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Enhancing higher education through hybrid and flipped learning: Experiences from the GRE@T-PIONEeR project

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ABSTRACT

GRE@T-PIONEeR is a Horizon 2020 project coordinated by Chalmers University of Technology, running over the period 2020–2024. 18 university teachers from 8 different universities located in 6 different countries gathered forces to develop and offer advanced courses in computational and experimental nuclear reactor physics and safety. All courses are flipped hybrid courses, i.e., students work on online preparatory activities at their own pace before attending a set of interactive sessions organized on five consecutive days. Those sessions can be attended either onsite or remotely. During the academic year 2022/2023, 8 different courses were offered, and 185 students successfully completed the courses, with a success rate of 87.7% for the students taking at least one activity during the interactive sessions. Student behaviour and performance were monitored via the Learning Management System (LMS) used in all courses. This paper presents an analysis of various metrics from the LMS and demonstrates a high level of engagement of the students committed to the courses and a high success rate for those students. Whereas all students are equally engaged in the online preparatory work and perform equally well, significant differences exist during the interactive sessions between the students who opted for onsite participation and those who attended the sessions online, with the onsite students outperforming the online students.

1. Introduction

With decisions concerning the future of the energy mix remaining at the member states level in the European Union, the situation with respect to nuclear power generation varies greatly from country to country. Construction of new nuclear power plants is already in progress, or the nuclear option is being considered or re-considered in some regions. Nevertheless, phasing out programs and early decommissioning of nuclear units are also being implemented in some countries.

All European countries face a challenging situation regarding the education and training of personnel required for the safe operation of the plants. Countries going forward with new constructions require many new graduates with nuclear engineering training on a very short term. This is further complicated by the large number of retirements in

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the nuclear community and the low number of recruited staff members in the past decades, resulting in a generation gap. Nuclear engineering programs also suffer from this gap. In addition, other factors, such as fewer students in sciences and engineering, demographical issues, and the unfavourable public opinion towards nuclear, resulted in a further lowering of the number of students enrolled in nuclear engineering programs. Therefore, these countries need additional resources in all levels of education and training for guaranteeing the safe operation of the new and existing nuclear units. This is especially true in tertiary education. At this level, very few students are enrolled in specialized and advanced courses. Such students are nevertheless at the forefront of the research in nuclear engineering, and their competences have a large impact on nuclear safety, irrespective of whether they pursue an academic career or a career in the industry.

Although nuclear power generation might still represent a large fraction of the energy mix for many years to come in the countries with phasing out programs, attracting students to nuclear engineering programs is thus becoming increasingly difficult. Political, economic, and societal factors create a negative climate for nuclear power generation, resulting in very few students choosing a nuclear engineering career.

As a result of the decreasing number of students enrolled in the various nuclear engineering programs, the corresponding departments of nuclear engineering at European universities are put under pressure by their management to close the programs. Although maintaining full bachelor or master programs at these universities open may be questionable, it is of prime importance to keep some of the advanced and specialized courses running. Such courses are also essential for the academic departments in terms of education of PhD students along the research directions followed by the respective research units. Without a minimum inflow of PhD students properly educated in such key areas, research in these research units will greatly suffer. Furthermore, access to fundamental and specialized courses in nuclear science and technology is important for students in other disciplines as well, such as, e.g., energy engineering and environmental protection.

In addition, according to the International Atomic Energy Agency (IAEA) convention on nuclear safety (INFCIRC/449), paragraph 11.2: "Each Contracting Party shall take the appropriate steps to ensure that sufficient numbers of qualified staff with the appropriate education, training and retraining are available for all safety-related activities in or for each nuclear installation, throughout its life" (International Atomic Energy Agency, 1994). Moreover, according to the Council Directive 2014/87/Euratom of 8 July 2014, article 7: "Member States shall ensure that the national framework requires all parties to make arrangements for the education and training for their staff having responsibilities related to the nuclear safety of nuclear installations so as to obtain, maintain and to further develop expertise and skills in nuclear safety and on-site emergency preparedness" (Official Journal of the European Union, 2014).

If no measure is taken, the closing of nuclear engineering programs will not allow the members states to fulfil their engagements with the IAEA and the European Union. Some countries realized the seriousness of the situation. In Sweden for instance, an investigation ordered by the Swedish government to the Swedish Radiation Safety Authority resulted in a report highlighting the need to support key areas of nuclear engineering, among others, reactor physics, thermal-hydraulics, and nuclear data, in order to maintain competences on the long run (Swedish Radiation Safety Authority, 2018). A series of measures was also proposed accordingly (Swedish Radiation Safety Authority, 2021).

Furthermore, potential closing-down of nuclear engineering programs in countries having phasing-out programs is a loss at a European level, affecting nuclear operation even in other parts of Europe. Countries with phasing-out programs have accumulated a large expertise and excel in specific fields. They also contributed to nuclear research and development at the European level, through networking, exchange of students and lecturers, joint research projects, double-degree programs, etc. Therefore, the closing-down of these nuclear programs would also be unfortunate for countries with nuclear development programs, especially in a critical period when extensive education and training efforts are needed due to the new constructions since the transfer of advanced knowledge and experience will be hindered by a lack of experts.

Moreover, a common challenge for all nuclear engineering programs in Europe is the small and decreasing number of training reactors. This makes the integration of practical exercises into nuclear engineering programs more and more difficult. Hands-on training exercises are fundamental for improving the understanding of difficult concepts among students. Such exercises also make the educational programs more attractive, aspect becoming increasingly important when various engineering disciplines compete against each other for getting a sufficient inflow of students. The existing training facilities also require enough students to make their operation sustainable.

In response to the above, a Horizon 2020 project, called GRE@T-PIONEeR https://great-pioneer.eu (GRaduate Education Alliance for Teaching the PhysIcs and safety Of NuclEar Reactors) was launched on November 1st, 2020, for a duration of four years, with a financing from the 2019–2020 European Union's Euratom research and training programme. The project gathers ten partners: Chalmers University of Technology (Sweden – coordinator), Ecole Polytechnique Fédérale de Lausanne (Switzerland), Technical University of Munich (Germany), TU Dresden (Germany), Budapest University of Technology and Economics (Hungary), Politecnico di Torino (Italy), Universidad Politécnica de Madrid (Spain), Universitat Politècnica de València (Spain), the European Nuclear Education Network (Belgium) and LGI Consulting (France).

The project aims at providing specialized and advanced courses in computational and experimental reactor physics at the graduate level (MSc and PhD levels) and post-graduate level, as well as to staff members working in the nuclear industry (utilities, consultancy companies, safety authorities and agencies, Technical Support Organizations, and research centres). Access to research facilities is an essential component of the consortium. In addition, web-based teaching techniques are largely used, allowing to offer such courses to the students enrolled at the respective universities irrespective of their location, both in Europe and outside. Although the number of students per university might be subcritical to maintain the courses open, sharing the students between universities using web-based techniques allows on the other hand to have enough students by combining the on-site and off-site students. A key aspect of the project was to offer such courses in a flexible manner while guaranteeing student engagement and learning.

Conceptually, the course designs build on a (social-) constructivist perspective on learning, embracing the ideas that knowledge is constructed through the learners' interactions with the environment and others, rather than passively received and the increasingly diverse needs of the students need to be recognized in the learning process. Thus, all courses follow the concept of active learning (Bonwell & Eison, 1991) emphasizing student engagement and participation. In practice, active learning involves interactive exercises, hands-on activities and group activities such as discussions or collaborative problem-solving (Freeman et al., 2014) through which passive recipients of information are transformed into active contributors to their own education. This method not only enhances comprehension but also fosters critical thinking skills, better preparing students for the challenges of nuclear engineering.

The central tenet of GRE@T-PIONEeR's pedagogical approach is the flipped classroom method, which entails reversing the traditional sequence of learning activities (Lage et al., 2000; Bishop & Verleger, 2013). In a flipped classroom, students engage asynchronously with instructional content online before attending synchronous sessions, allowing in-person class time with the presence of a teacher to be devoted to interactive discussions, problem-solving, and practical applications rather than traditional lecturing (Stöhr & Adawi, 2018). This method promotes deeper understanding, as students arrive prepared to actively participate in collaborative learning experiences (Barba et al., 2016; Lo et al., 2017; Lo & Hew, 2019).

