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(\*) Corresponding author

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## ENHANCING MEASUREMENT SCIENCE EDUCATION THROUGH EMERGING TECHNOLOGIES AND MODERN PEDAGOGIES

**Mare Srbinovska<sup>1\*</sup>**

ORCID: <https://orcid.org/0000-0003-4514-8562>, [mares@feit.ukim.edu.mk](mailto:mares@feit.ukim.edu.mk)

**Marco Faifer<sup>2</sup>**

ORCID: <https://orcid.org/0000-0002-8777-5444>, [marco.faifer@polimi.it](mailto:marco.faifer@polimi.it)

**Milan Dinčić<sup>3</sup>**

ORCID: <https://orcid.org/0000-0001-7508-0277>, [milan.dincic@elfak.ni.ac.rs](mailto:milan.dincic@elfak.ni.ac.rs)

<sup>1</sup>*Ss. Cyril and Methodius University - Skopje, Faculty of Electrical Engineering and Information Technologies – Skopje, North Macedonia*

<sup>2</sup>*Politecnico di Milano, Italy*

<sup>3</sup>*University of Niš, Faculty of Electronic Engineering - Niš, Serbia*

### Abstract

*This study analyzed the current state of Measurement Science education in engineering programs, focusing on curriculum relevance, teaching practices, and integration of modern technologies. A structured survey conducted among students from three European universities revealed that, while students have a solid foundation in traditional measurement principles, their exposure to advanced topics such as Digital Twins, Industry 5.0, artificial intelligence, predictive maintenance, and energy-aware sensing remains limited. The findings also showed that traditional lectures remain effective for theoretical understanding; however, active learning methods, collaborative work, digital tools, and industry engagement are not sufficiently incorporated into the learning process. Students emphasized the need for more hands-on, practice-oriented experiences that better reflect real-world engineering environments. Based on these insights, the study proposes recommendations for curriculum modernization, including the integration of emerging technologies and the wider adoption of student-centered learning approaches to strengthen competencies and improve workforce readiness in engineering fields.*

**Keywords:** *Measurement Science, Digital Twin, Industry 5.0, Artificial Intelligence, Active Learning, Curriculum Innovation, Engineering Education*

## INTRODUCTION

### Background

Measurement Science represents a fundamental discipline within engineering, supporting the development, monitoring, and optimization of complex technical systems across automation, control, energy, industrial production, environmental monitoring, healthcare instrumentation, transportation systems, and intelligent infrastructures. In the context of rapid technological evolution, particularly accelerated through Industry 4.0 and the transition toward Industry 5.0, traditional measurement curricula are no longer sufficient to meet industrial expectations. Modern measurement systems increasingly rely on smart sensors, pervasive connectivity, distributed data acquisition, cyber-physical integration, autonomous operation, computational modeling, edge processing, and intelligent analytical frameworks enabled by artificial intelligence and machine learning (Lee 2015; Roger 2021). As a result, the role of Measurement Science is expanding beyond classical metrology into a multidimensional ecosystem that supports adaptive manufacturing, predictive diagnostics, sustainability tracking, optimization of industrial processes, energy efficiency, and intelligent decision-making.

This transformation requires engineering faculties to adopt flexible instructional architectures that enable rapid adaptation to emerging industrial paradigms and non-linear technological growth cycles. In this context, developing an updated approach to teaching Measurement Science becomes essential to ensure that students are not only consumers of technology but active contributors to innovation within data-driven, intelligent, and autonomous systems.

### Problem Statement

Despite the widespread recognition of these paradigm shifts, educational programs in Measurement Science remain primarily rooted in classical lecture-based delivery and often provide limited exposure to emerging technological concepts and advanced sensing infrastructures (Kamp 2021). Consequently, students may graduate with strong theoretical foundations in measurement principles, instrumentation, uncertainty analysis, and calibration theory, while lacking the practical, interdisciplinary, and technology-augmented competencies expected by contemporary industry. This gap not only affects student learning outcomes but also contributes to long-term skills shortages in high-demand engineering domains such as industrial automation, predictive maintenance engineering, AI-assisted measurement, and digital manufacturing. Without active integration of novel pedagogical models and real-world industrial scenarios, graduates risk being insufficiently prepared to contribute effectively within data-driven industrial ecosystems.

### Objective

This study aimed to assess the current state of Measurement Science education at three European universities and examine how effectively advanced technologies, modern pedagogical approaches, and industry-aligned competencies are integrated into teaching and learning processes. The analysis focused on evaluating student exposure to emergent fields such as Digital Twins, IIoT platforms, Smart Sensor networks, Energy Harvesting methods, Sensor

Fusion, Predictive Maintenance concepts, and AI-enabled measurement pipelines. Furthermore, the study sought to identify how frequently active learning, laboratory-driven experimentation, collaborative learning strategies, and real-world industrial problem-solving opportunities are incorporated into Measurement Science courses.

