MISSION 4
EDUCATION
RESEARCH

PROJECT TITLE: EXTENDABLE - NETWORK OF EXTENDED REALITY-ENABLED LABORATORIES FOR REMOTE PRACTICAL TRAINING

SCIENTIFIC REPORT

TIMEFRAME 01/08/2024 - 30/11/2024

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
Università degli Studi di Napoli Federico II

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NATIONAL RECOVERY AND RESILIENCE PLAN (NRRP) – MISSION 4 COMPONENT 2 INVESTMENT 1.1 – "Fund for the National Research Program and for Projects of National Interest (NRP)"

Project: P2022L2KTA CUP: E53D23014680001

Project Title: EXTENDABLE - network of EXTENDed reAlity-enaBLEd laboratories for remote practical training

Principal Investigator: Prof. Annalisa Liccardo

Timeframe: 01/08/2024 – 30/11/2024

1. SECTION 1 – GENERAL TRENDS OF THE PROJECT

With regard to the specific timeframe, it is below provided:

a) a brief summary of the project;

Practical exercises are crucial in STEM education, providing hands-on experience to reinforce theoretical knowledge. Access to laboratories is vital at all educational levels, but challenges like overcrowded classrooms or movement restrictions during pandemics have highlighted the need for remote solutions. A research team from the University of Naples Federico II, Sannio, and Calabria proposes a network of laboratories utilizing extended reality to enable remote execution of lab activities. This system allows students to conduct experiments from home using real devices, ensuring immersive and responsive interactions. Key tasks include scanning, reconstructing, and functionalizing lab instruments, as well as managing complex operations and communication interfaces to minimize delays. The prototype will initially focus on measuring instruments, a common subject in metrology courses, and set up specific experiments for engineering students at different locations. This initiative aims to validate the system and maintain high-quality practical training, ensuring that students can continue their education effectively, even remotely.

b) names of the operational units involved in the implementation of the project;

Research Unit (RU) University of Naples Federico II – led by the PI, Prof. Annalisa Liccardo

RU University of Calabria – led by Prof. Francesco Lamonaca

RU University of Sannio – led by Prof. Luca de Vito

c) description of the achievement of the objectives connected to the project and related outcomes;

Research activities of the different Research Units in the considered timeframe were mainly focused on the definition and design of the single components both hardware and software of the remotely

accessible laboratory. In particular, research about 3D scanning and reconstruction started in the previous timeframe are now aimed at selecting the most feasible solution to accomplish the tasks. Other tasks involving (i) control proxy, (ii) performance assessment if communication delay, (iii) didactical material, (iv) remote control of reconfigurable circuits and (v) behavior observer started or are in progress in the considered time frame. Final outcomes for the considered activities are expected to be delivered since the next bimester.

d) description of the carried out activities which are in compliance with the *DNSH, Open Access* principles as well as with *gender*, *generationa*l principles and with those of *Equal opportunities*

The project activities of the considered timeframe were mainly related to the definition and design of the different components of the distance learning system associated with the research units. This way, no specific compliance with the DNSH, Open Access principles as well as with gender, generational principles and with those of Equal opportunities has been experienced. Nevertheless, all the objectives in terms of inclusivity and discrimination reduction presented in the project proposal remain.

e) description of the actions aimed at informing and disseminating knowledge

One of the main actions performed in the considered timeframe has involved the update of the website of the project, that can be freely accessed at the link:

extendable.dieti.unina.it

In the homepage, a new image demonstrating the last project achievement has been added.

Furthermore, the dissemination section has been enriched, by inserting the publication list and the news about group meeting and presentation at conference of the project activities.

Further dissemination activities are the following.

Presentation of the project and project results at the VIII Forum delle Misure, San Vincenzo Ligure, 12-14 September 2024. On that occasion a scientific paper on the project activities was presented as described in the following and a poster was prepared and shown to all participants (more than 100 people from all Italy).

Prof. Liccardo, Lamonaca and Spadafora are organizing a Special Session at the 3rd International Conference of IFToMM for SDG (I4SDG2025) (https://www.iftommitaly.it/i4sdg2025/) entitled "Innovative didactic systems and paradigms for STEM" (https://www.iftommitaly.it/i4sdg2025/index.php?id=thematic-invited-tracks). The conference will be held in Reggio Calabria (Italy) the 9-12 june 2025.

Prof. Lamonaca together with Prof. Giuseppe Spadafora and Prof. Teodora Pezzano (University of Calabria) are organizing the seminar entitled "In Class Educational Reflections About the Network of EXTENDed reAlity-enaBLEd laboratories for remote practical training" foreseen for December 17th, 2024, in room 43B2 at University of Calabria. In this seminar, the role of extended reality enabled laboratories in STEM will be analyzed from an educational point of view. Together with the pedagogist professors (Prof. Spadafora and Pezzano) Prof. Lamonaca (professor of electric and electronic measurement) will present to the class an actual laboratorial experience both in presence and remote way. The class will see what is behind the extended reality enabled laboratories, the

technical problems, how to foresee and overcome them from a technical and educational point of view. The comparison of the two modalities will permit the educational reflections with the goal to stimulate questions in the class. The final aim is to provide a comprehensive vision of the opportunities and challenges offered by the extended reality enabled laboratories with the active involvement of the students. In the following the flyer of the event is reported. It is already shared with the student by social media (MS Teams, WhatsApp etc..) and by posters posted on the noticeboards of the University of Calabria

