended student level, and the curriculum conditions in which it proves to be most effective.

3.1. ROS 2 as the reference infrastructure

ROS 2 is the dominant open-source middleware in modern robotics, constituting the foundation on which all other analysed platforms are built or integrated. Unlike its predecessors, ROS 2 has been designed for production deployment, incorporating real-time communication through the DDS (Data Distribution Service) standard, node lifecycle management and support for multi-robot systems.

From a pedagogical perspective, ROS 2 is not a simulator, but a communication framework that organizes robotic software into discrete nodes that exchange messages through publish-subscribe mechanisms, services and actions. This architecture directly shapes the philosophy of cyber-physical systems in Industry 4.0, making ROS 2 both a practical tool and a conceptual model for teaching systems integration. Long-term supportive distributions, such as the Humble Hawksbill (supported until May 2027)**,** provide necessary stability in the educational context (Macenski et al., 2022; Open Robotics, 2024).

3.2. Webots

Webots is the platform designed most explicitly for education. Its installation through a single package, native support for Windows, macOS, and Linux, eliminates the configuration overhead that frequently consumes lab time at the expense of learning time. Students can execute the first control program of a robot within minutes of the start of the session, a pedagogical advantage

directly aligned with cognitive load theory, which recommends minimizing extrinsic cognitive load in introductory instruction (Sweller, 1988).

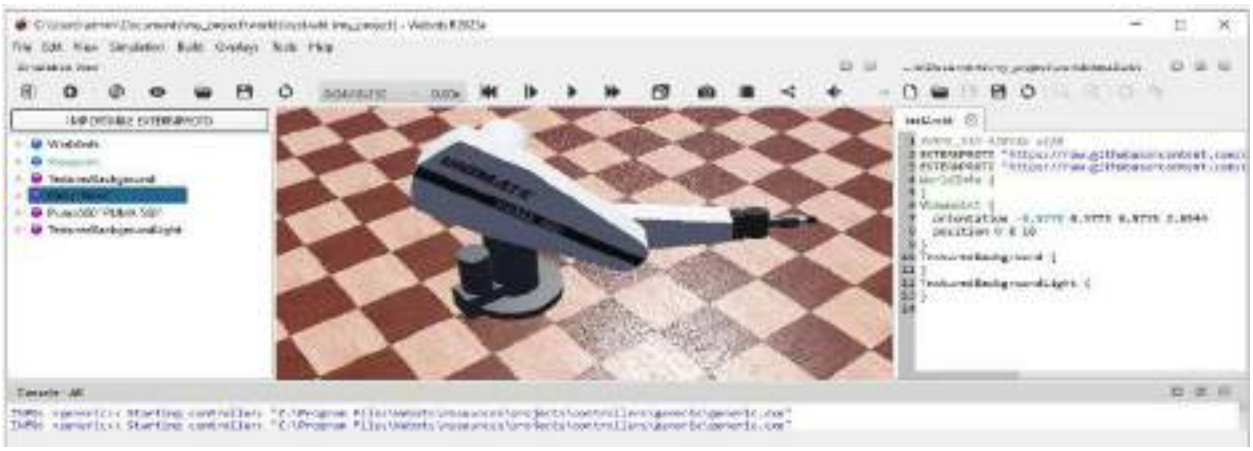

Figure 1. Webots simulation environment with industrial robot model and world editor.

Webots' Python API and extensive library of preconfigured robot and sensor models allow instructors to design exercises focused solely on the development of control algorithms, without requiring knowledge of Linux administration or ROS 2 workspace management. Its ROS 2 interface, through the webots_ros2 package, allows for progressive integration with the broader ecosystem when students are ready for that complexity (Michel, 2004; Cyberbotics, 2024).

3.3. Gazebo

Gazebo offers the tightest integration with ROS 2 of all the platforms evaluated. The native bridge allows ros_gz direct use of the entire ROS 2 toolchain, including RViz2, rqt, ros2bag, and ros2_control, without additional configuration. Pedagogically essential, the programming patterns, message types, and debug flows used in Gazebo simulation are identical to those used on ROS 2-compatible physical hardware (Koenig & Howard, 2004; Quigley et al., 2009). This simulation-reality continuity is a decisive pedagogical property for courses whose learning objective includes direct industrial employability (Koenig & Howard, 2004).

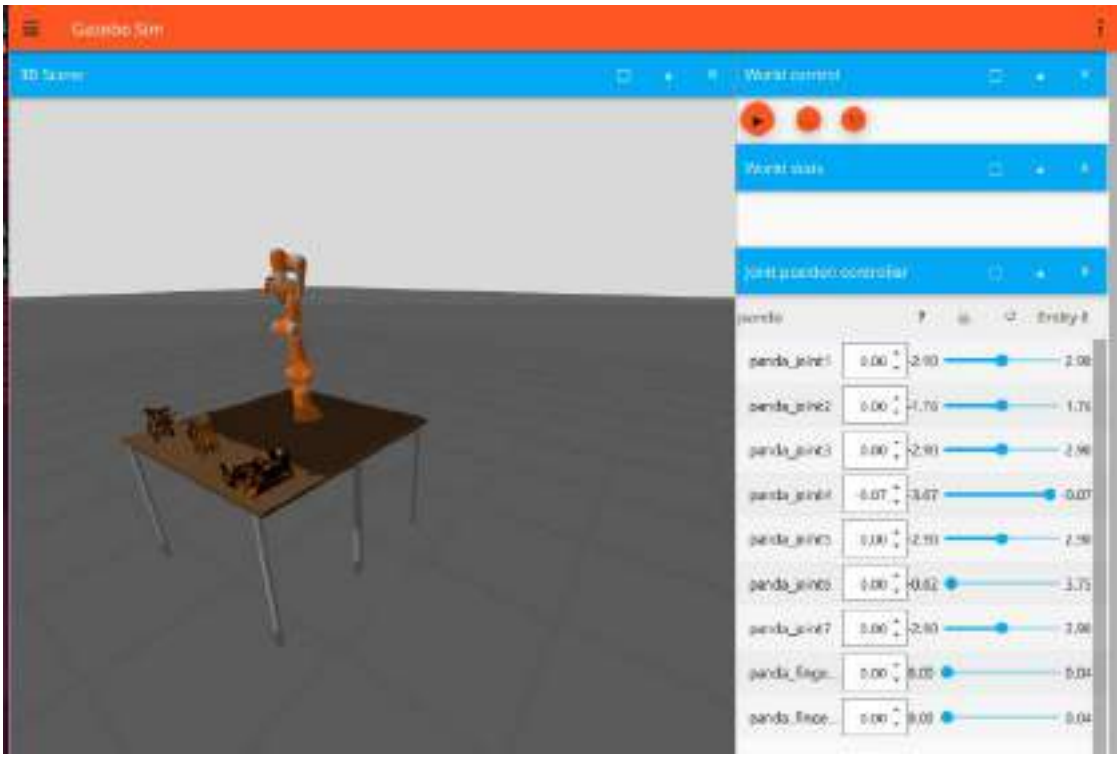

Figure 2. Gazebo simulation environment with industrial robot arm and joint position controller interface.

3.4. CoppeliaSim

CoppeliaSim follows a distributed control architecture in which the individual components of the scene are controlled by independent scripts integrated into Python or Lua. This architecture explicitly shapes the philosophy of decentralized and modular design of cyber-physical systems in Industry 4.0, making it a unique valuable pedagogical tool for courses focused on systems architecture and control design (Rohmer et al., 2013).

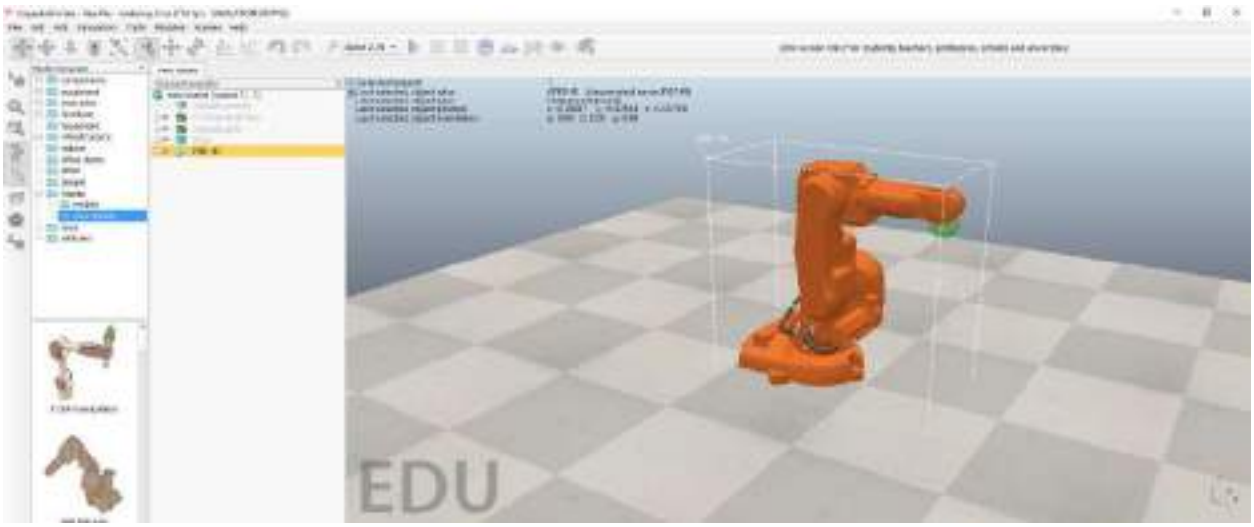

Figure 3. CoppeliaSim environment with distributed scripting architecture and physical engine selection.

Its support for five interchangeable physics engines, including MuJoCo, ODE, Bullet, Newton, and Vortex, enables comparative physics studies that are impossible on other platforms, a particularly valuable feature for advanced students investigating the relationship between simulation fidelity and real-world system behavior. The free educational license removes financial barriers while maintaining the platform's full functionality (Coppelia Robotics, 2024).

3.5. Emerging platform: NVIDIA Isaac Sim and MuJoCo

Two emerging platforms expand the horizon of open-source robotic simulation beyond the primary tools analyzed. NVIDIA Isaac Sim 5.0, released as open-source in 2025, offers GPU-accelerated photorealistic simulation, built on the NVIDIA Omniverse platform. Its main advantages are high visual fidelity, synthetic data generation for training artificial intelligence algorithms, and native support for digital twin workflows, aspects directly relevant to Industry 4.0 integration modules (NVIDIA, 2025). However, the hardware requirement for an NVIDIA dedicated GPU limits the wide educational deployment in standard laboratories for now.

MuJoCo (Model-based Optimization for Joints and Contacts), available for free from 2022 after acquisition by DeepMind/Google, offers a high-fidelity physical engine, optimized for contact-rich manipulation and reinforcement learning. Its MuJoCo Playground framework, recognized at the RSS 2025 conference, demonstrates simulation-reality transfer without additional adjustments on a wide range of robots. In an educational context, MuJoCo is recommended as a specialized

module in the advanced stage of the curriculum, for courses that address robotic learning and model-based optimization, not as an introductory platform for simulation (Todorov et al., 2012).

4. Evaluation Methodology and Results

The comparison between the primary platforms, Gazebo, Webots and CoppeliaSim, is based on a multi-criteria framework whose dimensions and weights were established according to the priorities of a curriculum designer for engineering education, not according to pure technical performance (Noori et al., 2022). Unlike existing studies that evaluate robotic simulators predominantly on technical criteria such as physics accuracy or computational performance, the framework proposed in this paper places pedagogical accessibility and compatibility with the standard industrial ecosystem as priority dimensions.

The evaluation applies four criteria: ease of use (30%), availability of pedagogical resources (25%), ROS 2 integration (25%) and hardware accessibility (20%). The weights reflect a deliberate hierarchy: ease of use receives the highest weight because a platform inaccessible to a student without prior experience cannot generate educational value regardless of its technical qualities. The availability of pedagogical resources and the integration of ROS 2 receive equal weights, reflecting the balance between the teaching support needed by the teacher and the alignment with the de facto industry standard. Hardware accessibility receives the lowest share not because it would be unimportant, but because all three platforms meet the minimum requirement to run on standard hardware without a dedicated GPU, the differences between them on this dimension being smaller compared to the other criteria (Noori et al., 2022; Dimmig et al., 2025).

Each criterion is scored on a scale of 1 to 5, where 1 represents minimal capability and 5 represents benchmark performance in that category. The scores were determined through a structured analysis of official documentation, recent academic literature, and feedback from university programs that use these platforms. The weighted total reflects each platform's overall suitability for educational use, not absolute technical performance.

Criterion	Gazebo	Webots	CoppeliaSim	Weighting	Educational Rationale

Ease of use	3/5	5/5	3/5	30%	Reduce extrinsically cognitive arching
Pedagogical resources	4/5	5/5	3/5	25%	Supports autonomous and flipped learning
ROS 2 integration	5/5	3/5	3/5	25%	Alignment with I4.0 competency targets
Hardware accessibility	4/5	**5/5**	4/5	20%	Supports access on personal laptops
Weighted total	3,95/5	4,55/5	3,20/5	—	—

Table 1. Multi-criterion pedagogical evaluation matrix. Weighted total = Sum (score x weight).

Webots obtains the highest weighted score (4.55/5) due to the exceptional ease of use and availability of pedagogical resources, confirming itself as the most suitable platform for introductory instruction. The maximum usability-of-use score reflects the one-step installation, intuitive graphical interface, and browser-based execution option, which completely eliminates the dependence on local configuration. Gazebo obtains a weighted score of 3.95/5, positioning itself as optimal for intermediate and advanced courses aimed at direct industrial skills, due to the maximum score at ROS 2 integration. CoppeliaSim's lower overall score (3.20/5) reflects its steeper learning curve and less systematized pedagogical resources, without diminishing its value as a specialized complementary tool for advanced multi-physics simulation and control system instruction.

An important aspect of the proposed framework is its scalability: the same four dimensions can be applied for the evaluation of any new platform that emerges in the open-source ecosystem, including NVIDIA Isaac Sim and MuJoCo, allowing the comparison to be periodically updated as the ecosystem evolves (Audonnet et al., 2022).

5. The Proposed Learning Path

The results of the assessment, combined with the competence framework in Section 2, underpin a progressive learning path structured in four stages. The central design principle is the progressive disclosure of complexity: each stage introduces a new level of technical abstraction only after the competencies of the previous stage have been consolidated, reducing cognitive overload and

maintaining student motivation throughout a multi-year program (Vygotsky, 1978). Unlike curricular approaches that introduce ROS 2 from first contact with robotics, the proposed path explicitly separates learning fundamental concepts from learning the technical ecosystem, allowing students to first build a mental model of robotic behaviour before being exposed to the complexity of software infrastructure.

The path integrates all the tools analysed in section 3, from primary simulation platforms to ROS 2 middleware and emerging platforms, ensuring that each tool is introduced at the curricular moment when it brings maximum pedagogical value. The cognitive levels in Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001) are used as anchors for defining learning objectives per stage, ensuring vertical program coherence and facilitating the design of assessments aligned with the targeted competencies (Anderson & Krathwohl, 2001).

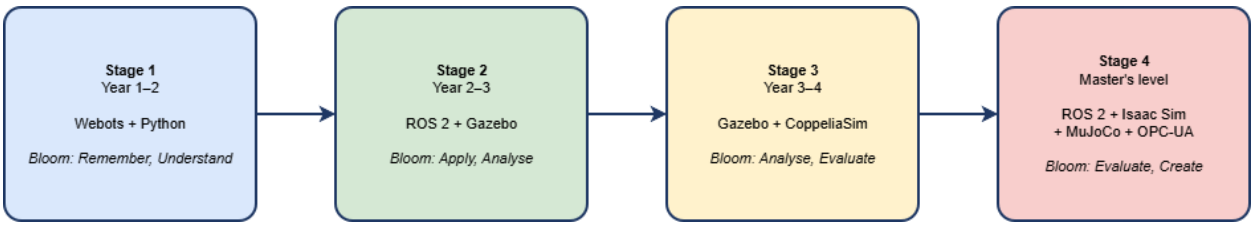

Figure 5. The proposed four-stage learning path for open-source robotics education.

Stage 1, corresponding to years 1-2, focuses on robotics fundamentals using Webots and Python. Students implement sensor-actuator loops, trajectory planning algorithms, and basic reactive behaviors without requiring ROS 2 or Linux knowledge. Webots is selected for this stage based on its maximum ease-of-use score in the proposed framework, which minimizes extrinsic cognitive load.

Stage 2, carried out in years 2-3, introduces middleware and integration through ROS 2 and Gazebo. Students configure node communication, integrate sensor data streams, and validate control logic in a native ROS 2 simulation environment. The transition to Gazebo is motivated by its maximum ROS 2 integration score, ensuring that programming patterns learned in simulation are directly transferable to physical hardware.

Stage 3, specific to years 3-4, addresses advanced robotic manipulation using Gazebo and CoppeliaSim. Students implement motion planning pipelines, compare physics simulation behavior, and design complete virtual robotic cells. CoppeliaSim is introduced at this stage for its

distributed control architecture and multi-physics support, enabling comparative exercises unavailable in Gazebo.

Stage 4, addressed to master's programs, integrates Industry 4.0 concepts using a complete ROS 2 stack with OPC-UA, Isaac Sim, and MuJoCo. Students develop integrated automation solutions for cyber-physical systems and analyse platform trade-offs in complex industrial contexts. Isaac Sim and MuJoCo are reserved for this stage due to their high hardware requirements, which become manageable only after accumulating competencies from stages 1-3 (Sweller, 1988).

The vertical coherence of the proposed path lies in the fact that each platform selection is anchored in the evaluation framework results from Chapter 4, transforming the learning pathway into a reproducible model applicable beyond robotics education.

6. Implications for Educators

The effective adoption of open-source tools in robotics education depends not only on the selection of the right platform, but also on how it is integrated into the curriculum, the available technical infrastructure, and the assessment strategies used. The chapter summarizes the main practical recommendations addressed to teachers who plan or update robotics engineering programs oriented towards Industry 4.0.

6.1. Curriculum and assessment design

Performance-based assessment is the most appropriate approach for practical competence-oriented robotics disciplines. Within this approach, students develop and validate a robotic behaviour in a defined simulation scenario and then adapt the solution according to new requirements or modified conditions. This type of assessment aims not only to obtain a functional result, but also to the student's ability to analyse problems, diagnose errors and adapt the system in real time, skills directly required in professional engineering practice (Biggs & Tang, 2011). The robotbenchmark.net platform facilitates formative assessment through automatic scoring and immediate feedback, while reducing the administrative burden of teachers in the introductory stages (Cyberbotics, 2024).

6.2. Virtual laboratory infrastructure

Webots, Gazebo and CoppeliaSim run on standard university hardware, without a dedicated GPU, with a minimum of 8 GB of RAM and a modern multi-core processor. The use of Docker containers with preconfigured images is recommended for intermediate and advanced stages, ensuring a uniform software environment and eliminating configuration inconsistencies that can consume lab time. For institutions with limited infrastructure, platforms like "The Construct" provide access to ROS 2 environments directly from the browser, without local configuration (The Construct, 2024).

6.3. Limits and challenges

The most significant limitation of simulation-based education is the gap between the behaviour of virtual environments and that of real physical systems. Robots used in industrial applications are influenced by sensor noise, calibration errors and communication delays, which are difficult to fully reproduce in simulation. For this reason, predominantly simulation-based curricula should be complemented by demonstrations or exercises on real physical platforms, even short ones, to develop a realistic engineering perspective on the limitations of robotic systems (Noori et al., 2022). Another challenge is the rapid evolution of the open-source ecosystem, which requires a continuous effort to update teaching materials and software infrastructure. In addition, although the proposed route develops vendor-independent ROS 2 competencies, exposure to at least one major industrial platform, such as Siemens, ABB or KUKA, remains recommended for professional integration in sectors with dominant commercial ecosystems (Schwab, 2016).

7. Conclusions

This paper brings two main contributions in the field of engineering education oriented towards Industry 4.0. The first is a multi-criteria evaluation framework explicitly calibrated for the educational context, which evaluates open-source robotic simulation platforms not by technical performance, but by their pedagogical adequacy, aiming at ease of use, availability of teaching resources, integration with the ROS 2 ecosystem and hardware accessibility. The second contribution is a four-stage progressive learning path, grounded in Kolb's Experiential Learning Theory and Bloom's Revised Taxonomy, in which the selection of the platform per stage is directly

justified by the results of the assessment framework, ensuring methodological coherence between benchmarking and curricular recommendation.

For an educator planning or updating a robotics program, the paper provides a concrete answer to a dilemma frequently encountered in teaching practice: choosing the right instrument and the optimal order of introduction of technical complexity. The proposed answer is not an arbitrary preference, but a decision anchored in a reproducible methodological framework, which places Webots in the fundamentals stage, ROS 2 and Gazebo in the integration phase, CoppeliaSim for advanced multi-physics control and simulation scenarios, and Isaac Sim together with MuJoCo at the master level. This model remains adaptable as the open-source ecosystem evolves, precisely because the logic of selection is pedagogical, not technological.

Future research may aim at the longitudinal assessment of the competencies developed by students in programs that adopt the proposed pathway, as well as the development of standardized open-source benchmarks for comparing educational performance between institutions. Also, the integration of generative artificial intelligence and simulation based on digital twins represent promising directions for the future evolution of simulation-based robotics education.

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Interdisciplinary Curriculum Reform: Integrating Sustainability and Employability in Higher Education

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Abstract

Universities worldwide face the twin challenges of preparing students for an increasingly uncertain employment landscape and enabling them to be agents of change in the world's sustainability transition. This paradigm of disciplinary silos has led to graduates with narrow but deep expertise, unsuited to the "wicked" problems of the 21st century. The paper proposes a conceptual model and design guidelines for interdisciplinary higher education curriculum reform that holistically incorporates sustainability literacy and postgraduate employability. The research, drawing on constructivist pedagogies, competency-based learning, and empirical data from higher education reform experiments, contends that integrating social-scientific inquiry, digital literacy, and sustainability ethics into the curriculum increases student motivation and employability. The new Sustainability-Employability Nexus (SEN) Model structures curriculum along three interlinked dimensions: systems thinking and ecological literacy; digital and data skills for sustainable development goals; and ethical leadership and multicultural collaboration. The case-study data show that graduates from SEN reforms are more likely to gain employment in mission-driven organizations and score higher on problems of interdisciplinary character. The paper also addresses the institutional challenges of reform, such as rigid accreditation standards, faculty pushback, and budget shortfalls, and offers governance principles for adapting the model to a variety of higher-education settings.

Keywords: Interdisciplinary curriculum, sustainability education, employability, higher education reform, digital literacy.

1. Introduction

The relationship between higher education and the labour market has become increasingly complex and crucial now more than ever. Interdisciplinary thinking, problem-solving related to sustainability challenges, and the ability to utilize technology in a socially responsible manner have emerged as valued competencies for employees in the modern workplace (Voogt & Roblin, 2012). However, the existing organizational structure of universities established mostly during the 19th century is not particularly congruent with these requirements.