To cater for the needs of diverse learner populations, the flipped classroom was implemented in hybrid form both as traditional and online flipped classroom (Chen et al., 2014, Stöhr et al., 2020). Hybrid teaching, within this context, involves a judicious combination of online and face-to-face instruction, where both online and on-campus students coexist concurrently during the synchronous parts. This method not only accommodates the diverse geographical locations of students but also capitalizes on the advantages of both in-person and virtual learning environments. By seamlessly integrating technology and traditional teaching methods, hybrid teaching maximizes flexibility, ensuring that students can access educational resources at their own pace and convenience.

The incorporation of these pedagogical methods is paramount in the context of nuclear engineering education. The complex nature of the discipline requires not only theoretical knowledge but also practical application and critical thinking skills. GRE@T-PIONEeR's commitment to active learning, flipped classroom, and hybrid teaching ensures that students receive a well-rounded education that prepares them not only for the current challenges but also for the dynamic landscape of the future in nuclear science and engineering. However, despite the growing popularity of the flipped classroom in higher education in general, there is an ongoing need to evaluate this pedagogical approach when implemented in nuclear engineering education and in hybrid form.

This paper investigates the efficacy of the course design by examining learning analytics data for all GRE@T-PIONEeR courses offered during the academic year 2022/2023. The research questions hereafter addressed are:

- Did the course design result in student engagement?
- Did the course design support student learning?
- How satisfied were the students with the course design?

The paper is structured as follows. The overall principles used in all courses are first presented, with a brief description of the various course elements. Thereafter, details about the courses offered during the academic year 2022/2023 are given and possible course specificities are discussed. Student engagement, performance and satisfaction are then analysed for all courses. The paper ends with some conclusions on the GRE@T-PIONEeR course design and highlights how the project contributes to the delivery of sustainable, resilient and democratized, top-class education in nuclear science and engineering.

2. Overall pedagogical design of the various courses

The essence of the pedagogical principles of the course offering relies on flipping, i.e., the delivery of some learning resources in an asynchronous self-paced fashion, followed by a set of synchronous sessions. The SOUL (Smart Open Universe of Learning) platform by Tecnatom, which is a Moodle-based Learning Management System (LMS), is used throughout the entire courses for the delivery of all teaching resources. Students were 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). Whereas the asynchronous learning phase is entirely online, the synchronous sessions are offered simultaneously onsite and online. The courses are thus hybrid for the onsite students because of the online asynchronous activities, whereas the courses are entirely web-based for the online students.

The asynchronous work 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 learning phase consists of (a) short summarizing lectures intertwined with (b) quizzes/discussions/Q&As with or without prior group discussions, and (c) more advanced hands-on activities that the students need to work on. This is primarily via the synchronous activities (b) and (c) that active learning takes place. The hands-on 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:

- Implementing nuclear reactor modelling techniques introduced in the other course elements via coding/programming assignments.
- Checking the proper understanding of key concepts via small computer-assisted assignments.
- Checking the proper use of third-party nuclear simulation software against some reference solutions.

For the activities on the training reactors, these include the planning, execution, and analysis of measurement campaigns on the reactors.

Fig. 1 gives an overview of the various activities proposed, together with a timeline of the activities. The activities are further categorized depending on whether they are offered in an asynchronous or synchronous fashion, and on whether the activities target low-order cognitive skills (acquisition) or high-order cognitive skills (participation). Student collaborations are strongly encouraged during the entire learning sequence of all courses. During the synchronous phase, exchanges between the online audience and the onsite audience are promoted, with students helping each other irrespective of whether they are onsite or online.

3. Main features of the courses offered in the academic year 2022/2023

During the academic year 2022/2023, the following GRE@T-PIONEeR courses were offered:

- Course "Nuclear cross-sections for neutron transport", labelled hereafter WP2. The synchronous learning phase took place between November 14th, 2022, and November 18th, 2022, at the Polytechnic University of Valencia, Valencia, Spain. This was a 3 ECTS (European Credit and Transfer System) course.
- Course "Neutron transport at the fuel cell and assembly levels", labelled hereafter WP3. The synchronous learning phase took place between December 16th and December 20th, 2022, at Chalmers University of Technology, Gothenburg, Sweden. This was a 3 ECTS course.
- Course "Core modelling for core design", labelled hereafter WP4. The synchronous learning phase took place between January 9th and January 13th, 2023, at the Polytechnic University of Valencia, Valencia, Spain. This was a 3 ECTS course.
- Course "Core modelling for transients", labelled hereafter WP5. The synchronous learning phase took place between February 6th and February 10th, 2023, at the Polytechnic University of Valencia, Valencia, Spain. This was a 3 ECTS course.
- Course "Reactor transients, nuclear safety and uncertainty and sensitivity analysis", labelled hereafter WP6. The synchronous learning phase took place between March 6th and March 10th, 2023, at the Polytechnic University of Valencia, Valencia, Spain. This was a 3 ECTS course.
- Course "Radiation protection in nuclear environment", labelled hereafter WP7. The synchronous learning phase took place between March 27th and March 31st, 2023, at the Budapest University of Technology and Economics, Budapest, Hungary. This was a 3 ECTS course.
- Hands-on exercises on the AKR-2 training reactor, labelled hereafter AKR-2. The synchronous learning phase took place between April 17th and April 28th, 2023, at the Technical University of Dresden, Dresden, Germany. This was a 4.5 ECTS course.

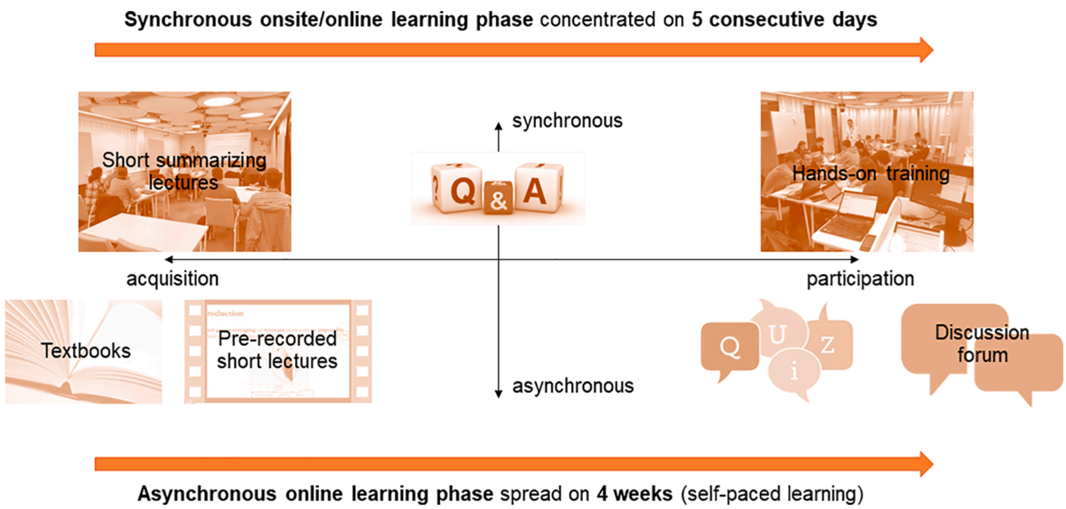

Fig. 1. Overview of the various course elements offered in the GRE@T-PIONEeR courses, categorized along two dimensions following Hrastinski (2008): acquisition versus participation, and asynchronous versus synchronous.

- Hands-on exercises on the CROCUS training reactor, labelled hereafter CROCUS. The synchronous learning phase took place between May 29th and June 2nd, 2023, at the Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland. The synchronous learning phase was only offered with the onsite option. This was a 2 ECTS course.

In total, for all courses together, the number of developed resources amounted to:

- For the asynchronous learning phase: 12 handbooks, 133 video lectures, and 611 quizzes.
- For the synchronous learning phase: 298 quizzes, and 115 hands-on assignments.