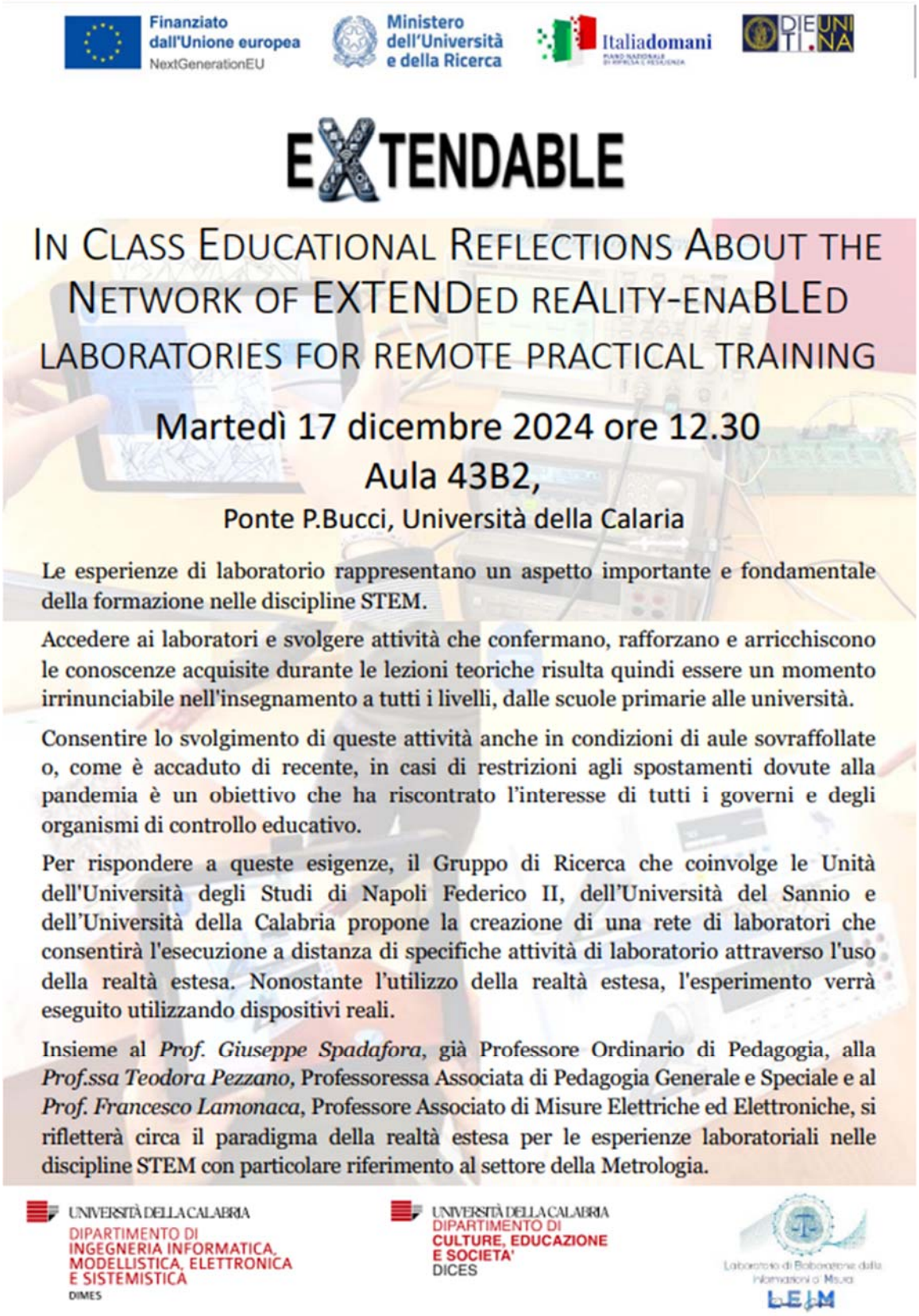
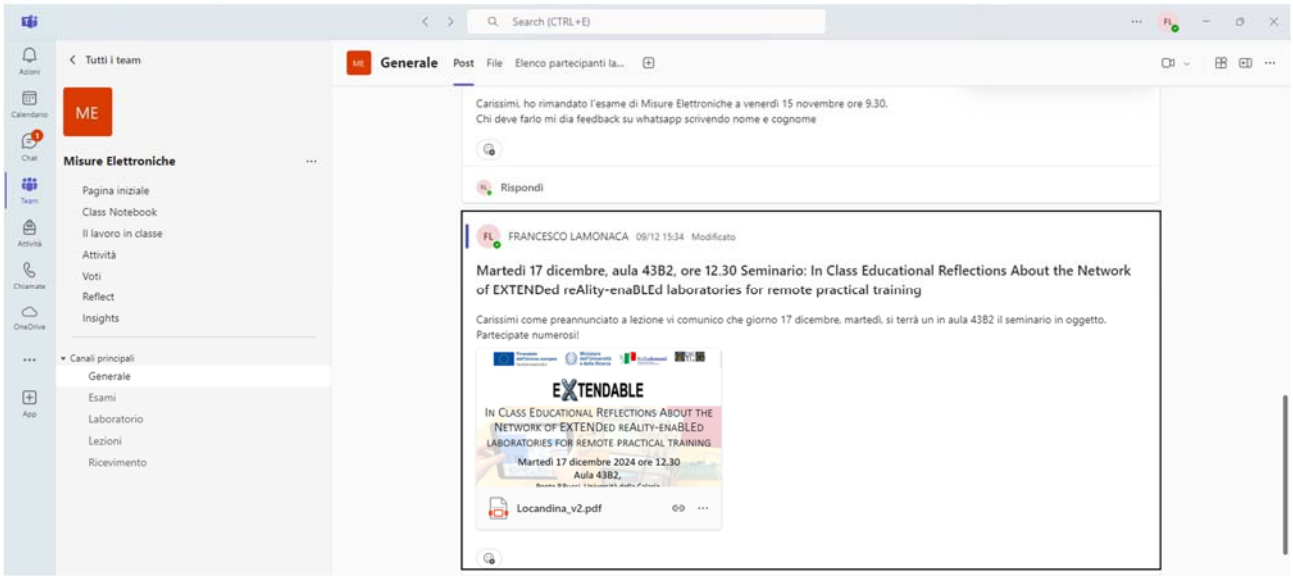


