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Sustainable nuclear education and training in Europe and beyond – Examples of the ENEN2plus, TOURR and GRE@T-PIONEeR projects

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Abstract. Maintaining education at an advanced level open at European universities has been a major challenge during the past 10–15 years. The aftermaths of the Fukushima accident and phasing out of nuclear power in some countries resulted in a decreasing student enrolment at universities in nuclear science and engineering. Although providing courses at the BSc and MSc level remained possible in some cases, offering more advanced and specialized courses was made difficult, due to too few students such courses typically attract at a given university. In response to the alarming situation, different initiatives at the European levels were undertaken. These initiatives were designed to foster collaboration among various European universities with the purpose of complementing each other's expertise, course offering, and access to facilities. Also, more flexible ways of providing education were implemented, so that the offered courses could attract enough students. This was made possible thanks to the use of online educational techniques, allowing to share students and teachers between courses. Finally, actions were undertaken to make nuclear science and engineering more visible and attractive. In this paper, examples from the ENEN2plus, TOURR and GRE@T-PIONEeR projects are reported.

1 Introduction

The European Nuclear Education Network – ENEN is an international organization established in 2003 with the aim of supporting the development of expertise in the nuclear field by higher education and training with support from its Members and Partner organizations [1–3]. ENEN develops strong partnerships to bring a European or global impact of initiatives in the nuclear field. Either if we are speaking of broad actions such as the ENEN2plus project, pin-pointed actions such as the GRE@T-PIONEeR (reactor physics) project or improving utilization of research reactors such as the TOURR project, we are committed in supporting relevant educational ideas and those dedicated to promote them.

The ENEN2plus project is designed to build in-house actions for attracting people to nuclear, providing necessary courses for career development, providing career opportunities events, providing lifelong learning and VET actions, and supporting the whole nuclear environment. More at: https://enen.eu/index.php/portfolio/enen2plus-project/

The TOURR project aims to assess the status of nuclear research reactors in Europe, their research-oriented usability and also the use of Research Reactors for production of medical radioisotopes.

The ENEN2plus (ENEN#) project represents the most comprehensive and integrated effort in nuclear education and training (E&T) to date in Europe. It aims to address the critical need for a skilled workforce to support the operation, development, and decommissioning of nuclear facilities. The major goal is to attract new talent to the nuclear field and provide advanced development opportunities through multidisciplinary, multicultural, and cross-disciplinary initiatives.

Key objectives of ENEN2plus include mapping the supply and demand of nuclear human resources across various sectors – industry, academia, regulators, and technical safety organizations. It emphasizes fostering interest in nuclear careers through targeted activities for students, postgraduates, lifelong learners, and even high school pupils. The project also features a robust mobility program, facilitating over 100 person-years of

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career-enhancing experiences for approximately 1000 participants, supported by a budget of e 2.5 million.

ENEN2plus supports cross-border and cross-disciplinary mobility within the EU and with global partners such as the USA, China, Korea, and Japan. It also seeks to create a centralized platform for educational, training, and job opportunities, complementing efforts to improve access to research infrastructure. Career fairs, competitions, and other outreach initiatives are integral to its strategy, aiming to secure a pipeline of nuclear professionals for the future.

The project highlights the need for nuclear E&T to maintain safe and efficient operation of existing facilities and the development of advanced technologies. By collaborating with international and European institutions, ENEN2plus is poised to strengthen nuclear education and ensure the industry's sustainability in the long-term [4–6].

The TOURR project, "Towards Optimized Use of Research Reactors in Europe", is a EURATOM-funded initiative addressing the challenges faced by Europe's aging and declining fleet of research reactors (RRs). These reactors are critical for applications such as nuclear energy research, material testing, and the production of medical radioisotopes essential for diagnostics and treatments. The project responds to financial pressures, aging infrastructure, and the absence of a cohesive strategy for their sustainable use. More at: https://tourr-platform.eu/.

TOURR's primary goal is to develop a comprehensive strategy for the efficient and sustainable use of European RRs, ensuring their continued contribution to the European Research Area. Key objectives include assessing the current status of the reactor fleet, identifying future needs such as new neutron sources, proposing upgrades, and raising awareness about their critical role among policymakers and the public.

Specific project outputs include:

1. a detailed inventory of existing RRs, their applications, and capacities.
2. Gap analyses in technological, medical, and educational applications.
3. Development of tools and strategies for optimizing reactor utilization, refurbishment, and resource allocation.
4. An online platform for coordinating RR use and disseminating findings.

The TOURR consortium involves nine partners, including six reactor operators, working collaboratively on strategies to enhance reactor efficiency, address supply-chain vulnerabilities, and maintain a steady supply of medical isotopes. This effort supports Europe's competitiveness in nuclear research and its socio-economic contributions, particularly in health and innovation [7–9].