The courses all adopted the same principles:

- Access to the synchronous elements was only possible if 50 % of all asynchronous work was completed, i.e., if the students had watched at least 50 % of the video lectures and had completed at least 50 % of

Table 1
Student statistics and categorization for the GRE@T-PIONEeR courses offered during the academic year 2022/2023.

Course	Received applications	Discarded applications	Accepted applications	Participants given access to the LMS	Participants labelled as "rejected"	Participants labelled as "onsite – active"	Participants labelled as "online – active"	Participants labelled as "online – inactive"
WP2	87	37	50: 14 onsite 36 online	51	11	13	22	5
WP3	41	3	38: 6 onsite32 online	38	10	6	17	5
WP4	56	6	50: 23 onsite27 online	52	21	13*	18	0
WP5	60	6	54: 16 onsite 38 online	57	15	16	23	3
WP6	54	2	52: 6 onsite46 online	52	16	2	33	1
WP7	51	0	51: 17 onsite34 online	53	12	11	24	6
AKR-2	24	2	22: 11 onsite11 online	21	11**	5	4	1
CROCUS	15	9	6:6 onsite 0 online	6	2	4	0	0
Total	**389**	**65**	**324: 100 onsite 224 online**	**330**	**98**	**70**	**141**	**21**

*A student who helped with the development of some of the teaching activities was first given teacher rights on the LMS, later converted to student rights. This conversion resulted in a partial loss of the tracking of the completion rate on the asynchronous activities. This student belongs to the category of "Onsite – active" student.
**A student not accepted to the synchronous sessions because of insufficient completion rate on the asynchronous activities later completed the asynchronous work. This student is nevertheless categorized in this analysis as "Rejected", as this student was not accepted to the synchronous sessions.

the asynchronous quizzes (irrespective of whether the quizzes were correctly answered or not).
- The asynchronous quizzes, synchronous quizzes and synchronous hands-on were all graded activities.
- The final grade of the courses was calculated using a relative weight of 25 % on the asynchronous activities and correspondingly a relative weight of 75 % on the synchronous activities. The number of points for the entire course was rescaled to 100 points.
- Course certificates were only delivered if a participant got at least 50 points (out of 100).

Students could always see their progress (completion) on the asynchronous activities and grades (performance) on all activities. Activities of the same type were not all given the same number of points. The teachers themselves were responsible for weighting the different activities within the asynchronous, synchronous, respectively, phases depending on the complexity of the activity and the time necessary to solve it.

Table 1 gives for each of the GRE@T-PIONEeR courses offered during the academic year 2022/2023 the number of received applications, the number of discarded applications and the corresponding number of accepted applications. 50 students were considered to be the upper limit for being able to efficiently support them during the courses. The selection of the candidates was based on a questionnaire the applicants had to answer, in which the prior knowledge of the candidates and their education and/or past experience was assessed. Questions about the participants' expectations and motivations were also used to further select the applicants. For the number of accepted applications, the number of candidates who opted for the onsite, online option, respectively, of the synchronous sessions is also given, together with the number of participants who got access to the LMS. This number might be different from the number of accepted participants, due to late cancellations or late registrations. The number of participants with LMS access is further subdivided in the following categories:

- A category called "Rejected" encompassing all students who did not reach the necessary level of completion rate on the asynchronous activities to qualify for the synchronous activities.
- A category called "Onsite – active" encompassing all students who qualified for the synchronous sessions, who chose the onsite attendance for the synchronous sessions and who completed at least one activity during those sessions.
- A category called "Online – active" encompassing all students who qualified for the synchronous sessions, who chose the online attendance for the synchronous sessions and who completed at least one activity during those sessions.
- A category called "Online – inactive" encompassing all students who qualified for the synchronous sessions, who chose the online attendance for the synchronous sessions but did not complete any activity during those sessions.

It should be noted that all onsite attendees completed at least one activity during the interactive sessions, explaining why there is no category called "Onsite – inactive". Furthermore, the number of "Onsite – active" students does not necessarily match the number of accepted students who chose the onsite option. Similarly, the sum of the numbers of "Online – active", "Online – inactive" and "Rejected" students does not systematically match the number of accepted participants who chose the online option. This is due to students changing their mode of participation to the courses from onsite to online and vice versa between the time when they were accepted to the courses and the time when the synchronous sessions started.

The above categories are used in the following of this paper when analysing student engagement and performance.

4. Analysis of student engagement

In this Section, the level of student engagement is assessed by tracking the completion rate of the students on the asynchronous and synchronous activities. "Completion" means that an activity is completed and can thus be graded, i.e., answers to the asynchronous and synchronous quizzes and to the synchronous hands-on exercises are submitted onto the LMS. For the sake of completeness, the completion rates on the video lectures are also reported. A video lecture is marked as completed when a student clicks on the video. This nevertheless does not guarantee that the student watched the video. The video completion rates have thus to be interpreted with care. The completion rates on the asynchronous and synchronous activities are summarized in Table 2 per course. The distributions of the number of students depending on their completion rates and for the different student cohorts are given in Fig. 2 for the videos, in Fig. 3 for the asynchronous quizzes, in Fig. 4 for the synchronous quizzes, and in Fig. 5 for the synchronous activities other than quizzes.

Before discussing the results, some specificities to some of the courses need to be highlighted:

- For the WP2 course, an LMS set-up flaw resulted in the fact that students could also mark themselves the completion of the asynchronous activities, in addition to the LMS automatically registering when an activity was completed. The completion rates of the asynchronous activities should thus be considered with care for this course. It is nevertheless believed that very few activities were manually registered as completed by the students.
- For the WP6 course, no activity completion for some of the synchronous activities was recorded by the system as the teachers forgot to track activity completion when setting those activities. Activity completion was "reconstructed" from the grades (a grade different from "-" on the LMS was considered as an activity being completed). As the students needed to complete 50 % of the asynchronous activities to be admitted to the synchronous sessions, this may have had an impact on student behaviour. This may explain why the completion rates on the asynchronous activities on WP6 are so high for the engaged students.
- For the AKR-2 and CROCUS courses, there was no video lecture offered as asynchronous preparations, only reading materials.
- For the CROCUS course, no synchronous quizzes were offered. Only more advanced synchronous activities in forms of hands-on were proposed.

As can be seen in Table 2, a high completion rate can be noticed on the asynchronous activities for the "Onsite – active", "Online – active" and "Online – inactive" student cohorts. It can nevertheless be noticed that, for the WP2, WP3 and WP7 courses, the completion rates on the asynchronous quizzes for the "Online – inactive" ones were significantly lowered and with a larger standard deviation. This might have been seen as an early sign of lower dedication of those students, explaining why they did not participate to the synchronous sessions. The "Rejected" student cohort has a very low completion rate, explaining why those students were not accepted to the synchronous sessions. The high standard deviation also reveals a large variety of engagement during the asynchronous phase for those students. As Figs. 2 and 3 show, the distribution of the completion rates on the asynchronous elements is mostly top-peaked for the "Onsite – active" and "Online – Active" students. For the synchronous activities in which per definition only the "Onsite – active" and "Online – active" student cohorts remain, Table 2 shows that the completion rates are significantly higher for the "Onsite – active" students than for the "Online – active" ones. In addition, the differences are higher for the synchronous activities other than quizzes that for the synchronous quizzes, except for the WP2 course for which the completion rates for the "Online – active" students are more or less identical on the two types of activities. The differences between the two student

Table 2
Mean values of the completion rates on the asynchronous and synchronous elements (with standard deviations given in parenthesis) for all GRE@T-PIONEeR courses offered during the academic year 2022/2023.