The misalignment is even more pronounced in Pakistan's higher education sector. There has been an enormous rise in the number of universities established under the umbrella of the Higher Education Commission (2023), and the number of students enrolled at these universities has also increased, surpassing 1.3 million in 2024 (Rind & Malin, 2024). However, the problem of unemployment and underemployment remains a major concern, with studies conducted by the Pakistan Bureau of Statistics (2025) over many years revealing that a large number of graduates could not secure a job commensurate with their educational qualifications, especially in the provinces of Baluchistan and Khyber Pakhtunkhwa, where the capacity of industries to absorb graduates is low (Ahsan & Khan, 2023).

At the same time, Pakistan has also formally adopted the 2030 Agenda for Sustainable Development and has integrated Vision 2025 and national development plans with the seventeen Sustainable Development Goals (SDGs). The Higher Education Commission has formulated frameworks that demand integration of content related to SDGs into course curricula; however, implementation has been inconsistent and is entirely voluntary. It must be noted here that the Sustainable Development Agenda does not make its presence felt in the core curriculum of any discipline. This issue can only be seen within the elective subjects of environmental science, and by adding an element of social responsibility in the business curriculum (Hinduja et al., 2023).

This paper proposes that it is not only efficient but also conceptually required to address both challenges (employability and sustainability) within a single curricula reform agenda. It is because, currently, sustainability is a cross-disciplinary issue that requires precisely the sort of flexibility and problem-solving ability that companies look for. Developing programs that integrate social studies, technology, and sustainability can help graduates not only pursue their career goals but also live up to the world's expectations as well.

2. Theoretical Foundations

2.1 Constructivism and Active Learning

Constructivist theories (Piaget, Vygotsky, Jonassen, 1999) suggest that learning is an active process based on interactions with authentic problems rather than on memorization and the reproduction of previously learned material. However, in Pakistan, the colonial British tradition of lecture and examination, coupled with large class sizes and traditional roles of faculty, is still being practiced in higher education. PBL integration calls for curriculum redesign and a pedagogical culture change, supported by meaningful professional development (Solano et al., 2023).

2.2 Competency-Based Education (CBE)

The UNESCO (2017) competency framework of Education for Sustainable Development (ESD) lists a set of competency areas that align with the outcomes of CBE assessment systems, including interdisciplinary problem solving, adaptability, and ethical decision making. These competencies are exactly those that CBE assessment systems are meant to be able to validate (Nodine, 2016). Pakistan's HEC introduced the National Qualifications Framework (NQF) in 2015 for outcomes-based education, but its implementation by departments has been inconsistent and most departments still use input-based metrics for their programmes. The three pillars of SEN are mapped with the three categories of HEC graduate attributes, making the efforts to reform both pedagogically grounded and administratively compliant

(Hinduja et al., 2023).

2.3 The T-Shaped Graduate Ideal

The 'T-shaped' professional model characterizes people with expertise across at least one of several fields, with a general integrative ability to work collaboratively across them (Hansen & von Oetinger, 2001). Employers in Pakistan, especially multinational companies, development organizations, and tech companies, are increasingly clearly defining their hiring preferences in ways that resemble the T-shaped ideal. This demand, in line with the statistics obtained from the World Economic Forum (2023), directly supports the significance of the SEN Model in the context of the Pakistani graduate market.

3. The Sustainability-Employability Nexus (SEN) Model

The SEN Model revamps the curriculum in three complementary strands that each address a facet of the competency deficit between traditional education in specific disciplines and the needs of the SDG-driven economy in Pakistan.

3.1 Pillar 1: Systems Thinking and Ecological Literacy

This pillar enhances students' ability to analyze complex adaptive systems (ecological, social, economic and technological) and points out feedback loops, tipping points and leverage points. Courses are co-taught by natural sciences, social sciences, and engineering faculty that are based on planetary boundaries frameworks, lifecycle assessment, and environmental economics (Rockström et al., 2009). The need is pressing in Pakistan, which is among the 10 most climate vulnerable countries (Eckstein et al., 2021), with Karachi, Lahore, Peshawar and Quetta being among the most polluted cities in the world and experiencing losses of USD 30 billion in 2022 due to the flood (UNFCCC/FAO, 2023). To equip students with an understanding of the ecological problems in their professional environments, the local case studies were introduced: Indus River basin management, coastal erosion in Karachi, and urban heat island in Lahore.

3.2 Pillar 2: Digital and Data Competencies for Sustainable Development

Pillar 2 provides students with the practical digital and data skills which are developed using SDG-related project tasks and are embedded in digital and data technologies, including data visualisation, GIS, machine learning basics, and digital ethics. This design process promotes technical skill development with social and environmental considerations. While the Digital Pakistan Policy (Ministry of Information Technology & Telecommunication, 2018) acknowledges the importance of data skills in Pakistan, the National Technology Council (NTC) and Pakistan Software Export Board (PSEB) have noted a significant disconnect: students excel at coding but cannot use digital tools for solving complex challenges in society. This is directly tackled by co-developing modules with technology firms, development banks, and planning departments (Boud & Falchikov, 2006) in SEN Pillar 2.

3.3 Pillar 3: Ethical Leadership and Cross-Cultural Collaboration

The third pillar focuses on the human and institutional aspects of sustainable development and the development of ethical thinking, interculturalism, stakeholder facilitation and governance literacy.

It is based on political science, sociology, philosophy, and communication studies, and equips graduates to manage multi-stakeholder processes, to understand and manage value conflicts, and to communicate complex trade-offs to multiple audiences. The competencies are particularly critical as Pakistan has 70 languages and various ethnic groups in four provinces and F.A.T. Being a linguistically and culturally diverse country, these competencies are crucial in Pakistan. Pillar 3 is implemented through community-based initiatives in rural Punjab and Sindh, governance simulations and in the form of civil society collaborations.

4. Research Methodology

4.1 Overview and Research Design

The research design in this study was a mixed-methods approach. This research was carried out in four stages: qualitative research and need analysis, design-based curriculum development, pilot implementation, evaluation, and policy synthesis. The three universities selected for the Pakistani component were one research-oriented public university in Punjab, another technology-oriented university in Islamabad, and a recently established private university in Balochistan. The Pakistani pilot was carried out in 2022-24 and involved 420 students, 38 faculty members, and 34 other employees who provided additional data.

4.2 Qualitative Phase: Semi-Structured Interviews

Faculty coordinators, students, and employer representatives were interviewed using a semi-structured format, which lasted 45-60 minutes. The interview protocol was designed to address participants' views on the level of adequacy of the existing curriculum, institutional limitations, and the conditions needed to support the successful implementation of interdisciplinary integration, based on the three pillars of the SEN Model. Interviews were transcribed and analyzed thematically using NVivo 14. Two independent coders used the initial codebook developed from the interview protocol, and open coding was used as an inductive method. Inter-coder reliability was achieved with a Cohen's Kappa score of 0.81, indicating strong agreement.

4.3 Quantitative Phase: Surveys and Graduate Tracking

This phase involved quantitative data collection through surveys. Pre- and post-sustainability competence and employability instruments, using a Likert scale, were completed at the start and

end of interdisciplinary modules. The survey instruments were modified from the validated Sustainability Competency Assessment (SCA) and the Graduate Employability Self-Assessment Scale (GESAS), both of which had Cronbach's alphas above 0.78. Follow-up questionnaires were used to gather data on employment status, sector of employment, and employer satisfaction ratings for the 12 months following graduation.

5. Thematic Analysis: Findings from the Pakistani Context

Thematic analysis of the qualitative data yielded seven overarching themes, organized around the three SEN pillars and institutional barrier dimensions.

Theme 1: Inadequate Systems Thinking in Existing Curricula

Faculty interviewees across all three institutions expressed concern that existing curricula prepare students to solve well-defined, discipline-specific problems but not to analyze the systemic interdependencies characteristic of real sustainability challenges. HEC accreditation data confirm that fewer than 15% of undergraduate programs in Pakistan include mandatory content on environmental systems, and fewer than 8% include structured interdisciplinary components (HEC Program Data, 2023). Inability to think in systems was a consistent theme among employer respondents from development organizations, water utilities, and provincial planning bodies, who cited it as their major motivator for investing in in-house training.

Theme 2: Digital Skills Disconnected from Sustainability Contexts

Students in computer science and IT programs reported proficiency in coding and limited awareness of how their skills could be used to monitor SDGs, analyze environmental data, or measure social impact. Non-technical faculty also found themselves poorly supported in their roles of supervising the integration of digital tools, stating there were no opportunities for faculty development and no incentives for collaboration across departments to integrate digital tools. The discovery suggests a problem with the rhetoric of national digital strategy and the implementation of curriculum in institutions, which the SEN Pillar 2 is designed to solve.

Theme 3: Ethical Leadership as an Undervalued Graduate Attribute

Employer respondents rated ethical reasoning and intercultural competence as the top three most desired graduate attributes. In contrast, faculty interviews showed that ethics content is generally limited to discrete stand-alone modules, evaluated in a declarative, not applied, fashion. The participants in the focus groups described their ethical formation as having largely occurred through informal peer interaction and family, rather than in a structured way at the university. This reinforces the need for SEN Pillar 3 to be seen as a core rather than a peripheral part of the curriculum.

Theme 4: HEC Accreditation Requirements as Structural Constraints

In Theme 4, the authors focus on the HEC accreditation requirements as structural constraints. HEC accreditation and quality assurance requirements were the most important structural constraints identified. The current HEC program recognition framework is based on single-discipline degree programs, making it difficult to validate degrees issued from multiple offerings across several departments. While a few universities devised innovative solutions, such as defining interdisciplinary modules as free electives, affixing them to a host department, or establishing multidisciplinary research centres, none completely overcame the fundamental regulatory issue.

Theme 5: Faculty Incentive Structures and Cultural Resistance

In all three pilot universities, research publications were given more weight than pedagogical innovation or interdisciplinary cooperation. In other words, as one associate professor explained, you can find no trace of the time spent working with engineering faculty to co-create a module on sustainability, compared to the tangible career boost that comes when the same time is invested in a journal article. In addition to the formal incentives, some faculty members mentioned that the interdisciplinary curriculum eroded disciplinary rigor or that it was an imposed concept of international development unrelated to Pakistan's epistemological traditions.

Theme 6: Resource Constraints and Scaling Challenges

In KPK and in public sector institutions in Punjab, resource constraints were particularly high. The four main constraints identified were: a lack of laboratory and digital infrastructure; a lack of access to international journals; a lack of space for collaborative, project-based learning; and a lack of support for funding curriculum development. Students also discussed issues related to

access to devices and to reliable Internet connectivity, which were prerequisites for the Pillar 2 data literacy modules. In response, the SEN Model is modular and scalable and can be adapted for institutions to start with low-resource Pillar 1 changes and then move to the more infrastructure-heavy Pillar 2 modules.

Theme 7: Employer-Graduate Competency Alignment and Positive Indicators

Students' confidence in system thinking, cross-disciplinary communication, and applied ethical reasoning increased after completing interdisciplinary sustainability modules. The employment rate in sustainability-related jobs was approximately 31% higher for pilot cohort graduates than for comparators, as revealed by longitudinal tracking. SEN-aligned graduates were rated higher than others on adaptability, communicating with stakeholders, and ethical responsibility in employer satisfaction surveys. Several employer respondents spontaneously mentioned that SEN-trained graduates were ready to deal with the complexities of the real world, compared to the more technical approach taken by traditionally educated graduates.

6. Pilot Implementation and Quantitative Outcomes

The quantitative evaluation data presented below are supplementary to the thematic findings presented above and are based on the Pakistani ISECF pilot. **Table 1** provides a detailed overview of the key outcome measures for competency assessment, graduate employment, and employer satisfaction. The data are shown graphically in **Figures 1, 2, and 3**.

Measure	SEN pilot	Comparator	Change/difference	Sig.
Pre–post competency scores (n = 312, scale 1–5)				
Overall sustainability competency	4.1	2.9 (pre)	+1.2	$p < 0.01$
Systems thinking subscale	4.2	2.7 (pre)	+1.5	$p < 0.01$
Ethical reasoning subscale	4.1	2.6 (pre)	+1.5	$p < 0.01$
Digital literacy subscale	4.0	3.0 (pre)	+1.0	$p < 0.01$

Employability readiness (GESAS)	4.0	3.1 (pre)	+0.9	p < 0.01
Capstone: distinguished/proficient	73%	—	—	—
Graduate employment outcomes (n = 187, 12-month tracking)				
Employed within 6 months	64%	49%	**+15 pp**	—
Employed in a sustainability-related role	38%	22%	**+16 pp**	—
Employer satisfaction ratings (scale 1–5, 6 & 12 months post-hire)				
Adaptability	4.3	3.4	+0.9	—
Stakeholder communication	4.2	3.5	+0.7	—
Ethical reasoning	4.4	3.4	+1.0	—
Interdisciplinary problem-solving	4.1	3.7	+0.4	—
Overall employer satisfaction	4.2	3.5	+0.7	—

Table 1. Summary of ISECF Pilot Quantitative Outcomes, Pakistani Universities (2022–2024)

Source: ISECF Pilot Evaluation Data, Pakistani Component (n = 312 students; 187 graduates tracked). pp = percentage points; GESAS = Graduate Employability Self-Assessment Scale.

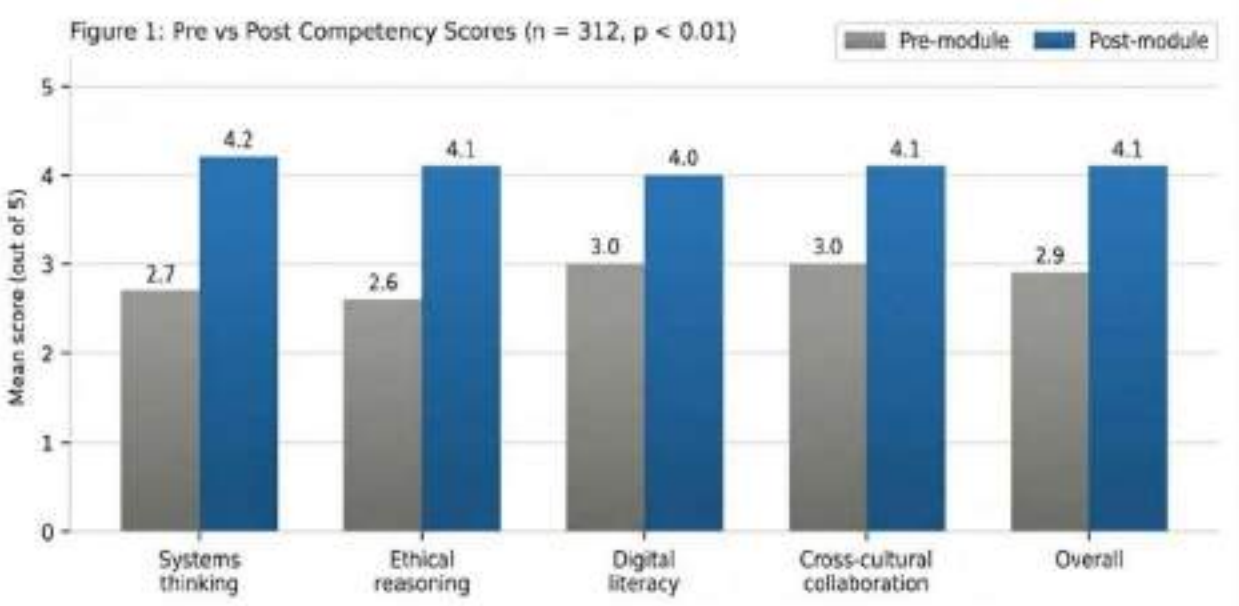

Figure 1. Pre vs Post Competency Scores

The pre- and post-survey analysis of students' sustainability competency scores showed a statistically significant increase after completion of the module. As seen in **Figure 1**, overall mean scores of the Sustainability Competency Assessment instrument rose from 2.9/5.0 to 4.1/5.0 ($p < 0.01$), with the greatest increase in mean scores of the ethical reasoning (+1.5) and systems thinking (+1.5) subscale scores.

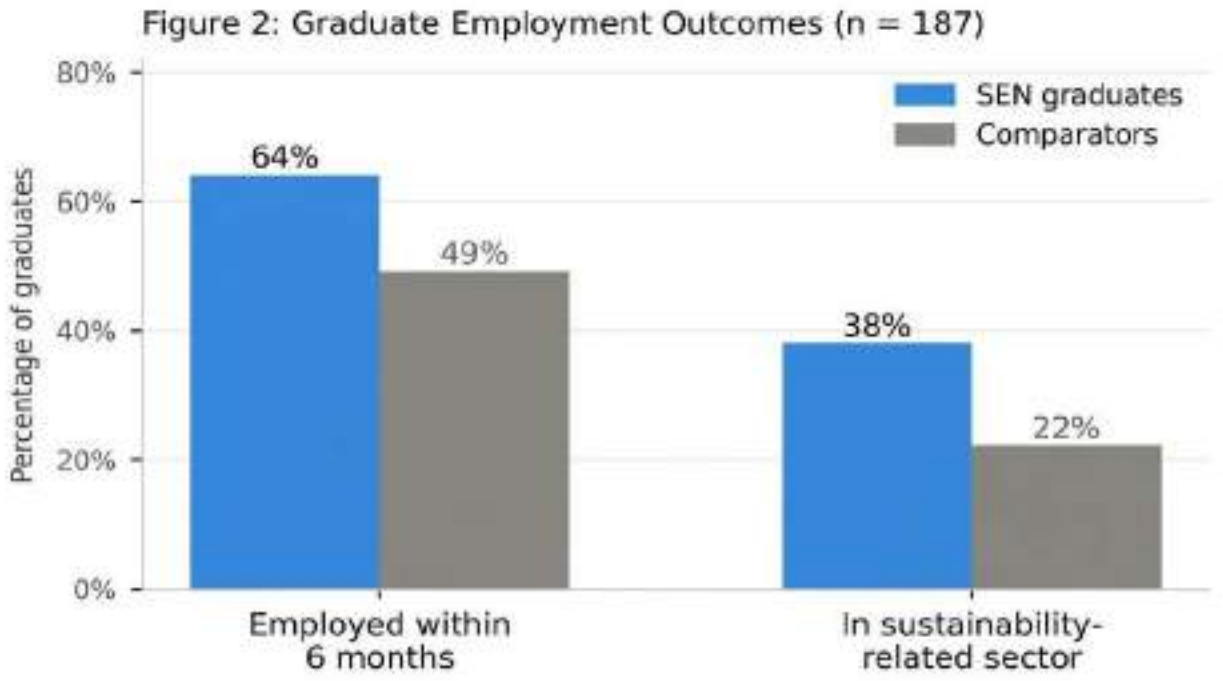

Figure 2. Graduate Employment Outcomes

Longitudinal graduate data of 187 students tracked over 12 months after completion of their degree showed that 64% of SEN-aligned graduates were employed within 6 months, whereas 49% of a matched comparator cohort (traditional graduates from the same institutions) were employed within the same time. **Figure 2** shows that 38% of employed graduates work in sustainability-related jobs, compared to 22% of the comparators.

Figure 3. Employer Satisfaction Ratings

An employer satisfaction survey showed that SEN-aligned graduates were more positive across all five measured domains at both the 6- and 12-month post-hire points. The highest discrepancies were seen in the ethical reasoning (+1.0) and adaptability (+0.9) areas, as shown in **Figure 3**. Employers' overall satisfaction was higher for SEN graduates (4.2/5.0) than for comparators (3.5/5.0).

7. Institutional Barriers and Governance Strategies in Pakistan

Thematic and quantitative evidence-based research provides strong justification for reforming the higher education curriculum in Pakistan from an interdisciplinary perspective. However, the qualitative evidence is just as clear that structural barriers are significant. This section collates barrier evidence and proposes governance options tailored to the context of barriers in Pakistan's regulatory, cultural, and resource landscape.

Interdisciplinary degree programs should have a dedicated pathway within HEC, as provided for in the Bologna Process of the European higher education system. HEC should provide guidance, at a minimum, on how to handle credit-hour attribution, program outcome mapping, and faculty workload allocation when a course is taught across departmental or faculty lines, without the need for new administrative structures at the institution.

Promotion and appraisal systems at universities must be updated to consider interdisciplinary curriculum development, 'engaged' teaching, and collaborative pedagogic innovation as valid modes of scholarly activity. HEC can help catalyze this change by including interdisciplinary teaching indicators in university ranking and performance evaluation systems.

HEC and the Government should establish a fund for Curriculum Innovation to develop an interdisciplinary sustainable development curriculum, prioritizing Colleges in KPK, Balochistan, and AJK with the highest resource gaps. Given their existing investments in Pakistan's green economy and digital transformation, international development partners such as the World Bank, the Asian Development Bank, and bilateral development partners are natural co-funders.

8. Conclusions

This paper has suggested that the dual imperatives of graduate employability and sustainability citizenship can be best addressed through an integrated, interdisciplinary curriculum strategy, and that the challenge facing the Pakistani higher education system is a newer one. The SEN Model provides a systematic and evidence-based approach to curriculum design for the social sciences, technology, and sustainability.

Preliminary findings from the three Pakistani Universities are encouraging: students with a SEN background demonstrated substantial gains in sustainability competency and employability readiness; they obtained jobs more frequently than their non-SEN peers and, when interviewed by their employers, were rated higher for their adaptability and ethical reasoning. Seven dimensions of the reform challenge were extracted from the curriculum, pedagogy, faculty incentives, accreditation, digital infrastructure, and resource allocation, using a thematic analysis.

Future Directions

First, HEC should create regulatory frameworks that allow, rather than prevent, the creation of interdisciplinary programmes. Second, universities must rethink how faculty members are assessed and include innovation in interdisciplinary pedagogy among the various forms of scholarship. Third, there is a need for dedicated funding for curriculum innovation, preferably within international development partnerships, and in institutional contexts where resources are limited.

Longitudinal tracking for more cohort years, an exploration of differential outcomes by student sub-groups, and an evaluation of the model in the specific institutional environments of community colleges and madrassa-related degree programs are recommended for future research. Knowledge sharing between South-South and South-North networks would be supported by collaborative research networks between Pakistani universities and international SEN pilot sites in Romania, the United Kingdom, and Southeast Asia, which would help to build up the evidence for comparison.

Limitations

The study was carried out in just three universities (one public in Punjab, one in Islamabad and a private one in Balochistan) reaching a total of 420 students and 187 monitored graduates. The findings were not random as the sample has been purposively selected, hence limiting the generalizability of findings for Pakistan's wider higher education system of more than 255 HEC recognized institutions. There is a lack of representation of universities in underrepresented regions like Sindh, Gilgit-Baltistan and AJK, which may result in missing some of the important contextual variations in terms of the availability of resources, faculty capacity and student demographics.

Only the employment outcomes for 12 months after graduation were examined. This period of time is not long enough to determine whether and how the competence increase seen is maintained in the medium to long term, or if the employment benefits of SEN-oriented graduates continue beyond early career entry. Conclusions about the impact of the model on career trajectories and lifelong employability would be made more robust if there was longer tracking 3-5 years.