## **Significance**

A systematic understanding of student perceptions and current curricular gaps can support evidence-based educational redesign in Measurement Science. Improving these programs through relevant technological integration, active learning methodologies, and applied industrial alignment is essential for strengthening engineering workforce readiness and enabling the transition toward data-driven, intelligent industrial ecosystems. The outcomes of this study can support universities in defining strategic curricular transformation priorities, guide course modernization through the introduction of simulation-based platforms, virtual laboratories, and Digital Twin-enabled experimentation, and contribute to the European higher education modernization agenda. In addition, the findings can support policymakers, curriculum developers, and industrial stakeholders in developing coordinated educational innovation initiatives that address the competence requirements of future engineers.

## **LITERATURE REVIEW**

The integration of emerging technologies within engineering education has become a strategic priority for modern higher education systems. Advanced sensing infrastructures, pervasive connectivity, distributed intelligence, predictive analytics, and digital replicas of physical assets significantly modify how measurement systems are designed, monitored, and optimized (Monostori 2014; Roger 2021). Academic programs must therefore evolve to reflect the complexity, interdisciplinarity, and data-centric nature of these new industrial paradigms. Modern engineering practice is increasingly shifting toward full lifecycle measurement ecosystems, where data-driven insight, intelligent calibration, multi-sensor fusion, and system-level autonomy become essential building blocks.

Recent research reports an increasing interest in the adoption of Smart Sensors, IIoT connectivity, edge AI, machine learning algorithms, and data-driven methodologies within engineering curricula (Ramos 2020). However, despite the availability of enabling technologies, practical implementation remains limited, fragmented, or inconsistently integrated across institutions. Traditional measurement laboratory environments continue to dominate, often focusing on static sensor characterization and classical instrumentation setups, while virtual labs, remote measurement environments, cyber-physical demonstrators, and Digital Twin-based learning remain insufficiently adopted (Kamp 2021). Remote and virtual laboratories also represent a key enabling infrastructure for digitally supported measurement education, supporting student experimentation outside traditional physical laboratory constraints and enabling scalable digital practical training environments (Alves, Henriques, and Tavares 2022). The gap between industrial technological readiness and academic adaptation results in a skills mismatch, delaying graduate preparedness and slowing the transfer of technological innovation from academia to industry.

Improving curriculum relevance requires not only updating content, but also redesigning learning architectures that integrate active learning, problem-based learning, team-based projects,

and simulation-driven environments (Lee 2015). Digital Twin pedagogies enable realistic experimentation, risk-free manipulation of parameters, and abstraction of complex physical behaviors without physical constraints (UNESCO 2015). Combining AI-based analytics with measurement datasets enables automated feedback, personalized learning paths, adaptive assessment, and dynamic competency tracking. These tendencies align with European priorities for the digital transformation of higher education, the development of high-skilled engineering talent, and the reinforcement of measurement-based innovation capacity across industry, research laboratories, and sustainable intelligent production systems.

Recent scholarly work also emphasizes that curriculum reform must be guided not only by technological capability but by emerging competency frameworks and comparative educational models. (Hazaveh, Sergeev, and Rawashdeh 2024) demonstrated that undergraduate mechatronics curricula in the U.S. and Germany still insufficiently reflect Industry 4.0 transversal technologies, revealing structural differences between theoretical emphasis and actual industrial skill requirements. This supports the argument that higher education must shift from traditional, hardware-centered measurement instruction toward digitally driven, integrated knowledge architectures. In parallel, advanced industrial research confirms that Digital Twin frameworks are becoming foundational in smart manufacturing, enabling real-time monitoring, performance optimization, and data fusion between computational simulations and physical measurement systems (Soori, Arezoo, and Dastres 2023). Digitalization of education also plays a central role. (Dede and Lidwell 2023) argue that future learning architectures for engineering will increasingly depend on massive digital learning ecosystems, AI-augmented instructional design, and platform-based educational models that scale individualized learning experiences.

Furthermore, Digital Twin methodologies are expanding rapidly beyond manufacturing toward intelligent systems validation, structural health monitoring, predictive maintenance, and cyber-secure operational control. Lai, Yang, He, Pang, Song, and Sun (2023) demonstrated how Digital Twin-based approaches combining measurement data with computational simulation models can significantly enhance structural integrity assessment in aerospace engineering examples, providing direct evidence that Digital Twin measurement integration is no longer theoretical, but practically operationalizable. Future industrial ecosystems will also involve blockchain-enabled trust layers, ensuring data integrity, interoperability, and secure real-time information exchange between decentralized digital twins across supply-chain networks (Roumeliotis et al. 2024). These studies collectively reinforce the need for Measurement Science education to shift toward multidomain integration, preparing students not only to understand how to measure but how to convert measurement into intelligent decision-making, automated control policies, and secure distributed information flows within Industry 4.0 and Industry 5.0 infrastructures.

## **METHODS**

A cross-sectional survey-based study was conducted to evaluate student perceptions, expectations, and learning experiences related to Measurement Science courses in three European higher-education institutions. The primary aim of the study design was to assess the relevance of the course, the effectiveness of existing pedagogical practices, the degree of exposure to emerging industrial and technological concepts, and the perceived alignment of course content with current and future industry needs. In addition to assessing instructional

practices, the study sought to identify the degree to which students felt prepared for advanced learning in Measurement Science and how effectively modern measurement-focused competencies required by Industry 4.0 and Industry 5.0 are integrated within their educational experience.