Figure 2. Flyer of the event "In Class Educational Reflections About the Network of EXTENDed reAlity-enaBLEd laboratories for remote practical training".


Search (CTRL+E)
Tutti i team
ME
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Pagina iniziale
Class Notebook
Il lavoro in classe
Attività
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Reflect
Insights
Canali principali
Generale
Esami
Laboratorio
Lezioni
Ricevimento
Generale
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Elenco partecipanti la...
Carissimi, ho rimandato l'esame di Misure Elettroniche a venerdì 15 novembre ore 9.30.
Chi deve farlo mi dia feedback su whatsapp scrivendo nome e cognome
Rispondi
FRANCESCO LAMONACA 09/12 15:34 Modificato
Martedì 17 dicembre, aula 43B2, ore 12.30 Seminario: In Class Educational Reflections About the Network of EXTENDed reAlity-enaBLEd laboratories for remote practical training
Carissimi come preannunciato a lezione vi comunico che giorno 17 dicembre, martedì, si terrà un in aula 43B2 il seminario in oggetto.
Partecipate numerosi!
EXTENDABLE
IN CLASS EDUCATIONAL REFLECTIONS ABOUT THE NETWORK OF EXTENDED REALITY-ENABLED LABORATORIES FOR REMOTE PRACTICAL TRAINING
Martedì 17 dicembre 2024 ore 12.30
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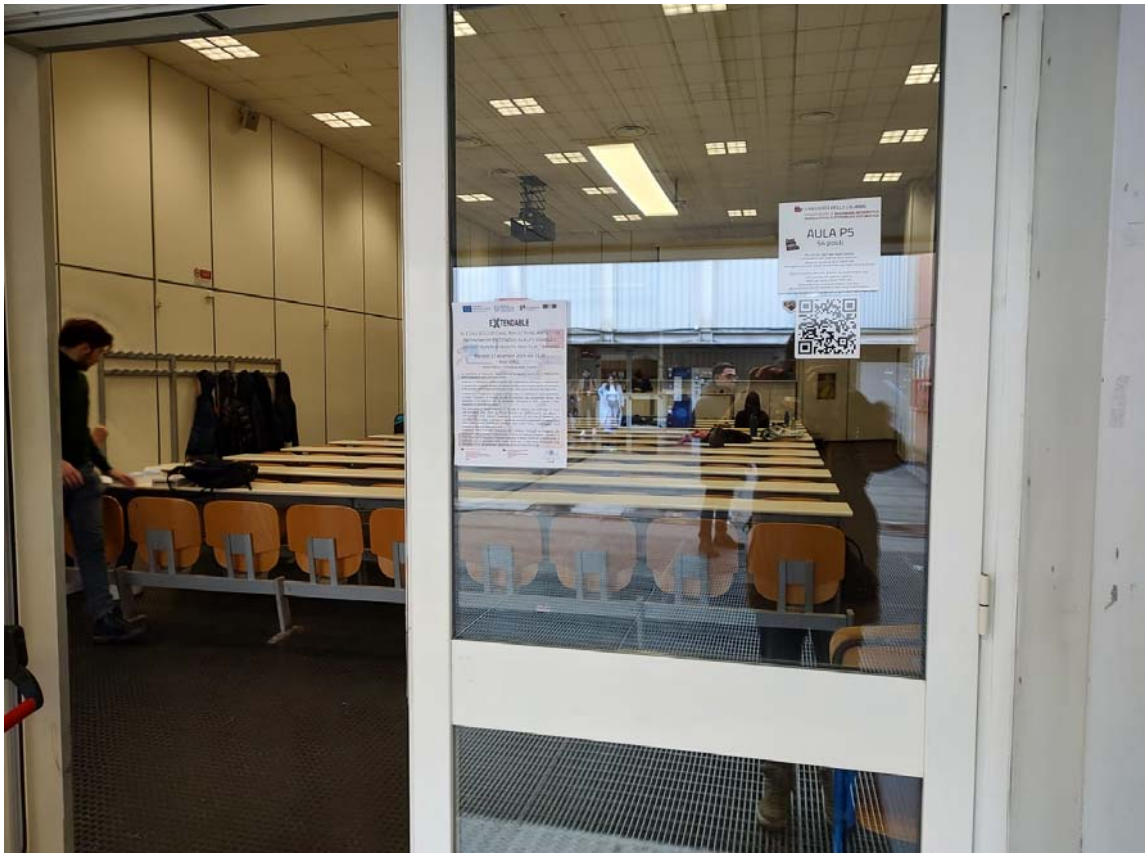
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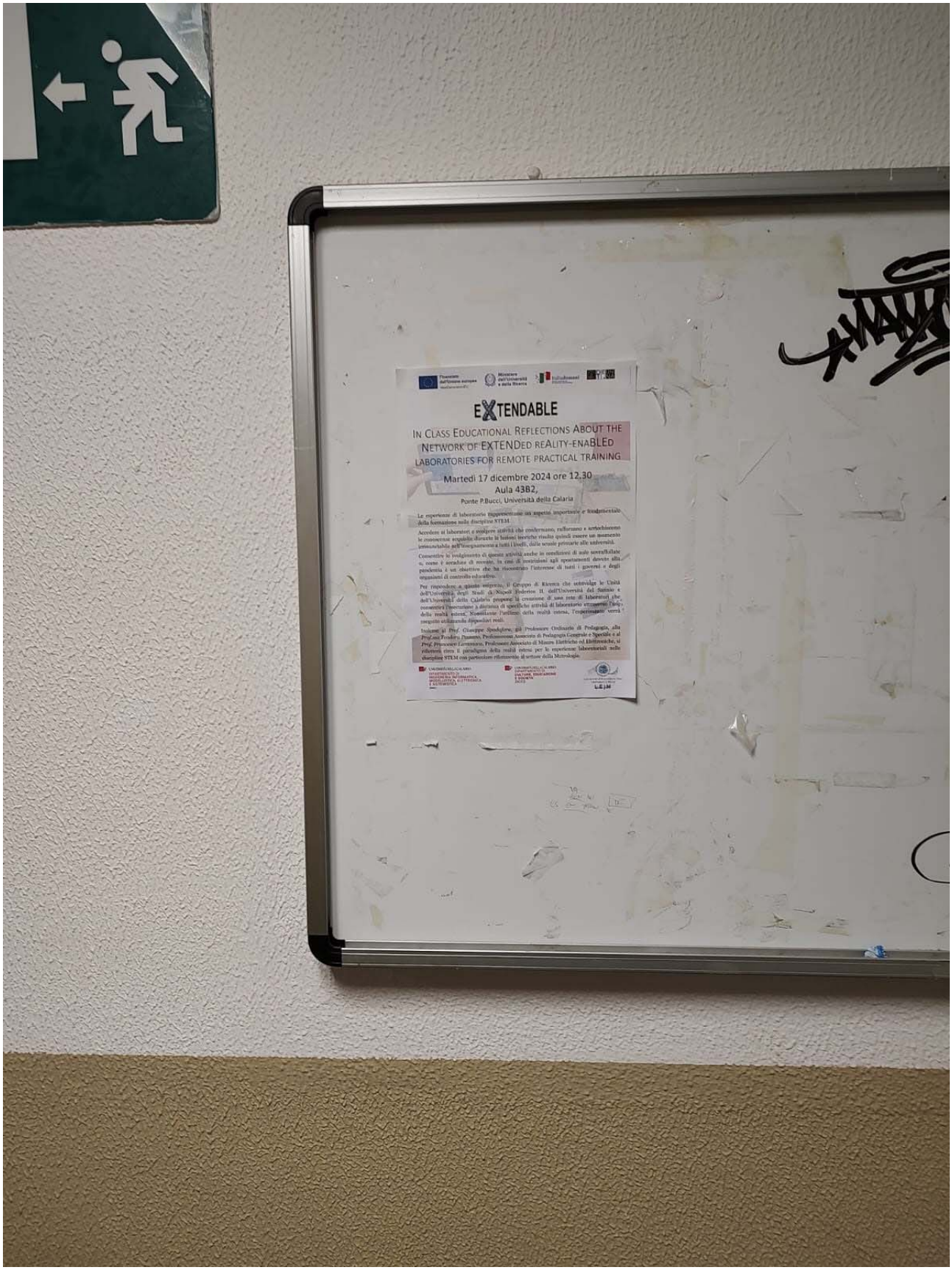
EXTENDABLE
IN CLASS EDUCATIONAL REFLECTIONS ABOUT THE NETWORK OF EXTENDED REALITY-ENABLED LABORATORIES FOR REMOTE PRACTICAL TRAINING
Martedì 17 dicembre 2024 ore 12.30
Aula 43B2,
Ponte P.Bucci, Università della Calabria

Figure3. dissemination of the flyer of the event “In Class Educational Reflections About the Network of EXTENDed reAlity-enaBLEd laboratories for remote practical training” and posters.