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Unpacking Class Unevenness in University Teaching: Deconstructing Hidden Curricula

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Abstract

Universities are usually identified as meritocratic institutions that reward efforts of talent regardless of their social origin. Yet underneath formal curricula and defined learning outcomes, a hidden curriculum operates, transmitting social norms, cultural codes, and behavioural expectations that systematically benefit students from middle and upper-class socio-economic backgrounds. Therefore, this research attempts to examine how implicit pedagogical practices, linguistic conventions, assessment cultures, and socio-politico-spatial norms in higher education institutions perpetuate socio-economic divides. By employing Pierre Bourdieu's concepts of habitus and cultural capital and Paulo Freire's framework of critical pedagogy, the paper analyses three key sites of class unevenness: the unspoken expectations of educational discourse, the deficit of low-income rural-class experience in prescribed curricula, and the performative norms embedded in classroom participation culture. The present research proposes selected critical pedagogical interventions, including dialogical teaching, reflexive curriculum design, and culturally responsive assessment mechanisms that educators could adopt to dismantle mechanisms of hidden curricula. The deficit of rural-peri-urban background students' experiences result in "objectification" that refers to the experiences of rural/peri-urban students perceiving their own communities as merely objects of study rather than sources of knowledge.

The argument is not merely emphasizing universities to acknowledge socio-economic diversity, but there should be an active reconstruction of their pedagogical architectures that recognise, validate, and build upon the diverse knowledge that all students bring with them.

Keywords: hidden curriculum, class unevenness, critical pedagogy, cultural capital, higher education, Bourdieu, Freire, socio-economic equity, habitus.

1. Introduction

Higher education has long been demonstrating a key role in the liberal democratic imagination as a source of social mobility, a space of intellectual emancipation, and a pathway that allows talent to rise unconstrained by birth. Yet large sociological and educational research has exacerbated complications to the higher education institutions (HEI's). Students who reach the Universities

with working-class backgrounds are typically faced not only with a curriculum of subject knowledge, but a curriculum of social compartmentalization. The question arises that it is usually not recognized by the planners,designers, and not understood by the receivers.

The hidden curriculum is the unspoken curriculum (unintentional lessons and values taught) that seeks conformity and obedience by students while they are at school, Philip Jackson (1968) studied in his research of elementary school life: norms of deference and self-presentation, ideas about intellectual independence and conventions of academic voice and register. The hidden dimensions are integral to higher education in uneven socio-political conditions, where students are expected to be self-governing adults thus failures to attain good outcomes are often attached to their individual's ability or efforts instead of disadvantage.

This paper attempts to unpack a few observed dimensions of hidden curriculum in university teaching as a class-coded artefact. Historically built, and tactfully used by educated middle and upper class to various advantages, It operates in a combination of norms, conventions and expectations that continues to serve as unspoken mechanisms of cultural gatekeeping. The paper analyzes four substantive sections: a theoretical basis on Bourdieu and Freire; three main locations of class unevenness (inequity) in university teaching; a brief overview of critical pedagogical interventions and a commentary on institutional conditions for the effective implementation of reform.

The research would attempt to investigate through the research question as given below;

Research Question:

How does the hidden curriculum in universities reinforce socio-economic class unevenness through tacit pedagogical practices, linguistic conventions, assessment cultures and classroom participation norms?

2. Theoretical Framework: Bourdieu, Freire, and the Pedagogy

This paper utilizes two theoretical constructs for analysis. The first one is Pierre Bourdieu's sociology of education, specifically focussing on “Reproduction in Education, Society and Culture” (Bourdieu & Passeron, 1977). Education valorizes the dominant class's habitus, a system of durable, transposable dispositions that structure perception, thought and action. The educational

institutions operate in a way to reproduce it by praising the intellectual merit of class advantage. The cultural capital builds upon cultural knowledge, competencies and credentials acquired in the family and formal educational socialization. It functions as the currency with which this process works.

The university is not a neutral field for Bourdieu. It is organized by the rules of the game '*illusio'* which are readily understood by the middle-class intellectuals however, neither understood by others nor socialized in their intellectual culture. The students who intuitively know how to speak to a professor and the way to critical engagement in a seminar and how to take his voice in writing for description to analysis. It is not necessarily that it rests on typical wisdom than those students who don't know such things. They hold a kind of cultural capital that is embodied and the institutions equate it with academic skills. In the terminology of Bourdieu, the hidden curriculum consists of the array of implicit and structured ways by which cultural capital is converted into academic distinction.

The second tradition is the critical pedagogy developed by Paulo Freire as described in Pedagogy of the Oppressed (Freire, 1970). Bourdieu provides a sociology of reproduction and Freire offers a philosophy of liberation. Freire critiques on the banking model of education, where students are treated as empty vessels into which authoritative knowledge is poured, is quite powerful in terms of the class dynamics of the hidden curriculum. In such instances, universities impose tacit norms without explicit mention, and various procedures punish students without already embodying these norms, so it imposes a kind of symbolic violence that precludes critical consciousness.

Thus dialogical education of Freire provides the normative basis for the prescriptions in this research paper, because it is based on identifying factors that occur in the experience of the learner. Critical pedagogy can not immediately add to the curriculum, but rather it seeks to reposition the pedagogical relationship, bringing to the fore the knowledge and lived experience of the learner as a resource rather than a deficit. Freire (1970), "Pedagogy of the Oppressed" introduces critical pedagogy, emphasizes dialogical teaching by dismantling oppressive educational structures. Therefore, it focuses more on schooling and community education than on universities' hidden curricula.

Brief Literature Gap

Recent studies on hidden curricula (e.g., mentoring, tacit knowledge) largely focus on inequality

but do not systematically connect these practices to class unevenness in academic discourse, curricula and participation norms. While prior scholarship has critiqued the myth of meritocracy in higher education (Bourdieu & Passeron, 1977; Freire, 1970) and identified hidden curricula in specific contexts (e.g., mentoring in graduate education). Integration of Bourdieu and Freire remains underdeveloped in higher education research, leaving a gap this study tends to address by combining symbolic domination (Bourdieu) with dialogical pedagogy (Freire). The classic text shows how education legitimizes social hierarchies through symbolic domination and cultural capital. It only critiques meritocracy but does not explicitly theorize hidden curricula in contemporary university teaching. Margolis, E., & Romero, M. (2020) The scholarly literature lacks due to insufficient theoretical and empirical evidence that could systematically examine how implicit pedagogical practices, linguistic conventions and classroom participation norms reproduce socio-economic unevenness/divides in universities teaching. This study specifically addresses the identified gap by integrating Bourdieu's sociology of reproduction linking with Freire's critical pedagogy to analyze sites of class unevenness and proposing reviewed interventions.

3. Three Sites of Class Unevenness in University Teaching

3.1 Academic Discourse and Linguistic Capital

Academic Discourse Question:

How do unspoken expectations around academic language, rhetorical style and disciplinary discourse privilege students with middle- and upper-class cultural capital and marginalize those from working-class or rural backgrounds?

In the light of academic discourse, the ground which is the least recognized form of class differences in university teaching is perhaps the field of academic language. The registers, genres, and rhetorical conventions of academic discourse are not natural and universal but rather historically produced through specific intellectual culture. But universities regularly regard

knowledge in these linguistic conventions as a measure of intelligence or devotion instead of previous socialisation.

The vocabulary, patterns of argumentation, and norms of citing that are required for academic writing are likely to be familiar to students raised in families with high educational capital, much like the vocabulary they already know, thanks to dinner-table discussion, recreational reading, and family cultural traditions. First-generation university students, by contrast, frequently encounter academic discourse as a foreign language, for which no systematic instruction is provided because it is assumed to be already known (Reay, 2001). The common feedback includes such as 'needs more critical analysis', 'argument lacks structure', 'write in a more academic register' presupposes having access to a metalanguage (academic practice) that they have never been taught.

This deficit is compounded by the hidden evaluative norms of classroom participation. Seminar cultures in many universities reward confident verbal performance, the ready marshalling of theoretical frameworks, and the ability to speak with authority under conditions of spontaneous intellectual debate. These are skills cultivated by years of middle-class socialisation dinner parties, family debates, private school debating societies not by the lived experience of low-income rural-class students, who may have been socialised into different but equally valid epistemic cultures.

3.2 The Invisible Low Income Rural-Class in Curricula

Curricular Exclusions and Invisible Rural back Ground:

Why does the prescribed curriculum fail to incorporate the lived experiences, knowledge systems, and socio-political realities of low-income or rural-class students, thereby reinforcing deficit perspectives?

In light of the above question, the second site of class unevenness could be seen in the prescribed content of the universities. Across disciplines from literature to management studies, from governance and public policy to economics, the canonical texts, particular cases, and selective reference points of university curricula are predominantly centered around middle and upper-class cultural norms and experience, leading to knowledge production. The deficit of rural-peri-urban background students' experiences result in “objectification” that refers to the experiences of rural/peri-urban students perceiving their own communities as merely objects of study rather than sources of knowledge.

This curricular absence has concrete socio-psychological and intellectual consequences. Students without seeing their experiences, communities, and specific epistemic traditions demonstrate that the curriculum embodies an implicit message: that knowledge is something produced about other things elsewhere, by others. This is what Moll et al. (1992) describe as a "failure to recognise students' funds of knowledge’ the cultural and intellectual resources that students bring from their particular communities and could provide as powerful platforms for academic elevation.

This widespread absence of low-income rural-class experience is not merely an omission, but it is constitutive of disciplinary identity formation. Thus, adding a low-income rural-class author to a reading list or a case study drawn from a low-income rural-class community is partially useful but largely insufficient. The critical task is to investigate why canonical knowledge looks the way it does, whose perspectives it systematically excludes, and how the standards judge academic work - originality, abstraction, universalisability encode particular class-based epistemologies.

3.3 Assessment Culture and the Performance of Competence

Participation Culture

How do performative norms in classroom participation (confidence of voice, assertive debate and familiarity with institutional codes) reproduce socio-economic unevenness/divides in perceived competence and academic success?

Assessment Practices

How do implicit criteria in assessment cultures (valuing originality, independent thinking or theoretical sophistication) structure class-coded assumptions that advantage students with greater cultural capital?

The above referred questions highlight the role of performative norms in classroom participation and criteria in assessment culture as the third site of class unevenness in assessment. While assessment is formally standardised and bound by explicit marking criteria, these criteria themselves embed class-coded assumptions about what good academic work looks like. The values of originality, independent thinking, and confident theoretical argumentation that are highlighted in assessment rubrics correspond well with students' habitus with high cultural capital. Crozier et al. (2008) have noted self-regulated learning of middle-class students as an assumption that students can self-manage their own learning, prepare longer assignments and search their supplementary resources without being explicitly instructed.

Time-pressured examinations are a disadvantage to students with heavier domestic responsibilities, more prevalent among students with lower incomes in rural areas. The hidden curriculum of assessment is also transmitted non-formally: students whose parents and siblings have gone to university are provided with plenty of guidance on what they should do, how they should respond to feedback, and how they should navigate the murky world of successful academic work. Students lacking this type of social capital find an evaluation path more complicated and without a roadmap.

4. Methodological Overview and Empirical Analysis:

The research utilizes thematic analysis for exploring norms, values, and hidden curricula that contributes class unevenness in university education. Therefore, it might help researchers to go

beyond a surface-level analysis of curricula to reveal norms, values, and expectations that are implicit in the practices of academics. Thematic analysis extracts common themes from the codes, revealing the socio-economic hierarchies to which the institutional structures and pedagogical conventions conform, identifying possible areas of agency, assertiveness, and transformation. This approach is both methodologically sound and insightful, and provides a critical perspective on the mechanism of class bias within the mundane practices of everyday teaching and assessment. The selective purposive sampling was adopted to collect first-hand responses from university students studying their Bachelor's degree final semester from the National University of Modern Languages (NUML). The sample of respondents comprises three female students and five male students with differentiated socio-economic backgrounds and socio-cultural capital. The qualitative semi-structured interviews with 8 respondents detailed interviews for exploratory study [n=8; f=3, m=5] students at the National University of Modern Languages (NUML), Islamabad. Participants were selected through purposive convenient sampling to represent diversity in socio-economic background, geographic origin (urban/rural), and first-generation university status. Interviews were audio-recorded, transcribed verbatim, and analysed using Braun and Clarke's (2006) framework of thematic analysis assigned codes as the first step of thematic analysis. The second step was generating themes and sub-themes to interpret respondents' responses. Then, finally, report writing to explain the empirical findings of the research.

Initial open coding was followed by pattern coding, with emerging themes systematically mapped onto the study's theoretical constructs including Bourdieu's concepts of “habitus and cultural capital” and Freire's “critical pedagogy”. The analysis proceeded deductively through three pre-theorised sites of class unevenness: academic discourse, curriculum content and assessment culture, while remaining open to inductively emergent sub-themes from participants' narratives. Phase 1 involved open coding of raw interview excerpts, generating initial codes such as 'unexplained academic expectations', 'curricular invisibility', and 'domestic burden in assessment'. Phase 2 categorised the codes into sub-themes, per site. The final stage (Phase 3) was writing the final thematic narratives in the Claim–Evidence–Analysis–Implication format. To enhance credibility, member checking and reflexive bracketing were used.

Code	Gender	Socio-Economic Background	Urban/Rural Origin	First-Generation Student	Study Programme	Year
P1	Male	Low-middle income	Peri-Urban	No	Governance and Public Policy	Final
P2	Male	Middle-income	Peri-urban	Yes	Governance and Public Policy	Final
P3	Male	Low-middle income	Rural	No	Governance and Public Policy	Final
P4	Male	Low-middle income	Peri-urban	Yes	Governance and Public Policy	Final
P5	Male	Middle income	Rural	Yes	Governance and Public Policy	Final
P6	Female	Low-middle income	Peri-urban	Yes	Governance and Public Policy	Final
P7	Female	Low-middle income	Urban	No	Governance and Public Policy	Final
P8	Female	Low income	Rural	No	Governance and Public Policy	Final

Table 1. Table of Respondents

5. Results

Three analytical sites were noted for five themes that were linked together. These themes do not exist in isolation but are interwoven into a series of mechanisms that create and perpetuate class-based disadvantage in higher education.

Theme 1: The Linguistic Capital; Academic Discourse as a Class-Coded Gateway

Claim

Academic language is not a skill taught at universities, but is assumed as a prior competency of students. This assumption normalises the language from educationally privileged homes and stigmatises the language use of students from the first generation and low-income families.

Evidence

Pupils' accounts of a mismatch between the language and the resources they may use were

regularly reported. One participant was very clear in summarizing this:

> *P1 and P2 rural and prei-urban background with low middle income responded to a question about unspoken expectations in the classroom "Always heard and read word critically by the teachers in multiple interactions but hardly deciphered true meaning from such expressions" It was indicative of unevenness in learning experience by weak cultural capital among low socioeconomic background.*

The unspoken expectations from the students that they will arrive with the requisite knowledge of how to 'think critically' thus not being taught what that term means. It was rather experienced by students with low socioeconomic background as a teaching omission, considering as an assumption that the academically fluent already knew that, and those that lack it are deficient, as a class signal. It is often appeared as gap that exacerbated due to non bridging of the feedback,

> *P7 and P8 rural and urban background with low middle and middle income responded to a question about unspoken norms of the classroom" Whenever a teacher remarks that includes the word 'lacks' does not help me to improve."*

In this response it shows that unspoken classroom hierarchies are entrenched due to the absence of explicit scaffolding in academic discourse of higher education institutions. One P3 respondent gave a thorough account of the social functioning of linguistic dominance:

> *" There were "unspoken rules and norms clearly dividing different experiences of different students based on gender tension, curriculum tension… The rules were created to declare some students as confident to dominate, and others just sit quietly."*

Analysis

The experiences themselves embody Bourdieu's (1986) notion of linguistic capital, which refers to the ability to speak the dominant registers of language and it is an inherited cultural asset that is unevenly distributed among social classes. For Bourdieu, the university is a space where various types of capital are recognized and rewarded. It is,therefore, academic language may not be seen as a priori universal medium, but rather a class-coded field of practice sanctioning to the cultural weight of educated, middle and high income households.

Students who develop habitus outside of school contexts usually reach the university with the tacit

linguistic codes that some have picked up from family socialisation. It reinforces 'feel for the game' that Bourdieu describes as cultural capital. The university's reluctance to state these codes explicitly points to Freire's (1970) "banking model of education" in which knowledge is deposited in students. Because they are expected to be passive recipients embracing a ready-made intellectual culture instead of being active agents in their own right.

The hidden curriculum of academic discourse, therefore, functions as an invisible filter; people with fluency are not marked as deficient in their language, but others are described deficient due to language barrier.

Implication

The hidden curriculum of language is one of the most powerful, yet most invisible machines of class reproduction in higher education. The invisibility of its naturalisation is the reason to turn it invisible. It is not a class specific practice but rather a universal standard. In order to reform institutions, there is a need to rewrite the code, making it explicit, by creating structured academic literacy development, clear assessment criteria and pedagogical approaches that validate use of different communicative repertoires without showing any bias.

Theme 2: Rural and Low-Income Experience as Invisible Curricula

Claim

The lived experiences, community knowledge, and epistemological frameworks of low-income, rural students are systematically ignored and rendered invisible in university curricula, such that the community that is being studied is the source of legitimate knowledge and the subject of the study is the background.

Evidence

Winners from the rural and peri-urban areas consistently said that there was no connection between the content of the course and their social realities. P5 and P6 talked about a time of non-recognition:

> *"I found out in my university experience that I have been mostly misunderstood based upon peers' perceptions due to history, identity and social values. The institutional mechanisms denying any channel to get redressal was another problem. All examples are from big cities, corporates, elite families making me a nonrecognized person."*

The P4 shared his experience of curricular erasure which was compounded by the devaluation of community-based knowledge:

> *"What I know from my community feels worthless here because the prescribed syllabus did not reflect my experience of knowledge. The subjective sensitivities of different students hardly matched with prescribed content."*

Particularly P7 expressed striking observation that the curriculum's relationship to marginalised experience was that of a researcher to a subject — studying these communities rather than learning with or from them:

> *"The problem is that what we study in prescribed course content is completely disconnected, turning them as objects of study (Objectification), not the people's lived experiences of what they are made to study."*

The educational biography of one participant P1 further illustrated how structural instability (itself a product of class) produced knowledge that curricula are entirely unequipped to engage:

> *"Early academic life is replete with many experiments... Being a descendant of a politically active father, I sought extensive education, turning into a bumpy schooling track for me... it resulted in finding out strange class codes in which I started university learning with various emotional experiences."*

Analysis

The findings are in consonance with Moll et al.'s (1992) description of the term “Funds of Knowledge framework”, which holds that low-, middle-, and working-class families have deep stores of knowledge and understandings (practical, historical, cultural and relational) that are continually ignored and underrated by schools and universities. These cultural landmarks in the community are interpreted as absentees rather than cognitive and epistemological resources.

Bourdieu's notion of the habitus helps explain the structural aspect of such exclusion. The culture of rural, first-generation students, who learned through first hand knowledge on farming practices, survival skills, interdependence in communities and oral language. It appears to be in conflict with the implicit valuation of urbanised, middle-class, text-based knowledge in the academic field. This imbalance is demonstrated as lacking, not as an injustice.

Freire (1970) has identified one of the key characteristics of dominant educational systems, silencing instead of engaging the epistemological discourses of oppressed/invisible communities. The 'object of study' (objectification) dynamic, which participant P1 described as 'students from the margins learning texts about the margins', is a very stark example of what Freire called the 'culture of silence'.

Implication

The lack of inclusion of the experiences of low socioeconomic rural communities can not be explained as an insufficient content issue, but a structural issue, reflecting whose knowledge is valued and whose not. In order to address this, there needs to be a paradigm shift in the way the curriculum is designed. It can begin from representation and introduction of 'diverse examples' to include epistemic inclusion by drawing on students' “Funds of Knowledge” as a legitimate resource for academic inquiry.

Theme 3: Class Performance, Competence, and Participatory Norms

Claim

The norms for participation in class and in a seminar becomes the criteria of verbal confidence and the rules of interaction among fellow students are all class-coded performances. It benefits only such students who have been educated and socialized in a way to perform it in expected ways.

Evidence

The participants P1 P6 P8 students reported Classrooms were actually social fields organized by inequalities of social and cultural capital. Where the holders of specific social and cultural capital held dominant roles in academic performativity.

> *"The students with social capital seem to know how to behave in seminars, we kept quiet and just watched."*

The limits of acceptable speech and behaviour were never described as explicit rules as such, but rather as a tacit class code, which was picked up intuitively by some students forcing others seeing from the outside:

> *"Teachers mostly expect us to speak fluently but we never had that back home."*

Analysis

The concept of the field of Bourdieu (1984) is central here. The university seminar is a space termed a social field with its own rules of the game, its own *illusio*, which are not expressed but to be internalized. Students from privileged backgrounds enter the university with specific dispositions required to do academic work, as they grow up in environments with the same participatory norms as those of private schooling, dinner-table debates and extracurricular oratory. Such norms of participation act as symbolic violence in the sense because they impose a social code specific to a class as though a universal standard of academic seriousness for first-generation students. It works in silence, as well as in words, the disciplining of non-dominant voices.

Freire's dialogic pedagogy provides an alternative, a classroom should not be organized around multiple voices of the dominant culture, but rather organized around multiple epistemological standpoints, one of which is “silence”, which may not be a sign of lack of intelligence, but of power.

Implication

If pedagogies adopt participatory approaches and remove all types of the class coded nature of participation, then they may address inequity in classrooms. Pedagogical reforms should work towards conditions where multiple modes of participation are respected, and where speaking power is not something that is passed down, but it is truly given.

Theme 4: Assessment as a Class-Coded Filter

Claim

Assessment systems reinforce inequity within the classroom through favouring certain ways of assessment. In a way, students likely to have parents’ support in their educational tasks, paid work and generational guidance/supervision grant them an advantageous position to succeed with doing assessment.

Evidence

The structural challenges of assessment were grouped under three sub-themes:

Structural disadvantages. It unfolds conflict of assessment demands and material conditions in life. The participants P2 P6 responded about assessment demands and linking with material conditions of life;

> *"We work part-time, so timebound exams are really hard for us to prepare for exams without any*

> *distraction."*
>
> *P6 responded in words; "I have three younger siblings at home, I can't self-study like others to prepare for exams."*

Second structural challenge includes, that the transfer of 'tricks of the trade' that are not available to first generation students:

> *P6 P4 responded in their words; "Students whose parents went to university better know tricks which we don't."*

Thirdly, a culture of marking that equates confidence, theoretical fluency and understanding:

> *P2 responded in his words; "Teachers reward confidence and theory but I know the content not the "standards performance."*

Analysis

This is directly connected to Bourdieu's (1986) notion of cultural reproduction. The assessment is fundamentally a subjective evaluation of academic achievement. And it needs an objective measure of academic achievement, which is a measure of endorsement of dominant academic culture. There is a tacit practice that first-generation students miss out on as the non-academic 'tricks' too. (the way to navigate the pressure of a test, the way to write to authority, to pose with certainty, to sound like an educated adult)

Assessment systems assume a "free learner" with no caring responsibilities, free of the constraints of part-time work and able to study in a setting that is ideal for the student. Therefore, there is a problem with such an "ideal assessment" for low-socioeconomic background students with low level of domestic freedom and heavy burden of caring responsibilities. This ideal could not be neutral; it's a class fiction that becomes the universal norm for student life, the middle class.

It would be Freire's (1970) understanding of the concrete dimension of the banking model that promotes the ability to reproduce a body of knowledge in a predetermined way. It obstructs the way of thinking critically from one's own position. The student who 'knows the content but not the performance' has understood but could not perform the class script and thus assessed as such.

Implication

The reforms of assessment must be directly linked to the material conditions of students' life. This means that assessment forms are varied, and the question of what may be assessed under what conditions of possibility could not be taken for granted when put to the test. These findings reflect institutional responses such as the application of the principles of Universal Design for Learning, contextual assessment and explicit preparation of the conventions of learning should be integral components of possible assessment reforms.