GRE@T-PIONEeR is a project aimed at developing a specialized education in reactor physics and nuclear reactor safety for PhD and postdoc students, for nuclear engineers, and taken as advanced courses for MSc students. The education encompasses both theory and hands-on training exercises, the latter heavily relying on the use of research/training reactors and of computer-based modelling environments. The aim is the students are able to perform nuclear reactor safety simulations understanding all the approximations on which such simulations rely. This is considered essential knowledge in the education of highly skilled nuclear safety analysts. The project has been running since November 1st, 2020, and for a duration of four years, with a Horizon 2020 financing (through the 2019–2020 European Union's Euratom research and training programme). A financing recently obtained from the Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten – SSM) will allow offering the courses during the period 2025–2028. More info about the project is available on the project website https://great-pioneer.eu.

The paper presents the approaches and results obtained by the ENEN2plus, TOURR and GRE@T-PIONEeR EC funded projects in terms of development of qualified Human Resource for the nuclear field.

2 Collaboration rather than competition

2.1 Complementarity of expertise

The ENEN2plus project leverages the complementarity of its 50-member consortium, consisting of diverse institutions with extensive expertise across nuclear fields, to achieve its ambitious goals. These partners include universities, research centers, industry stakeholders, technical safety organizations, and international collaborators. Together, they provide the breadth and depth required to enhance nuclear education and training (E&T) in Europe.

Comprehensive expertise utilization: the consortium members bring expertise across various domains which represent also the main focus areas for which the mobility funding is used and the mobilities can be obtained for. These areas are: nuclear engineering, radiation protection, waste management and disposal, medical applications, radio chemistry, safety culture, nuclear materials and safeguards. This diversity enables the ENEN2plus project to cover a wide spectrum of nuclear E&T needs for students, PhDs and researchers. For example, medical radioisotope production experts can collaborate with radiation safety professionals to develop interdisciplinary training programs.

Tailored human resource analysis: by combining knowledge from industry, academia, and regulators, the consortium will analyse gaps and critical resources in nuclear human resources (HR). This analysis will guide the development of strategies to meet EU needs in both power and non-power nuclear applications, supporting sectors such as energy transition, medical technology, and research.

Building on past success: ENEN2plus builds on the achievements of previous projects such as ENEN+, ANNETTE, and CINCH. These initiatives have established frameworks for E&T, mobility programs, and vocational training. The consortium will refine and expand these frameworks, ensuring that the lessons learned are applied effectively.

Mobility and networking programs: mobility programs, supported by the consortium's global network, will allow over 1,000 learners to gain international experience. Collaboration with organizations such as the IAEA, OECD/NEA, and institutions in the USA, Japan, and China ensures a global perspective, enriching the educational experience.

Vocational training programs (VET): the consortium emphasizes developing sustainable VET programs, crucial for preparing specific professionals, such as decommissioning specialists and reactor operators. These programs are supported by analyses of existing offers and the creation of dedicated VET communities.

Outreach and attractiveness: the consortium members will jointly organize career fairs, competitions, webinars, and events to attract new talent. These efforts aim to inspire students and professionals from diverse backgrounds, highlighting the dynamic and impactful nature of nuclear careers. Up to date, as regards the mobility program which is dedicated to the whole nuclear community, it proved to be very attractive both for scientists/researchers and for organizers of Education and Training courses. The number of researchers requesting support for the mobility exceeds the initially estimated numbers proving the impact the project had on the nuclear community. In the same time, ENEN2plus supports the other projects developed in the framework of the EURATOM program (but does not limit to it) with respect to education and training actions.

The ENEN2plus project's collaborative structure ensures a robust response to Europe's nuclear HR needs. By integrating the unique strengths of its members, it addresses challenges holistically, ensuring the development of a skilled, mobile, and diverse workforce ready to support Europe's nuclear ambitions in energy, research, and non-power applications.

In GRE@T-PIONEeR, 18 university teachers from eight different universities located in six different countries work together to develop a set of complementary courses, most courses making use of several teachers each bringing their own expertise. The participating universities are: Chalmers University of Technology – CHALMERS (Sweden – coordinator), Ecole Polytechnique Fédérale de Lausanne – EPFL (Switzerland), Technical University of Munich – TUM (Germany), Technical University of Dresden – TUD (Germany), Budapest University of Technology and Economics – BME (Hungary), Politecnico di Torino – POLITO (Italy), Universidad Politécnica de Madrid – UPM (Spain) and Universitat Politècnica de València – UPV (Spain). Nine courses were developed as part of the project:

- course "Nuclear cross-sections for neutron transport" (worth 3 ECTS – European Credit and Transfer System). This course focuses on the whole range of activities in the "nuclear data life cycle". This course covers all steps in nuclear cross-section handling, starting from cross-section measurements to cross-section validation and final use in nuclear reactor calculations.
- Course "Neutron transport at the fuel cell and assembly levels" (worth 3 ECTS). This course focuses on the study of the transport of neutrons at the fuel cell and assembly levels, to provide useful information for the next steps of reactor physics analysis, such as full core simulation in steady-state and transient conditions.
- Course "Core modelling for core design" (worth 3 ECTS). This course aims to enable students to master the methods used for the neutron transport modelling at the core level in steady-state conditions using Monte Carlo and deterministic methods.
- Course "Core modelling for transients" (worth 3 ECTS). This course deals with the modelling of nuclear reactors in transient conditions, focusing on the modelling of neutron transport, heat transfer, fluid dynamics, fuel thermo-mechanics, and their interdependencies.
- Course "Reactor transients, nuclear safety and uncertainty and sensitivity analysis" (worth 3 ECTS). This course aims at giving the participants a full and comprehensive overview of: (a) the principles of nuclear reactor safety and system behaviour from the point of view of nuclear safety, and (b) the principles of uncertainty and sensitivity analysis applied to nuclear reactor simulations and their importance in the evaluation of the simulations' results.
- Course "Radiation protection in nuclear environment" (worth 3 ECTS). This course aims to modernize the radiation protection briefing obligatory for any student or trainee entering a nuclear installation, couple radiation protection and health physics with the particle transport calculation tools and methods touched upon in other GRE@T-PIONEeR courses and present the specificities of shielding and dose rate calculations.
- Three series of hands-on exercises on the AKR-2 training reactor (4.5 ECTS), on the CROCUS training reactor (2 ECTS) and on the BME training reactor (4 ECTS course). The sets of measurements offered as part of the hands-on exercises on the training reactors complement the topics of the six courses delivered by the project and allow the application of the acquired knowledge in practice. Besides learning and experiencing fundamental principles of reactor physics, the aim is to compare measurements and simulations and demonstrate the importance of modelling details and achievable accuracy.

The overall philosophy of the courses is to guide nuclear engineers/safety analysists in the different steps of nuclear reactor physics modelling and experiments, starting from nuclear cross-sections to the study of complex reactor transients. Table 1 also demonstrates the complementarity of the teachers for the various courses. As seen in this Table, all courses, except the course "Nuclear cross-sections for neutron transport", make use of several teachers complementing each other's expertise. For the course "Nuclear cross-sections for neutron transport", several guest lecturers external to the consortium intervene throughout the course.

Table 1. GRE@T-PIONEeR partners core expertise in relation to the given courses.

Partners	Nuclear cross-sections for neutron transport	Neutron transport at the fuel cell and assembly levels	Core modelling for core design	Core modelling for transients	Reactor transients, nuclear safety and uncertainty and sensitivity analysis	Radiation protection in nuclear environment	Hands-on exercises on the training reactors
CHALMERS		■	■	■	■		
EPFL				■			■
TUM					■	■	
TUD				■			■
BME		■	■			■	■
POLITO		■		■			
UPM	■		■	■			
UPV			■	■			

2.2 Complementarity of facilities

The TOURR project emphasizes leveraging the diverse status-quo of European research reactors (RRs) to achieve optimized utilization and enhanced cooperation. Europe hosts a wide array of RRs serving distinct purposes, from low-power critical assemblies for core testing to high-performance reactors used for neutron beam experiments. These reactors are not merely neutron sources; they play a vital role in medical radioisotope production, neutron transmutation doping of silicon, non-destructive examinations, neutron activation analysis, and advanced research in materials science. TOURR aimed at establishing a coordinated strategy to optimize the use of these reactors for sustainable research, education, and industrial needs.

The complementarity of these facilities is a key of TOURR's objectives. The RRs in Europe address a broad range of scientific and technological needs: basic research, medical applications, materials testing, education and training, and zero-power core physics testing. Medical applications include radioisotope research and beam therapies, while materials testing reactors contribute to nuclear component and fuel research. The available reactors can also facilitate the use of neutron energies such as cold, thermal, hot, or fast, expanding their utility. Despite their different designs and uses, these reactors are linked by their capability to provide neutron sources, making them indispensable for numerous applications.

A major challenge faced by Europe is the aging RR fleet. Many RRs are 30 to 50 years old but have been well-maintained and upgraded. Nevertheless, some facilities have closed due to financial constraints, such as R2 in Sweden and OSIRIS at CEA-Saclay, France. This reduction has led to a significant gap in neutron availability. Although newer RRs such as the Heinz Maier-Leibnitz neutron source, Germany, and the upcoming Jules Horowitz reactor, France, aim to fill this void, they cannot fully compensate for the growing demand. TOURR's role is essential in evaluating current and future needs, optimizing capacities, and planning new infrastructure development.

TOURR also integrates education and training (E&T) as a central pillar of its strategy. The RRs serve as crucial infrastructure for E&T in nuclear technologies, providing hands-on experiences for students, trainees, and professionals. Training reactors allow for close supervision during experiments, fostering a deep understanding of reactor physics, safety, radiation protection, and waste management. These training opportunities are essential for developing future experts in the nuclear field, helping to maintain a steady stream of skilled personnel competent in operating both research and power reactors. This is increasingly important as suitable training facilities diminish, requiring a coordinated approach to ensure broader access.

The TOURR project's strategy is underpinned by a comprehensive assessment of existing facilities, including their capabilities and accessibility. This inventory forms the basis of a coordinated approach to maximize efficient use of RRs for experimental, educational, and production purposes. This project has developed an online tool (https://tourr-platform.eu/) consolidating information on reactor availability, free capacities, and communication interfaces to facilitate interaction between users and reactor operators. This ensures reactor capacities are aligned with the needs of the European research community, promoting sustainable and efficient use of these scarce resources.