	Asynchronous activities								Synchronous activities			
	Video completion rates [%]				Asynchronous quizzes completion rates [%]				Synchronous quizzes completion rates [%]		Synchronous activities (except quizzes) completion rates [%]	
	Onsite - active	Online - active	Online - inactive	Rejected	Onsite - active	Online - active	Online - inactive	Rejected	Onsite - active	Online - active	Onsite - active	Online - active
WP2	93.8 ± 13.3	93.6 ± 14.3	80.0 ± 18.7	0.0 ± 0.0	90 ± 17.4	93.2 ± 13.7	78.0 ± 26.6	0.0 ± 0.0	98.6 ± 3.4	84.7 ± 29.5	89.7 ± 16.0	83.3 ± 28.6
WP3	100.0 ± 0.0	99.1 ± 3.7	72.3 ± 26.3	9.6 ± 13.7	100.0 ± 0.0	92.6 ± 16.2	68.4 ± 32.4	4.0 ± 8.4	97.9 ± 5.1	79.8 ± 24.4	78.3 ± 4.1	53.5 ± 31.2
WP4	94.0 ± 15.1	95.2 ± 12.0	–	17.7 ± 31.2	88.1 ± 14.4	92.4 ± 11.1	–	2.0 ± 6.1	92.3 ± 24.9	86.1 ± 20.9	85.6 ± 11.8	58.3 ± 27.7
WP5	95.1 ± 11.1	98.3 ± 5.3	96.7 ± 5.2	19.4 ± 35.0	92.5 ± 14.1	91.7 ± 12.1	92.5 ± 13.0	10.8 ± 26.1	81.2 ± 13.0	62.6 ± 24.9	83.3 ± 15.0	54.7 ± 34.5
WP6	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	51.2 ± 46.0	100.0 ± 0.0	95.2 ± 10.0	100.0 ± 0.0	15.6 ± 27.6	100.0 ± 0.0	94.9 ± 16.9	100.0 ± 0.0	71.2 ± 34.8
WP7	100.0 ± 0.0	97.3 ± 9.4	97.1 ± 7.1	12.0 ± 26.6	98.3 ± 5.5	92.3 ± 12.8	68.2 ± 41.9	3.3 ± 11.4	88.4 ± 13.7	68.9 ± 27.7	86.4 ± 24.0	57.3 ± 36.3
AKR-2	–	–	–	–	98.3 ± 3.7	100.0 ± 0.0	100.0 ± 0.0	9.1 ± 30.2	98.3 ± 3.7	91.7 ± 16.7	53.3 ± 15.1	35.4 ± 25.8
CROCUS	–	–	–	–	100.0 ± 0.0	–	–	–	–	–	91.7 ± 16.7	–

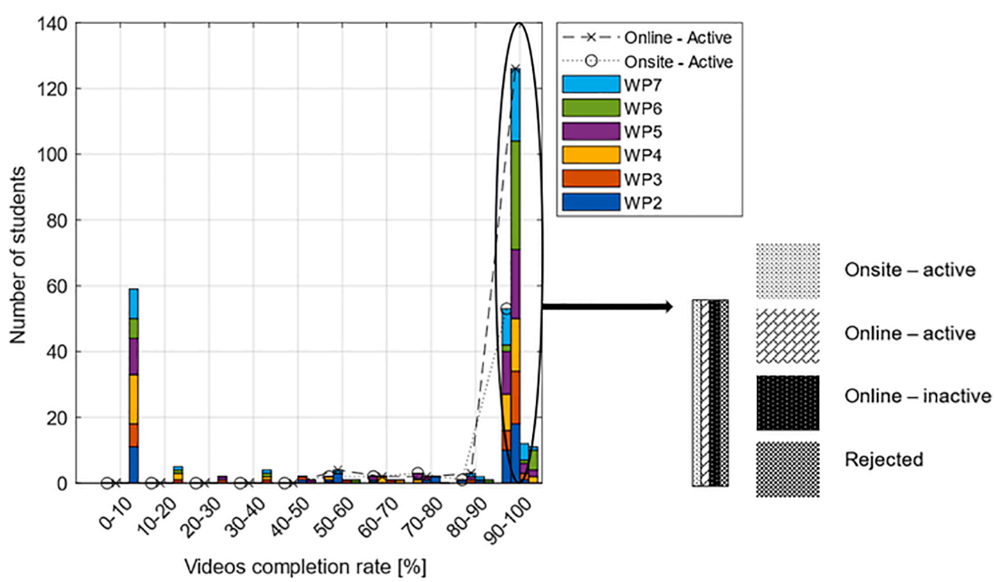

Fig. 2. Cumulative distributions of the number of students for all courses depending on their completion rates on the videos and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the "Onsite – active" and "Online – active" categories are superimposed onto the distributions.

cohorts are also clearly visible in the distribution of the completion rates on the synchronous elements depicted in Figs. 4 and 5. Whereas the distribution for the "Onsite – active" students is again top-peaked for the synchronous quizzes, a somewhat flatter distribution at intermediate completion rates appears for the "Online – active" students. Flatter distributions at intermediate completion rates are present for both student cohorts for the other synchronous activities, again at a relatively higher level for the "Online – active" students compared to the "Onsite – active students".

5. Analysis of student performance

In this Section, the level of student performance is assessed by estimating the grades of the students on the asynchronous and synchronous activities. All points were renormalized to 100 points for each type of activity, i.e., for the asynchronous quizzes, the synchronous quizzes, and the other synchronous activities, respectively. The total number of points for each course was also renormalized to 100 points. An activity not completed was given a grade of zero. The grades on the asynchronous and synchronous activities are summarized in Table 3 per course, as well as the overall course grades. The distributions of the number of students depending on their grades and for the different student cohorts are given in Fig. 6 for the asynchronous quizzes, in Fig. 7 for the synchronous quizzes, in Fig. 8 for the synchronous activities other than quizzes, and in Fig. 9 for the entire courses.

The total course grades were unfortunately incorrectly calculated by the LMS. More specifically, instead of adding points for each activity within the asynchronous, synchronous, respectively, groups, the activities were all rescaled to the same number of points (possibly weighted if the teachers had used such a feature) and then added. As those incorrectly calculated grades were displayed to the students on the LMS and used for issuing the grades, we decided to use this measure in the present

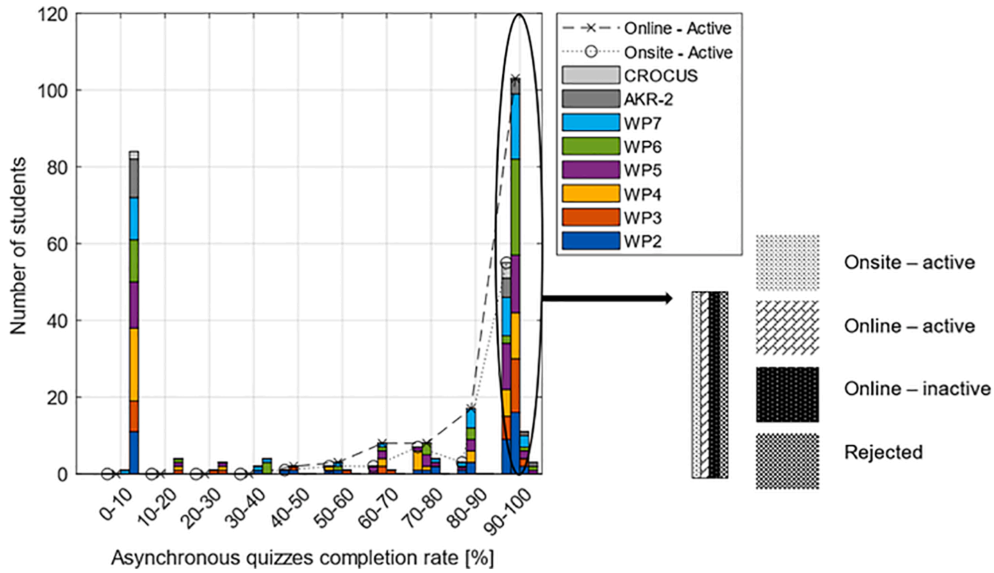

Fig. 3. Cumulative distributions of the number of students for all courses depending on their completion rates on the asynchronous quizzes and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the “Onsite – active” and “Online – active” categories are superimposed onto the distributions.