Theme 5: Student Agency, Resistance, and Navigational Strategies

Claim

The power of the hidden curriculum to reproduce classes is great, but students are not its passive victims. The data shows a range of critical awareness, ways of negotiating and new emerging methods of resistance (conscientização) in which students challenge and partly negotiate the situation of their marginalisation Hunaepi et al. (2024).

Evidence

Students' responses showed high levels of understanding, but sometimes painful how the class is organised. The recognition of 'unspoken rules' of the classroom despite being subject to these indicates a form of critical consciousness.

> *P1 P3 P6 responded in a way; "As soon as you recognise unspoken rules in the classroom you realise that your performance is challenged due to invisible toxicity insulating under these rules."*

The assertion of oneself as a subject who has a history and refuses to be erased. Thus naming oneself as a nonrecognized person is the very act of articulating one's erasure is a refusal of that erasure. Likewise, the students who employ a navigability between distinct school systems and institutional cultures depict a resistant adaptability that is not noted in the academic field but nonetheless exhibits real epistemic labour.

Analysis

The analytical lens of Freire's idea of "*conscientização"* helps us explain critical consciousness that comes from the naming of one's oppression. Students' skills to recognise, explain and "do" a reflexive analysis of why they are marginalized is not just a mere survival skill, it is in fact the prerequisite for transformative action, whether personal or collective.

However, Bourdieu (1984) has recognized such people who have agency in the field and that can become “reflexive of the game” they are playing, which in turn opens up if they are open to some even if there is not a significant space present for strategic manoeuvre. The navigational approaches reflected in the data (code switching, reference to dominant norms, critical reflection on institutional culture) are just such limited but genuine reflections of agency.

Implication

Critical consciousness of students could turn their experiences into a pedagogical resource and not a sign of disadvantage. The structural change is more likely to result in meaningful change likely to occur when institutional responses engage students as co-analysts of educational inequity, through participatory research, student-led curriculum review, and dialogical pedagogy than institutions treating students as objects of intervention.

6. Conclusions

This analysis has helped establish that there are three mutually interdependent sites of the hidden curriculum in higher education in Pakistan. It operates as an academic discourse, curriculum content and assessment culture which systematically privileges students’ habitus, cultural capital and material conditions endorsing unspoken norms of academic field. The five themes identified linguistic penalty, curricular invisibility, participation as class performance, assessment as class filter, and student navigational agency collectively constitute a coherent and mutually reinforcing mechanism of cultural reproduction resulting in class unevenness.

A key finding helps to go beyond previous literature’s focus (mentoring, tacit knowledge) that highlight inequality but do not systematically connect these practices to class unevenness in discourse, curricula, and participation norms. The empirical analysis illustrates the specific articulation of 'objectification,' the experience of seeing one's own community treated as the object of academic study rather than as a source of academic knowledge. (Giroux, 1983). This dynamic appears as an outcome of empirical analysis demonstrating, it is particularly acute in the Pakistani context, where rural and peri-urban student populations are often researched by the same institutional culture that excludes them.

It is based upon my few years of teaching experience with students from different socio-economic

backgrounds at the NUML University that the hidden curriculum operates in an implicit way. The hidden curriculum of higher education is not a marginal or incidental feature of university life. But it's a central mechanism through which class advantages are transmitted, naturalised and reproduced under the notion of merit. Its exposure requires the tools of critical social theory, particularly Bourdieu's account of symbolic violence and Freire's account of *conscientisation.* It calls forth sustained commitment of educators who are willing to turn a critical gaze upon their own routine practices to deconstruct mechanisms of hidden curriculum.

The findings of study highlights that class unevenness operates at three principal sites in university teaching; in the norms of academic discourse, in the content and framing of the curriculum, and in the design and evaluation of assessment. At each site, critical pedagogical interventions are available, but their effectiveness depends upon institutional commitment as well as individual commitment. There is evidence of student agency and critical consciousness has been registered in the empirical analysis of students' navigational techniques. The hidden curriculum is not all powerful; students resist, adapt, observe and name. Therefore, pedagogical transformation is a major asset in this critical awareness which, if not disregarded, could be offered by the institution as a resource. Thus the ultimate goal is not to lower standards, but to shift the definition of standards, from being the ones the privileged have built in the course of their lives, to the ones that embrace intellectual engagement, critical thinking and knowledge production of all, regardless of their socio-economic status.Yosso, T. J. (2005) It is not a gesture of humanity towards the unprivileged. It is a form of epistemic justice towards the production of knowledge.

7. Recommendations

The recommendations are directed at three aspects of institutional responsibility: Curriculum design, Pedagogy, and institutional policy.

8.1 Curriculum Restructuring

- Systematic review of current curricula to identify socioeconomic, geographic, and cultural assumptions found in case studies, examples, and theoretical frameworks.

- Include Funds of Knowledge in curriculum design; intentionally seeking out and developing the community-based knowledge, hands-on skills, and experiences that students bring from family and lived environments in low-resource communities.
- Create inclusive reading lists and course materials that recognize, value, and include knowledge production by the rural working-class.
- Global South scholars and communities are not just subjects of study. Make sure that examples in the course content reflect a variety of socioeconomic and geographic settings (not just urban, corporate, or elite).

8.2 Pedagogical Interventions

- Establish explicit and structured academic literacy development in subject disciplines — make academic writing, critical analysis and participation in seminars skills to be taught, not assumed.
- Offer detailed rubrics, examples of student work, and formative feedback that communicate abstract academic goals into tangible, specific feedback.
- Diversify assessment forms to minimize the use of timed tests and written papers as the only methods of determining academic skills and incorporate oral, project, collaborative and portfolio assessments.
- Establish opportunities for dialogical pedagogy (seminar, collaborative inquiry, peer discussion) that are structured in a way that multiple forms of participation are valued, and the authority to participate is actively distributed.
- Recognise and support students with caring, household and work duties and opportunities for flexible assessment submission arrangements.

8.3 Institutional Policy and Reforms

- Implement 'first generation' student support initiatives, which extend financial support to the academic cultural capital gap through mentoring from first generation graduates, peer networks and critical academic skills development.
- Institute academic staff training in critical pedagogy and awareness of hidden curriculum; unmask the unspoken class codes of academic culture, and challenge and change them.

- Establish processes for participatory research and create student advisory panels, co-design processes, and student-led review of curriculum to empower students from marginalized backgrounds to be co-analysts and co-designers of institutional change.
- Ensure that systematic data collection on the relations between socioeconomic status and academic attainment is carried out on an institutional level with special focus on assessment performance, drop out and participation patterns.
- Engage in policy dialogue with higher education regulators to revise accreditation standards to include equity and hidden curriculum indicators as dimensions of institutional quality.

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Bilingual Teaching in Geography: Effects on Students' Motivation and Academic Performance in Secondary Education

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Abstract

The growing interest in multilingual education has encouraged schools to explore new ways of combining subject teaching with foreign language learning. In this context, the present paper discusses the possible impact of bilingual teaching on students' motivation and academic achievement in secondary Geography classes. Particular attention is given to the CLIL (Content and Language Integrated Learning) approach, which allows learners to study school subjects while using a foreign language as a means of communication. The paper combines theoretical perspectives with a proposed methodological framework designed for future classroom implementation. The research focuses on how the integration of English into Geography lessons may influence students' participation, classroom interaction, motivation, and understanding of geographical concepts. The proposed methodology includes classroom observation, interactive learning activities, assessment tasks, and the use of bilingual instructional materials adapted to secondary education. In addition, digital resources such as interactive maps, visual presentations, and multimedia materials may support both language learning and geographical understanding. The anticipated findings suggest that bilingual Geography instruction may contribute to increased learner motivation, more active participation during lessons, and improved communication skills in English. At the same time, CLIL-based activities may support the development of transferable competences such as collaboration, critical thinking, and intercultural awareness. The paper also discusses possible challenges related to language proficiency, instructional planning, and classroom implementation while emphasizing the educational value of bilingual teaching approaches in Geography education.

Keywords: CLIL, bilingual education, Geography education, student motivation, academic performance

1. Introduction

Recent educational developments have highlighted the importance of multilingual competence and interdisciplinary learning within modern school systems. As globalization continues to influence educational policies and classroom practices, schools increasingly encourage the integration of foreign language learning with subject-specific instruction. In this context, English has become an important educational tool that may support students' academic, social, and intercultural development.

Among the approaches that promote bilingual learning, CLIL (Content and Language Integrated Learning) has gained considerable attention in recent years. This approach combines subject teaching with foreign language use and allows learners to develop both disciplinary knowledge and language competences at the same time. Through communication-oriented and interactive activities, CLIL may contribute to more engaging learning experiences while also supporting critical thinking and collaboration.

Geography represents a suitable subject for bilingual teaching because it combines visual resources, maps, diagrams, case studies, and contextual learning activities that facilitate comprehension and communication. Integrating English into Geography lessons may help students expand their subject-specific vocabulary, improve their understanding of geographical phenomena, and participate more actively during classroom activities. In addition, bilingual Geography instruction may support the development of transferable competences such as teamwork, problem-solving, and intercultural awareness.

Learner motivation is another important factor influencing academic achievement and classroom participation. Traditional teaching approaches may sometimes reduce students' engagement, while interactive and student-centered instructional methods can stimulate curiosity and active involvement in the learning process. From this perspective, bilingual teaching may contribute to the creation of a more dynamic and motivating educational environment.

The present study explores the possible effects of bilingual teaching through the CLIL approach on students' motivation and academic performance in secondary Geography education. The paper also seeks to identify potential educational benefits and challenges associated with the integration of English into Geography lessons.

The study is guided by the following research questions:

1. Does bilingual teaching increase students' motivation in Geography classes?

2.Does the CLIL approach improve students' academic performance?

3.How do students perceive bilingual Geography lessons?

2. Literature Review

2.1. Bilingual Education

The increasing importance of multilingual communication in contemporary society has contributed to the growing interest in bilingual education within modern school systems. Bilingual education involves the use of two languages during the teaching and learning process, enabling learners to develop both academic knowledge and language competences simultaneously. It may also contribute to the development of communication abilities, cognitive flexibility, and intercultural awareness, preparing learners for the demands of an increasingly interconnected world (Baker, 2011).

Specialists in the field of bilingual education have emphasized a variety of educational benefits associated with learning through a foreign language. Learners exposed to bilingual instruction frequently demonstrate improved problem-solving skills, greater adaptability in communication, and increased confidence in academic interaction. Cummins (2001) argues that bilingual learning environments may positively influence cognitive development and academic achievement when appropriate instructional strategies are applied.

Within the European educational context, bilingual education has attracted considerable attention as schools increasingly seek to integrate foreign languages into subject teaching. This interdisciplinary approach supports the development of key competences required in the 21st century, including communication, collaboration, and intercultural understanding. Nevertheless, the successful implementation of bilingual education depends on several important factors, such as teacher training, learners' language proficiency, and the availability of suitable teaching resources.

Recent educational research highlights the growing importance of bilingual and CLIL-based instruction in contemporary school systems. Recent studies suggest that bilingual education may positively influence learner motivation, classroom participation, communication skills, and intercultural awareness, particularly in student-centered learning environments (Macaraeg, 2024;

Ohki, 2024). Moreover, the integration of foreign languages into subject teaching continues to gain relevance in the context of modern multilingual education.

2.2. The CLIL Approach

Content and Language Integrated Learning (CLIL) is widely recognized as one of the most important approaches used in bilingual education. Introduced by Marsh (2002), CLIL refers to the integration of subject content and foreign language learning within the same educational context. Through this approach, learners simultaneously acquire subject-specific knowledge and develop communication skills in a foreign language.

The CLIL approach is based on the 4Cs Framework proposed by Coyle (2010), which includes Content, Communication, Cognition, and Culture. These interconnected dimensions support both academic learning and language development while encouraging critical thinking, collaboration, and intercultural understanding.

In Geography education, CLIL represents an effective instructional strategy because the subject naturally integrates visual materials, maps, diagrams, discussions, and real-world contexts. Geography lessons may therefore provide meaningful opportunities for learners to develop communication abilities while exploring geographical concepts and phenomena.

Recent studies emphasize the growing relevance of CLIL methodologies in contemporary education, particularly in multilingual and student-centered learning environments. Current research suggests that CLIL-based instruction may improve learner motivation, communication skills, classroom participation, and subject comprehension while supporting both language development and academic achievement (Ohki & Cross, 2024; De Benetti, 2025)

2.3. Motivation in Learning

Motivation represents an essential aspect of the educational process and plays an important role in students' academic achievement and classroom participation. Educational psychologists such as

Deci and Ryan (2000) distinguish between intrinsic motivation, associated with personal interest and satisfaction, and extrinsic motivation, influenced by external rewards or expectations.

According to Self-Determination Theory, intrinsic motivation contributes to meaningful and long-term learning outcomes (Deci & Ryan, 2000). Students who are intrinsically motivated tend to participate more actively in classroom activities, show greater persistence in completing learning tasks, and achieve better academic results.

In foreign language learning environments, motivation becomes particularly important because learners may experience insecurity or hesitation when communicating in another language. Scheidecker and Freeman (1999) emphasize that motivating learning environments are closely related to active participation, meaningful interaction, and positive classroom experiences. Similarly, Dörnyei (2001) argues that supportive classroom environments, interactive teaching methods, and positive teacher-student relationships can significantly increase learners' motivation and involvement in the learning process.

Recent educational research continues to highlight the close connection between learner motivation, classroom engagement, and academic achievement in bilingual and CLIL-based educational settings. Contemporary studies suggest that interactive teaching strategies, collaborative learning activities, and student-centered instruction may positively influence students' motivation and participation, particularly in foreign language integrated classrooms (Macaraeg, 2024; De Benetti, 2025). In addition, the use of digital educational resources and multimedia-based activities may further increase students' interest and active involvement during lessons.

Within CLIL-based Geography education, motivation may also be supported through the use of visual materials, map analysis, interactive tasks, and communication-oriented activities. Such approaches may encourage students to participate more confidently and actively during bilingual lessons while supporting both language development and academic achievement.

2.4.Geography Teaching through CLIL

Geography is often considered a suitable subject for the implementation of CLIL because it combines theoretical information with visual and practical learning experiences. Maps, diagrams,

multimedia materials, and case studies may facilitate comprehension and support the acquisition of subject-specific vocabulary in a foreign language (Coyle, Hood, & Marsh, 2010).

Modern Geography teaching increasingly emphasizes interactive and student-centered instructional approaches that encourage observation, interpretation, and active participation during classroom activities (Dulamă, 2017).

The integration of English into Geography lessons may contribute to the development of communication abilities and improve learners' understanding of geographical concepts and phenomena. Through bilingual instructional activities, students are encouraged to interpret maps, describe geographical processes, and express ideas using specialized terminology.

Furthermore, CLIL-based Geography instruction may support the development of transferable competences such as teamwork, creativity, critical thinking, and problem-solving abilities. Learners may become more actively involved in the educational process and gain greater confidence in using English within academic contexts.

Recent educational research suggests that the integration of CLIL into Geography education may positively influence both learner motivation and academic achievement. However, the effectiveness of bilingual instruction depends on careful lesson planning, appropriate language support, and the adaptation of instructional materials to students' educational and linguistic needs (Coyle, Hood, & Marsh, 2010).

3. Methodology

3.1. Research Design

The present research is based on a mixed-method approach that combines qualitative and quantitative perspectives in order to examine the possible influence of bilingual teaching on students' motivation and academic achievement in secondary Geography education. At the current stage, the study remains in the process of preparation, while the practical implementation is planned for the 2026–2027 academic year through CLIL-based Geography instruction.

The research aims to analyze the educational value of integrating English into Geography lessons and to explore how bilingual instructional activities may influence students' participation, classroom engagement, communication skills, and understanding of geographical concepts. The

methodological design combines theoretical analysis with the development of instructional activities adapted to the educational and linguistic needs of secondary learners.

The practical component of the study will include classroom observation, student questionnaires, formative assessment tasks, and the analysis of students' participation during CLIL-based Geography activities. Observation sheets and feedback questionnaires will be used in order to monitor students' motivation, classroom engagement, communication abilities, and academic involvement throughout the instructional process.

In addition, the study aims to identify appropriate teaching strategies that may facilitate the gradual implementation of bilingual instruction in Geography education while promoting interactive and student-centered learning experiences.

3.2. Participants

The proposed research focuses on secondary students from a Romanian public school. The participants are expected to include students from grades V–VIII who study Geography within the national curriculum and learn English as a foreign language.

The selection of participants is based on students' involvement in regular Geography classes and on the possibility of implementing bilingual learning activities appropriate to their age, educational needs, and language proficiency level. The study mainly targets learners with beginner to intermediate English language skills who may benefit from the gradual integration of English into Geography instruction.

Since the practical component of the research is still in progress, the present study primarily focuses on the planning and preparation of CLIL-oriented instructional activities adapted to secondary learners.

The learners involved in the future implementation of the study are expected to participate in collaborative and communication-based classroom activities designed to encourage the use of English within Geography lessons while supporting motivation, classroom engagement, and active participation.

3.3. Proposed CLIL Activities in Geography

The practical dimension of the research is based on the integration of bilingual teaching strategies into Geography instruction. The proposed activities aim to combine geographical content with the

use of basic English language structures in order to create engaging and interactive learning experiences.

Practical and interactive learning activities play an important role in Geography education because they facilitate the understanding of geographical concepts and encourage active student involvement (Mândruț, 2023). Within CLIL-based Geography instruction, students may participate in various educational activities such as map analysis tasks, vocabulary exercises, matching activities, visual interpretation exercises, group discussions, short oral presentations, and collaborative learning tasks. These activities are designed to encourage communication, classroom participation, and the development of both geographical and linguistic competences.

Geographical terminology in English will be introduced gradually and adapted to learners' language proficiency level. Maps, images, visual organizers, and graphic materials may facilitate comprehension and reduce language-related difficulties during bilingual activities.

Digital resources and multimedia materials may also play an important role in the implementation of CLIL-based Geography instruction. Interactive maps, educational videos, online learning platforms, and visual presentations may support comprehension and increase students' engagement during bilingual lessons. The integration of technology into Geography education may contribute to both language acquisition and the understanding of geographical concepts through visually supported and meaningful learning experiences.

The proposed bilingual Geography activities may address various educational topics, including continents and oceans, climate and weather, population and settlements, natural environments, and administrative organization. These instructional activities are intended to support communication, collaborative learning, active participation, and the gradual development of both geographical knowledge and English language skills.

3.4. Research Methods and Instruments

Several research methods are proposed for the future implementation of the study, including classroom observation, student questionnaires, didactic experiments, and assessment activities. These methods are intended to provide a broader perspective on the educational benefits and possible challenges associated with the implementation of the CLIL approach in secondary Geography education.

Classroom observation may be used to monitor students' participation, interaction, communication skills, and engagement during bilingual Geography lessons. Observation sheets may help identify learners' attitudes toward bilingual education as well as their level of involvement during CLIL-based instructional activities.

Student questionnaires may also contribute to the collection of information regarding learners' perceptions of bilingual instruction, their motivation toward Geography learning, and their confidence in using English during classroom activities. In addition, assessment activities and instructional worksheets may be designed in order to evaluate students' understanding of geographical concepts and the development of basic geographical vocabulary in English.

The didactic experiment proposed within the study aims to explore how bilingual instructional activities may influence classroom participation, communication, and academic engagement. Formative assessment techniques may also contribute to monitoring students' progress and participation throughout the instructional process.

The collected data are expected to be analyzed through qualitative and descriptive methods, focusing on students' classroom interaction, participation, feedback, and responses provided during questionnaires and instructional activities. The interpretation of the results may provide useful insights into the educational value of CLIL-based Geography instruction and its potential influence on learner motivation and academic involvement.

4. Results and Discussions

4.1. Expected Educational Benefits

Drawing on the theoretical framework and previous research on bilingual education and CLIL methodologies, the integration of bilingual teaching strategies into Geography lessons may generate a variety of educational benefits for secondary learners.

Based on classroom observation, student questionnaires, and formative assessment activities proposed within the methodological framework of the study, the research is expected to identify a possible increase in students' motivation and classroom engagement during bilingual Geography lessons. Interactive CLIL-based activities may encourage learners to participate more actively in classroom discussions and develop more positive attitudes toward the learning process.

Questionnaire responses and observation sheets may also provide information regarding students' confidence in using English during Geography classes and their willingness to communicate within bilingual educational contexts. Through map analysis, visual resources, and collaborative learning activities, learners may gradually develop communication abilities and acquire subject-specific geographical terminology in English.

In addition, the proposed instructional activities may contribute to the development of transferable competences such as teamwork, critical thinking, problem-solving, and intercultural awareness. CLIL-based Geography instruction may encourage students to interpret visual information, analyze geographical processes, and communicate within meaningful educational situations while supporting active participation and collaborative learning.

The interpretation of the collected data may offer valuable insights into the educational potential of bilingual Geography teaching and its possible influence on students' motivation, participation, and academic involvement within secondary education.

4.2. Possible Challenges

Despite the educational benefits associated with the CLIL approach, several difficulties may arise during the implementation of bilingual teaching strategies in Geography education.

One important challenge is related to the different levels of English language proficiency among learners. Some students may experience insecurity or anxiety when using a foreign language during classroom activities, particularly if they are not familiar with bilingual learning environments. In such situations, excessive linguistic difficulty may reduce participation and learner confidence.

Another possible challenge concerns the preparation and adaptation of instructional materials. Teachers need to adapt geographical content to learners' language proficiency levels while maintaining the scientific accuracy of the information presented. This process may require additional preparation time, careful instructional planning, and the use of accessible visual and interactive resources.

Based on previous research on CLIL implementation and bilingual instruction, classroom management and time limitations may also influence the effectiveness of bilingual educational activities. Observation-based activities and instructional planning may reveal that combining both

content-related and language-related objectives within the same lesson can become demanding, particularly in classes characterized by different learning abilities and language proficiency levels. Consequently, the gradual implementation of CLIL strategies and differentiated instruction may represent important factors in supporting effective bilingual Geography teaching.

In addition, teacher training represents an essential factor in the successful implementation of bilingual education. Educators need both subject-specific knowledge and adequate language competences in order to design effective bilingual learning experiences and support learners throughout the instructional process.

4.3. Pedagogical Implications

The integration of bilingual teaching strategies into Geography education emphasizes the importance of flexible and innovative teaching approaches adapted to contemporary educational needs. The CLIL methodology encourages interdisciplinary learning and supports the simultaneous development of academic knowledge and language competences within meaningful educational contexts. Geography education may contribute to the development of analytical thinking, interpretation skills, and real-world understanding through inquiry-based and student-centered activities (Lambert & Balderstone, 2021).

The successful implementation of bilingual Geography lessons requires careful instructional planning, accessible teaching materials, and activities adapted to students' age and language proficiency level. Visual support, collaborative tasks, and interactive activities may facilitate comprehension and reduce language-related anxiety during bilingual instruction.

The use of digital technologies and multimedia resources may further improve the effectiveness of CLIL-based Geography education. Educational applications, interactive maps, online platforms, and multimedia presentations can contribute to the creation of more engaging and accessible learning environments. Technology-supported activities may also encourage collaboration, independent learning, and active participation while supporting the development of both geographical understanding and communication abilities.