In summary, the complementarity of Europe's RRs, as leveraged by the TOURR project, ensures that the continent can meet its current and future needs for neutron sources. By promoting coordination, optimizing reactor use, and enhancing access for research, education, and medical applications, TOURR lays the foundation for a sustainable and innovative European Research Area. The coordinated utilization of these RRs addresses scientific and technological challenges and strengthens Europe's capabilities in nuclear research and development, contributing to societal growth and technological advancement.

3 Visibility and attractivity

3.1 Changing the mindset of youngsters

The ENEN2plus project of Euratom aims to inspire young people towards the nuclear sector through engaging educational experiences. It organizes events such as summer schools and competitions to promote learning and collaboration. Notable activities include the 3rd European Nuclear Competition and Summer School for Secondary

Schools held in Hungary in July 2023, and the 4th edition for BSc and MSc students in Slovakia in July 2024. Upcoming events include a BSc and MSc Summer School in 2025 at BME, Hungary, and a Summer School for Secondary Schools in Italy in July 2025. These initiatives are part of ENEN2plus mission to provide training, career opportunities, and mobility support for students across Europe, helping to develop the next generation of nuclear professionals.

ENEN2plus emphasizes fostering interest in nuclear science by targeting students early in their education. By engaging secondary school, BSc, and MSc students, ENEN2plus bridges the gap between theory and practice, sparking interest in nuclear energy and its role in sustainable development and energy security. This project encourages young people to view nuclear energy as a viable and exciting career path, contributing to the broader goal of a sustainable energy future.

Beyond technical knowledge, ENEN2plus events focus on building networks among young nuclear professionals across Europe, fostering teamwork, problem-solving, and communication skills. The project also provides practical training opportunities across Euratom projects, helping students gain hands-on experience in nuclear research and operations. This approach ensures a well-prepared workforce to meet the nuclear industry's evolving needs and supports the long-term sustainability of the sector.

3.2 Central repository approach

ENEN was involved during its existence in several Education and Training projects. Majority of these projects if not all chose to have a dedicated webpage where the results and actions were promoted. After a while, ENEN found out that it was quite difficult for the nuclear community to recall a specific project title and to assimilate that title with a specific nuclear topic or course. In this regard, ENEN decided to have a more systematic and integrated approach and created a dedicated webpage for each project it partnered with. This webpage was hosted on the main ENEN website: https://enen.eu/ Later on, we observed that the community became more demanding and, at the same time, noticed the benefits of having a centralized approach. As a follow-up, we have developed a separate webpage where ENEN members could issue courses on various thematics, could allow people to register to those education and training actions, and would also allow the action initiator to retrieve some statistics about the attendants (https://nuclear-education.eu/). This was called "Educational HUB" and it was developed under the ENEN2plus project.

Previously, the TOURR platform had a similar approach with the Research Reactors where it created a platform (https://tourr-platform.eu/) where the reactor operators could plan the use of their facility together with the researchers for a better use of the existing resources and facilities. The platform is still maintained and used. It also created a RR facilities listing for a faster update with the researchers. The database provided info also about the person in charge and allowed (logged in) users to get in contact with the respective person.

The platform represents a good information tool for Education and Training purposes especially for PhDs and researchers where they can find relevant information about the experiments a facility is able to perform. Some of the facilities chose to share also the isotopes they have or able to accommodate. The platform allows also planning for use of the facility, offering this possibility so that an operator and a PhD/researcher can find anytime the workload/availability of a facility for performing experiments. The platform developed within the project allows a secure connection between PhDs/researchers and Research Reactor operators where they can also do direct planning of the scientific visits and the experimental sessions.

3.3 Use of modern communication channels

The ENEN2plus project represents an ambitious effort in nuclear education and training (E&T), addressing the demand for a highly skilled and motivated workforce capable of navigating the complexities of nuclear power and non-power technologies. Modern communication channels are essential for achieving the project's overarching goals: attracting top talent, fostering excellence through education and training, and enabling collaboration across disciplines, cultures, and borders.

Engaging diverse audiences with targeted outreach.
Modern communication channels, in particular social media, enables ENEN2plus to effectively target its diverse stakeholders, ranging from high school students to established professionals in the nuclear field. Different means are used depending on the target groups, as described hereafter:

- High School Students and Teachers: to attract young talents, the project uses visually engaging and educational content on platforms like Instagram and YouTube (soon TikTok could be included). Campaigns showcasing nuclear science experiments, career paths, and competitions can spark interest. Teachers can be reached through webinars and other teaching materials or courses available online via the hub.
- University Students, Postdocs, and Professionals: LinkedIn posts and groups serve as ideal platforms for promoting scholarships, internships, and career-related events. Additionally, alumni testimonials and stories shared via these channels can inspire current participants and strengthen their connection to the project.
- Global Stakeholders and Partners: Newsletters, blogs, and virtual networking events can keep international organizations, regulators, and industry partners informed of ENEN2plus' milestones, fostering collaboration across continents.