The participants included students enrolled in Measurement Science courses at Politecnico di Milano (POLIMI), Ss. Cyril and Methodius University in Skopje (UKIM), and the University of Niš (UNI). A total number of respondents participated in the study, with the highest proportion of students originating from POLIMI (58.1%), followed by UKIM (34.5%) and UNI (7.4%), reflecting diverse institutional contexts and different levels of curriculum modernization among the three universities. The sample consisted of 63.7% Bachelor-level students and 36.3% Master-level students, representing both early-stage engineering learners and more advanced academic profiles. Students represented multiple engineering disciplines, including Electrical Engineering (45.6%), Automation Engineering (22.8%), Physics Engineering (12.1%), Computer Science (9.8%), Electronics (4.7%), and Telecommunications (3.3%), ensuring that the results reflect a wide spectrum of engineering areas where measurement concepts are foundational.

A structured online questionnaire was designed and administered, comprising multiple-choice questions, closed-ended Likert-scale items, and perception-based evaluative statements. The questionnaire evaluated students' familiarity with modern measurement-related technologies (e.g., AI-based measurement systems, IIoT architectures, Digital Twins, Smart Sensor networks), perceptions of teaching methods and their effectiveness, levels of engagement and motivation during course activities, the extent and nature of practical/laboratory work exposure, and perceived relevance of curriculum content to the industrial environment and future employment demands.

The survey was implemented simultaneously during the active academic semester across all three universities. Participation was strictly voluntary, and responses were kept anonymous to avoid bias. Students were informed in advance about the research purpose, ethical considerations were respected, and all responses were collected electronically to ensure consistency, transparency, and secure digital archiving of data.

Quantitative data were analyzed using descriptive statistics (percentage frequencies and distribution analysis). Results were processed, grouped, and visualized using bar diagrams and pie charts to clearly illustrate patterns related to institutional representation, disciplinary distribution, familiarity with advanced technological concepts, satisfaction with teaching methodologies, engagement levels, laboratory exposure, and alignment with industry needs. The graphical results supporting the analysis and interpretation of survey outcomes are presented in Figures 1–9.

## **RESULTS**

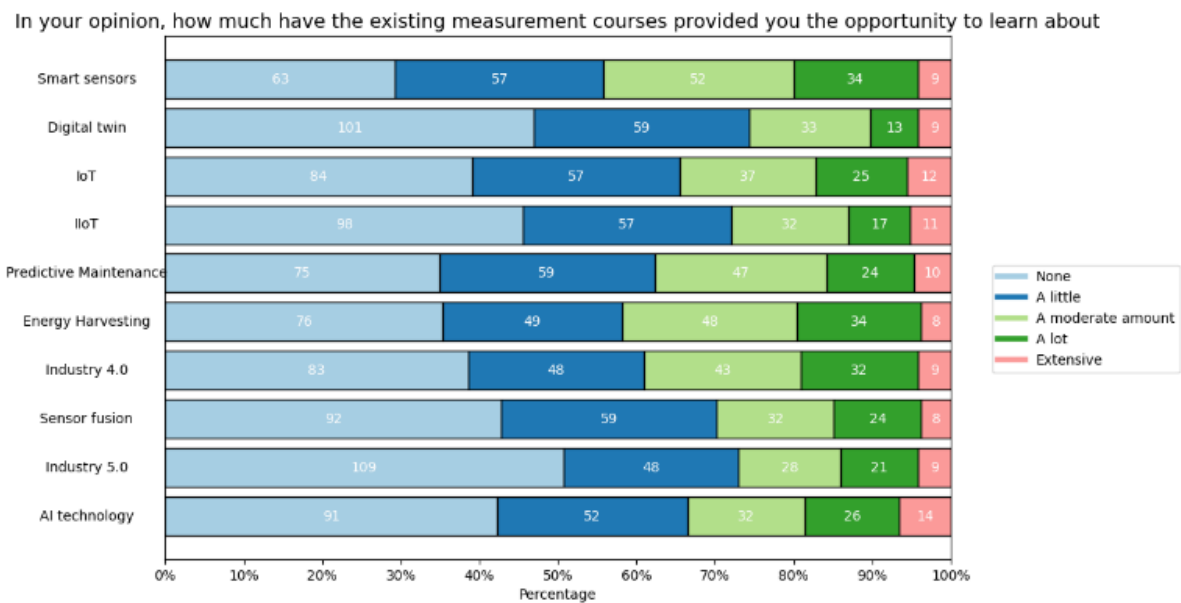
### **Findings**

The analysis of the collected survey data provides comprehensive insights into the current state, strengths, and deficiencies of Measurement Science courses across the three surveyed European universities. The demographic distribution confirms the strong connection between Measurement Science and classical core engineering domains, with the majority of respondents coming from Bachelor-level programs and primarily enrolled in Electrical Engineering and

Automation Engineering-related profiles. This reinforces that the student population directly represents the major workforce pipeline that will later be involved in industrial automation, smart manufacturing, energy monitoring, cyber-physical systems and implementation of Industry 4.0/5.0 concepts in practical environments.