At the same time, the teacher plays a central role in creating supportive and motivating classroom environments. Teachers should gradually integrate bilingual elements into Geography lessons and encourage learners to communicate confidently without fear of making mistakes. Positive

feedback, differentiated instruction, and student-centered activities may contribute significantly to increasing learner confidence and classroom participation.

The anticipated findings of the present study suggest that bilingual teaching through the CLIL approach may positively influence students' motivation, engagement, and learning experiences in Geography education. Although the practical component of the research is still ongoing, the proposed instructional framework may offer useful perspectives for future educational practices and further research in the field of bilingual and multilingual education.

4.4. Limitations of the Study

The present study includes several limitations that should be acknowledged. First, the practical component of the research is still in progress, which means that the study does not yet provide final classroom-based results or detailed quantitative statistical analysis. Consequently, the current paper focuses primarily on the theoretical framework and on the proposed methodological and pedagogical approach.

Another limitation is associated with the relatively limited number of participants involved in the future implementation of the study. Since the research is intended to be conducted within secondary Geography classes, the findings may not be generalized to all educational settings or learner populations.

Furthermore, differences in students' English language proficiency levels may influence classroom participation, communication, and learning outcomes during bilingual instructional activities. Time limitations, classroom management issues, and the availability of appropriate teaching resources may also affect the implementation of CLIL-based Geography instruction.

Despite these limitations, the study aims to provide valuable pedagogical perspectives regarding the integration of bilingual teaching strategies into Geography education and may contribute to future research concerning CLIL methodologies and multilingual learning environments.

5. Conclusions

The present paper highlights the educational potential of bilingual teaching through the CLIL approach in secondary Geography education. In the context of contemporary educational reforms and the increasing importance of multilingual competences, the integration of English into

Geography lessons may represent an effective strategy for supporting both subject learning and language development.

The theoretical perspectives discussed throughout the study suggest that bilingual instruction may positively influence students' motivation, classroom participation, and engagement in the learning process. Geography, as an interdisciplinary subject that combines visual, practical, and communicative dimensions, offers multiple opportunities for the implementation of CLIL-based activities adapted to secondary learners.

At the same time, the study underlines the importance of carefully planned teaching strategies, accessible instructional materials, and supportive classroom environments in order to facilitate successful bilingual learning experiences. The gradual introduction of English terminology, collaborative tasks, and interactive activities may contribute to the development of communication abilities, learner confidence, and transferable competences such as critical thinking, collaboration, and problem-solving.

Although the practical component of the research is still ongoing, the proposed methodological framework outlines several possible educational benefits and pedagogical perspectives related to the future implementation of bilingual Geography instruction. Additional classroom-based studies may provide a deeper understanding of the relationship between CLIL methodologies, learner motivation, and academic achievement.

Overall, the paper supports the idea that bilingual teaching represents a valuable educational approach capable of responding to the needs of contemporary learners while promoting more interactive, student-centered, and interdisciplinary Geography education. Future research may focus on the long-term effects of CLIL-based Geography instruction on students' academic achievement, language development, and classroom engagement, as well as on the effectiveness of digital resources and bilingual assessment strategies in secondary education.

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From Cheating to Competence: A Pedagogical Framework for Reimagining Machine Translation in Higher Education

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Abstract

The rapid advancement of Neural Machine Translation (NMT) and Large Language Models (LLMs) has sparked a crisis of academic integrity in Higher Education, particularly in Foreign Language departments. Traditional pedagogical models often categorize the use of tools like DeepL or ChatGPT as "cheating," a view that increasingly conflicts with the demands of the global professional market. This paper proposes a paradigm shift from prohibition to Machine Translation Literacy (MTL).

Using a "Human-in-the-Loop" (HITL) instructional design within English Linguistics and Practical Language courses, this study explores how the student's role evolves from a passive learner to a critical evaluator. The proposed framework replaces traditional rote translation with a three-tiered educational process: collaborative drafting, diagnostic post-editing (error taxonomy), and sociolinguistic critique. Preliminary observations indicate that this approach promotes high-level metacognitive skills, as students must justify linguistic choices that the AI fails to make.

Rather than diminishing rigor, the integration of AI into the curriculum fosters "translingual competence," transforming the classroom into a laboratory for critical thinking. The paper concludes that by embracing AI, educators can move beyond the "cheating" narrative to cultivate the sophisticated analytical skills essential for the modern researcher.

Keywords: Machine Translation Literacy, Post-Editing, Academic Integrity, Higher Education Pedagogy, Applied Linguistics, Human-in-the-Loop.

1.Introduction

The emergence of high-fidelity Neural Machine Translation (NMT) and Large Language Models (LLMs) has fundamentally disrupted the epistemological foundations upon which Foreign Language (FL) departments have historically operated. For decades, the prevailing pedagogical consensus held that autonomous, unaided text production constituted the most reliable index of language competence - a paradigm that positioned the learner as an independent linguistic agent whose proficiency could be meaningfully measured in the absence of external technological intervention. This consensus has been rendered increasingly untenable by the rapid proliferation of AI-assisted translation tools now embedded in the professional and academic lives of language students worldwide. The current moment is therefore characterized by a fundamental tension: on one side stands an institutional reflex toward prohibition, in which the use of tools such as DeepL, ChatGPT, or Gemini in assessed work is routinely framed as academic dishonesty; on the other stands the sociotechnical reality of a global workplace in which proficiency with - and critical awareness of - these same tools is increasingly regarded as a core professional competency.

In translation studies and language faculties - where students are being trained as future translators, literary specialists, terminologists, and legal or medical language professionals - the stakes of this tension are particularly high. Raw LLM output, while impressively fluent, frequently falls short when it comes to rendering the cultural nuance of literary prose, the pragmatic force of speech acts, or the terminological precision demanded by legal contracts and medical records. Educators and students alike must develop what might be called *AI literacy for language professionals*: the ability to craft targeted, context-sensitive prompts, to critically evaluate and post-edit model output, and to intervene where necessary to restore the human judgment that automated systems inevitably lack. Professors bear a dual responsibility here - becoming proficient users of these tools themselves while designing pedagogical frameworks that guide students through the complexities of prompt engineering, ethical AI use, and domain-specific quality assessment. Yet many institutions continue to respond with prohibition rather than integration, a position that, as Selwyn (2022) has argued, reflects institutional anxiety more than sound pedagogical reasoning, and that, as Fyfe (2023) has shown, is increasingly impossible to enforce. The challenge, then, is not policing, it is redesign. The institutional reflex of prohibition has proven both pedagogically counterproductive and practically unenforceable, leaving language faculties without coherent tools for developing the critical AI literacy that the contemporary professional landscape demands. The

present study responds to this gap by proposing a structured pedagogical framework - Machine Translation Literacy - grounded in Human-in-the-Loop instructional design, which repositions the student as a critical evaluator of machine output rather than a passive recipient of it.

2. Theoretical Background

Neural Machine Translation tools have undergone dramatic development since the mid-2010s, when deep learning architectures began to displace earlier rule-based and phrase-based statistical systems. DeepL, a neural machine translation service developed by the German company DeepL SE and first launched in 2017, is a representative case in point. Built initially on a convolutional neural network architecture and subsequently enhanced with transformer-based models, it has become widely regarded among translators and linguists as the highest-fidelity publicly accessible MT system for European language pairs, consistently outperforming competing services on fluency and domain-specific accuracy benchmarks (Nurminen et al., 2023; Vanmassenhove et al., 2021).

Moreover, the Human-in-the-Loop paradigm originates in machine learning and human-computer interaction research, where it designates a design philosophy in which human judgment is preserved as an active, iterative component of an otherwise automated process (Monarch, 2021). Applied to the domain of translation, the HITL model reframes the student not as a passive recipient of machine-generated output, but as a trained evaluator who interrogates, revises, and assumes epistemic responsibility for that output. Rather than outsourcing cognition to the machine, the HITL translator deploys metalinguistic, cultural, and pragmatic knowledge to identify where automated output fails and why. It is this disposition, rather than the capacity for unaided production, that the present paper argues should constitute the new target competency in FL higher education.

On the other hand, the contemporary NMT landscape, exemplified by DeepL, Google Translate's Neural mode, and the multilingual capabilities of models such as GPT-4 and Claude, represents a qualitative departure from earlier MT paradigms. Output quality has improved to the point where errors are often subtle, stylistic, or register-dependent rather than grammatically catastrophic, which means that detecting and correcting them demands a higher, not lower, order of linguistic competence. For students at Faculties of Foreign Languages, this has consequential implications:

exposure to NMT in the classroom is no longer a question of if, but how, and the nature of the competence it demands calls for a reconceptualization of what translation performance means in assessed contexts. Against this backdrop, the present study develops a pedagogical framework for what we term Machine Translation Literacy (MTL): a structured, competency-based approach to integrating NMT tools into FL curricula in ways that cultivate critical, reflective, and professionally relevant language use. Drawing on data from students enrolled in translation and language courses at the Faculty of Foreign Languages, the study examines how engagement with DeepL and comparable tools mediates translation performance, shapes metalinguistic awareness, and challenges prevailing assessment paradigms. The overarching argument is that the transition from policing AI to leveraging it pedagogically is not a concession to academic dishonesty, but an affirmative response to the demands of twenty-first-century language education.

The concept of Machine Translation Literacy (MTL) has emerged as a response to the widespread, often uncritical adoption of automated translation tools across both professional and academic contexts. Bowker & Ciro (2019) define MT literacy as the capacity to understand what machine translation can and cannot do, to evaluate its output critically, and to make informed decisions about when and how to use it. This definition foregrounds competence over prohibition: rather than treating NMT tools as threats to authentic language learning, MTL positions them as objects of study whose affordances and limitations must be systematically understood. For students enrolled in language faculties, acquiring MT literacy is not a supplementary skill, but a professional necessity, given that post-editing of machine-generated content has become a standard workflow in the translation and localization industries (Bowker, 2023). Post-editing - the process of reviewing and correcting machine-translated text to meet a defined quality standard - has been extensively theorized in translation studies as both a professional practice and, more recently, a pedagogical tool. Rather than having students produce translations from scratch - a task that, as Pym (2013) notes, tends to prioritize output speed over metacognitive reflection, post-editing tasks require them to adopt a forensic orientation toward language, diagnosing error types, hypothesizing causes, and evaluating alternative formulations. This reorientation from producer to critical evaluator represents a significant and productive shift in pedagogical design.

The pedagogical value of post-editing has been empirically supported across several recent studies. Castilho et al. (2017) found that students who engaged with post-editing tasks demonstrated

heightened awareness of syntactic divergence between source and target languages, while Koponen (2016) identified post-editing as an effective vehicle for developing error-recognition skills that are transferable across text types and domains. Of particular relevance for language faculties is the domain-specificity of NMT errors: the quality degradation that occurs when general-purpose MT systems encounter specialized terminology - whether legal, medical, or literary - provides rich material for discipline-grounded analysis. A legal translation course, for instance, can leverage the systematic miscalibration of NMT output in contractual or regulatory texts as a resource for teaching terminological precision and register awareness; a literary translation course can exploit the flattening of stylistic variation and the suppression of pragmatic nuance that characterizes machine-rendered fiction as an entry point into discussions of authorial voice and cultural mediation.

Beyond post-editing competencies, there is also the prompting engineering. Unlike the relatively passive interaction with standalone NMT engines, engaging with LLMs requires the user to actively formulate input - specifying the task, the target audience, the desired register, the relevant domain constraints - in ways that make the quality of the output directly contingent on the sophistication of the prompt. For language students, this dynamic is pedagogically significant in at least two respects. First, it renders visible the relationship between metalinguistic awareness and communicative outcome: a student who understands the difference between a legal brief and a policy summary, or between a literary translator's interpretive freedom and a technical translator's fidelity constraints, will formulate qualitatively different prompts and obtain qualitatively different results. Second, it positions the language specialist, rather than the technician or the data scientist, as the primary competent user of the tool, since the ability to specify and evaluate language quality is precisely the expertise that language education cultivates. Cope & Kalantzis (2024) have argued that AI-mediated writing environments call for a new form of "cybersocial literacy," in which the learner must navigate collaboratively between human intention and machine execution; prompt engineering in applied linguistics contexts is a concrete instantiation of that broader shift.

Traditional language assessment has long operated on the premise that linguistic competence can be reliably measured under closed-book, controlled conditions - timed translation passages, unseen grammar tests, written examinations completed without reference materials - on the assumption that what a student produces independently reflects what they have genuinely internalized. This

model rests on what might be called a stable epistemological contract between institution and learner: the examiner controls the conditions of production, and the output can therefore be read as transparent evidence of underlying knowledge. As Pym (2013) has argued, however, translation pedagogy has historically prioritized measurable output over the metacognitive processes that actually constitute professional competence, a tendency that leaves assessment frameworks structurally ill-equipped to respond when the conditions of production change. Large language models have changed them irrevocably. When a student can generate grammatically impeccable, register-appropriate, stylistically polished prose within seconds, the surface features that closed-book assessment traditionally used as proxies for linguistic knowledge, syntactic accuracy, lexical range, textual cohesion, fluency, are no longer reliable indicators of what the learner actually understands.

The institutional response to this disruption has, in many cases, taken the form of an academic integrity narrative: the student "cheated," the output is inauthentic, the submission must be penalized. This reaction, while understandable, conflates a pedagogical failure with a moral one. The deeper problem is not ethical but epistemological, and it maps directly onto what AI research has described as the "black box" problem: the opacity of machine-generated output whose internal reasoning cannot be audited or traced (Selwyn, 2022). A student who submits AI-generated text without critically engaging with it presents precisely the same interpretive challenge to the assessor: a polished surface with no window onto the processes that produced it, no evidence of syntactic decision-making, no trace of the sociolinguistic or pragmatic reasoning that Bowker & Ciro (2019) identify as the core of genuine machine translation literacy. The assessor cannot determine whether the student has grappled with the register demands of the target culture, the semantic ambiguities of the source text, or the terminological constraints of the domain, because the assessment instrument was never designed to make such processes visible. As Cope & Kalantzis (2024) observe, AI-mediated writing environments demand a new form of cybersocial literacy in which the boundary between human intention and machine execution must be actively negotiated rather than simply policed; an assessment model built on prohibition cannot, by definition, cultivate that negotiation. The "cheating" narrative, in this light, is less a diagnosis of student misconduct than a symptom of institutional unpreparedness - a defensive response to the collapse of output-based measurement, and a signal that the linguistic rigor traditional assessment

claimed to enforce was always more dependent on controlled conditions than on genuine insight into the learner's competence.

The challenges of teaching and learning a foreign language have never been straightforward, but the emergence of large language models as default translation and writing aids has introduced a qualitatively new layer of difficulty: one that is arguably more insidious than the errors produced by earlier generations of machine translation systems. The central paradox of the current moment is this: the more fluent and grammatically sophisticated AI output becomes, the harder it is for learners to detect its errors, and the more likely those errors are to be absorbed, reproduced, and eventually normalized. This section examines the specific mechanisms through which AI-assisted translation produces false analogies, collocation errors, and lexical interferences in the English-Romanian language pair, drawing on empirical evidence from the PhD thesis of Dumitran (2021) on lexical errors in machine translation of medical texts, from Dumitran's comparative study of false friends across human learners and AI systems, and from classroom observations of legal translation students at the faculty level. In the English-Romanian linguistic contact zone, false friends are structurally overdetermined: as Roibu (2014) has argued, the partial Latinity of English vocabulary, combined with the accelerating influence of English as a global *lingua franca* and primary intermediate language in Romanian educational settings, has created a large and growing inventory of deceptive cognates whose surface similarity actively misleads both human learners and automated systems. Where earlier MT systems produced dysfluent outputs that a moderately competent reader could identify as erroneous, current LLMs produce morphosyntactically well-formed, stylistically plausible sentences in which the false friend error is embedded within grammatically impeccable prose, rendering it effectively invisible to a learner who lacks the metalinguistic awareness to look past surface fluency.

3. Methodology

The present study adopts a mixed-methods design, combining quantitative corpus analysis with qualitative classroom observation, in order to capture both the measurable patterns of AI-generated translation errors and the pedagogical processes through which students learn to identify and correct them. The quantitative component draws on a corpus of 230 texts translated from English into Romanian using Google Translate, sourced from official WHO and Gavi communications

produced during the COVID-19 pandemic. Each text was subjected to systematic error annotation following an adapted version of the ISO 18587:2017 post-editing quality framework, with errors coded across four primary categories: lexical collocation failures, false friend interference, syntactic transfer, and domain-specific terminological miscalibration. Frequency counts and proportional distributions were calculated for each error category, enabling comparison across domains: legal, medical, and administrative and across the English-Romanian language pair specifically. Additional quantitative data were drawn from Dumitran's (2021) doctoral corpus on lexical errors in machine translation of medical texts, which provided a validated baseline for error distribution figures, including the finding that collocation errors account for 31.7% of all lexical errors and false friend errors for 10.3%.

The qualitative component of the study was conducted within the framework of Human-in-the-Loop (HITL) instructional design, implemented across practical language and legal translation courses at the Faculty of Foreign Languages. Classroom observations were carried out over the course of one academic semester, during which students engaged with a three-tiered pedagogical sequence: collaborative AI-assisted drafting using DeepL and comparable LLMs, structured diagnostic post-editing guided by the error taxonomy developed from the corpus analysis, and sociolinguistic critique requiring students to justify their corrective choices with reference to target-language register conventions. Data collected qualitatively included field notes from classroom sessions, analysis of annotated student submissions, and informal reflective discussions in which students were asked to articulate why specific AI-generated forms - collocational calques, false cognate renderings, syntactically transferred structures - were professionally inadequate. These classroom interactions provided the primary evidence for assessing whether and how the pedagogical framework fostered metalinguistic awareness and critical evaluative competence.

The integration of quantitative and qualitative methods was deliberate and theoretically motivated: the corpus data established the structural predictability and domain-specific distribution of AI translation errors, while the classroom observations revealed the conditions under which those errors become pedagogically productive rather than merely diagnostic. Taken together, the two strands of evidence address complementary research questions: *what* errors AI systems systematically produce, and *how* structured exposure to those errors develops the critical competencies that Machine Translation Literacy requires. The methodology was not designed to

test a hypothesis in the experimental sense, but to construct, document, and iteratively refine a pedagogical model grounded in empirical evidence from both corpus linguistics and applied classroom practice. As such, it is best characterized as practitioner research with a mixed-methods orientation, situated at the intersection of translation studies, applied linguistics, and higher education pedagogy.

4. Results and Discussions

The evidence from the classroom corpus collected for the present study confirms this trajectory at every level of specialization. In legal translation practice, the term *expertise* is systematically rendered by AI systems - as well as by students who have internalized AI output as a model - as *expertiză*, a false cognate that carries a generalized meaning of "skill" or "competence" in Romanian (*DEX*: "pricepere, iscusinţă"), whereas the correct legal equivalent for the English *expertise* in the sense of a formal expert report or judicial assessment is *expertiză judiciară* or simply *raport de expertiză*. The semantic overlap between the English and Romanian forms is sufficient to generate the error, but the legal register demands terminological precision that the false cognate entirely fails to provide. Similarly, the English legal term *section* - referring to a numbered subdivision of a legislative text, a contract, or a statutory instrument is recurrently mistranslated as *secţiune* by both students and AI systems, when Romanian legal convention consistently uses *articol* for statutory subdivisions and *clauză* for contractual ones. The substitution of *secţiune* for *articol* is not a random error: it is a predictable product of the formal similarity between the English *section* and the Romanian *secţiune*, and it illustrates precisely the mechanism that Chuquet and Paillard (1989: 224) described as the core of the false friend phenomenon - "words that are close by form but partially or completely different by meaning." In a legal context, however, the stakes of such errors extend well beyond stylistic infelicity: a contract clause that references the wrong structural unit of a legislative text is not merely inelegant but potentially legally void.

The medical translation domain reveals the same pattern operating at scale. The analysis of 230 texts translated from English into Romanian by Google Translate, drawn from official WHO and Gavi communications during the COVID-19 pandemic, found that false friend errors accounted for 10.3% of total lexical errors. Representative cases include the rendering of *support* as the

physical *suport* (a stand or rack) rather than the social and medical *sprijin* (assistance, backing), and the translation of *actual* as *de fapt* (in fact, actually) rather than the Romanian *actual* meaning "current" or "present" - a paradigmatic instance of bidirectional false-friend interference, since the English and Romanian terms are formally identical but semantically inverted. In the pandemic context, where accurate public health communication carried life-or-death implications, such errors were not merely academic: a Romanian reader encountering *suport* where *sprijin* was intended, or *actual* where "real" or "factual" was meant, received not an approximate message but a structurally misleading one.

If false friends represent the most structurally predictable category of AI-generated error in the English-Romanian pair, collocation errors are by far the most frequent and, from a pedagogical standpoint, the most consequential. Dumitran (2021) establishes that collocation errors constitute 31.7% of all lexical errors in the MT corpus, by a substantial margin the dominant error category, exceeding borrowing errors (17.2%), false friend errors (10.3%), and stylistic errors (10.3%) combined. This distribution reflects a fundamental architectural limitation of neural MT systems: as Zinsmeister & Heid (2004: 311) have argued, collocational knowledge - the language-specific conventions governing which words legitimately combine with which other words - encodes constraints that cannot be derived from general syntactic or semantic rules and must instead be acquired through extensive exposure to authentic language use.

The classroom evidence from legal translation courses at the faculty is particularly revealing in this regard. Students consistently produced and, when surveyed, frequently attributed to AI assistance collocations such as *consecinţele adverse* for "adverse consequences" (the established Romanian medical collocate being *efectele adverse*), *scădere abruptă* for "steep fall-off". In legal texts specifically, the collocation error pattern extends to the rendering of fixed legal phrases whose component words may individually be correctly translated but whose combination violates Romanian legal usage: *administrarea dovezilor* (management of evidence) appears in place of *administrarea probelor*; *cheltuielile financiare* (a semantically redundant construction that combines two expressions for the same concept) appears where *cheltuieli* alone is standard; and *atac bioteror* appears in place of the recognized Romanian legal and security term *atac biologic*. In each case, the AI system has processed the lexical components of the source expression correctly

but has failed to retrieve the target-language collocate - the "lexical bond," as Dumitran (2021) describes it - that Romanian convention requires.

The false friend pairs documented across both the SLA and the AI corpora in Dumitran's research illustrate this diagnostic challenge concretely. Terms such as *eventual* (Romanian: "possible/perhaps") rendered as "eventually" (English: "in the end, finally"), *a avertiza* (Romanian: "to warn") confused with "to advertise" (English: "to promote"), *audienţă* (Romanian: "a formal meeting or hearing") rendered as "audience" (English: "spectators, public"), and *evidenţă* (Romanian: "registry, record") confused with "evidence" (English: "proof") all produce output that is grammatically acceptable and superficially plausible, but that is semantically wrong in ways that matter acutely in legal, medical, and administrative contexts. A legal document in which *audienţă* is used where "public hearing" is intended, or in which *evidenţă* is offered where "evidence" is required, does not merely fail stylistically: it communicates the wrong institutional reality, with potentially serious consequences for the parties it concerns.