Enhancing cross-cultural and cross-disciplinary collaboration

Given ENEN2plus' focus on mobility and multidisciplinary approaches, modern tools are pivotal for bridging geographic and cultural divides:

- Virtual Collaboration Tools: platforms such as Microsoft Teams and Zoom allow seamless interaction between participants in cross-border and cross-disciplinary projects, fostering participation and involvement in initiatives despite physical distances.
- Centralized "Nuclear-Education" Hub: a robust, user-friendly platform can provide a single source for educational opportunities, training programs and job openings, ensuring accessibility and inclusivity for participants worldwide.

Promoting mobility and career-enhancing opportunities.

The ENEN2plus mobility program, supporting over 100 person-years of experience for 1000 learners, requires strategic communication to ensure its full potential is realized:

- Interactive Portals: an interactive, well-designed website (or in the future an app) enables participants to explore and apply for mobility opportunities, track progress, and connect with peers and mentors.
- Social Media Campaigns: a good feature to include in our communication strategy could be highlighting success stories of those benefiting from the mobility program. Sharing testimonials tends to motivate others to participate and showcase the program's impact on personal and professional growth.

Advancing awareness of vocational training and research.

The HUB, as a centralized platform can serve as a repository of all vocational training programs developed during the project. Accessible through desktop and mobile devices, this platform can feature:

- a searchable database of training courses, certifications, and workshops.
- Information on complementary projects and research infrastructure access, promoting synergy across initiatives.
- User-friendly interfaces for learners and trainers to interact, share resources, and provide feedback.

Inspiring excellence through events and competitions.

Dedicated events and competitions for high school pupils, students, and professionals can be amplified through modern communication channels. Livestreaming, event hashtags, and interactive polls can enhance virtual participation, while post-event summaries shared through newsletters or posts on social media or the website ensure wider outreach.

Data-driven insights and impact measurement.

Modern communication tools equipped with analytics capabilities allow ENEN2plus to measure the effectiveness of its outreach. Metrics such as social media engagement, website visits, webinar attendance, and participant feedback through Google forms can guide the refinement of strategies, ensuring that the project's goals are met efficiently.

Modern communication channels are indispensable to the ENEN2plus project, facilitating attraction, education, and mobility while fostering international collaboration. Through tailored outreach, centralized platforms, and effective storytelling, ENEN2plus can achieve its mission of equipping a new generation of nuclear specialists with the skills and knowledge to excel in complex, multicultural, and multidisciplinary environments. By embracing these tools, ENEN2plus ensures that its legacy is not only impactful but enduring.

Making course offerings known to the relevant stakeholders is one of the biggest challenges encountered by most consortia. In the case of GRE@T-PIONEeR for instance, several communication channels were developed, maintained and used. Those included:

- a website, presenting general information about the project, the various courses and the pedagogical approach followed in each course. As of September 2024, the website was visited 42883 times, with a total number of 764 website visitors.
- Advertising videos developed for each course and widely used on social media to promote course registration. Due to the nature of communication on social media, the videos were short promotional videos of professional standard. In addition, some examples of recorded video lectures used in the various courses were also put on the website, to give a flavour of the technical content and quality of the courses to prospective course applicants. A total of 24 videos were created, counting a total of over 2960 views, with 124 views in average per video.
- Social media channels, which were created for the general public (using Twitter/X) and for a more professional audience (using LinkedIn). Those channels were heavily used to inform the community about course registration, status of the project, as well as cross-project and cross-partner collaboration. As of September 2024, the LinkedIn account had 1282 followers, and the Twitter account had 176 followers, which adds to a total of 1458 followers.
- Newsletters, issued to the newsletter subscribers three times during the course of the project. Also, four dedicated "Save-the-date" and "Workshop reminder" newsletters were released to promote specific workshops. As of September 2024, the project had a total of 136 subscribers.
- Participation to events/meetings, to report on the status of the project, to make the various stakeholders aware of the project and to attract possible applicants to the courses. As of September 2024, the project has been represented at 20 events.
- Networking with other educational initiatives and with various organizations (such as the European Nuclear Society – ENS, the Sustainable Nuclear Energy Technology Platform – SNETP, the International Atomic Energy Agency – IAEA, the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development – OECD/NEA). Also, having the European Nuclear Education Network (ENEN) as part of the GRE@T-PIONEeR consortium was instrumental.

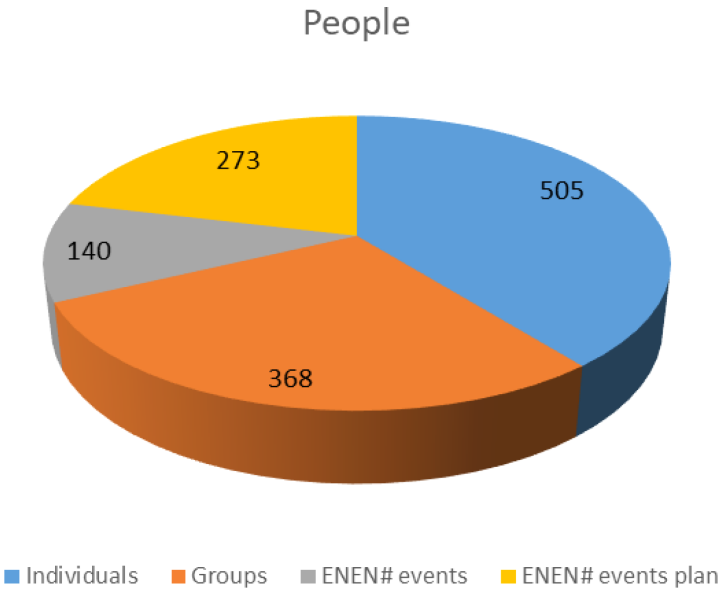

Fig. 1. Status of the mobility support through the ENEN2plus program on November 2024.