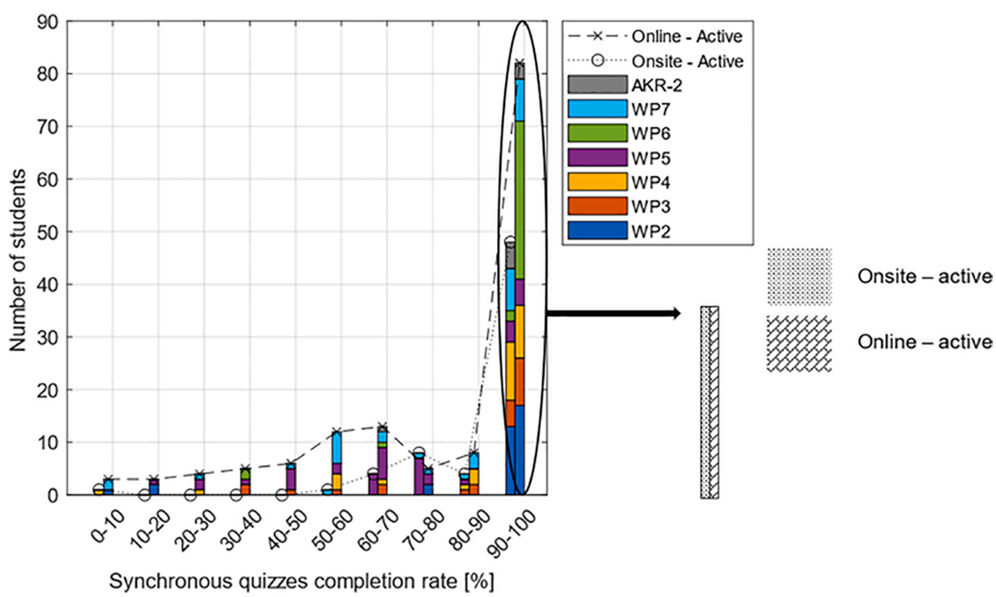

Fig. 4. Cumulative distributions of the number of students for all courses depending on their completion rates on the synchronous quizzes and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the “Onsite – active” and “Online – active” categories are superimposed onto the distributions.

analysis as well. An independent calculation of the correct grades executed for each courses revealed that the incorrectly calculated grades give a relatively fair representation of the actual grades.

As can be seen in Table 3, the “Onsite – active”, “Online – active” and “Online – inactive” students performed very well on the asynchronous quizzes, with the “Onsite – active” students slightly outperforming the “Online – active” students. For the WP3 and WP7 courses, it can also be noticed that the success rates for the “Online – inactive students” were significantly lower than for the “Online – active” students. Obviously, the “Rejected” students have a very low success rate due to the low level of engagement during the asynchronous phase. Looking at the distribution of the grades in Fig. 6, one notices that there is a quite significant spread in the grades on the asynchronous quizzes. Those remain nevertheless above 50 points for all student cohorts engaged in the activities, demonstrating that the theoretical concepts were properly acquired during the preparatory phase. For the synchronous activities, the “Onsite – active” students perform significantly better than the “Online – active” students. This is also visible from Figs. 7 and 8 in the distribution of the number of students for the synchronous quizzes and other synchronous activities, respectively. For the synchronous quizzes, the distribution of the number of “Onsite – active” is top-peaked, whereas the distribution of the number of “Online – active” students has three peaks: one at relatively high success rates (above 90 points), one around 70–80 points, and one around 50–60 points, with relatively lower distributions in between. For the synchronous activities other than quizzes, the distributions of the two student cohorts are more similar, with two clear peaks being common between the two student cohorts: one above 90 points, and one around 60–70 points. Nevertheless, the

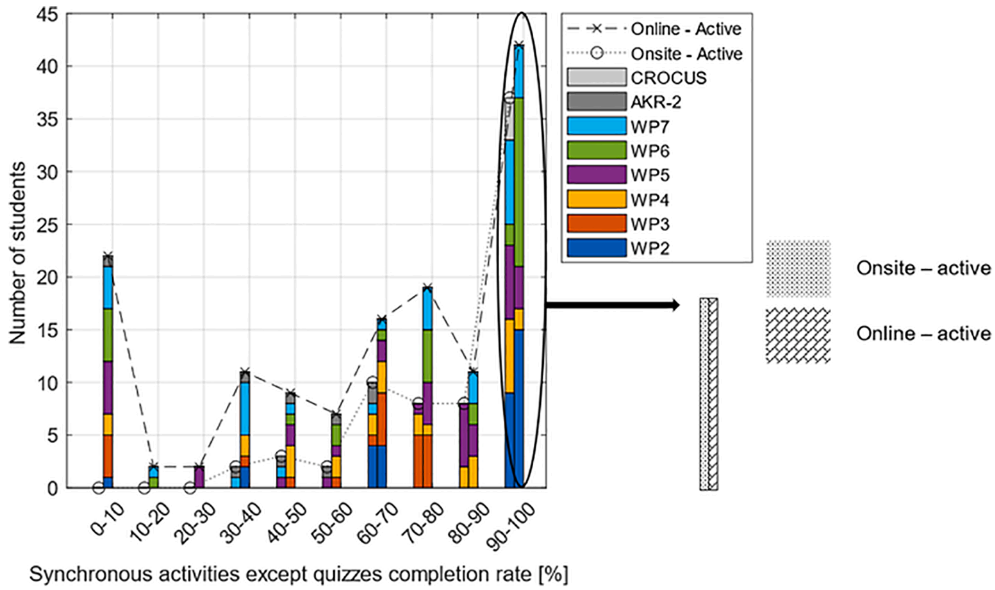

Fig. 5. Cumulative distributions of the number of students for all courses depending on their completion rates on the synchronous activities other than quizzes and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the "Onsite – active" and "Online – active" categories are superimposed onto the distributions.

Table 3
Mean values of the grades on the asynchronous and synchronous elements, as well as of the final course grades (with standard deviations given in parenthesis) for all GRE@T-PIONEeR courses offered during the academic year 2022/2023.

	Asynchronous activities				Synchronous activities				Final course grades[1]	
	Asynchronous quizzes grades[1]				Synchronous quizzes grades [1]		Synchronous activities (except quizzes) grades [1]			
	Onsite - active	Online - active	Online - inactive	Rejected	Onsite - active	Online - active	Onsite - active	Online - active	Onsite - active	Online - active
WP2	83.7 ± 16.1	76.7 ± 17.4	74.7 ± 30.2	0.13 ± 0.4	90.7 ± 5.9	76.7 ± 28.7	97.4 ± 9.2	71.1 ± 32.7	92.2 ± 6.5	78.5 ± 17.0
WP3	80.5 ± 10.4	70.4 ± 16.0	53.9 ± 25.1	2.9 ± 6.2	73.5 ± 22.9	48.1 ± 21.1	74.0 ± 17.3	45.3 ± 29.4	64.0 ± 8.8	47.2 ± 16.1
WP4	76.9 ± 21.7	69 ± 15.1	–	1.8 ± 5.8	73.8 ± 23.1	47.1 ± 21.3	61.4 ± 11.1	43.1 ± 17.4	73.9 ± 11.1	50.3 ± 14.8
WP5	80.6 ± 15.2	72.9 ± 15.4	68.2 ± 20.0	8.1 ± 15.5	82.6 ± 10.6	50.0 ± 29.0	61.6 ± 15.0	38.7 ± 28.8	79.4 ± 10.3	54.2 ± 22.8
WP6	91.1 ± 3.7	80.6 ± 14.6	79.3 ± 0.0	10.0 ± 23.4	83.5 ± 23.3	66.3 ± 28.4	91.1 ± 3.5	61.6 ± 30.8	90.2 ± 0.1	67.2 ± 21.9
WP7	78.9 ± 10.5	74.23 ± 12.2	45.5 ± 24.9	1.9 ± 6.6	49.9 ± 13.6	39.8 ± 17.5	66.5 ± 31.6	35.1 ± 27.9	77.7 ± 13.1	58.1 ± 19.7
AKR-2	88.5 ± 4.8	80.0 ± 9.4	85.8 ± 0.0	6.8 ± 22.5	87.0 ± 4.7	66.2 ± 12.9	44.2 ± 16.0	31.2 ± 22.9	65.9 ± 6.7	52.7 ± 15.3
CROCUS	89.5 ± 3.7	–	–	–	–	–	75.0 ± 20.8	–	78.6 ± 15.8	–

number of "Online – active" in the range 40–60 is rather significant in relative terms compared to the number of "Onsite – active". Furthermore, as those activities are much more involved, one notices that some of the "Online – active" students fail on those activities, leading to a peak below 10 points for some of those students.