This is the core pedagogical challenge that AI-era language teaching must confront. The errors that AI systems produce most reliably are not the errors that beginners make: phonetic substitutions, morphological misconstructions, elementary vocabulary confusions, but precisely the errors that distinguish an advanced learner from a competent professional: collocational precision, terminological appropriateness, register sensitivity, and pragmatic adequacy. By generating output that is advanced enough to pass as student work but flawed in the ways that professional formation is specifically designed to remediate, LLMs create a feedback loop that, if left pedagogically unaddressed, risks producing graduates who have never been forced to confront the precise competences they lack. As Koponen (2016) has argued, the detection and analysis of MT errors is itself a high-order linguistic skill; the challenge for language faculties in the AI era is to ensure that this skill is systematically cultivated - not as an ancillary critical exercise, but as the central methodology through which professional translators and language specialists are formed.

The theoretical framework of Machine Translation Literacy acquires its full pedagogical weight only when it is tested against the concrete difficulties that students encounter in actual translation practice: difficulties that, as the preceding section has established, are increasingly shaped not by the limitations of machine output but by its deceptive competence. The present subsection proposes a working error taxonomy derived from classroom observation in practical language and

translation courses at the faculty level, organized around three analytically distinct, but empirically interrelated categories: syntactic interference, lexical collocation failure, and domain-specific terminological miscalibration. What unites these categories is not merely their frequency in student and AI-generated output, but the specific pedagogical trap each one sets: in each case, the error is structurally similar enough to a correct form to pass undetected by a learner who has not been trained to look for it, and sufficiently reinforced by AI output to acquire, over time, the false authority of a model.

The most immediately recognizable category of AI translation error in the English-Romanian pair, and yet, paradoxically, the one that students are least equipped to identify when it is embedded in otherwise fluent prose is the syntactic interference - the importation of source-language word order, clause structure, or morphosyntactic patterning into target-language output - represents the most immediately. Romanian and English diverge fundamentally in their syntactic organization: Romanian is a pro-drop language with rich inflectional morphology that allows considerable constituent order flexibility, governed by pragmatic principles of topic and focus distribution rather than by the relatively rigid subject-verb-object sequencing of English. Neural MT systems, trained on large parallel corpora in which English functions as either source or pivot language (Turovsky, 2016), systematically under-represent these pragmatic-syntactic distinctions, producing Romanian output in which the linear order of the English source is preserved at the expense of the discourse-functional organization expected in target-language text.

In classroom practice, this error manifests most visibly in nominal constructions and prepositional phrases. English favors premodification - the accumulation of attributive adjectives, noun adjuncts, and participial phrases before the head noun - a pattern that Romanian renders through postmodification, using adjectival agreement, prepositional phrases, and relative clauses. AI-generated translations of English noun phrases such as *"evidence-based public health intervention"* or *"risk-stratified clinical management protocol"* - the type of compound nominal structure that characterizes legal, medical, and administrative discourse - routinely produce Romanian strings that preserve English-style pre-modification, generating output such as **intervenție bazată-pe-dovezi de sănătate publică* rather than the syntactically and collocationally appropriate *intervenție de sănătate publică bazată pe dovezi*. Students who have consulted AI output before producing their own translations reproduce these structures in their submitted work, not because they cannot

recognize the Romanian norm when it is pointed out to them, but because the AI-generated form has been absorbed as plausible.

Verbal constructions present an analogous challenge. English aspectual distinctions between simple and progressive forms, and between active and passive voice in administrative and legal registers, are mapped by NMT systems onto Romanian equivalents that are formally adequate but pragmatically misaligned: the English passive, pervasive in legal and scientific writing, generates Romanian passive constructions (*este tradus*, *a fost aprobat*) where Romanian convention particularly in legal drafting - often prefers the reflexive-passive (*se traduce*, *s-a aprobat*) or an impersonal active construction. The student who has relied on AI output for a first draft and who lacks the legal or administrative register awareness to detect this misalignment will submit a translation that reads, to a native-speaking practitioner, as foreign - correct in its denotation, wrong in its institutional voice.

In legal translation practice, this distinction is acutely visible in the handling of verb-noun collocations that are fixed by convention in both English and Romanian but whose components do not align across the two systems. English legal usage requires *to bring an action* (not *to make* or *to take*); Romanian legal usage requires *a introduce o acțiune* or *a promova o acțiune* not *a aduce o acțiune*, which would be the literal calque of the English. AI systems consistently produce the calque, because they optimize for lexical correspondence rather than collocational convention. Similarly, English *to reach a verdict* maps in Romanian legal usage onto *a pronunța o hotărâre* or *a da o sentință*, not *a atinge un verdict*, but the latter is precisely what current NMT systems generate. The same mechanism operates in the medical discourse. Dumitran (2021) documents cases such as *doze timpurii* for "early doses" - where *timpurii* correctly translates "early" in a temporal sense, but violates the medical collocational convention that requires *doze din primele tranșe* or *doze disponibile în faza inițială*; *descărcări din nas* for "nasal discharge" - where *descărcare* (electrical discharge, psychological unburdening) violates the medical collocate *scurgeri nazale*; and *a prinde Covid-19* for "to catch Covid-19" - where the literal rendering of the English idiom produces a collocation that is pragmatically unacceptable in Romanian medical usage, which conventionally uses *a contracta* or *a lua*. In each case, the AI system has produced a string that is grammatically legal but collocationally wrong - and wrong in a way that specifically signals non-native professional competence to a practitioner in the field.

The foregoing analysis suggests that the specialized text: legal, medical, or administrative is not merely a challenging translation exercise, but a uniquely diagnostic pedagogical instrument: it is precisely in these domains that the limits of AI output become most clearly visible, and precisely here that the distance between surface fluency and professional adequacy is most measurable.

This is the pedagogical reorientation that the present study proposes for the classroom practice component of language faculty courses: rather than treating specialized texts as advanced exercises to be introduced only after general competence has been established, they should be used early and deliberately as diagnostic mirrors - texts through which students, confronted with AI output, are required to identify *why* a given rendering is wrong and *what competency* its correction demands. The question is not "is this a good translation?" - a question that students can often answer by feel, but "is this the right collocate, the right term, the right syntactic construction for this register, and what is the evidence for that judgment?" This shift from impressionistic evaluation to evidenced linguistic reasoning is, we argue, the core of what Machine Translation Literacy means in practice: not the capacity to avoid AI, but the capacity to audit it with the precision that the domains it serves require.

5. Conclusions

The argument developed across the preceding sections converges on a single, foundational claim: that the most urgent task facing language faculties in the age of AI is not the prevention of machine translation use, but the systematic mapping of its failure patterns and the deliberate integration of that mapping into the design of translation and language pedagogy at every level. The evidence assembled in this study, drawn from the empirical corpus of Dumitran (2021), from classroom observation in legal and medical translation courses, and from the broader theoretical framework of Machine Translation Literacy, demonstrates that the errors produced by current NMT systems and large language models are neither random nor unpredictable. They are systematic. They follow identifiable structural logics: the logic of false-cognate interference, the logic of collocational calquing, the logic of syntactic transfer - that recur with sufficient regularity to constitute what this paper has called a grammar of machine deformation: a set of predictable distortions that AI systems impose on target-language text when the constraints of authentic linguistic convention are not externally enforced by a competent human evaluator. The pedagogical implication is direct

and consequential: language faculties must develop and maintain structured error taxonomies - organized by error type, language pair, and domain - that function as shared diagnostic instruments for both instructors and students. Such taxonomies do not merely catalogue past errors; they generate expectations about where future errors will occur, enabling the instructor to design exercises that target the specific competency gaps that AI output systematically conceals. The classroom practice documented in this study - in which students are confronted with AI-generated translations of legal, medical, and administrative texts and required to identify, name, and correct errors by reference to established Romanian legal and medical convention - represents one model for how such a taxonomy can be operationalized. The specialized text, as argued in Section 3.2, is not simply a difficult exercise: it is a diagnostic mirror, and it is most useful precisely when AI output has made the error, because it forces the student to articulate why the machine was wrong and what genuine competence would look like in its place.

The rapid integration of Neural Machine Translation tools and Large Language Models into the daily academic and professional lives of language students has created an urgent crisis that existing pedagogical frameworks are ill-equipped to address. As AI-generated output grows increasingly fluent, the errors it produces - collocational failures, false-cognate interference, and syntactic transfer - become harder to detect and more likely to be absorbed by learners as authoritative models, particularly in high-stakes specialized domains such as legal and medical translation.

The second major conclusion of this study concerns the role of the educator in an AI-mediated learning environment and it is a conclusion that carries institutional as well as individual implications. The teachers who ban AI tools from the translation classroom are not protecting linguistic rigor: they are removing the primary diagnostic instrument through which that rigor can be made visible, discussed, and cultivated. Conversely, the teacher who permits AI use without methodological scaffolding - who accepts AI-drafted translations without requiring students to account for their choices, defend their collocations, or justify their syntactic decisions - is not fostering technological fluency: they are abdicating the responsibility of formation. The position this paper has argued for throughout lies between these two failures, and it requires something more demanding than either prohibition or permissiveness: it requires the educator to become, themselves, a fluent and critical reader of AI output, capable of recognizing the deformations that

NMT systems characteristically introduce and of designing learning tasks that make those deformations productive rather than harmful.

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Students' Use of AI Tools in Music Learning: A Preliminary Study

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Abstract

The growing use of artificial intelligence (AI) in education has also influenced music learning, offering students new possibilities for study, practice, and creativity. Although AI tools are increasingly accessible, their actual use in music education remains insufficiently documented. This preliminary study explores how university music students use AI tools in their learning

process. A total of 36 questionnaires were administered to undergraduate students in music programs (Transilvania Univeristy of Brasov, Romania). The survey investigated frequency of use, preferred platforms, purposes of use, and students' perceptions regarding the benefits and limitations of AI technologies. The results indicate that students mainly use AI tools for quick explanations, idea generation, research support, practice guidance, and study organization. The findings highlight the growing presence of AI in music education and suggest the need for responsible pedagogical integration that supports learning while preserving critical thinking, creativity, and essential musical skills.

Keywords: artificial intelligence, music education, higher education, student learning.

1. Introduction

Artificial intelligence (AI) has become an increasingly significant presence in contemporary society, influencing education, communication, professional activity, and everyday life. Among the many domains shaped by recent technological innovation, music represents one of the most dynamic and complex areas of AI application. The relationship between artificial intelligence and music has generated new opportunities for composition, performance, production, analysis, and digital interaction with musical content. Current developments in AI technologies show that these systems are evolving beyond purely technical functions and are beginning to contribute to processes traditionally connected with human creativity and artistic interpretation (Jiang, 2025; Mazlan et al., 2026; Pfeiffer & Krishna, 2025; Ventayen, 2026). AI applications are now capable of generating original musical material, reproducing stylistic characteristics associated with well-known composers, assisting creative workflows, and supporting interactive musical experiences. In addition, intelligent virtual systems can adapt to expressive and emotional parameters, offering new possibilities for experimentation and artistic exploration. As a result, artificial intelligence is increasingly redefining the ways music can be created, studied, interpreted, and experienced in contemporary culture (Belibou & Iftene, 2025; Civit et al., 2022; Wei & He, 2026; Willmann, 1944; Zhu, 2025).

Although the educational impact of AI has become a widely discussed topic, relatively few studies investigate music students' perspectives, particularly within the European higher music education

context, where student opinions are still rarely addressed in research, compared to the broader body of extra-European studies (Chen, 2025; Wang, 2025; Wang & Li, 2024; Wu & Qin, 2025; N. Yuan, 2024; S. Yuan, 2020; Zhang et al., 2024). Understanding how students actually use AI tools in their daily academic preparation may provide useful perspectives for future pedagogical approaches and curriculum development.

The present preliminary study investigates the use of AI tools among undergraduate music students at Transilvania University of Brasov. The research focuses on identifying the frequency of use, the purposes for which students employ AI applications, and their perceptions concerning the advantages and limitations of these technologies in music learning.

2. Methodology

The research instrument consisted of a short structured questionnaire containing two open-ended questions: “What AI tools do you use as students in your musical training?” and “What is your opinion regarding the use of artificial intelligence in musical training?”. The questionnaire was designed specifically for the purpose of this study. The survey was administered anonymously, and no personally identifiable information was collected. Participation was voluntary, and respondents did not receive any financial compensation for completing the questionnaire. Ethical research principles regarding confidentiality and respondent anonymity were respected throughout the study.

The average completion time for the questionnaire was approximately 5–8 minutes. Due to the exploratory nature of the study and the limited number of questions, the questionnaire was not pretested prior to distribution. The responses were interpreted manually through qualitative reading and analysis. The researcher carefully reviewed all answers and identified the main recurring ideas, opinions, and themes expressed by the participants. The collected responses were analyzed qualitatively and descriptively. Because this study is preliminary in nature, the research focuses primarily on identifying recurring tendencies and common patterns in students’ experiences rather than establishing statistically generalizable conclusions.

The participants included 36 students from the Faculty of Music enrolled in the Instrumental Performance and Music Pedagogy study programs. The respondents were between 19 and 23 years old. Of the total participants, 20 were male and 16 were female.

3. Results

The responses reveal a varied but generally positive attitude toward the use of AI technologies in academic music learning. Most participants reported using AI tools in at least some aspects of their studies, while a smaller number expressed skepticism regarding the reliability and pedagogical value of such technologies. The most frequently mentioned platforms were ChatGPT and Gemini. Students mainly associated these applications with rapid access to information, synthesis of complex materials, and support in organizing study content. Several recurring categories emerged from the analysis of the responses.

3.1. Support for Theoretical Learning and Research

35 students reported using AI tools to support their understanding of music history, music theory, analysis, and specialized academic terminology. 30 of them emphasized the usefulness of AI applications in synthesizing large amounts of information and reformulating content in a clearer, more accessible, and academically appropriate manner. According to the responses, students frequently rely on platforms such as ChatGPT and Gemini when preparing for theoretical courses, especially in disciplines that involve extensive reading, historical information, analytical concepts, or complex terminology.

As one participant explained, “I use ChatGPT and Gemini to synthesize information for subjects such as music history,” while another stated that “I use AI to obtain information that is difficult to access through other methods.”

The responses indicate that AI tools are used most frequently for historical perspectives and for organizing information from courses taught by professors. 6 students explained that they use AI primarily to create summaries of lecture materials, reorganize information chronologically, and facilitate revision before examinations. In this context, AI is perceived mainly as a support instrument that helps structure and condense academic content rather than as an independent source of knowledge. One student wrote: “Due to limited time, I use AI tools to create summaries and synthesize theoretical information more efficiently.”

Students also reported using AI to clarify difficult theoretical notions and to improve the academic language of written assignments, presentations, or seminar papers. However, important reservations emerged regarding the reliability of AI-generated content in more specialized musical

domains. Several respondents observed that, in the case of musical analysis, AI systems do not always employ accurate or sufficiently specialized terminology. Others noted that responses related to music theory frequently contain conceptual inaccuracies or errors in content, especially when addressing more advanced theoretical subjects. One participant mentioned that they had stopped using ChatGPT after discovering that "some of the information it provided was incorrect," particularly in specialized musical subjects.

As a result, many participants stated that they do not fully trust AI-generated information and consider verification through academic literature, course materials, and direct consultation with professors to be essential. These responses suggest that students perceive AI primarily as a supplementary educational tool that can facilitate organization and initial understanding, while authoritative knowledge and specialized musical competence continue to be associated with traditional academic instruction and direct pedagogical guidance.

3.2. Musical Creativity and Technical Exploration

A smaller number of respondents referred to the use of AI technologies in creative and technical musical activities. Unlike the students who mainly relied on AI for theoretical learning and academic organization, these participants explored the potential of artificial intelligence in areas directly connected to musical creation, production, and artistic experimentation.

Several students (9 of them) mentioned using AI platforms to generate musical ideas, discover new creative directions, or explore alternative approaches to composition and arrangement. Some respondents reported listening to AI-generated musical projects out of curiosity or as a source of inspiration for their own artistic work. 5 students stated that AI tools helped them identify materials related to composition techniques, orchestration, instrumentation, and musical analysis, particularly when searching for examples or introductory explanations. A number of 4 students also associated AI with technical aspects of music production. In these cases, AI applications were used to obtain suggestions regarding mixing and mastering processes, sound design, or digital audio production. Participants appeared particularly interested in the speed with which AI systems

can provide practical recommendations or generate examples that may support individual experimentation.

Despite this interest, 19 students did not perceive AI as a substitute for artistic creativity or professional musical competence. On the contrary, they generally described these technologies as complementary tools capable of stimulating imagination, facilitating experimentation, and supporting exploratory learning processes. Several participants (19 of them) emphasized that authentic musical expression, interpretative sensitivity, and compositional originality remain fundamentally human dimensions that cannot be entirely reproduced through automated systems.

The responses therefore suggest that students tend to view AI primarily as a supplementary creative resource rather than as an autonomous artistic agent. Its role appears to be associated more with inspiration, assistance, and technical support than with the replacement of individual artistic work or musical decision-making. One student stated: “I do not believe that creativity and artistic expression can be replaced by artificial intelligence.”

3.3. Critical Perspectives and Limitations

An important aspect of the responses concerns the critical attitudes expressed by several students regarding the reliability and applicability of AI in professional musical training. Some respondents (24 of them) stated that they avoid using AI because the information provided may not always be accurate or derived from official academic sources. Others emphasized that artistic and interpretative skills cannot be acquired exclusively through technological assistance.

Particular skepticism appeared in relation to practical musical disciplines such as performance technique and interpretation. Students argued that instrumental and vocal practice depends primarily on direct study, repetition, and interaction with teachers rather than on automated explanations. One recurring perspective was that AI cannot fully understand the complexity of artistic interpretation or the individuality of technical development in music performance. Respondents emphasized that certain aspects of musicianship can only be developed through practical experience and specialized pedagogical guidance. At the same time, several students acknowledged that AI may still be useful for general cultural information, exploratory learning,

and introductory documentation. One respondent stated that "Technical and artistic skills in music cannot be learned from AI alone, but through practice and direct interaction with teachers."

4. Discussion

The findings of this preliminary study suggest that AI technologies are already present in the academic lives of music students, although their use remains relatively limited to general educational and informational purposes. Most respondents demonstrated familiarity with widely accessible AI platforms such as ChatGPT and Gemini, which they primarily use for summarizing information, organizing course materials, clarifying theoretical concepts, and reformulating academic texts. These practices indicate that students perceive AI mainly as a practical support tool for theoretical disciplines and academic efficiency. At the same time, the responses reveal a relatively low level of engagement with AI platforms specifically designed for music creation, composition, or advanced musical interaction. Only a small number of participants mentioned AI-generated music, compositional experimentation, or production-oriented applications (**Figure 1**).

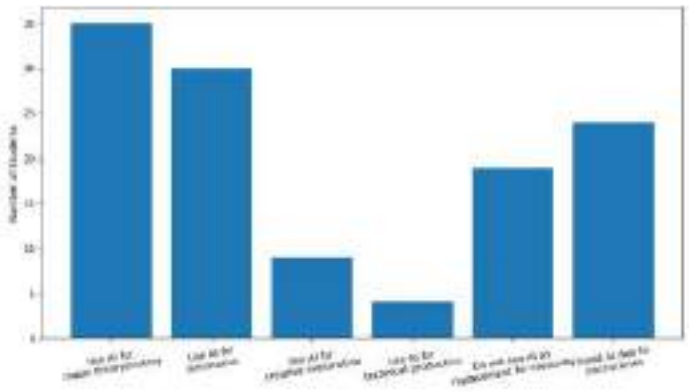

Figure 1. Students' Uses and Perceptions of Al in Music Education

This limited familiarity with specialized musical AI platforms may suggest that students' interest in AI-assisted creative musical practices remains relatively low within the current educational context. An important aspect emerging from the responses concerns students' critical attitudes toward the long-term implications of AI in the musical profession. Several participants expressed reluctance toward encouraging AI systems to compose, perform, or create music in place of human

musicians. These responses reflect an underlying concern that the increasing autonomy of AI-generated artistic products could eventually diminish the social and professional role of musicians themselves. For some students, the replacement of human interpretation and creativity by automated systems represents not only a technological issue, but also a threat to artistic authenticity and professional identity.

The study also indicates that, despite the intense international discourse surrounding AI and music, there is currently no strong orientation toward AI-based musical creation within the university music environment investigated in Brașov, Romania. Students' use of AI appears to remain concentrated primarily on informational and textual functions, such as generating summaries for music history courses, reorganizing lecture content, clarifying terminology, or reformulating academic texts. In most cases, AI is not integrated directly into the development of practical musical competencies.

A particularly significant finding is the absence of responses referring to the use of AI for ear training, aural skills development, interpretative refinement, or performance practice. None of the participants mentioned employing AI technologies to develop listening abilities, improve instrumental or vocal interpretation, or enhance expressive performance skills. This absence may indicate that students continue to associate core musical training primarily with direct pedagogical interaction, personal practice, and traditional methods of artistic development rather than with technological mediation.

Overall, the results suggest that music students currently approach AI in a pragmatic and cautious manner (**Figure 2**). AI is valued for its efficiency in handling theoretical and organizational tasks, yet students remain hesitant to accept a more substantial role for AI in artistic creation or professional musicianship. This balance between technological openness and artistic skepticism may become an important point of reflection for the future integration of AI within higher music education.

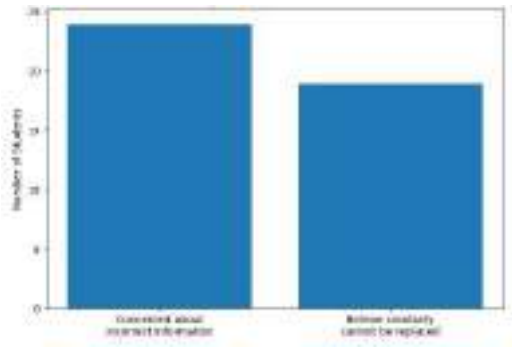

Figure 2. Critical Perspectives on Al

5. Limitations

The present research is exploratory and based on a relatively small sample of students from a single institution. In addition, some responses were brief and repetitive, limiting the depth of qualitative analysis. Therefore, the conclusions should be interpreted as indicative tendencies rather than statistically representative findings.

6. Conclusions

This preliminary study highlights the growing presence of AI tools in the academic preparation of music students. The findings indicate that students primarily use AI technologies for explanations, research support, practice guidance, creative inspiration, and study organization.

Although students generally perceive AI positively, they also recognize its limitations and continue to value the role of teachers, personal effort, and direct musical experience in their professional formation. The results suggest that AI technologies may become increasingly relevant in music education, making it important for universities and educators to develop clear pedagogical frameworks for their responsible use. Future research involving larger participant groups and more detailed quantitative analysis could provide a deeper understanding of the long-term impact of AI on musical learning and artistic development.

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AI Literacy in Education across Regulatory Frameworks: A Comparative Analysis of the European Union, United States and China

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Abstract

AI literacy is no longer just an educational objective or an individual competence. State authority now uses it as a governance framework to manage risks and assign accountability for AI use in education. Yet, current literature continues to frame the concept almost entirely around user competence and ethical boundaries. This leaves its growing institutional role, specifically how it acts as a mechanism for legal responsibility, largely unexamined. To address this gap, the article examines how AI literacy is defined, framed, and translated into educational responsibility across three important, yet different governance models: the European Union, the United States and China. These frameworks were selected because they represent three different approaches to AI literacy governance in education: a legal-compliance model in the European Union, a decentralised, and incentive-based model in the United States, and a centralised, state led model in China.

