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Remote STEM education in the post-pandemic period: challenges from the perspective of students and faculty

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Abstract

This study examines the critical aspects of remote STEM education in the post-pandemic period, from the perspectives of students and faculty at four European universities. This research was conducted approximately four years after the COVID-19 pandemic began, aiming to evaluate the effectiveness and challenges of remote learning alongside advancements in educational technology and teaching models. Data were collected via structured questionnaires from over five hundred students and almost two hundred faculty members from four European universities. The study focused on *resource availability*, *technical responsiveness*, *training adequacy*, *online assessment feedback*, and *social dynamics*. Results reveal notable discrepancies between student and faculty perceptions regarding both *assessment feedback* and the significance of *student-faculty interactions*. While students viewed timely and detailed feedback as essential to their learning, faculty placed less emphasis on it, prioritizing instead the importance of direct interactions with students, a factor that students themselves considered less critical. Despite these differences, both groups acknowledged the broader challenges to *educational quality* and *academic integrity*. The study also found a general consensus among the universities involved, with no significant gender bias. These findings provide valuable insights for educational policymakers and institutions, helping refine remote teaching strategies and assessment methods to improve the quality and effectiveness of remote STEM education.

Keywords: Remote learning, Remote assessment, STEM education, Post-pandemic education, Questionnaire analysis, Students' experience, Lecturers' perspective

Introduction

The global shift to remote learning, accelerated by the COVID-19 pandemic, has profoundly impacted educational paradigms, particularly within the STEM (science, technology, engineering, and mathematics) disciplines. *Remote learning*, or *remote teaching*, refers to a mode of education where instruction and learning occur entirely at a distance, with no physical contact between teachers and students; interactions are facilitated through digital platforms and communication tools. Unlike *blended* or *hybrid* learning, which combine in-person and online activities, remote learning is characterized by the complete absence of face-to-face interaction. Initially adopted as an emergency solution during the pandemic, it has since evolved into a more structured and strategic approach (Mineshima-Lowe et al., 2024; Rapanta et al., 2021).

Four years after the pandemic, remote learning has transitioned from a temporary measure to a recognized educational option, enriched by advancements in digital tools that have made the experience more engaging and interactive. Today, remote learning is viewed as a high-quality and effective solution, especially when well-organized, offering flexibility and accessibility that complement traditional in-person learning, rather than replacing it (Broadbent et al., 2023).

Faculty and students have significantly increased their awareness and proficiency in remote learning. Numerous digital platforms, equipped with advanced tools, now facilitate customised learning paths that respond to individual student needs, allowing more flexible choices than in the past. Continuous training, both institutional and self-directed, has enabled lecturers to develop advanced skills in using educational technologies (Casadesús et al., 2024; Franceschini & Terzago, 1998; Maisano et al., 2020). Remote learning increasingly complements in-person teaching, with hybrid approaches becoming more common. For instance, digital tools now allow virtual tours of laboratories or research environments, following theoretical in-person lectures, providing access to spaces that are often difficult to visit physically.

Despite the significant progress made within *higher education institutions* (HEIs) worldwide in adapting to remote teaching and assessment methods, critical issues and intrinsic difficulties remain. These challenges continue to raise significant questions about the effectiveness of remote learning in promoting essential educational outcomes, such as knowledge acquisition, critical thinking, problem-solving skills, and collaborative learning (Adot et al., 2023; Iglesias-Pradas et al., 2021; Lockee, 2021; Wang et al., 2021). Remote learning, while offering additional opportunities for students and faculty, has introduced new challenges, including reduced social interactions, emerging technological barriers, and an increased demand for student autonomy in learning (Palvia, et al., 2018). These challenges underscore the necessity of a thorough evaluation of remote learning practices to gauge their effectiveness and identify areas for improvement, aiming to ensure optimal student engagement and learning outcomes (Carter et al., 2020; Guangul et al., 2020).