### Learning Opportunities for Cutting-Edge Topics

A critical finding of the study is the insufficient coverage of modern technological concepts in measurement courses. Students reported limited opportunities to engage with advanced topics, including Digital Twins, Smart Sensors, Industrial IoT, Predictive Maintenance, Energy Harvesting, Artificial Intelligence, and Industry 4.0/5.0 concepts (see Figure 1).



**Figure 1: Opportunities provided by Measurement Science courses to learn about cutting-edge topics (Source: Authors' depiction)**

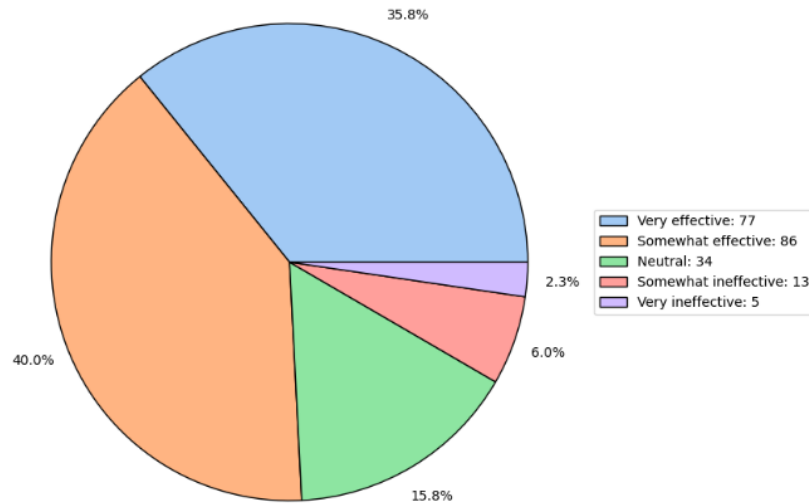
The highest levels of insufficient exposure were reported in Digital Twins (74% reporting none/little exposure), Industry 5.0 (73%), IIoT (72%), and Sensor Fusion (70%). These disciplines are foundational pillars for next-generation engineering systems and the future skill set required by industrial companies. This result highlights a major structural content gap (Fig. 1). The fact that the majority of students still experience measurement curricula primarily through classical concepts underscores the need for accelerated curricular modernization aligned with industrial evolution.

### Effectiveness and Engagement of Teaching Methods

Most respondents (75.8%) believe traditional lectures are very effective (35.8%) or somewhat effective (40%), confirming that lectures remain a valuable baseline teaching methodology in measurement education (see Figure 2). However, the student engagement dimension reveals a weaker picture. Only 25.1% of students reported that the current teaching

methods were very engaging and motivating. In comparison, 42.3% found them only somewhat engaging, and nearly 15% reported that the methods were not engaging or motivating.

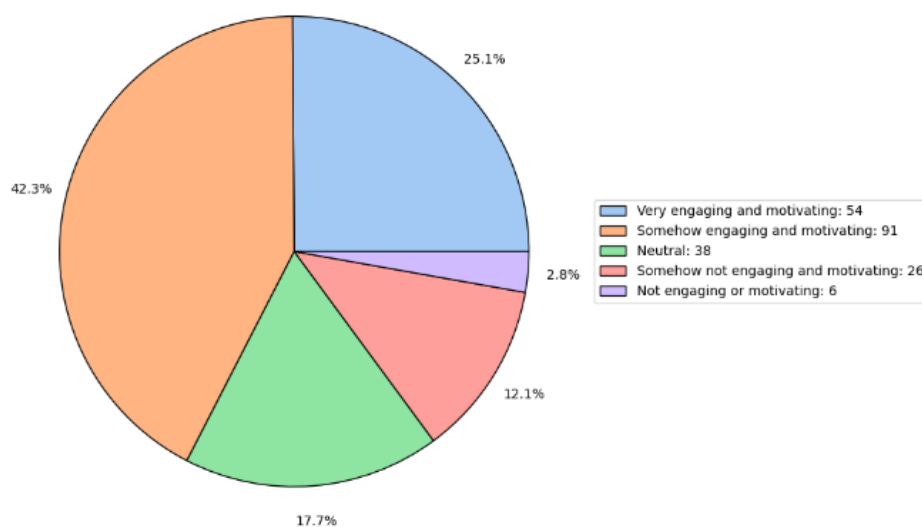
In your opinion, how effective do you find the use of traditional lectures in delivering knowledge?



**Figure 2: Effectiveness of traditional lectures in knowledge delivery (Source: Authors' depiction)**

This inconsistency indicates that although lectures successfully deliver theoretical knowledge, they do not necessarily support high student involvement, attention, or the development of intrinsic motivation (see Figure 3).

In particular, how engaging and motivating are the current teaching methods used in Measurement courses?