AGGIUNGERE ALTRE ATTIVITÀ DI DISSEMINAZIONE SVOLTE (LAMONACA)

Moreover, the following papers, concerning the project activities have been published:

1) *Liccardo A.; De Vito L.; Lamonaca F.; Bonavolontà F.; Carnì D.L.; Daponte P.,”Progetto PRIN PNRR 2022 EXTENDABLE - network of EXTENDed reAlity-enaBLEd Laboratories for Remote Practical Training”, in Italian, VIII Forum Nazionale delle Misure, S.Vincenzo (LI), 12-14 September 2024.*
   The paper mainly aimed at informing Italian researchers in metrology and measurements about the accepted project proposal. The project activities and expected outcomes have been clearly presented also in a dedicated poster session, where the project was met with great interest from the scientific community.

2) *D. L. Carnì, F. de Pandi, F. Lamonaca, A. Liccardo, F. Bonavolontà, “Reconfigurable Measurement setup for laboratory activities in Augmented Reality”, XXIV IMEKO World Congress “Think Metrology”, August 26-29, 2024, Hamburg, Germany*
   The challenge of limited access to laboratory equipment relative to the students is a pervasive

issue across many academic institutions. This limitation can deny practical learning experiences and hinder the understanding of theoretical concepts. Consequently, the development of innovative solutions to address this challenge is crucial for enhancing the quality of university education and Vocational Education and Training (VET).
The approach presented by the researchers in this paper provides an effective solution using an IoT protocol for remote control of laboratory instrumentation and the Device Under Test (DUT). This solution not only addresses the issue of insufficient laboratory equipment availability but also opens new opportunities to enrich students' educational experiences. By enabling direct interaction with instrumentation and the DUT through remote platforms, students can acquire practical skills in a more flexible and accessible manner, without physical space constraints or equipment availability limitations.

2. SECTION 2 – PROGRESS OF ACTIVITIES

With regard to the specific timeframe (bi-monthly/end of project activities), it is below provided:

a) detailed description of activities carried out by each operational unit with a focus on the timeframe for their implementation

According to the presented project GANTT, activities of the RU University of Naples Federico II were mainly mandated to 1) Definition and design of innovative scan and reconstruction methods for 3D modeling of devices and instruments, 2) Definition and design of the control proxy for remote control, and 3) Definition and design of HW/SW solutions for AR-based remote control of reconfigurable circuits.
As for Item 1), current activities are heavily focused on the development of advanced scanning techniques and robust data processing algorithms. Researchers are actively working to improve technologies such as laser scanning and structured light to achieve higher resolution and more detailed 3D data acquisition. These efforts include refining hardware configurations and optimizing scanning workflows to improve efficiency and accuracy. At the same time, significant progress is being made in developing sophisticated algorithms for processing raw data. This includes generating, filtering, and optimizing point clouds to ensure accurate reconstruction of 3D models. These algorithms aim to handle complex geometries and large data sets while minimizing errors and computational overhead.
Regarding Item 2), research unit of Naples is only supporting that of Sannio by providing information and requirements about possible case studies involved in the successive experimental part.
Interesting results have already been achieved in the activities of the item 3) that have been also partially described in the above reference [2]: In particular, the research unit started addressing the challenge of changing dynamically the device under test of a AR-based laboratory experience. Within the augmented reality (AR) application, students can select components from a menu to create and assemble complex circuits according to the specific experiment requirements and adjust parameters using a user-friendly interface. In the physical laboratory, dynamic reconfiguration of the DUT is made possible using a Field Programmable Analog Array (FPAA) device.
It is worth noting that the research unit started also to investigate metaverse-based solutions in order to further improve students' immersiveness and engagement for the remote lab sessions; to this aim, a suitable provision of a metaverse service by the company GAV S.r.l. has been defined, in which students can enter to attend a lecture on the use of the laboratory instrumentation and then operate it themselves.

Regarding the activities at the RU of the University of Calabria, the measurement of the delay introduced by the GPIB-MQTT converter, the solutions for reconfigurable circuits implementation, and the other tasks foreseen in cooperation with the other RU are going on as reported above and after. Moreover, the definition and design of didactic material for AR-based distance learning is ongoing in strict collaboration with the professors of pedagogy, biology and physics. A first testbed is developed for implementing a fundamental laboratory didactic experiment, the "experimental verification of the voltmeter calibration". In this experience the students will learn about the use of power supply, multimeter, analog voltmeter. Will learn what is a measurement instrument class, what means sampling, measurement uncertainty, hysteresis, measurement instruments metrological characteristics, statistical tests such as mean test, data elaboration, critical detection of outliers and how to manage them. Concerning all the problems related to the sustainability of old instrumentation, the use of the webcam will allow the use of an analog voltmeter used as "device under verification". The analog voltmeter represents a unique experience since nowadays all laboratories are equipped with digital instruments less prone to hysteresis and reading errors. So such an experience will be a rare opportunity for students to have a first hand experience about these real problems that are always present in different forms in many practical cases. This experience will be presented to the 3rd year class of the bachelor degree of Electronic Engineering at the University of Calabria during the Event entitled "In Class Educational Reflections About the Network of EXTENDed reAlity-enaBLEd laboratories for remote practical training" above mentioned.