Research in this area has pinpointed several crucial aspects for the effective implementation of remote learning: student engagement, teaching methodologies, the role of academic staff, and the integration of information technology. Students in remote settings are expected to exert greater control over their learning, utilizing various technology-mediated forms of assessment that serve not only to measure their academic progress but also to enhance their digital literacy (Fidalgo et al., 2020; Ho et al., 2021). However, there remains a substantial gap in understanding how to effectively adapt teaching methodologies to the specificities of remote teaching and assessment (Flores et al., 2022; Gupta et al., 2020). Academic staff certainly play a critical role in the transition to online education, responsible for designing engaging content and employing pedagogical strategies that promote active learning and student participation. At the same time, the role of advanced digital platforms and technologies, which are crucial for delivering and managing remote education, requires further exploration to ensure they are fully integrated with effective teaching practices (Reedy et al., 2021).

The present study, conducted approximately four years after the onset of the pandemic, seeks to systematically investigate the prevailing challenges and to identify potential gaps in remote STEM education, from the dual perspectives of students and faculty members. In particular, it aims to answer the following research questions (RQs):

RQ#1: "What are the current challenges of remote STEM education, as perceived by students and lecturers?";
RQ#2: "What are the main discrepancies between perceptions of students and lecturers regarding the effectiveness of remote learning and assessment?";
RQ#3: "Are there factors—such as university affiliation, class size and gender of the respondents—that significantly influence the answers to the questionnaire?".

This study is an integral part of an ongoing Erasmus + project called "Assessing and evaluating remote learning practices in STEM" (REMOTE), which involves four universities—Universitat de Girona (UdG) from Spain, Politecnico di Torino (PoliTO) from Italy, Universitat Internacional de Catalunya (UIC) from Spain, Universidade do Minho (UMinho) from Portugal—as well as three external agencies for quality assurance in higher education: AQU Catalunya (Spain), ANVUR (Italy), and A3ES (Portugal). The activities conducted so far within the REMOTE project have highlighted several critical aspects of remote teaching and assessment, affecting both students and faculty. Marimon et al. (2024) identified key challenges in assessing students in STEM fields, particularly due to the integration of emerging technologies like Artificial Intelligence, as well as the potential for gender bias in evaluation processes. Through interviews with academic experts in Southern Europe, this study provided valuable insights into regional variations and specific assessment challenges. Similarly, Manatos et al. (2024) explored faculty perceptions of remote learning, emphasizing difficulties in maintaining student engagement, limited interaction between students and instructors, and technological barriers, all informed by interviews with academic experts. Finally, Casadesús et al. (2024) reviewed remote learning practices in STEM, classifying issues into four categories: students, teaching methodologies, faculty, and technologies.

These studies have revealed common challenges, which serve as the foundation for the design and dissemination of structured questionnaires across the aforementioned European partner universities, aimed at illuminating the peculiarities of remote teaching, learning, and assessment experiences, focusing on resource availability, technical responsiveness, training adequacy, remote assessment methods, and social dynamics. A preliminary analysis of the data collected through these questionnaires focuses on identifying significant gaps in remote education, discerning any systematic differences between students' and faculty perceptions, and exploring the impact of various demographic and institutional factors. Data from a relatively large sample of respondents (i.e., several hundred students and lecturers from the four European universities mentioned above) are analysed.

The rest of this article is organized into five sections. Sect. "Methodology" provides a description of the methodology, divided into two parts pertaining to the construction and administration of questionnaires. Sect. "Results" illustrates the results of the student-side and lecturer-side questionnaires, highlighting their similarities and differences. Sect. "Discussion" discusses and interprets the most relevant results, focusing on the key findings and their implications for both students and lecturers. The conclusions (Sect. "Conclusions") then summarize the main findings of the analysis, practical implications, limitations, and insights for future developments. Finally, the appendix contains additional, more detailed material on the questionnaires and the statistical analysis of the corresponding responses.

Methodology

This section is divided into two subsections dedicated respectively to (i) the description of the construction and (ii) the administration of the questionnaires.