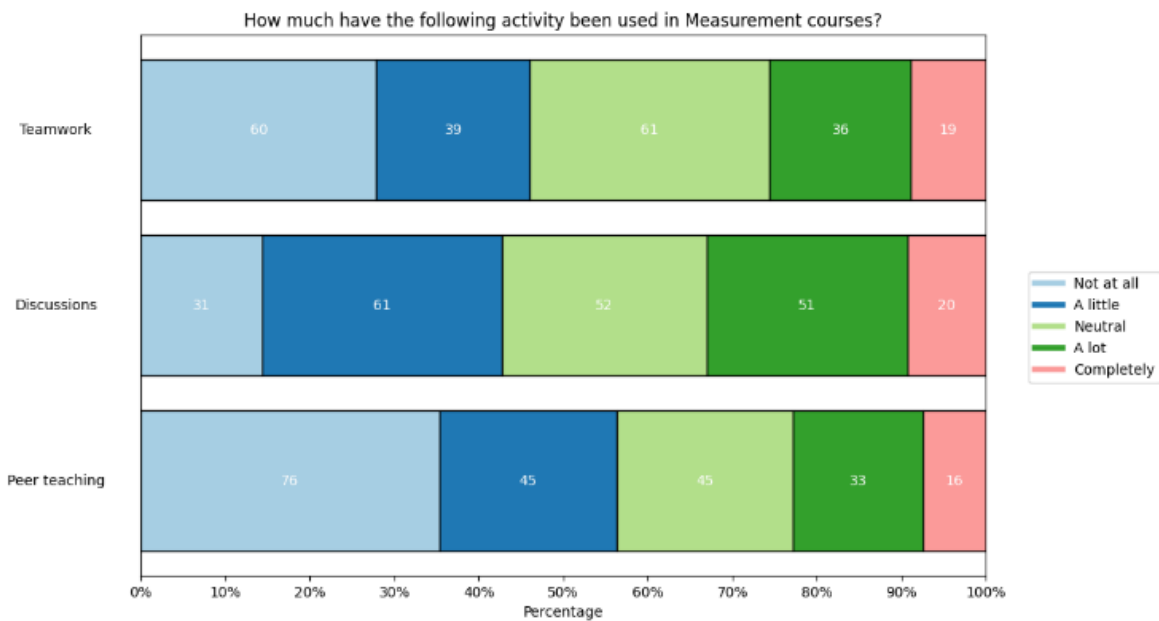


**Figure 3: Engagement and motivation of current teaching methods in Measurement Science courses (Source: Authors' depiction)**

This result strongly suggests that teaching strategies must evolve to include interactive digital platforms, problem-based learning, flipped classroom activities, and integrated AI-supported learning modules, which are already common across many modern STEM education frameworks.

### Active Learning Practices and Hands-On Laboratory Experience

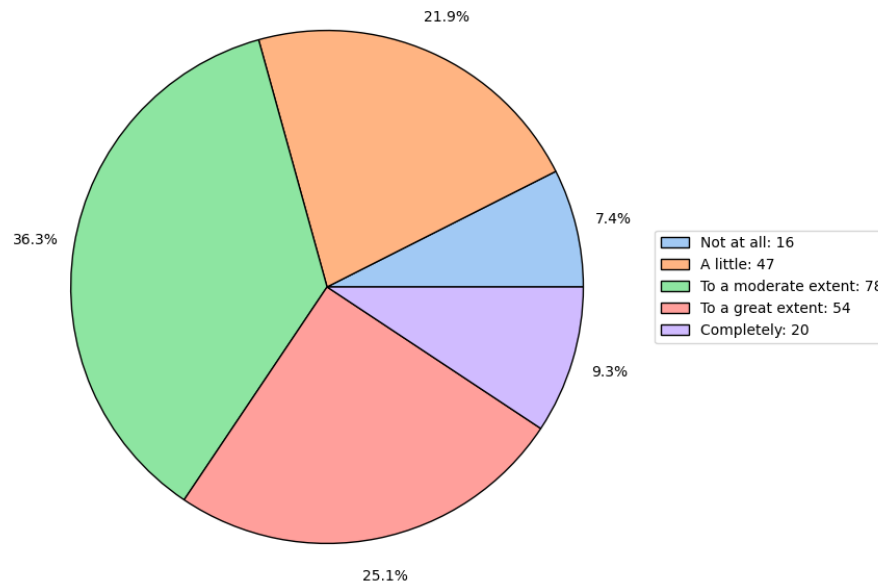
The degree of active learning implemented in measurement courses is limited. Approximately 75% of students indicated that teamwork was either not used, only slightly used, or used neutrally. Similarly, 77% reported low to neutral use of peer-teaching and knowledge-exchange activities. In comparison, 67% reported low or neutral use of discussion-based activities, indicating a lack of a collaborative learning culture (see Figure 4).



**Figure 4: Utilization of teamwork, discussion, and peer-teaching activities in Measurement Science courses (Source: Authors' depiction)**

Collaboration skills are a dominant requirement in modern Industry 4.0/5.0 work environments, particularly in interdisciplinary industrial teams developing embedded systems, cyber-physical systems, next-generation manufacturing diagnostics, and digital twin integration challenges. This gap, therefore, affects not only classroom dynamism but also industrial readiness. The situation regarding practical work exhibits a similar divergence: 36.3% reported practical components present to a moderate extent, 25.1% reported higher exposure, but 29.3% reported minimal or no practical activities. Since measurement courses are traditionally laboratory-driven subjects, the absence of uniform practical exposure may hinder the development of critical operational and metrological competencies that are essential for future engineers working in sensor design, instrument calibration, and measurement data analysis (see Figure 5). These results clearly indicate a need for stronger integration of experiential design and practice-based learning.