Finally, the project had an Advisory Board and an End-User's Group, made of several organizations from the nuclear industry.

During the duration of the project, the most efficient communication channels were through the digital presence of the project and networking activities. The digital presence was mostly achieved through social media communication, used to later canalize interested parties to the project website, the videos available on the website, and finally course registration. The LinkedIn channel has been particularly efficient, with a number of followers far exceeding expectations.

3.4 Mobility

Mobility is an important tool to increase a person's competence, to build networks of educated people, and professionals and to support the nuclear industry regardless of physical borders. Mobility was promoted in ENEN since its creation with specific actions such as the European Master of Science in Nuclear Engineering (EMSNE) certification which started 19 years ago. Several other projects developed support for mobility of people (students, researchers, lecturers). The ENEN2plus project is the biggest mobility program up-to-date with a 2.5M*e* program dedicated to the whole nuclear community (regardless the respective person and institution is a project member or not). The target was to support 1.000 people with 100 person-years of mobility in 4 years. The project is planned to come to an end in June 2026. As it can be seen in Figure 1, in November 2024, ENEN2plus supported 1.005 persons.

4 Sustainability in teaching/learning

Different teaching set-ups and learning behaviours emerged during the last decade, such as online teaching/learning, hybrid teaching/learning and flipping. Whereas the two first categories allow to offer some flexibility in teaching/learning, the last set-up concentrates on the efficacy of learning, as described hereafter. Also, the sustainability aspects of those set-ups are discussed below.

4.1 Online teaching/learning

Online teaching/learning often refers to the delivery of teaching materials occurring exclusively on the web due to a physical separation between the teachers and the students (and sometimes between the students themselves). Several variations exist. The students can entirely learn at their own pace by studying learning resources prepared for that purpose without immediate support from the teachers or without any support at all from the teachers. The students can also participate to online sessions during which they directly interact with the teachers. Or a combination of both can be implemented. Due to the timing between when the teaching resources are delivered/received and the possible interactions between the teachers and learners occur, the first variation is often called asynchronous learning, whereas the second variation is called synchronous learning.

The main advantage of online teaching/learning is the possibility to offer courses anywhere to anyone, and, in case of asynchronous learning, at any time. As a consequence, the running costs of such courses can be very low. Combined with the ease of accessibility, those courses are very well suited for a sustainable deployment, as they do not require the students/teachers to travel to the same physical location. Those courses thus represent a possibility to provide education on a large scale across borders. The main difficulty of this teaching set-up is to maintain student engagement, as a pure online set-up often results in large drop-out rates.

4.2 Hybrid teaching/learning

Hybrid teaching/learning, on the other hand, represents a combination of teaching activities occurring online and onsite. This could either be students first having to study some materials entirely online, followed by some onsite face-to-face activities with the teachers, or vice-versa. Or this could be two different cohorts of students attending the same teaching sessions with the teachers: one cohort of students attending the activities onsite, combined with a cohort of students attending the same session online.

The second alternative is particularly attractive from a sustainability point of view, as it allows offering interactive synchronous sessions to remote students, who most likely would never have had the possibility to attend such sessions onsite (due to financial reasons or other obligations preventing onsite travel). The main challenge of this

second alternative is to offer the same learning environment to all students, irrespective of the nature of their presence (onsite or online).

4.3 Flipping for guaranteeing learning

Flipping is a pedagogical method capitalizing on asynchronous self-paced online activities. During this phase, students acquire knowledge and get prepared for more involved activities thereafter offered in a synchronous fashion [10]. The asynchronous phase is typically arranged onsite. This pedagogical format was demonstrated to result in better student engagement and performance. This is explained by the use of active learning techniques during the synchronous phase, during which students apply the knowledge they acquire during the asynchronous phase on specific activities [11]. In GRE@T-PIONEeR, the set-up was modified by organizing the synchronous sessions simultaneously onsite and online. For each of the GRE@T-PIONEeR courses, students are given four weeks to complete the necessary asynchronous work, followed by the synchronous sessions typically arranged on five consecutive days, alternatively ten consecutive days (with a weekend in between). The synchronous sessions were offered at one of the following locations: Universitat Politècnica de València (Spain), Chalmers University of Technology (Sweden), Budapest University of Technology and Economics (Hungary), Ecole Polytechnique Fédérale de Lausanne (Switzerland) and Technical University of Dresden (Germany).

The asynchronous phase consists of (a) reading a set of handbooks specifically written for the courses, (b) watch some short summarizing video lectures aimed at capturing the main concepts presented in the handbooks, (c) answer some quizzes associated to each of the video lectures, and (d) put questions on and participate to a forum discussing the technical aspects of the courses.