Due to the weighting of the different activities (not only asynchronous versus synchronous activities, but also synchronous quizzes versus other synchronous activities), the distribution of the grades is clearly top-peaked for the "Onsite – active" students, whereas the distribution for the "Online – active" has a peak just above 50–60 points, a significant fraction of the students above 60 points, and a non-negligeable fraction below 50 points. This last category of students failed to reach the 50 points mark and did not receive any course certificate. Again, one notices that the "Onsite – active" students outperform the "Online – active" ones. Although Fig. 9 indicates a few "Onsite – active" students in the range 40–50 points, those students were all very close to the 50 points mark and were issued a certificate of successful completion. Thus, all "Onsite – active" students passed the courses.

6. Analysis of student satisfaction

A course evaluation questionnaire was given on the last day of the synchronous sessions for each of the courses. Time was allocated to let the student answer the questionnaire on a voluntary basis. The questionnaires were not anonymous. Due to the different nature of the WP2-WP7 courses compared to the AKR-2 and CROCUS courses, two sets of questionnaires were used: one for the WP2-WP7 courses, and another one for the AKR-2 and CROCUS courses. The questionnaires contained statements that the students had to respond to on a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5) and that are analyzed hereafter. Those statements give an overview of student satisfaction.

For the WP2-WP7 courses, those statements were:

- Q1: I benefited from this course.
- Q2: This course met my expectations.
- Q3: I experienced and learned new things in this course.
- Q4: The content covered in this course was NOT interesting.
- Q5: I would like to take more courses like this one.
- Q6: I would recommend this course to others.

It should be noted that Q4 contains a negative statement where, unlike the other items, low agreement scores are indicative of high satisfaction ratings.

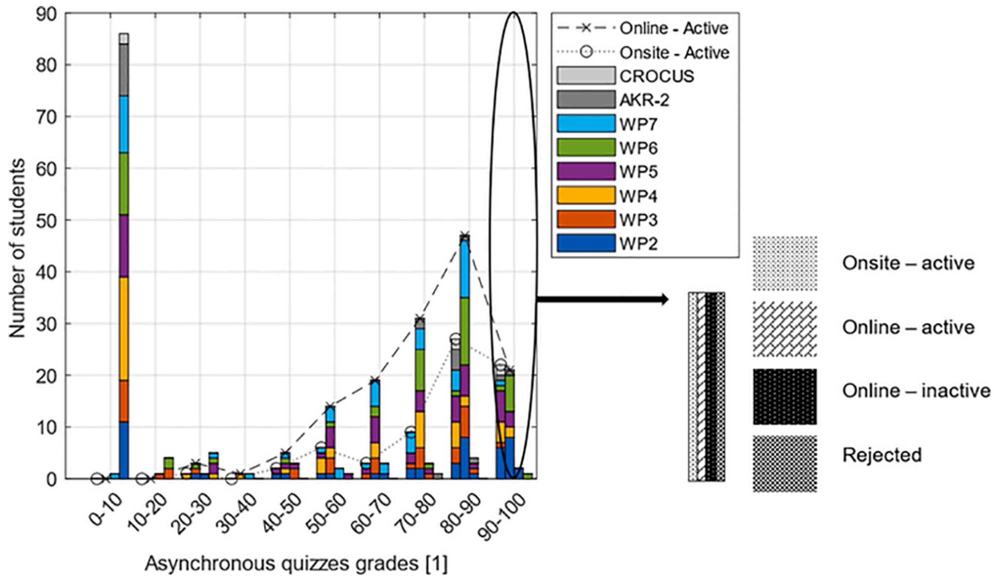

Fig. 6. Cumulative distributions of the number of students for all courses depending on their grades on the asynchronous quizzes and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the “Onsite – active” and “Online – active” categories are superimposed onto the distributions.

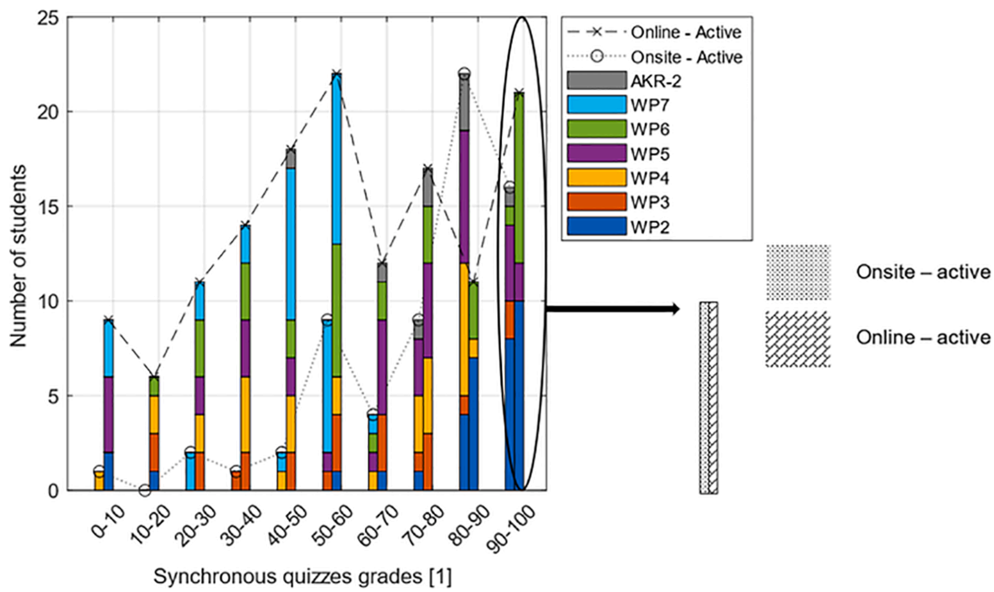

Fig. 7. Cumulative distributions of the number of students for all courses depending on their grades on the synchronous quizzes and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the “Onsite – active” and “Online – active” categories are superimposed onto the distributions.

For the AKR-2 and CROCUS courses, those statements were:

- Q1: I gained a deeper understanding of the theoretical concepts.
- Q2: I developed practical skills relevant to the nuclear field.
- Q3: The course content was well-organized and easy to follow.
- Q4: The teaching methods used were effective in facilitating my learning.

Table 4 gives the number of respondents for each of the courses, as well as the number of active participants (“Onsite – active” and “Online – active” students). The results of the two questionnaires are summarized in Figs. 10 and 11, for the WP2-WP7 courses and AKR-2/CROCUS courses, respectively.

Fig. 10 presents data on course satisfaction across the six different survey questions for the different courses. Overall, course participants express high satisfaction, all courses receive a score exceeding 4 points on a 5-point Likert scale across the five positive statements and below 2 for the fourth statement, respectively. There are, however, some variations. WP2 consistently reports high satisfaction across all questions, with scores close to 5. Across most work packages, Q2 about the practical skill development tends to have lower satisfaction scores. While still scoring high, this potentially suggests that this aspect of the course could benefit from further improvement. Error bars indicate variability within the responses for each course and question, with some questions showing more variability (e.g., Q2 and Q5) and others showing less (e.g., Q1 and Q6), suggesting that opinions on Q2 and Q5 might be more divided.