To what extent is practical work currently included in your Measurement courses?

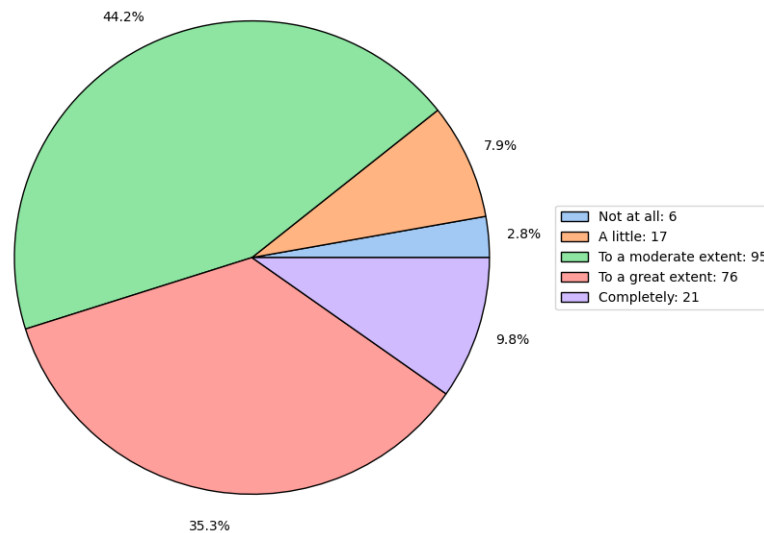


**Figure 5: Inclusion of practical work in Measurement Science courses (Source: Authors' depiction)**

### Sufficiency of Foundational Knowledge for Advanced Measurement Learning

Furthermore, students were asked to assess whether their prior education in measurement-related subjects provided sufficient foundational knowledge to progress to more advanced course content successfully.

Do you believe you acquired sufficient foundational knowledge in the field of Measurement during your prior education to successfully follow advanced courses?



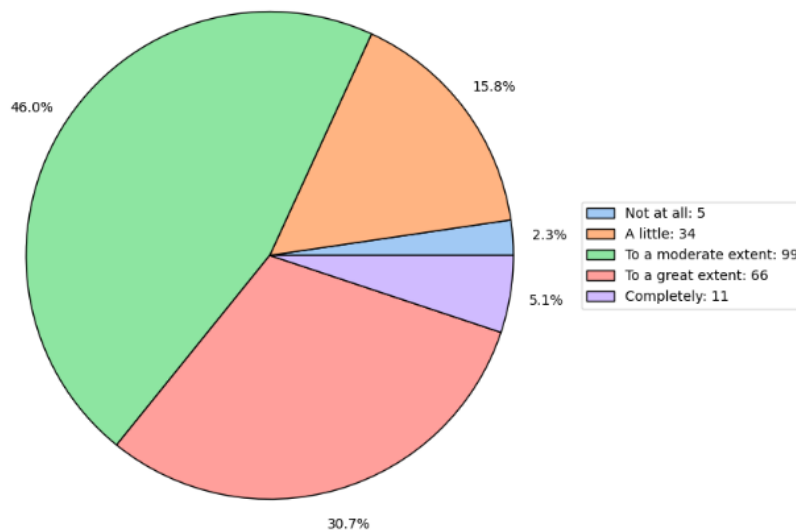
**Figure 6: Sufficiency of foundational knowledge in Measurement Science for advancing to higher-level courses (Source: Authors' depiction)**

The majority of respondents (89.3%) indicated that they possessed at least moderate to complete foundational preparedness, while 10.7% felt insufficiently prepared (see Figure 6). These results suggest that although classical baseline measurement education appears structurally sound, the challenge is not in the coverage of basic concepts but rather in reinforcing higher-level applied skills and deepening exposure to advanced technologies. Strengthening the transition between foundational theory and application-intensive modules could therefore facilitate a more efficient progression toward advanced-level Measurement Science competencies.

### Industry Alignment and Job Market Relevance

When asked how well current measurement curricula reflect industrial needs, 46% believed they match industry requirements to a moderate extent, 30.7% believed they match them to a greater extent, whereas 18.1% reported minimal or no alignment (see Figure 7).

To what extent do you think the Measurement curriculum reflects the needs of the industry and job market?