A further case of study concerns the experimental set-up for the characterization of memory shape alloy. This advanced experience is devoted for master class students of bio-engineering, mechanics, physics, electronics.

To perform such testbeds, the external service of installation and maintenance of equipment was needed. The procedure was started and completed in due time with winner the company "Computer Controls S.R.L"

A feedback survey (Fig.4) was designed to acquire information about the perception of students, teachers, and administrative staff about the extended reality-enabled laboratories. The form was disseminated at international level including developing countries. The form is available at https://docs.google.com/forms/d/e/1FAIpQLScjoVXLIgjI9uk7j0nKx-9pDriNclJpKGafpmw3hyQ1dGsmQw/viewform?pli=1

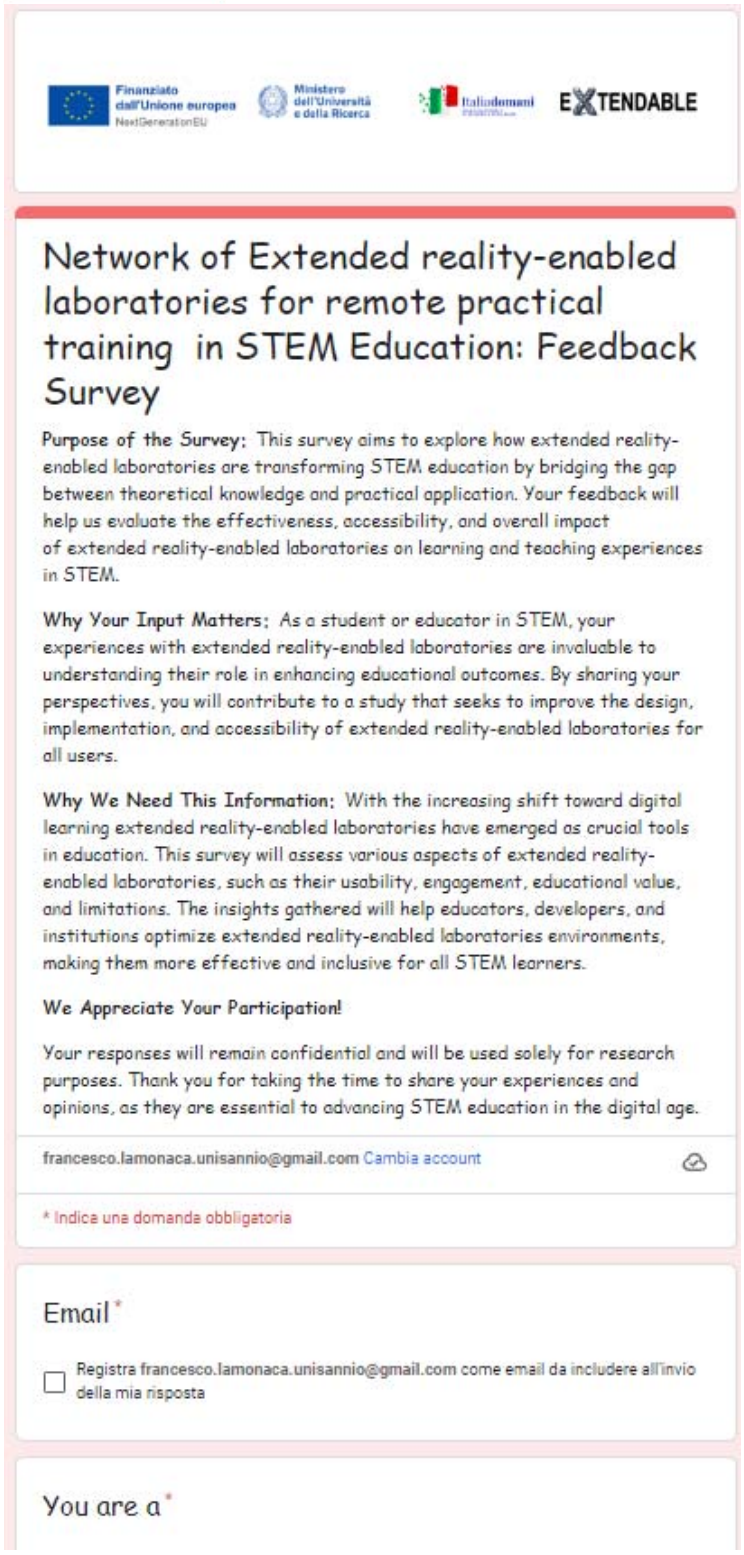

Figure 4. Screenshot of the first page of the feedback survey.