Fig. 11 shows satisfaction ratings for the training courses AKR2 and

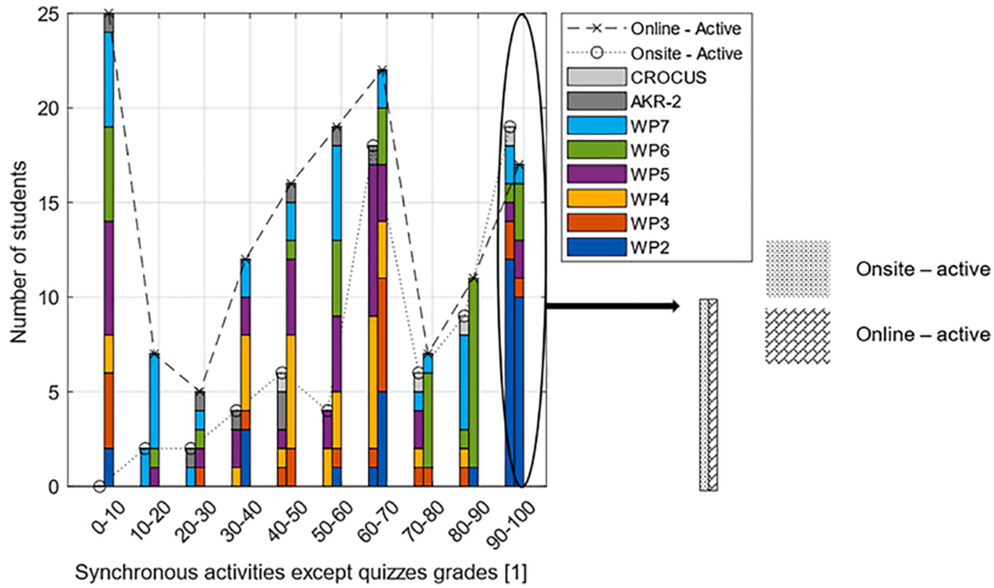

Fig. 8. Cumulative distributions of the number of students for all courses depending on their grades on the synchronous activities other than quizzes and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the “Onsite – active” and “Online – active” categories are superimposed onto the distributions.

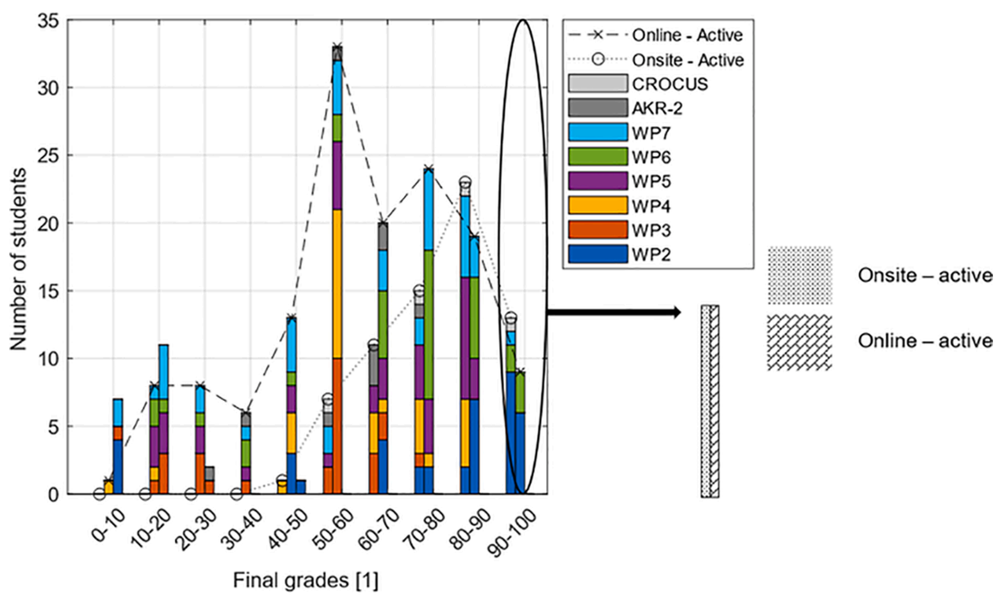

Fig. 9. Cumulative distributions of the number of students for all courses depending on their overall course grades and the student cohorts (the histograms for the different cohorts are exemplified on the right hand-side). Curves showing the distributions for the “Onsite – active” and “Online – active” categories are superimposed onto the distributions.

CROCUS across the four survey questions. Both AKR2 and CROCUS report similar levels of high satisfaction across all questions as both courses receive scores exceeding 4 points on a 5-point Likert scale across the four statements with little variation despite the low number of student responses.

In sum, the data indicates that all course areas assessed by the survey questions are well-received by the students indicating that the implementation of the hybrid flipped classroom approach resulted in a high course quality for both the pure online and in class versions.

7. Conclusions

As the analyses presented in this paper reveal, the design of the courses resulted in a high engagement of the students. Out of the 330 students granted access to the LMS, 70.3 % of those (232 students) were sufficiently engaged in the asynchronous learning phase to be admitted to the synchronous sessions. Out of those, 79.7 % (185 students) obtained a course certificate, demonstrating a high success rate and good performance of those students. All “Onsite – active” students were issued a certificate. 81.6 % (115 students) of the “Online – active” participants received a certificate, which indicates a high success rate for the engaged online participants. Out of the 211 active students (either onsite or online), 87.7 % of those (185 students) successfully completed the courses. The “Rejected” participants and the “Online – inactive” students failed to pass the course, the former because of poor engagement in the asynchronous phase, and the latter because of no participation to any of the synchronous activities. Similarly, the participants to the various courses who answered the course questionnaires were overwhelmingly

Table 4
Number of respondents given in absolute terms and in relation to the number of active participants for all GRE@T-PIONEeR courses offered during the academic year 2022/2023.

Courses	Number of respondents to the questionnaires	Number of active participants (“Onsite – active” and “Online – active”)	Fraction of the number of respondents to the number of active participants[%]
WP2	33	35	94
WP3	17	23	74
WP4	26	31	84
WP5	27	39	69
WP6	25	35	71
WP7	22	35	63
AKR-2	7	9	78
CROCUS	3	4	75

positive about the courses and their learning experience.

As expected, the success rate on the asynchronous activities is higher than on the synchronous activities, as the former ones target less involved/difficult activities. Concerning the synchronous activities, a lower engagement and a significantly lower success rate for the online students is noticeable (which also resulted in 18.4 % of the “Online – active” students failing on the courses). Several reasons might explain the differences in engagement and performance of the online students compared to the onsite students. First, following the synchronous activities remotely is definitely more challenging than being onsite. Although the participants were encouraged to ask questions via audio communication channels when problems were faced, the chat was mostly used, which makes communication less natural and less efficient. Second, the quizzes offered during the synchronous sessions were only open during limited times, typically a couple of minutes when the quizzes were presented and discussed by the teachers. As some remote students were not always present during the whole of the synchronous sessions, these students missed the possibility to answer those quizzes. Finally, although a more thorough analysis would be required, it is believed that the LMS providing immediate update on the grades when an activity is completed might be responsible for the lower success rate of the online participants in particular. As those participants most likely combine their synchronous participation with other duties (job, family, other studies, etc.), they need to optimize their time. As a result, simply passing the course might be “good enough” for this category of students, i.e., getting a grade of just 50 points is enough. The onsite participants, on the other hand, by the nature of their onsite attendance, are more dedicated to the synchronous activities. By taking more activities, they also have a better chance to perform better and further improve their grades.

All courses are being re-offered during the academic year 2023/2024. Although the main features of the courses were retained, some small adjustments were made to further improve the student learning experience. Those adjustments were the results of the student feedback gathered along the different courses and discussions thereafter held among the teachers.

On the long run, the project strengthens the European graduate nuclear engineering education network and provides additional training resources at an advanced level for the countries having limited nuclear education. The possibility to follow the courses entirely online is particularly interesting for the participants who do not have the financial resources to participate onsite. The courses are mostly joint courses between different teachers involved in the GRE@T-PIONEeR consortium. The courses cross-utilize each other’s expertise and infrastructures, thus guaranteeing a sustainable nuclear education network. Furthermore, the pedagogical format allows to prepare the students to undertake advanced hands-on training exercises in a highly complex discipline under the close supervision of the teachers. Finally, the courses result in the building of a community of nuclear reactor physicists, by the contacts and interactions the participants have during the courses between themselves and with the teachers. The interactions between the onsite and remote participants also lead to a global community.