The synchronous phase consists of (a) short summarizing lectures intertwined with (b) quizzes/discussions/Q&A's with or without prior group discussions, and (c) more advanced hands-on activities that the students need to work on. Those more advanced activities heavily rely on the use of computer simulation tools and/or the use of training reactors. For the computer simulation tools, three main types of activities having different objectives are given: (a) implementing nuclear reactor modelling techniques introduced in the other course elements via coding/programming assignments, (b) checking the proper understanding of key concepts via small computer-assisted assignments, and (c) checking the proper use of third-party nuclear simulation software against some reference solutions. The activities on the training reactors include the planning, execution, and analysis of measurement campaigns on the reactors. The entire learning sequence the students are exposed is presented in Figure 2.

This project has been extremely successful and has had a major impact on nuclear education and training, not only in Europe, but also beyond. The GRE@T-PIONEeR courses were offered during the academic year 2022/2023 and 2023/2024. During those two years:

- 851 participants from all continents applied for the courses.
- 716 participants were accepted to participate and granted access to the courses.
- Out of those, 450 participants joined the synchronous sessions, either onsite or online.
- Out of those, 411 participants were issued certificates of successful completion (all activities – both asynchronous and synchronous – were graded, and only participants obtaining a total score of least 50% of the maximum score were issued a certificate).

An in-depth analysis of student engagement/participation, performance and satisfaction is reported in [12], demonstrating the efficacy of the teaching methods and the adequacy of the set-up to both the online and hybrid audiences.

As earlier explained, hybrid teaching offers a flexibility allowing students from any part of the world to join the courses. Combined with flipping, the GRE@T-PIONEeR courses were accessible to many and resulted in efficient learning. This was demonstrated by the issuance of course certificates of successful completion.

4.4 Cross-border community of students/teachers

The European Nuclear Education Network (ENEN) enforces international collaboration by building cross-border communities within various nuclear education initiatives. One key example is the ENEN2plus project, which actively engages young nuclear professionals through workshops and competitions, as highlighted by the collaboration among EFOMP, IRPA, FuseNet and ENS. The initiative focuses on cross-sectional cooperation to integrate nuclear disciplines such as medical physics, radiation protection and nuclear fusion which involves students from diverse countries in competitions and summer schools that strengthen both technical knowledge and social networks.

The Nucleation Community is another community established by the ENEN2plus project, which also plays an important role in building such cross-border connections, serving as a vibrant platform for educators, researchers and students in the nuclear field across Europe. The Nucleation initiative aims to enhance cooperation in nuclear education through innovative approaches and collective experiences shared among member organizations of the Nucleation Community. This platform supports collaborative learning and research by providing opportunities for members to engage in projects, workshops, and internships across borders, thereby cultivating a cohesive nuclear education ecosystem in Europe.

The Alumni Network of the EC INSC Project MC3.01/20, related to training and tutoring (T&T) activities, is another vital example of enhancing cross-border collaboration. In building this alumni network, emphasis was placed on facilitating not just professional

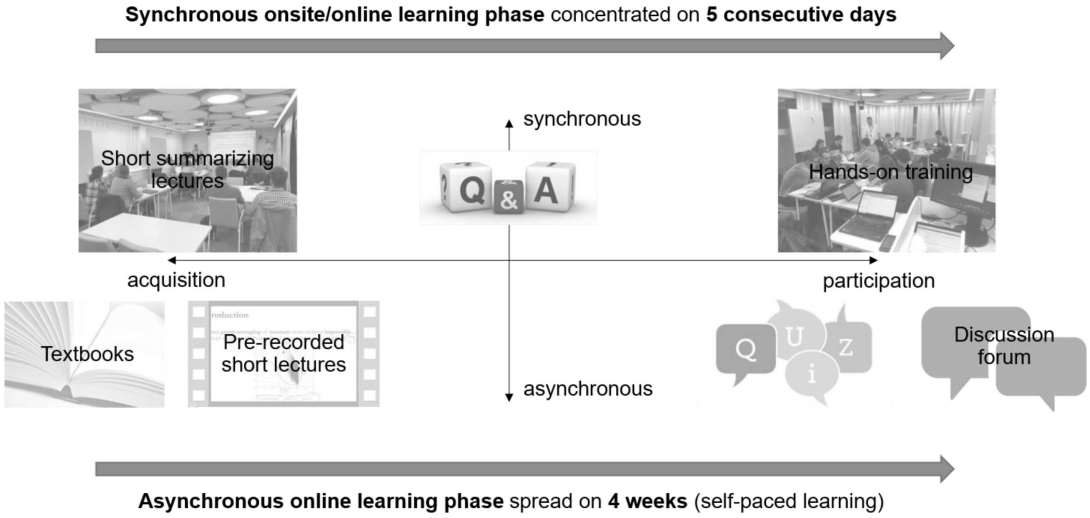

Fig. 2. Overview of the various course elements offered in the GRE@T-PIONEeR courses, categorized along two dimensions following [13]: acquisition versus participation, and asynchronous versus synchronous.

growth but also personal relationships among participants. During the training, the organizers provided shared accommodation, sightseeing tours, and cultural activities to encourage informal networking. Formal networking was also supported by joint introduction sessions, group exercises, and collaborative consultation sessions. This integration of professional and personal elements has laid a solid foundation for future collaboration among experts from diverse national backgrounds. Additionally, alumni of the T&T courses are encouraged to join a LinkedIn group that further expands and strengthens these international networks by staying connected and engaging in discussions related to regulatory and technical developments.