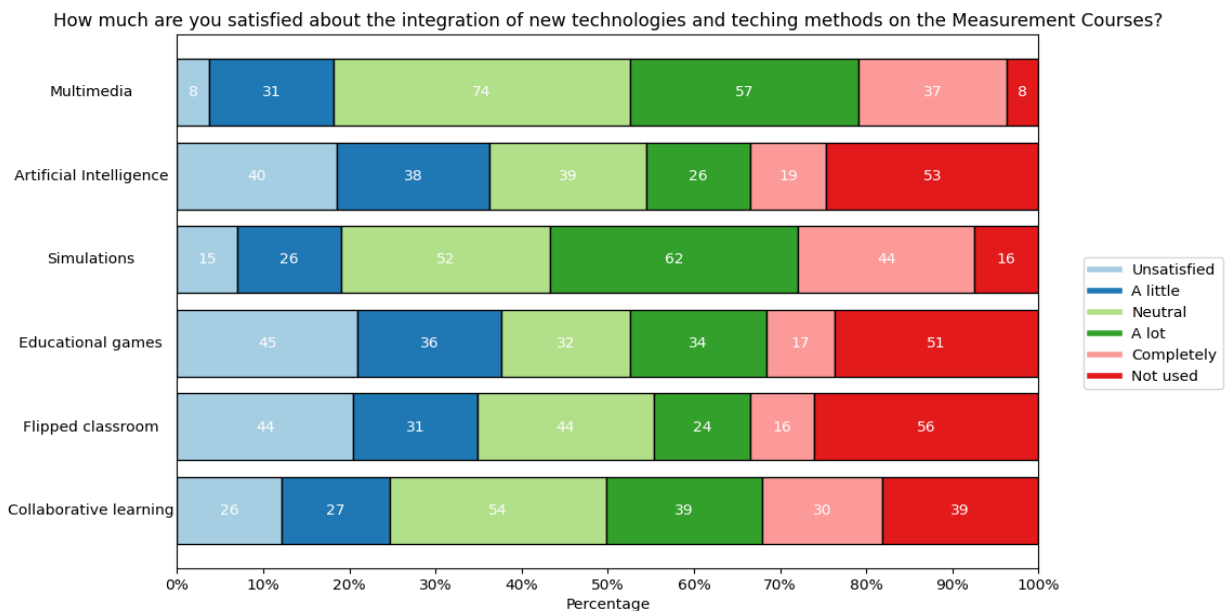


**Figure 7: Alignment of the Measurement Science curriculum with industry and job-market needs (Source: Authors' depiction)**

This demonstrates partial compatibility and confirms that industry-driven enhancements are necessary. In the present European engineering context, rapid transformation toward AI-based industrial systems, autonomous production lines, advanced manufacturing diagnostics, predictive maintenance infrastructures, digital twin implementation, and IIoT devices is already dominant across industrial policy and innovation programs. Therefore, curriculum alignment and direct industrial co-design represent a mandatory direction, not an optional future improvement. Integrating industry guest lectures, simulation-based case studies, real-world industrial measurements, short-term internships, and applied measurement project modules is expected to increase employability-readiness and domain-specific professional competence significantly.

## Integration of New Technologies and Innovative Teaching Approaches

In addition to evaluating traditional methods, students were asked to assess how well new technologies and modern teaching innovations are integrated within Measurement courses. The results show mixed satisfaction levels, with a high percentage of respondents reporting unsatisfied, little satisfied, or neutral satisfaction values for artificial intelligence (54%), flipped classroom methodology (55%), and collaborative learning formats (49%). These results imply that although lecturers remain the dominant methodological structure, there is insufficient adoption of modern educational technology-driven approaches that are increasingly becoming standard in European engineering programs (see Figure 8). Strengthening AI-supported learning environments, constant digital feedback cycles, adaptive learning personalization, and collaborative student-centered classrooms would significantly elevate the effectiveness of teaching practices in this domain.



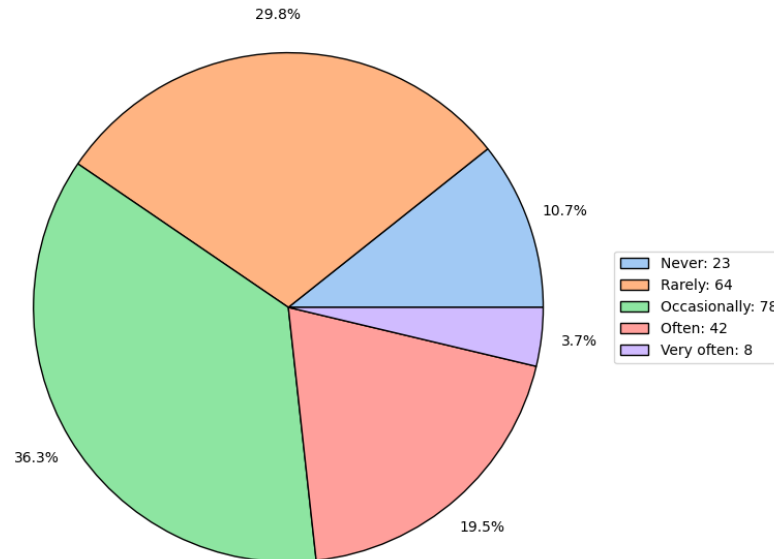
**Figure 8: Satisfaction with the integration of new technologies and teaching methods in measurement courses (Source: Authors' depiction)**

## Real-World Problem-Solving Experience and Application Transfer

Students were also asked about the frequency with which they are given opportunities to solve real-world engineering problems in Measurement courses. Results show that 29.8% reported that such opportunities were rarely provided, 36.3% occasionally, and fewer than 25% experienced these activities often or very often. This low frequency in exposure to real-world measurement scenarios limits students' ability to apply theoretical knowledge to practical industrial contexts (see Figure 9). In rapidly evolving cyber-physical production systems and smart sensing infrastructures, the ability to address authentic measurement challenges is essential for achieving true engineering readiness. Increasing the number of real industrial case studies,

real sensor data processing exercises, and domain-specific project-based learning would significantly improve students' application skills in future professional environments.