In addition, to the immediate successes observed in the analyses of student engagement, performance, and satisfaction, it is crucial to underscore the long-term ambitions and sustainability of the GRE@T-

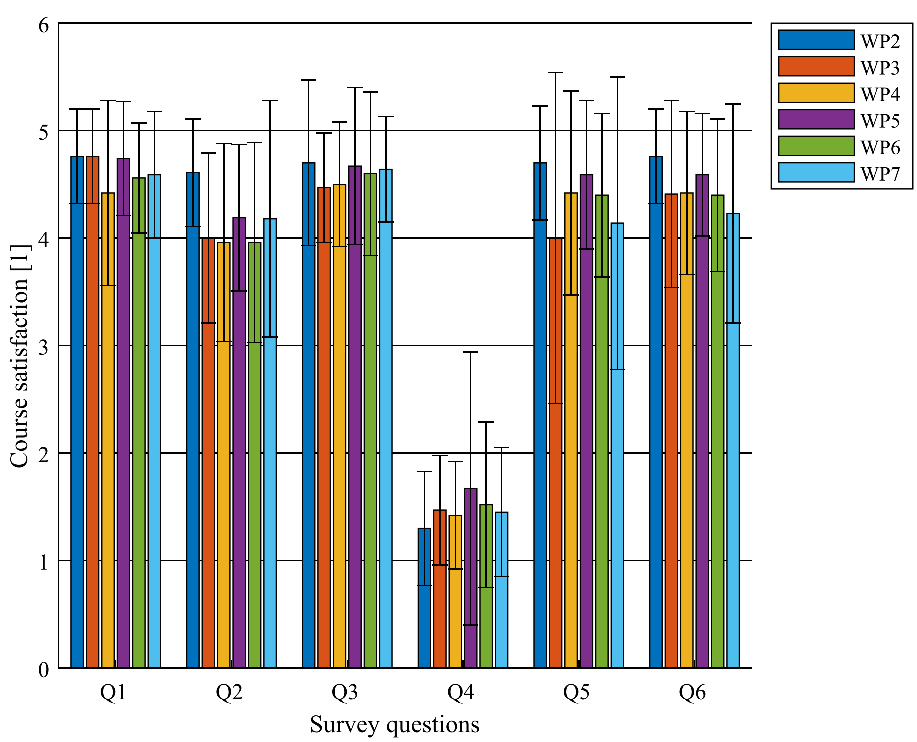

Fig. 10. Mean values and associated standard deviations of agreement with the statements regarding course satisfaction for the WP2-WP7 courses (1 = strongly disagree – 5 = strongly agree).

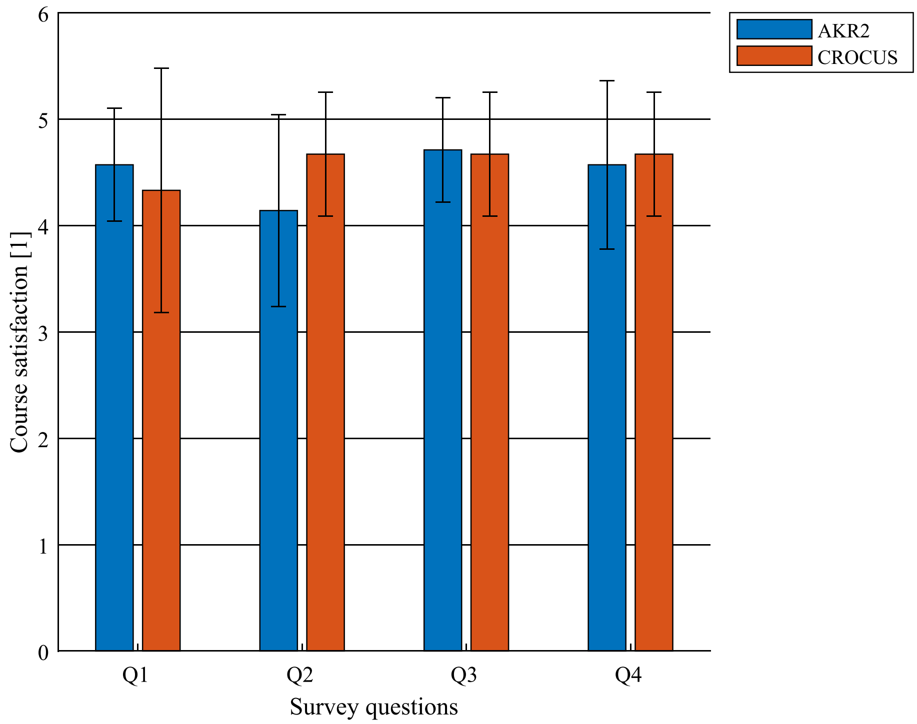

Fig. 11. Mean values and associated standard deviations of agreement with the statements regarding course satisfaction for the AKR-2 and CROCUS courses (1 = strongly disagree – 5 = strongly agree).

PIONEeR project. The initiative goes beyond its current achievements to lay the foundation for a lasting impact on European nuclear engineering education.

The sustainability of GRE@T-PIONEeR is evident in its commitment to re-offering all courses during the academic year 2023/2024. This continuity ensures that the project's educational benefits persist, fostering a continuous cycle of learning and skill development. The iterative process of course refinement based on student feedback reflects a dynamic approach to adapting and improving, emphasizing the project's commitment to staying relevant and responsive to evolving educational needs.

Moreover, the collaborative nature of the consortium, bringing together ten prominent European institutions, strengthens the bonds within the European graduate nuclear engineering education network. By cross-utilizing expertise and infrastructures, GRE@T-PIONEeR not only consolidates existing resources but also paves the way for sustained collaboration in the realm of nuclear education. This collaborative model sets a precedent for the development of a robust and interconnected European community dedicated to advancing nuclear science and engineering.

The project's online delivery format, a response to the financial constraints faced by some participants, contributes to its long-term sustainability. By offering courses online, GRE@T-PIONEeR ensures accessibility and inclusivity, transcending geographical and economic barriers. This approach not only democratizes access to advanced nuclear education but also establishes a resilient framework that can adapt to unforeseen challenges, ensuring the project's endurance. The project makes high-quality nuclear education accessible to a broader and more diverse audience but also introduces a dynamic model capable of flexibly responding to the evolving needs of the educational landscape.

The use of an online platform provides a scalable infrastructure that can readily accommodate fluctuations in student enrollment, allowing the project to maintain its efficacy even during times of varying demand. This scalability ensures that the benefits of GRE@T-PIONEeR can be extended to a wide spectrum of learners, fostering a more inclusive and globally connected community of nuclear engineering enthusiasts.

As GRE@T-PIONEeR progresses, it aspires to become a beacon for the future of nuclear engineering education in Europe and beyond. The ambition extends further than individual courses to the creation of a lasting legacy – a community of nuclear reactor physicists who, through their interactions and shared experiences, contribute to the broader global nuclear community. By nurturing this community, GRE@T-PIONEeR envisions a sustained exchange of knowledge, ideas, and collaborative endeavors that transcend the project's formal duration.

In conclusion, the GRE@T-PIONEeR project not only addresses the immediate challenges faced by European nuclear engineering programs but also charts a course for long-term impact and sustainability worldwide. Through continuous refinement, collaboration, and a commitment to inclusivity, the project aims to be a catalyst for the ongoing advancement of nuclear science and engineering education in Europe and beyond. The legacy of GRE@T-PIONEeR lies not only in the courses offered but in the enduring community and networks it cultivates, ensuring a lasting impact on the future of nuclear education.

In essence, GRE@T-PIONEeR's commitment to online education not only democratizes access but also establishes a flexible and responsive educational ecosystem that is not just resilient in the face of challenges but poised to thrive and evolve in an ever-changing educational landscape.

CRediT authorship contribution statement

C. Demazière: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **C. Stöhr:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Y. Zhang:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **O. Cabellos:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **S. Dulla:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **N. Garcia-Herranz:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **R. Miró:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **R. Macian:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **M. Szieberth:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **C. Lange:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **M. Hursin:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **S. Strola:** Writing – review & editing, Writing – original draft, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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