Through a qualitative comparative analysis of legal texts, official guidelines, and education-specific policy documents, the study analyses how the same concept is assigned different regulatory and educational functions across three jurisdictions. The findings prove that AI literacy extends far beyond personal skills and competences, and it now operates primarily as a mechanism of institutional governance, fundamentally reshaping educational policy, teacher liability, and

algorithmic responsibility.

Keywords: AI literacy, AI governance, education policy, responsible AI, AI regulation, European Union, United States, China

1. Introduction

As a concept, AI literacy barely had a moment to settle. When the earliest definitions emerged, between 2016 and 2020, the focus was almost exclusively pedagogical. The entire debate revolved around individual skillset: teaching students to understand basic algorithms, or showing teachers how to actually use these new platforms in their daily teaching (Long & Magerko, 2020; Ng et al., 2021). Yet, the rapid evolution of AI systems has very rapidly outpaced this theoretical focus. Before schools and universities could even properly institutionalise these basic competencies, automated tools flooded academic life. Today, algorithms filter admissions, grade student performance, draft content, or generate lesson planning, often without formal institutional approval (Williamson & Hogan, 2021).

The OECD's *Digital Education Outlook 2026* explicitly flags this exact blind spot. Unlike previous waves of educational technology, the new generation of AI tools is widely accessible for free and frequently used outside any formal procurement process or institutional oversight. Because of this, the current challenge is less about pedagogical preparedness and more about a severe vacuum of authorisation. Whilst early guidelines, such as the *UNESCO Guidance for Generative AI in Education and Research* (2023), established vital baselines for "human-centred use" and "age-appropriate safeguards", they also highlighted an alarming lack of institutional readiness. Currently, most AI tools shaping the academic work are neither formally approved nor systematically supervised. We are operating in a regulatory grey zone of well intended, but abstract warnings, completely avoiding the most critical administrative question: who is actually accountable when the rules are superficially defined or simply don't exist?

This vacuum forces a fundamental redefinition of AI literacy itself. The concept must cease being viewed merely as a personal pedagogical checklist and instead take on an explicit institutional mandate. Measuring the competency level of students and educators is no longer sufficient. The critical question is now what an academic system actively enforces.

While upskilling efforts remain necessary, educational communities must move beyond basic

training and build a tangible "architecture of responsibility" (Holmes et al., 2021). Institutions must determine what acceptable use looks like and decide exactly who has the responsibility when a system fails.

Yet, on a global scale, this push for AI literacy governance intersects with a fragmented geopolitical reality. Recent global events, such as the 2026 India AI Impact Summit, where the US delegation explicitly rejected a unified global AI framework, demonstrate that the major powers remain fiercely loyal to their own models to secure market dominance. By extension, AI literacy also inherits the ideological marks of its parent system and this reality makes a comparative approach a methodological necessity. For this reason, this paper does not treat the European Union, the United States, and China as isolated case studies, but as actual competing administrative philosophies with operational differences. The EU anchors AI literacy directly to legal obligation and compliance standards (European Parliament, 2024). The US deliberately avoids federal mandates, opting instead for a fragmented, decentralized approach (US Department of Education, 2023). Meanwhile, China frames the concept within its centralized administrative machinery (Cyberspace Administration of China, CAC, 2023). The analytical goal of this paper is to understand how each framework justifies its authority at the exact moment AI literacy evolves from personal skillset into a mechanism of institutional governance.

2. Literature Review and Research

The traditional skill-based focus on AI literacy has created a profound disconnect between academic theory and institutional practice. Existing literature remains largely anchored in a pedagogical bubble and existing frameworks, such as the UNESCO *AI Competency Frameworks* (2024), still define AI literacy primarily as a matter of individual knowledge and ethical awareness. This competence-based approach is necessary, but it completely ignores the administrative reality of schools.

Currently, the closest attempt to bridge this gap is the work of Yang et al. (2024), who examine AI policy through the lens of policy diffusion, comparing frameworks across the EU, US, India and China. They explicitly treat national strategies as engines for "domestic talent cultivation" and global competitiveness, they also effectively map the geopolitical race for an AI-ready workforce, but leave a critical vacuum by not examining AI literacy as a tool of educational

governance.

Looking at the broader literature, we observe a similar imbalance. We have an abundance of research on what students and teachers should know, exemplified by the UNESCO AI Competency Frameworks (2024) or Swiecki et al., (2022), but there is little to no documentation on who actually has the administrative responsibility once a system is deployed in a school. As Pesek (2026) notes in *Rethinking Education Governance in the Age of AI*, integrating artificial intelligence in schools shifts who makes the actual decisions.

We also have to acknowledge a massive administrative void when it comes to schools and universities. Unlike the corporate sector, where technology mainly exists to generate profits, in education AI has multiple and sensitive roles. It is both a tool for learning and a subject of study, yet it also evaluates students, filters admissions, and helps in daily administrative tasks. This specific dynamic turns education into a major vulnerability for AI governance (Selwyn et al., 2022). When a single technology can dictate institutional access and grade human performance, it can, ultimately, influence a student's entire academic trajectory. As Panagopoulou, Parpoula and Karpouzis (2025) note, this raises severe issues of equity and institutional accountability. In this context, AI literacy can no longer be just a personal pedagogical checklist. Instead, this reality transforms students and educators from simple users, to subjects of an automated bureaucracy.

To directly address this administrative void, this paper is organised around three research objectives. First, it seeks to redefine AI literacy by reframing it from a strictly institutional perspective, moving the definition from "pedagogical skill" to "governance tool". Then, it maps and compares how three major political actors, the EU, the US and China, allocate administrative responsibility when regulating AI in their educational systems. On that basis, by analysing these three regulatory models, the paper introduces a practical analytical instrument, the Policy-to-Practice Translation Matrix, to measure the degree to which AI literacy is translated from high-level policy into on-the-ground governance in education.

3. Methodology

Mapping the transition of AI literacy from a policy ambition into an enforceable administrative reality demands more than a standard thematic review. Merely scanning these national (the U.S and China) and regional (the EU) strategies and searching for keywords like "ethics" or "safety"

fails to explain how accountability actually works on the ground and how it is implemented by educational actors in schools and universities (Rizvi & Lingard, 2010; Curaj et al., 2020). Policymakers routinely rely on this type of vocabulary to project a sense of regulatory control, yet this rhetoric is not enough to become an actual administrative tool, and it almost never translates into clear instructions for school boards. Simply counting the frequency of "safe AI" or "responsible AI" in a government document cannot expose an actual chain of command. Ultimately, a keyword-driven approach deliberately avoids the single most critical bureaucratic question a policy must answer: who actually carries the legal responsibility when a system fails while being used in an academic setting?

To answer this exact question, the paper proposes a comparative Critical Policy Analysis (CPA) framework (Diem et al., 2014; Taylor, 1997). Rather than evaluating pedagogical outcomes, the methodology introduces a strict institutional lens that examines official texts through precise governance indicators. To structure this, the paper develops the Policy-to-Practice Translation Matrix, tracking key elements like policy drivers, legal responsibility, and implementation mechanisms across jurisdictions. To apply this matrix, the paper relies on a strict defined corpus of policy documents, spanning from 2022 to April 2026, chosen precisely because they reflect contrasting governance logics.

To map the European Union's approach, the paper examines texts that strongly anchor educational technology (EdTech) within a rigid risk classification. The primary text examined is the *Artificial Intelligence Act* (European Parliament, 2024), specifically Article 4 and Recital 56, which directly target educational use cases and outline institutional obligations. However, because this legal architecture is actively updating, the corpus also incorporates the proposed *Digital Omnibus on AI* alongside the European Commission's *Ethical Guidelines*(2026). This addition is critical for tracing how the initial statutory burden is currently being renegotiated, demonstrating how it translates abstract legislative categories into administrative reality.

The United States, meanwhile, actively resists any influence toward a centralised federal mandate. To map this deliberately fragmented approach, the corpus traces the American policy trajectory from its early theoretical principles to its current funding mechanisms. The analysis reviews the White House's *Blueprint for an AI Bill of Rights* (Office of Science and Technology Policy, OSTP, 2022), the recent *Executive Order 14277* (2025) and the voluntary US Department of Labor *AI*

Literacy Framework (2026) against the US Department of Education's funding guidelines. Furthermore, to properly understand the complex administrative reality of the US, the methodology contrasts these soft-law federal documents with state level hard laws, specifically looking at recent legislation like the *Colorado Act* (2024). Together, these documents illustrate a clear strategy to avoid the federal legislative path, highlighting a fragmented governance characteristic that creates major differences between school districts.

Breaking completely from the EU and the US models, China deliberately rejects both the European legal framework and the American free-market and innovation-oriented model, choosing instead to merge compliance with strict ideological control. To understand this third model, the paper extracts governance indicators from the *Interim measures for the management of Generative Artificial Intelligence Services* (Cyberspace Administration of China, CAC, 2023). To track how this strict national security approach actually influences the use of AI in classrooms, the analysis also incorporates the Ministry of Education (MOE) guidance on AI literacy (2024) alongside the new *AI + Education Action Plan* (April 2026).

4. Comparative Analysis and Results

Applying the Critical Policy Analysis (CPA) matrix to the selected texts reveals a major administrative discrepancy. Globally, the public rhetoric on AI literacy is almost identical, promising ethical deployment and student well-being, the actual bureaucratic reality is highly fractured. This geopolitical fracture surfaces the moment we examine the first set of governance indicators: the actual legal weight of the mandate and the precise allocation of institutional responsibility.

4.1 The European Union's approach to AI governance: strictly binding legal architecture

By passing the Artificial Intelligence Act in 2024 as a regulation rather than a directive, Brussels guaranteed the text immediate statutory force across all 27 Member States, entirely bypassing the need for national parliaments to transpose the rules into national law. The defining feature of this legislation is its risk-based approach. Rather than regulating the technology itself, the EU regulates the specific use case, forcing AI systems into a rigid four-tier risk matrix, classified from "minimal" to "unacceptable". Under this strict hierarchy that Article 4 of the AI Act changes the

rules for academic institutions. Because AI systems used in education end up directly dictating human trajectories, by filtering university admissions, or grading student performances, they are explicitly classified as “high-risk” systems.

Here, AI literacy loses its pedagogical focus and becomes a strict organisational duty. The original statutory text explicitly states that both software providers and institutional deployers, meaning the schools and the universities themselves, must ensure a “sufficient level of AI literacy” to manage these high-risk systems.

Once a university deploys a high-risk educational algorithm, it has to legally guarantee continuous human oversight and maintain incident logs. Also, it cannot shift the liability to the software vendor if an automated grading tool starts hallucinating facts or discriminating. As the statutory deployer, the academic institution carries the immediate administrative responsibility. Selwyn et al. (2022) note that this dynamic turns schools into “automated bureaucracy” hubs, forcing local boards to absorb legal risks for technologies they do not entirely understand. Expecting a local high school to meet the same regulatory standards as a multinational tech company is, however, practically unsustainable. Recognizing this, the European compliance model is currently undergoing a major shift. As negotiations extend into mid-2026, the proposed Digital Omnibus on AI signals a profound administrative shift.

Recognising the severe legal exposure placed on local educators, the Omnibus attempts to simplify and amend this dynamic. The proposed text shifts the risk oversight away from individual deployers, transferring regulatory burden directly to the European Commission and the Member States, under the monitoring of the EU AI Office. This renegotiation shows the EU acknowledging a structural flow in its initial allocation of accountability. By absorbing the compliance burden at state level, the EU is actively redesigning its chain of responsibility in education. Yet, even as this power shift is negotiated, the core European philosophy remains intact: given its strategic role, AI literacy will always require statutory compliance, never a voluntary recommendation.

4.2 The United States: the decentralised, incentive-based model

Unlike Brussels, Washington actively supports a regulatory vacuum at the central level. The federal American model proposes a “soft law” approach, a deliberate strategy of governance philosophy that privileges market agility and innovation over centralised compliance. As mapped

through the White House Executive Order 14277 (2025) and the US Department of Labor AI Literacy Framework (2026), the federal government explicitly frames AI literacy not as a legal duty, but as a workforce capacity-building exercise.

While this decentralised approach gives the corporate sector exactly the agility it wants, for local school boards, this hands-off approach creates a more challenging reality. Because the federal government, through the Department of Education, offers funding incentives and voluntary guidelines rather than a hard legal framework for educators to actually rely on, academic institutions are left to navigate algorithmic responsibility on their own. Also, in the absence of federal rules, individual states have started to act, creating what is essentially a fragmented legislative patchwork. States like Colorado, with its Colorado AI Act passed in 2024, and California have introduced their own hard laws targeting algorithmic discrimination. For a school district, this creates legal inequality. Depending on where they are located, schools are either facing strict state-level penalties or relying entirely on legacy privacy laws, like the 1974 FERPA law, trying to fit old rules to cover modern machine learning. Ultimately, this turns student protection into a "zip code lottery". A school's capacity to actually enforce AI literacy ends up depending on its local legislation and tax revenue rather than a guaranteed national standard.

4.3 China: the centralised, state-led model

Breaking completely from both the European compliance framework and the American market-led approach, Beijing treats AI literacy as a strict matter of national security. Looking at the Interim Measures (Cyberspace Administration of China, 2023) and the recent AI + Education Action Plan (April 2026), the state clearly has no intention of letting local schools to assess algorithmic risks by themselves. Instead, the central government handles the entire regulatory audit long before any software reaches the classroom. Before even touching the education market, tech developers must pass severe and rigorous state security assessments to prove that their generated outputs align with "socialist core values".

For Chinese schools, this creates a strictly top-down reality. Controlled entirely by the Cyberspace Administration of China (CAC), they do not act as legally liable "deployers" as they are in Europe, nor are they left legally exposed like the American schools and universities. They have no compliance burden because the state takes all responsibility. However, this heavy central filtering

alters the very nature of educational technology. Because Beijing controls in such a heavy way all compliance decisions, ideologically unwanted AI never even makes it to classrooms. This completely shifts the concept of AI literacy: it stops being a vehicle for open pedagogical inquiry and turns into a highly monitored instrument for political compliance.

4.4 Cross-regional comparison: the architecture of responsibility

Looking across these three jurisdictions, it becomes clear that their antagonistic positions on AI literacy have almost nothing to do with actual teaching. On paper, their position is practically identical: every region promises to nurture critical thinking, protect student privacy, and prepare learners for an automated economy. But as Ben Williamson (2021) rightly points out, the reality of an educational technology policy is never found in its pedagogical promises, and it's actually located in its administrative wiring. The real geopolitical divide happens the moment we talk about liability: when a system fails, hallucinates, discriminates, or extracts data without consent, who is to be legally held accountable?

The European Union, the United States, and China resolve this crisis in completely different ways. Brussels initially treated AI literacy as a strict institutional compliance, forcing schools and universities to absorb the legal burden of high-risk algorithms, an approach it is now trying to correct through the 2026 Digital Omnibus on AI negotiations. Washington, meanwhile, actively maintains a federal regulatory vacuum to protect market innovation. By refusing to enforce a national framework, the US effectively pushes the administrative burden down to local schools, leaving them legally exposed and financially outmatched by tech developers. Beijing handles the entire risk management right at the top. By treating algorithms as a national security issue, the Chinese state removes any compliance authority from schools, using AI literacy as a vehicle to enforce political conformity.

What these three models show is that we can no longer treat AI literacy globally as just a universal set of technical skills. Depending on the geopolitical context, the concept serves different institutional functions: it operates as a strict legal obligation in the EU, a locally founded workforce competency in the US, and a direct instrument of state control in China.

4.5 The Policy-to-Practice Translation Matrix: a comparative framework

Simply scanning official documents for keywords like "responsible AI" fails to capture how an AI

literacy policy actually works in real life. Recent empirical evidence supports this argument As Park et al. (2026) note, building AI skills without enforcing strict rules makes societies more vulnerable. According to them, AI literacy works safely when supported by mature governance.

But while quantitative models confirm that governance is crucial, they cannot explain how these rules actually function once deployed within an academic ecosystem. To bridge this gap, this paper introduces the Policy-to-Practice Translation Matrix, a qualitative analytical tool that maps exactly how abstract regulations translate into daily academic life.

The five indicators comprising this matrix are highly pragmatic. Moving past the surface of official documents, this framework shifts the focus away from what educational policies claim to achieve, asking a much more practical question: who actually has the power and the responsibility to enforce them?

To trace this accountability across these three regions, the matrix applies five specific criteria:

1. The policy driver: Analyzing a policy requires identifying its geopolitical context. This indicator assesses the actual justification for state intervention, whether the goal is to protect human rights, promote market innovation, or secure ideological control.

2. Legal responsibility: This indicator maps who bears the legal consequences when an algorithm fails or discriminates. It also identifies the specific agencies in charge, from the EU AI Office to China's Cyberspace Administration (CAC).

3. Implementation mechanism: This indicator measures the regulatory weight of the policy, distinguishing between hard law that demands strict compliance and soft-law recommendations.

4. Implementation support: It evaluates whether schools receive the actual financial and administrative resources needed to enforce the rules, or if they are left to absorb the regulatory burden alone.

5. Student protection: This final indicator examines how learners are practically protected in practice. Moving beyond abstract ethical promises, it interrogates the concrete mechanisms in place to prevent an algorithm from causing harm.

Governance indicator	The European Union	The United States	China

The policy driver *(Why the state acts)*	**Risk-based approach.** Focuses on human rights and risk management. The main goal is to protect citizens from automated harm.	**Market-based approach.** Focuses on the economy. The goal is to build a highly skilled workforce and push market innovation.	**Security-based approach.** Focuses on national security and regime stability. The primary goal is strict ideological control.
Legal responsibility *(Who takes the legal blame)*	**Shifting to macro-level (State / EU).** Monitored by the EU AI Office. The burden of ensuring AI literacy is shifting away from schools (as deployers) and companies, moving directly to the European Commission and Member States under the proposed Digital Omnibus	**Pushed to micro level (local / district).** There is no central AI agency. Schools and universities carry the primary risk under outdated privacy laws, relying entirely on voluntary recommendations from NIST and the Department of Education.	**Absolute centralisation.** Controlled entirely by the Cyberspace Administration of China (CAC). The state takes all responsibility, and local schools carry zero compliance burden.
Implementation mechanism *(How rules are enforced)*	**Uniform hard law.** The AI Act demands strict legal audits based on a four level risk system.	**Soft law, decentralised rules.** The federal government offers voluntary recommendations. Meanwhile, individual states like Colorado and California are passing their own strict AI laws, creating legal inequality between school districts	**Strict state approval.** Mandatory state registry. Every AI system must pass a central security assessment before schools can even test them.
Implementation support *(What help schools get)*	**Low / delegated to the deployer.** Under the 2024 EU AI Act, schools (as deployers) absorb the compliance burden. While Member States must create oversight agencies, they have no legal obligation to provide direct financial or administrative support for schools, leaving them exposed (a regulatory flaw the 2026 Digital Omnibus is now attempting to address)	**Low & highly unequal / delegated to local districts.** The federal government provides soft-law guidance and competitive funding, but no guaranteed administrative protection. Support depends entirely on state-level legislation and local tax revenue, placing a major influence on the "zip code lottery" where poorer districts are left to manage risks	**High / centralised state absorption.** Schools face zero compliance burden because the central state machinery (CAC) handles the entire regulatory security audit before the software reaches the classrooms. The state absorbs the administrative responsibility completely.

		independently.	
Student protection *(Actual safety rules)*	**Strong legal protection.** High / Legally enforced. Algorithms that make decisions about a student's future are strictly classified as "high-risk"	**Vulnerable / outdated legal protection.** Left to outdated privacy laws. Schools try to fit the 1974 FERPA law to cover modern machine learning, which is not enough.	**State-filtered protection.** Subordinated to socialist core values. Protecting the student simply means ensuring the AI aligns with state ideology.

Table 1. The Policy-to-Practice Translation Matrix

As **Table 1** demonstrates, applying these governance indicators reveals that AI literacy is far from a universal educational goal. Instead, it reflects distinct geopolitical agendas. The EU regulates to protect rights, the US prioritizes market innovation, and China restricts to maintain state control. As the matrix shows, the real barrier to safe AI in schools is not the technology itself, but the problem is the mismatch between what governments demand and what they can actually support. For the EU and the US, this gap creates a serious paradox. Both want to dominate the global AI race and expect local schools to train a highly skilled workforce for it. Yet, as the legal liability indicator shows, by pushing the legal risk down to local districts, they trigger a defensive administrative response. Because schools receive fragmented or low implementation support, they are forced to absorb the legal responsibility alone. Historically more cautious and avoiding legal risks (Selwyn, 2021), academic institutions facing the threat of bias lawsuits or data breaches under outdated privacy laws will likely opt for safe and heavily restricted AI tools. Ultimately, institutional self-preservation will sabotage the very pedagogical innovation these policies claim to promote.

In contrast, China resolves this liability right at the top. Because the central government (via the CAC) handles the entire approval mechanism, schools face no legal risk. As the student protection indicator reveals, this administrative safety comes at the cost of pedagogical autonomy. The

technology ceases to be an open platform for learning, and AI literacy is reduced to an instrument for behaviour monitoring and political alignment.

5. Conclusions

This paper began by tracing a fundamental shift in educational technology: AI literacy is no longer just a pedagogical checklist. As academic institutions are flooded with different automated grading tools, content generation, even automated filters for school admission, the challenge has moved from the classrooms directly into institutional bureaucracy. Our objective was to look beyond the pedagogical definitions of AI literacy and to examine how this new "architecture of responsibility" actually translates in reality.

By applying the proposed matrix across the three jurisdictions, the analysis reveals that AI literacy does not exist as a universal governance standard. Instead, it functions as an extension of its parent system and acts the same as any other political instrument does.

More importantly, by placing the three models in competing positions, we discover a major structural flaw: both Washington and Brussels expect academic institutions to cultivate an AI-ready new workforce generation to dominate the global market. Yet, by placing the entire accountability of high-risk systems onto local schools and districts they actually trigger a predictable administrative reaction: institutional self preservations. On the other hand, China resolves this liability by centralising all approvals at state-level. The cost, here, is that technology serves as a control instrument and a total lack of pedagogical autonomy.

In reality, all three frameworks fail the educational system, because safe AI in education is a matter of institutional responsibility, not just ethics. If governments genuinely want AI-literate students, teachers and overall academic institutions, they must move beyond publishing guidelines or recommendations, and they must also stop forcing schools to act as legal deployers. The education sector needs real legal and financial support to implement a real and effective AI literacy governance. Ultimately, none of these approaches builds AI-ready generations or academic institutions, but they manage to build defensive bureaucracies. Until policymakers learn to protect schools from liability without transforming AI into a tool for authoritarian control, AI literacy will remain a fractured policy ambition.

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Predictors of Teacher Burnout Across Career Stages: Evidence from the Romanian Educational Context

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Abstract

The emergence of burnout among teachers represents a major international concern, being associated with reduced teacher well-being, lower levels of engagement, and poorer educational outcomes among students. Although extensive research has examined the phenomenon of burnout, relatively few studies have addressed the relationship between its predictors and teachers' stages of professional development. In this context, the present study investigates the extent to which burnout predictors vary across stages of the teaching career within the Romanian pre-university education system.