Regarding the activities at the RU of the University of Sannio the evaluation of the Guacamole-lite framework was continued with the aim to design a web application providing access to the laboratory

resources. In particular, a comparison of the Guacamole-lite and the Guacamole java web application have been conducted to verify what is the most suitable solution for the remote laboratory application, according to the features provided by the two frameworks.

Moreover, a preliminary evaluation of the didactical experiences to be provided by the remotely accessible platform was carried out, considering the equipment and connection requirements of the different laboratory experiences provided by the Electronic Measurement group at the University of Sannio.

b) description of potential changes to what has been originally approved mentioning the impacts on the aim of the intervention, on the achievement of intermediate and long- term goals, on the proposed actions for improvement;

As stated above, besides the accepted AR-based solution for distance learning, the project proposal has been enriched with a further improved oriented to a metaverse implementation of the remote laboratory. According to the researchers' best opinion, the new implementation would further improve students' immersiveness and engagement.

c) description of potential challenges encountered and of the proposed actions for improvement;

The research activities carried out during the reporting period did not present any specific challenges requiring further analysis and definition of appropriate solutions.

d) brief description of potential publications.

Publications are expected in the successive bimesters,

A. Liccardo, F. Bonavolontà, F. Lamonaca, D. Luca Carnì, G. Spadafora, E. Bilotta, A. M. Palermo, and A. Monaco, "Remote Control of a Digital Oscilloscope for Use in Distance Learning", 3rd International Conference of IFToMM for SDG, Villa San Giovanni, Calabria, Italy, 09-12 June 2025.

This paper presents the development of a remote laboratory system for distance learning applications, designed to replicate hands-on experiences in a digital environment. The system, based on the "miniverse" concept, allows students to interact with real instruments, such as the Tektronix TDS210 oscilloscope, through a client-server platform. It communicates using the MQTT protocol for reliability and scalability, and uses a GPIB interface supported by an ESP32 card for wireless connectivity. On the software side, the lab uses modern technologies such as Node.js and TypeScript to ensure stability and ease of use. This innovative approach bridges the gap between theory and practice in distance learning, providing an immersive and interactive experience. The system is a scalable solution for improving technical education, expanding its accessibility and quality, and opening new perspectives for science and engineering education.

F. Bonavolontà, A. Monaco, E. Caputo, A. Liccardo, "IM-MetaLAB: The First Digital Laboratory for Teaching the Fundamental Concepts of Instrumentation and Measurement in Metaverse", to be submitted to IEEE Transactions on Instrumentation And Measurement.

The paper will introduce IM-MetaLAB, a pioneering virtual laboratory for teaching foundational concepts in instrumentation and measurement within the metaverse. Addressing limitations of traditional online and remote labs, IM-MetaLAB will offer a fully immersive 3D environment where students interact with digital twins of actual lab instruments, achieving a realistic and dynamic learning experience. By leveraging IoT protocols, specifically MQTT, IM-MetaLAB will synchronize virtual and physical instruments in real-time, allowing students to operate lab devices with high fidelity through VR controllers that replicate real-world actions. The lab will provide flexible access, enabling both synchronous and asynchronous learning, thereby supporting diverse learning schedules and increasing individual time with lab equipment, typically restricted in traditional labs due to limited stations. Beyond instrument interaction, the environment will facilitate group work, social engagement, and collaborative exercises, addressing isolation issues often associated with remote learning. Enhanced learning functionalities, such as wall screens for shared materials and interactive dashboards, will further support hands-on experience and foster critical skills, such as problem-solving and teamwork.

Ihtisham Ul Haq, Abdul Mohiz, Giuseppe Spadafora, Anna Maria Palermo, Eleonora Bilotta, Francesco Lamonaca, "Artificial Intelligence in the Network of Extended reality-enabled laboratories for STEM Education: Current Applications and Future Potential for Adaptive Learning",3rd International Conference of IFToMM for SDG, Villa San Giovanni, Calabria, Italy, 09-12 June 2025.

Artificial Intelligence (AI) integration into the Network of Extended Reality-Enabled Laboratories (NExRL) is a game changer in the field of STEM (Science, Technology, Engineering, and Mathematics) education. This novel and innovative framework utilizes virtual reality (VR), augmented reality (AR) and mixed reality (MR) to create immersive and adaptable environments that enable remote, hands-on experimentation. These laboratories enable inclusive and sustainable learning by overcoming key challenges such as socio-economic limitations, crowded classrooms and mobility restrictions due to the pandemic. AI boost the effectiveness of these networks since it can improve real time interaction, adaptable learning pathways and effective laboratory management. Key applications include dynamic scheduling for laboratory resource allocation, intelligent tutoring systems, behavior observation utilizing digital twins, and AI driven 3D instrument reconstruction. This study explores current uses of AI in the laboratory and its potential to improve STEM education through collaboration, initiative, and rapid feedback to students. The paper also discusses difficulties such as latency, data security and inclusiveness and presents AI driven solutions to these limitations. This overview would stimulate the research in the application of AI in enhancing NExRL laboratories in order to expand access to STEM education, improve learning outcomes, and promote lifelong interdisciplinary learning.