How frequently are you given opportunities to solve real-world problems in your Measurement courses?



**Figure 9: Frequency of real-world problem-solving opportunities in measurement courses**  
(Source: Authors' depiction)

### Statistical Significance

As a descriptive survey, no inferential statistics were applied. Percentages and frequency distributions were used to highlight predominant trends and identify areas for curriculum improvement.

## DISCUSSION

The results of this study indicate that while Measurement Science courses are perceived as foundational and generally effective in delivering theoretical knowledge, they do not sufficiently expose students to modern technological concepts required for future industrial environments. Limited engagement, low application of active learning methods, and inconsistent practical work highlight the gap between traditional academic approaches and the competencies required for Industry 4.0 and Industry 5.0 technologies. The insufficient integration of new teaching innovations (e.g., flipped learning, AI-assisted tools) and the limited inclusion of real-world problem-solving tasks further indicate that current curricula are not optimally preparing students for applied engineering contexts.

These findings align with global trends reported in contemporary engineering education research, where theoretical measurement content remains dominant. In contrast, advanced industry-driven innovations, such as cyber-physical systems, intelligent sensors, and digital twin-

based measurement environments, are often introduced late or not at all in bachelor-level coursework. Prior studies emphasize that modern measurement engineering increasingly depends on data-driven reasoning, computational modeling, and AI-supported instrumentation. However, similar to the present results, the literature also shows that many universities still rely heavily on lecture-based knowledge transfer, with slow progress toward student-centered, experiential learning paradigms. This study confirms those theoretical expectations while providing quantitative evidence supporting the need for modernization.

The study is descriptive and based on students' self-perceptions rather than on objective measures of learning performance. The sample, although covering three universities, may not fully represent all European or global measurement programs. Additionally, differences in national educational frameworks, course structures, laboratory facilities, and available equipment could influence students' perceptions and were not controlled in this survey phase.

Future work should examine specific interventions and pilot implementations of modern learning strategies, such as digital twinning laboratories, AI-driven measurement experiment simulation platforms, project-based measurements in real industrial systems, and hybrid virtual-physical labs, and evaluate their impact on measurable learning outcomes and competencies. Comparative longitudinal studies across multiple institutions, including performance-based assessments, industry-based capstone projects, and curriculum co-design with enterprises, would provide a stronger evidence base for curriculum transformation policies in Measurement Science.

## CONCLUSION

The survey results provide an in-depth understanding of students' perceptions of Measurement Science courses, revealing both strengths and areas for improvement. While traditional lectures remain effective and well accepted by the majority of students, there is a clear need for more engaging, technology-enhanced learning approaches. Students consistently emphasized insufficient exposure to modern Industry 4.0 and 5.0 concepts, including Digital Twins, Predictive Maintenance, Sensor Fusion, Energy Harvesting, and IoT, as well as limited opportunities for practical experimentation, active learning, and real-world problem-solving activities. These findings indicate that the existing measurement curricula must evolve to reflect current industrial trends and future engineering workforce needs.

In addition, the modernization of Measurement Science curricula should be aligned with European digital transformation priorities and long-term industrial innovation agendas to ensure the sustainability and scalability of educational reform. By implementing these targeted improvements, universities will not only raise academic performance outcomes but also foster a new generation of engineers capable of contributing to intelligent, automated, and future-ready industrial environments.

To better prepare students for the complexity of modern industrial environments, Measurement Science education should progressively shift toward integrating advanced technologies, digital pedagogies, and applied problem-based experiences. Strengthening collaboration with industry partners, expanding hands-on laboratory activities, and applying AI-assisted adaptive learning methods will significantly enhance both learning outcomes and student readiness. By adopting these improvements, educational institutions can ensure that graduates possess the necessary competencies, innovation capabilities, and practical mindset required to succeed in the rapidly evolving engineering landscape.

### **CRedit AUTHOR STATEMENT**

**Mare Srbinovska:** Supervision; Conceptualization; Writing – Original Draft; Writing – Review & Editing. **Marco Faifer:** Investigation; Methodology; Writing – Original Draft; Writing – Review & Editing. **Milan Dinčić:** Investigation; Methodology; Writing – Original Draft; Writing – Review & Editing.

All authors have read and agreed to the published version of the article.

## **COMPLIANCE WITH ETHICAL STANDARDS**

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### **AI Declaration:**

The authors acknowledge the use of AI tools—specifically ChatGPT-5—to assist in translating and enhancing the clarity and quality of the English language in this manuscript. These AI tools were employed solely for language refinement and were not involved in the conceptualization, analysis, or development of the scientific content. The authors assume full responsibility for the manuscript's originality, accuracy, validity, and integrity.

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All procedures performed in studies involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and the Declaration of Helsinki and its later amendments, or comparable ethical standards.

### **Statement on the Welfare of Animals:**

This article does not contain any studies with animals performed by any authors.

### **Informed Consent:**

Informed consent was obtained from all individual participants included in the study.

### **Disclosure statement:**

No potential conflict of interest was reported by the author/s.

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