The study adopts a quantitative design based on a sociological survey using a questionnaire, administered to a sample of 194 teachers. The variables analyzed include organizational factors (role overload, learning opportunities, and development opportunities), transactional factors (satisfaction of basic psychological needs for autonomy, competence, and relatedness), and individual factors (distress reactivity and stress mindset). These variables are examined in relation to the dimensions of burnout. Data were analyzed using multiple regression analysis, conducted separately for each career stage. The results indicate that burnout predictors vary depending on professional stage, with certain variables exerting stronger effects in the early stages of the career, while others become more relevant in later stages. These differences suggest the need for differentiated interventions tailored to the specific developmental needs of teachers at each stage of their professional trajectory.

This study contributes to the literature by highlighting the dynamic nature of burnout across the teaching career and offers relevant implications for educational policies and teacher support programs.

1. Introduction

Concerns regarding the psychological well-being of teachers have been present in international research for more than half a century. Consequently, a substantial body of empirical evidence has examined the influence of organizational, individual, and transactional factors on stress, work

engagement, organizational commitment, motivation, and performance, as well as on negative outcomes such as burnout.

Burnout has received considerable attention from researchers, with numerous studies investigating its associations with a range of variables, including interpersonal and environmental factors (Carroll et al., 2022), high workload (Kokkinos, 2007), lack of social and administrative support (Rennert & Stoeber, 2008), personality traits such as high neuroticism and low extraversion (Swider & Zimmerman, 2010), as well as time pressure and work overload (Leiter & Maslach, 2009).

In recent years, an increase in the prevalence of teacher burnout has been observed. This trend can be explained by the high levels of responsibility teachers are required to assume, the emotionally demanding nature of their work, and additional contextual pressures such as time constraints, workload intensity, limited infrastructure, and insufficient social support from parents, colleagues, and school leadership. Research indicates that early-career teachers are particularly vulnerable to these stressful conditions (Gavish & Friedman, 2010).

Against this background, the present study investigates the predictors of burnout among teachers, with a specific focus on differences across stages of professional career development.

2. Literature Review

Burnout has been described as “an erosion of engagement; what started as important, meaningful, and challenging work becomes unpleasant, unfulfilling, and meaningless” (Maslach, Schaufeli, & Leiter, 2001, p. 416). In this sense, positive attitudes toward work gradually shift into negative experiences. Conceptualized as a tripartite syndrome, burnout is characterized by emotional exhaustion, which replaces feelings of energy; cynicism, which replaces hope and engagement; and reduced professional efficacy, which replaces a sense of accomplishment (Maslach, Schaufeli, & Leiter, 2001).

The literature on burnout is highly diverse; within this body of research, the Job Demands - Resources (JD-R) model (Demerouti, Bakker, Nachreiner, & Schaufeli, 2001) has become one of the most widely used theoretical frameworks. According to this model, burnout arises from an imbalance between excessive job demands and insufficient job resources. In this framework, job resources include aspects such as control over work, access to information, supervisory support,

innovative school climate, and social climate (Hakanen, Bakker, & Schaufeli, 2006). Job demands, in contrast, refer to factors such as student misbehavior, workload, and a psychologically unfavorable work environment (Hakanen, Bakker, & Schaufeli, 2006). Job demands are defined as those physical, psychological, social, or organizational aspects of work that require sustained physical and/or psychological (cognitive or emotional) effort and are therefore associated with certain physiological and/or psychological costs (Demerouti, Bakker, Nachreiner, & Schaufeli, 2001). Job resources refer to those physical, psychological, social, or organizational aspects of work that reduce job demands and their associated costs. Burnout occurs when job demands exceed the available resources available to counterbalance them. Organizational, individual, and transactional factors may function both as job demands and job resources. For instance, social support from principals and colleagues, documented in studies by Pyhältö, Pietarinen, and Salmela-Aro (2011), Barutcu (2013), Maslach et al. (2001), and Bakker et al. (2010), can operate as a protective resource in teachers' work. However, when such support is lacking, it may become a source of strain, contributing to the burnout process.

Research by Javadi (2014) shows that teacher autonomy is significantly and negatively associated with burnout. The study highlights that many teachers lack control over how they teach, which may generate dissatisfaction, reduced motivation, and hindered professional development (Javadi, 2014). The negative impact of demotivation and reduced job satisfaction on teachers' professional development has also been documented by Fernet, Guay, Senécal, and Austin (2012). Perceived autonomy varies depending on both individual characteristics and contextual factors such as educational policies, institutional constraints, and teaching methodologies. Findings suggest that teachers who are more self-regulated and engaged in developing their instructional skills report lower levels of helplessness, disillusionment, and emotional exhaustion (Javadi, 2014). Furthermore, emotional exhaustion has been identified as a key predictor of perceived autonomy. Reduced autonomy, in turn, is associated with lower professional accomplishment. Studies by Fernet et al. (2012) also link teacher autonomy to professional development, showing that autonomy-supportive contexts enable teachers to make meaningful decisions about their work and foster professional growth. Within the JD-R model, autonomy is conceptualized as a job resource that enhances intrinsic motivation by supporting learning and development. According to Self-Determination Theory (Deci, Vallerand, Pelletier, & Ryan, 1991), social contexts that satisfy basic

psychological needs for autonomy, competence, and relatedness promote well-being and increase engagement.

Previous research has primarily focused on early-career teachers. For instance, Gavish and Friedman (2010) examined how novice teachers perceive their work environment and how these perceptions influence burnout. Their study highlights the role of organizational conditions and work-related difficulties, particularly job demands, in shaping professional adjustment. Factors contributing to emotional exhaustion and dissatisfaction among novice teachers include lack of rewards, limited promotion opportunities, low salaries, role conflict, role ambiguity, and both qualitative and quantitative overload, as well as insufficient encouragement of initiative. Their findings indicate that novice teachers are often not fully satisfied with their organizational environment during their first year of teaching. They report difficulties in integration and adaptation, which hinder effective functioning and professional performance. In addition, they express limited satisfaction with professional and personal support, recognition from school leadership, parents, and colleagues, as well as with school culture and public status (Gavish & Friedman, 2010). Similarly, Høigaard et al. (2011) found that newly qualified teachers report excessive workload and job demands that are not directly related to instructional activities.

3. Methodology

The main objective of the study was to identify the significant predictors of the emergence of teacher burnout among pre-university education teachers in Romania and to analyse how these predictors vary according to career development stage. In direct relation to the theoretical framework, the following hypotheses guided the research: H1: *we assume that the presence of work overload, a low level of satisfaction of basic psychological needs (autonomy, competence, and relatedness), a dysfunctional coping style in relation to stress, a low level of learning opportunities, and a lack of development opportunities predict the occurrence of burnout among teachers*. H2: *we assume that there are differences between the five groups of teachers regarding the predictors that contribute to the emergence of burnout*.

Sample characteristics

A total of 194 respondents participated in this study. Snowball sampling was used, and the research instrument was distributed online via the Google Forms platform. The questionnaire was disseminated in online teacher groups on social media platforms and through person-to-person sharing. The main inclusion criterion was being a teacher in the pre-university education system. The response rate could not be calculated, and the questionnaire was not subjected to a pre-testing process. The sample consisted of 194 teachers (90.2% female), with a mean age of M = 35 years, SD = .998. **Table 1** presents the detailed characteristics of the sample.

N	194	100%
Gender		
Female	175	90,2%
Male	19	9,8%
Age		
18-25	18	9,3%
26-35	65	33,5%
46-55	39	20,1%
56-65	7	3,6%
The environment in which they teach		
Rural	84	43.3%
Urban	110	56,7%
Marital Status		
Married	112	57,7%
Unmarried	66	34%
Level of education		
High School Education	2	1%
Short-term higher education	23	11,9%
Long-term higher education	165	85,1%
PhD studies	4	2,1%
Ciclul de predare		
Kindergarten	15	7,7%
Primary school	81	41,8%
Middle School	50	25,8%
High school	47	24,2%
Post secondary	1	0,5%
Professional degrees		
Novice	39	20,1%
Qualified teacher status	38	19,6%
Didactic level II	23	11,9%

Didactic level I	71	36,6%
Without qualifications corresponding to their position	23	11,9%
Sector of activity		
Public	180	92,8%
Private	14	7,2%

Table 1. Demographic Characteristics of the Sample Participants

Research Method. Research Instruments

The research method employed in this study is a survey-based sociological inquiry using a questionnaire. The research instrument consists of a battery of internationally standardized and validated scales, integrated into a 78-item questionnaire.

Burnout was measured using the Maslach Burnout Inventory - General Survey (Schaufeli, Bakker, & Demerouti, 1996), which assesses three dimensions: emotional exhaustion, cynicism, and reduced professional efficacy. For our sample (N = 194), the Cronbach's alpha reliability coefficient was α = .86 for emotional exhaustion, α = .76 for cynicism, and α = .84 for reduced professional efficacy.

Work overload was measured using the role overload subscale from the Occupational Stress Index. For our sample (N = 194), the Cronbach's alpha reliability coefficient was α = .83.

Learning opportunities were assessed using the Learning Opportunities subscale from the Questionnaire on the Experience and Assessment of Work (QEAW) (Veldhoven & Meijman, 1994). For our sample (N = 194), the Cronbach's alpha reliability coefficient was α = .83.

Development opportunities were measured using the Development Opportunities subscale from the Job Demands–Resources Questionnaire (Bakker & Demerouti, 2014). For our sample (N = 194), the Cronbach's alpha reliability coefficient was α = .81.

The three basic psychological needs from Self-Determination Theory: autonomy, competence, and relatedness (Deci & Ryan, 2000) were assessed using the Need Satisfaction at Work (NSW) Questionnaire, developed by Van den Broeck et al. (2010) and culturally adapted for Romania by Țânculescu and Iliescu (2014). For our sample (N = 194), Cronbach's alpha values were α = .80 for relatedness, α = .85 for competence, and α = .80 for autonomy.

Distress reactivity was measured using the Responsive Distress scale, part of the International Personality Item Pool (IPIP), in the culturally adapted Romanian version by Iliescu, Popa, and Dimache (2015). For our sample (N = 194), the Cronbach's alpha reliability coefficient was α = .80.

Stress coping orientation was assessed using the Stress Mindset Measure. For our sample (N = 194), the Cronbach's alpha reliability coefficient was α = .78.

Career development stage was operationalised by grouping teachers into the following categories: unqualified teachers (those occupying substitute positions without relevant formal qualifications for the role), novice teachers, teachers with the teaching certification (definitivat), second-degree teaching certification, and first-degree teaching certification.

4. Research Results

In order to test the hypotheses proposed in this study, multiple regression analysis was employed to identify the models that best predict burnout among teachers. Based on the correlation matrix, predictors that did not correlate with burnout were excluded from the analysis. The remaining variables were entered simultaneously into a linear regression procedure using the stepwise method, with burnout as the dependent variable. To identify differences according to career development stage, the groups were first separated using the "Compare Groups" procedure, after which the regression analyses were repeated. Independent variables were entered simultaneously.

Regarding the models generated with burnout as the dependent variable, the first model identified the need for autonomy (within the framework of Self-Determination Theory) as the first variable contributing significantly to the regression model, $F_{change}(1,192) = 84.22$, $p < .001$, accounting for 31% of burnout variance. The second model introduced learning opportunities, which explained an additional 10% of burnout variance, $F_{change}(1,191) = 32.85$, $p < .001$, significantly increasing the value of R^2. The inclusion of the need for competence in the third model, $F_{change}(1,190) = 14.71$, $p < .001$, explained an additional 4% of the variance in burnout. The fourth model introduced overload, accounting for an additional 3% of burnout variance, $F_{change}(1,189) = 10.76$, $p < .001$. The fifth model added stress mindset, explaining an additional 3% of burnout variance, $F_{change}(1,188) = 9.37$, $p < .001$. Relatedness need satisfaction was introduced in the sixth model, increasing R^2 by 1%, $F_{change}(1,187) = 4.05$, $p < .05$. In the seventh model, the need

for autonomy was removed, while the remaining variables were retained, resulting in only a 1% decrease in R^2. Overall, burnout among teachers was explained in proportion of 51% by perceiving learning opportunities as excessively demanding ($\beta = .33$, $p < .001$), dissatisfaction of the need for competence ($\beta = –.26$, $p < .001$), perceived overload ($\beta = .25$, $p < .001$), a debilitating stress mindset ($\beta = –.16$, $p < .01$), and dissatisfaction of the need for relatedness ($\beta = –.15$, $p < .01$).

Variabila	B	*T*	*p*	*R*	R^2	ΔR^2
Model 1				.55	.31	.31
Autonomy	-.55	-9.18	.001			
Model 2				.64	.41	.10
Autonomy	-.36	-6.13	.001			
Learning opportunities	.36	5.85	.001			
Model 3				.67	.45	.04
Autonomy	-.30	-4.54	.001			
Oportunități de învățare	.36	6.01	.001			
Competence	-.23	-3.84	.001			
Model 4				.69	.48	.03
Autonomy	-.18	-2.57	.011			
Learning opportunities	.36	6.01	.001			
Competence	-.25	-4.37	.001			
Overall	.20	3.28	.001			
Model 5				.71	.50	.03
Autonomy	-.15	-2.14	.033			
Learning opportunities	.33	5.60	.001			
Nevoia de competență	-.26	-4.60	.001			
Competence	.20	3.38	.001			
Modul de raportare asupra stresului	-.16	-3.06	.003			
Model 6				.72	.51	.01
Autonomy	-.11	-1.55	.123			
Learning opportunities	.30	5.14	.001			
Competence	-.24	-4.04	.001			
Overall	.21	3.50	.001			
Stress mindset	-.15	-2.81	.005			
Relatedness	-.13	-2.01	.046			
Model 7				.71	.51	.01
Learning opportunities	.33	5.76	.001			
Competence	-.26	-4.71	.001			
Overall	.25	4.73	.001			
Stress mindset	-.16	-2.99	.003			

Relatedness	-.15	-2.50	.013

For novice teachers, the multiple regression analysis generated two models. The first model identified learning opportunities as the first significant predictor of burnout, Fchange (1,37) = 23.66, p < .001, accounting for 39% of burnout variance among novice teachers. The second model introduced overload, Fchange (1,36) = 8.57, p < .01, explaining an additional 12% of variance. Model 2 explained 51% of burnout variance among novice teachers, with the strongest predictor being the perception of excessive learning opportunities (β = .62, p < .001), followed by perceived overload (β = .34, p < .01).

Variabila	B	*T*	*p*	*R*	R^2	ΔR^2
Model 1				.63	.39	.39
Learning opportunities	.63	4.86	.001			
Model 2				.71	.51	.12
learning opportunities	.62	5.26	.001			
Overload	.34	2.93	.006			

For teachers with qualified teacher status the regression analysis generated four models. According to the first model, the need for relatedness was the first variable contributing significantly to the regression model, Fchange (1,33) = 14.74, p < .001, accounting for 29% of burnout variance. The second model included relatedness and competence needs, explaining 43% of burnout variance. In the third model, overload was added, explaining an additional 8% of variance, Fchange (1,34) = 5.58, p < .05. The fourth model introduced stress mindset, Fchange (1,33) = 5.32, p < .05, explaining an additional 7% of burnout variance. This final model included four statistically significant predictors, the most important being dissatisfaction of the need for competence (β = –.41, p < .001), followed by a debilitating stress mindset (β = –.30, p < .05), dissatisfaction of the need for relatedness (β = –.27, p < .05), and perceived overload (β = .27, p < .05).

Variabila	B	*T*	*p*	*R*	R^2	ΔR^2
Model 1				.54	.29	.29
Relatedness	-.54	-3.84	.001			
Model 2				.65	.43	.14

Relatedness	-.47	-3.56	.001			
Competence	-.38	-2.90	.006			
Model 3				.71	.51	.08
Relatedness	-.40	-3.21	.003			
Competence	-.40	-3.24	.003			
Overload	.29	2.36	.024			
Model 4				.76	.58	.07
Relatedness	-.27	-2.00	.044			
Competence	-.41	-3.55	.001			
Overload	.27	2.36	.025			
Stress mindset	-.30	-2.31	.028			

For teachers holding the Second Didactic Degree, the regression analysis generated three models. According to the first model, relatedness need satisfaction was the first variable contributing significantly to burnout, Fchange (1,21) = 37.89, p < .001, accounting for 64% of burnout variance. The second model added autonomy need satisfaction, explaining an additional 15% of variance, Fchange (1,20) = 13.94, p < .001. The third and most comprehensive model explained 85% of burnout variance among teachers holding the Second Didactic Degree and added learning opportunities as a predictor, Fchange (1,19) = 7.13, p < .05. According to this model, burnout among teachers holding the Second Didactic Degree results from dissatisfaction of autonomy (β = –.47, p < .001) and relatedness needs (β = –.33, p < .05), as well as perceiving learning opportunities as excessively demanding (β = .33, p < .05).

Variabila	B	*T*	*p*	*R*	R^2	ΔR^2
Model 1				.80	.64	.64
Relatedness	-.80	-6.16	.001			
Model 2				.89	.79	.15
Relatedness	-.57	-4.72	.001			
Autonomy	-.45	-3.73	.001			
Model 3				.92	.85	.06
Relatedness	-.33	-2.35	.030			
Autonomy	-.47	-4.44	.001			
Learning opportunities	.33	2.67	.015			

For teachers holding the First Didactic Degree, the first regression model identified learning opportunities as the first significant predictor of burnout, Fchange (1,69) = 46.73, p < .001,

accounting for 40% of burnout variance. The second model introduced autonomy need satisfaction, explaining an additional 7% of burnout variance, Fchange (1,68) = 9.07, p < .01. Overall, the second model explained 47% of burnout variance among teachers holding the First Didactic Degree, with the strongest predictor being the perception of excessive learning opportunities (β = .40, p < .001), followed by dissatisfaction of the need for autonomy (β = –.35, p < .01).

Variabila	B	*T*	*p*	*R*	R^2	ΔR^2
Model 1				.64	.40	.40
Learning opportunities	.64	6.84	.001			
Model 2				.69	.47	.07
Learning opportunities	.40	3.45	.001			
Autonomy	-.35	-3.01	.004			

For teachers without qualifications corresponding to their teaching position, the regression analysis generated three models explaining burnout. The first model identified development opportunities as the first significant predictor, Fchange (1,21) = 9.11, p < .01, accounting for 30% of burnout variance. The second model added relatedness need satisfaction, explaining an additional 19% of burnout variance, Fchange (1,20) = 7.47, p < .05. The third model introduced learning opportunities, Fchange (1,19) = 5.41, p < .05, explaining an additional 12% of variance. Thus, among unqualified substitute teachers, the strongest predictor of burnout was the lack of development opportunities (β = –.77, p < .001), followed by dissatisfaction of the need for relatedness (β = –.48, p < .01) and lack of learning opportunities (β = –.46, p < .05).

Variabila	B	*T*	*p*	*R*	R^2	ΔR^2
Model 1				.55	.30	.30
Development opportunities	-.55	-3.02	.007			
Model 2				.70	.49	.19
Development opportunities	-.47	-2.92	.009			
Relatedness	-.44	-2.73	.013			
Model 3				.78	.61	.12
Development opportunities	-.77	-3.96	.001			
Relatedness	-.48	-3.27	.004			
Learning opportunities	-.46	-2.33	.031			

5. Discussion and Conclusions

The results obtained at the level of the entire sample explain the occurrence of teacher burnout through a combination of factors. The resulting model accounts for 51% of the variance in burnout, as a function of a high perception of learning opportunities ($\beta = .33$, $p < .001$), low satisfaction of the need for competence ($\beta = -.26$, $p < .001$), perceived work overload ($\beta = .25$, $p < .001$), a dysfunctional stress mindset ($\beta = -.16$, $p < .01$), and low satisfaction of the need for relatedness ($\beta = -.15$, $p < .05$). This model partially confirms the first hypothesis of the study. The partial confirmation is due to the fact that the need for autonomy and development opportunities do not enter the model structure, while, in the case of learning opportunities, the results contradict international findings, which indicate that a high number of learning opportunities contributes to increased performance (Borko, 2004). Moreover, within the Job Demands-Resources model (Demerouti, Bakker, Nachreiner, & Schaufeli, 2001), learning opportunities are conceptualised as job resources that reduce the impact of job demands. Our findings indicate the opposite pattern. This is particularly noteworthy, as it opens new research directions regarding the professional development process of teachers. Policy analyses conducted in previous research on continuous professional development of teachers in Romania have highlighted that training is often perceived as a bureaucratic requirement within the system. The institutionalisation of professional development as both a right and an obligation in legislation, alongside the requirement to accumulate 90 transferable credits over a five-year period, has contributed to a "credit accumulation culture." In this context, participation in training activities may be perceived as an additional administrative burden, particularly in a context characterised by high workload and an organisational culture oriented towards compliance and credit accumulation. The results support the relevance of Self-Determination Theory (Deci & Ryan, 2000) in explaining the emergence of burnout through the inclusion of competence and relatedness needs in the model, with negative valences. It is

observed that Romanian teachers perceive themselves as less competent and do not feel that they belong to the group of teachers to which they are assigned. Thus, they do not experience a sense of control over their environment nor a sense of developing new skills (Deci & Ryan, 2000), nor do they feel connected to others, belonging to a group, or experiencing close relationships (Deci & Ryan, 2000). These results support the view that teachers' psychological well-being depends not only on reducing job demands, but also on the existence of professional contexts that facilitate social support, professional recognition, and a sense of personal efficacy. Work overload is a significant predictor of burnout, confirming previous research findings (Hakanen, Bakker, & Schaufeli, 2006), which position overload within the category of job demands (Chang, 2009). Teachers who perceive stress predominantly as a debilitating factor report higher levels of burnout. This finding supports the conclusions of Crum, Salovey, and Achor (2013), according to which stress mindset influences how individuals respond to professional demands and their psychological consequences.

With regard to the second hypothesis of the study, the results reveal significant differences between stages of career development. Burnout predictors differ both in structure and intensity across the analysed groups, suggesting the dynamic nature of the phenomenon across the professional trajectory. Among novice teachers, burnout is mainly associated with the perception of learning opportunities as excessive and with work overload. These results may reflect the difficulty of professional integration in a context characterised by multiple demands and high responsibilities from the very beginning of the career. For teachers with teachers with qualified teacher status and second-degree certification, basic psychological needs, particularly competence, autonomy, and relatedness, become central predictors of burnout. In the more advanced stages of the teaching career, dimensions related to professional recognition, autonomy, and belonging to the school community appear to become more relevant than the mere management of job demands. In the case of teachers without relevant formal qualifications for the position, lack of development opportunities represents the main predictor of burnout, suggesting increased vulnerability in this professional category.

The main limitations of the study relate to the research methodology adopted. First, this is a cross-sectional study, which does not allow causal conclusions to be drawn. Second, the snowball sampling technique leads to the underrepresentation of certain populations within the sample, and some sub-samples are considerably smaller than others. Another limitation stems from the operationalisation of career development stages, which was carried out in accordance with the Romanian teacher career management system. Although this approach provides more nuanced results in the national context, it reduces direct comparability with international studies. These limitations do not invalidate the findings; rather, they serve to contextualise the results within a specific framework. The findings highlight the need for differentiated educational policies and support programmes tailored to the professional stages of teachers in Romania.

AI Tools Usage Statement

During the preparation of this manuscript, artificial intelligence tools (ChatGPT, OpenAI) were used exclusively as a support for text revision, clarification of wording, and improvement of academic coherence. These tools were not used for data generation, statistical analysis, or the formulation of research results. All scientific content, data interpretation, and conclusions are solely the responsibility of the author.

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