Ihtisham Ul Haq, Abdul Mohiz, Giuseppe Spadafora, Anna Maria Palermo, Eleonora Bilotta, Annalisa Liccardo, Francesco Lamonaca, "The Role of Network of Extended reality-enabled laboratories in Enhancing STEM Education: Bridging Theory and Practice in the Digital

Classroom",3rd International Conference of IFToMM for SDG, Villa San Giovanni, Calabria, Italy, 09-12 June 2025.

Integrating practical training into Science Technology Engineering and Mathematics (STEM) education is critical for bridging the gap between theoretical concepts and real-world applications. Minimal accessibility, high operational expenses, and logistical constraints are some of the recurrent issues that traditional laboratory facilities face, especially in settings with minimal resources. This study evaluates the Network of Extended Reality-Enabled Laboratories (XR-enabled), an innovative system to create scalable, interactive, and immersive educational settings. A regulated survey comprising 200 participants, including academics, administrators, researchers, and students, assessed XR-ENABLED labs concerning many aspects of STEM education. Although technology accessibility and collaborative learning suggest areas for improvement, ANOVA analysis revealed significant variations in perspectives across positions, hence underscoring benefits such as enhanced engagement, conceptual understanding, and motivation. The findings highlight the need for more research on long-term benefits, cost-effectiveness, and improvements in accessibility, demonstrating the transformative potential of XR-ENABLED laboratories in enhancing the inclusivity, flexibility, and practicality of STEM education

Francesco Felicetti , Elio Matteo Curcio, Stefano Rodinò , Luigi D'Alfonso , Emanuele Sgambitterra, Carmine Maletta, Carbone Giuseppe, Domenico Luca Carnì, Annalisa Liccardo, Giuseppe Spadafora, and Francesco Lamonaca, "Extended Laboratory for Biomedical Applications: Development and Validation of an Automated NiTiNol Thermo-Electro-Mechanical Characterization System", 3rd International Conference of IFToMM for SDG, Villa San Giovanni, Calabria, Italy, 09-12 June 2025.

Practical exercises are vital in STEM education, reinforcing theoretical knowledge through hands-on activities. Access to labs is crucial from primary schools to universities, even in crowded classrooms or during movement restrictions like pandemics. To meet these challenges, a research team from the Universities of Naples Federico II, Sannio, and Calabria proposes a network of labs enabling remote experiments via extended reality. Students or workers can perform real-device experiments from home at any time, ensuring access to critical training despite physical constraints. Each experiment is unique to an individual or group, preserving authenticity and quality. This paper presents the development of an automated measurement system designed to simultaneously measure and correlate the thermal, electrical, and mechanical properties of NiTiNol specimens. The importance of this didactical experience is highlighted by the increasing implementation of NiTiNol-based actuators in biomedical applications. In the immersive experience guaranteed by the proposal, the students will be able to acquire a comprehensive understanding of the NiTiNol complex thermo-electro-mechanical behavior.

3. SECTION 3 – COMMON INDICATORS

Below the updates on the indicator RRFCI 8 – "*Number of researchers who work in research centres which are recipients of financial support (women; men; non-binary)*" – as per the description in the guidelines included in the n.34 MEF notification from the 17th of October 2022.

Common indicators (University of Naples)	*Planned value*	*Implemented value*
Researchers who work in research centers which are recipients of financial support (women)	0,19	0,16
Researchers who work in research centers which are recipients of financial support (men)	0	0
Researchers who work in research centers which are recipients of financial support (non-binary)	0	0

Common indicators (University of Calabria)	*Planned value*	*Implemented value*
Researchers who work in research centers which are recipients of financial support (women)	0,033	0,05
Researchers who work in research centers which are recipients of financial support (men)	0,393	0,68
Researchers who work in research centers which are recipients of financial support (non-binary)	0	0

Common indicators (University of Sannio)	*Planned value*	*Implemented value*
Researchers who work in research centers which are recipients of financial support (women)	0	0
Researchers who work in research centers which are recipients of financial support (men)	0,324	0,336
Researchers who work in research centers which are recipients of financial support (non-binary)	0	0

4. SECTION 4 – PREDICTIVE ANALYSIS AND FINAL COMMENTS

Below it is provided a description of the forecast scenario on the development of the project, any potential change which is deemed necessary for the future as well as comments on the document.

1) Predictive analysis

Research activities of WP2 started in the previous four months are currently in progress during reporting period accordingly to the original Gantt. Stemming from the analysis of the state-of-the-art achieved in Q1 and Q2, the research units are defining and developing suitable solutions to fulfill the project objectives. No specific drawbacks or challenges are expected to be experienced in the

successive months.

2) Final comments

Operational units are carrying out their activities according to the predicted timelines. At the moment, no specific concerns have been highlighted. Activities more related to active research started in the last four-month period, according to the project schedule.

Principal Investigator

(digital signature)

Firmato digitalmente da
Annalisa Liccardo
CN = Liccardo Annalisa
O = Università degli Studi di Napoli Federico II
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5. SECTION 5 – ATTACHMENT

The below documents are also attached to the technical – scientific report:

Att.1 – Declaration of compliance with DNSH principle and compliance with other principles as per the Environment code;