For GRE@T-PIONEeR, another outcome of the project, beyond providing certified education, is the creation of a worldwide community of reactor physicists, nuclear engineers and safety analysts. The onsite participants to the courses had an opportunity to network with each other and with the teachers. Bounds were also created with the online participants. During the synchronous sessions, most of the online participants interacted using the chat of the web-based conferencing software (beyond using audio and video). The teachers noticed that the onsite participants also connected to the chat, interacted with the online participants and helped each other. The connections thus created between the online participants and the onsite participants survived after the completion of the courses, resulting in a growing network of contacts between the participants, irrespective of the mode of attendance, and the teachers.

5 Conclusions and outlook

The ENEN2plus, TOURR, and GRE@T-PIONEeR projects underscore the critical role of education, training, and infrastructure in securing the future of nuclear science and technology in Europe. These initiatives represent a unified effort which tackle the workforce development, resource optimization, and international collaboration, ensuring that Europe remains at the forefront of innovation and safety in the nuclear field. This project address critical challenges posed by a declining workforce, aging infrastructure, and evolving societal needs, demonstrating how collaboration and innovation can secure the future of nuclear expertise.

ENEN2plus offers a comprehensive approach to attracting, developing, and retaining talent in the nuclear field. Its focus on mapping workforce needs, promoting mobility, and fostering international collaboration ensures that the European nuclear sector remains competitive and well-equipped to face emerging challenges.

The TOURR project highlights the role of research reactors in nuclear science, technology, and healthcare. By optimizing their use and promoting awareness among stakeholders, the project underscores the importance of maintaining and upgrading these facilities to support Europe's research and medical isotope production capabilities.

GRE@T-PIONEeR Project complements these broader efforts by delivering specialized training in reactor physics and nuclear safety. Its hands-on approach, combining theoretical and practical elements, prepares highly skilled professionals essential for ensuring nuclear safety and innovation.

This project also showcase the importance of flexibility and modern communication strategies in nuclear E&T. By leveraging online platforms, hybrid learning, and outreach initiatives, they have succeeded in engaging diverse audiences, from young students to seasoned professionals. The development of a cross-border community of educators and learners further amplifies their impact, creating a resilient network dedicated to nuclear science and safety.

To sum-up, the ENEN2plus, TOURR, and GRE@T-PIONEeR projects collectively highlight the role of innovative, collaborative, and sustainable approaches in maintaining and expanding nuclear expertise. Their success demonstrates how targeted efforts can address challenges,

promote visibility, and ensure the long-term sustainability of nuclear education and training.

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Conflicts of interest

The authors declare that they have no competing interests to report.

Data availability statement

No data are associated with this article.

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References

1. L.P. Gabriel and al., The ENEN's role in shaping the European nuclear education, Nuclear Eng. Design **420**, 112999 (2024), https://doi.org/10.1016/j.nucengdes.2024.112999
2. L. Cizelj and al., Towards strategic agenda for European nuclear education, training, and knowledge management, Nuclear Eng. Design **420**, 113001 (2024), https://doi.org/10.1016/j.nucengdes.2024.113001
3. W. Ambrosini and al., Sustainable online initiatives for the dissemination of nuclear energy culture, Nuclear Eng. Design **420**, 112988 (2024), https://doi.org/10.1016/j.nucengdes.2024.112988
4. Available in December 2024, https://enen.eu/index.php/2022/06/30/enen2plus-has-started/
5. Available in December 2024, https://www.nucleareurope.eu/project/enen2plus/
6. Available in December 2024, https://www.euronuclear.org/enen2plus-project/
7. Available in December 2024, https://www.djs.si/nene2021/proceedings/pdf/NENE2021_1103.pdf
8. Available in December 2024, https://enen.eu/index.php/portfolio/tourr-project/
9. Available in December 2024, https://cordis.europa.eu/project/id/945269/reporting
10. J. Bishop & M.A. Verleger, The flipped classroom: A survey of the research, in *2013 ASEE Annual Conference and Exposition* (2013), pp. 23–1200.
11. C.C. Bonwell, J.A. Eison, Active Learning: Creating Excitement in the Classroom, in 1991 ASHE-ERIC Higher Education Reports. ERIC Clearinghouse on Higher Education, The George Washington University, One Dupont Circle, Suite 630, Washington, DC 20036-1183, 1991.
12. C. Demazière, C. Stöhr, Y. Zhang, O. Cabellos, S. Dulla, N. Garcia-Herranz, R. Miró, R. Macian, M. Szieberth, C. Lange, M. Hursin, S. Strola, Enhancing higher education through hybrid and flipped learning: Experiences from the GRE@T-PIONEeR project, Nuclear Eng. Design **417**, 113028 (2024).
13. S. Hrastinski, Asynchronous and synchronous e-learning, Educause Quarterly **31**, 51 (2008)

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