Construction of questionnaires

A thorough review of the scientific literature allowed for the identification of a set of fifteen potentially problematic *aspects* (or *constructs*) characterizing remote learning and teaching in STEM fields. These aspects were grouped into five dimensions to facilitate a more practical analysis.

The first dimension addresses *resource availability and accessibility*, with a particular focus on equity of access. The literature highlights that the lack of access to technological resources can significantly impact the educational experience, particularly in the context of online assessments (Rice & Ortiz, 2021; Rodriguez-Ascaso et al., 2017). This issue has been observed not only during the COVID-19 pandemic but also in pre-existing educational settings, especially concerning the digital divide (Botto et al., 2023). The second dimension focuses on *technical responsiveness*, including the stability of digital platforms and the quality of online interactions between students and faculty (Lockee, 2021). The ability to manage technical issues effectively is crucial, as highlighted by various studies analyzing the success of digital platforms in supporting online teaching (Capone & Lepore, 2022; Guangul et al., 2020). The third dimension relates to *training* of lecturers, emphasizing the importance of adequate preparation not only for online teaching but also for managing remote assessments (Martin et al., 2020). A lack of institutional support is frequently cited as a barrier to the effective transition to online learning, with several studies underscoring the need for continuous training in technological tools (Bolliger, 2004; West et al., 2021). The fourth dimension, *online assessment*, represents one of the major challenges in terms of the adequacy of assessment methods and the timeliness of feedback (Panadero et al., 2022). Students have often reported difficulties in receiving prompt and detailed feedback, identifying this as a key concern (Jeong et al., 2020; Sedaghatjou et al., 2023). Finally, the fifth dimension explores *social dynamics*, such as academic integrity and the sense of belonging to the university community. Some studies suggest that online activities may weaken the sense of community by reducing social interaction between peers and faculty (Fidalgo et al., 2020). Academic integrity has also been widely discussed in the literature, with many scholars emphasizing the need for more robust measures to prevent cheating and other forms of academic dishonesty in online exams (Reedy et al., 2021).

Returning to the fifteen aspects/constructs identified, these are detailed in the second column of Table 1. For each aspect, a brief description is provided along with its relevance for students and/or lecturers, and a corresponding reference from the scientific

Table 1 List of aspects/constructs considered potentially problematic, based on a literature review

Dimension	Aspect/Construct	Description	Applicable to (S)	Applicable to (L)	Reference
1. Resource availability and accessibility	1.1 Accessibility to materials	Ease of access to teaching materials from any location	✓		Rodriguez-Ascaso et al., 2017
	1.2 Accessibility to evaluation resources	Ease of access to resources (software and hardware) for an effective online evaluation	✓	✓	Rice & Ortiz, 2021
	1.3 Access equity	Equal access to technological resources for online teaching and assessment	✓	✓	Botto et al., 2023
2. Technical responsiveness	2.1 Connection and web platform adequacy	Technological stability and reliability of online platforms for lectures and exams, in addition to the quality of the Internet connection	✓	✓	Lockee, 2021
	2.2 Student–lecturer interaction	Effectiveness of communication, mutual interaction and support in an online learning context	✓	✓	Capone & Lepore, 2022
	2.3 Technical problem solving	Ability to manage technical problems during online lectures and exams	✓	✓	Guangul et al., 2020
3. Training	3.1 Preparation and training for managing lectures	Preparation and training of lecturers on the use of online technologies to conduct exams and online evaluation		✓	West et al., 2021
	3.2 Preparation for managing the evaluation	Preparation and training of lecturers on the use of online technologies to conduct online exams effectively, including the creation of assessment materials		✓	Martin et al., 2020
	3.3 Institutional support to lecturers	Level of support and assistance provided to lecturers by the institution for online teaching and evaluation		✓	Bolliger, 2004
4. Online assessment	4.1 Adequacy of assessment methods	Adequacy of assessment methods in use to the online context	✓	✓	Panadero et al., 2022
	4.2 Adequacy of evaluation feedback	Promptness and quality of feedback provided to students following exams	✓	✓	Jeong et al., 2020
	4.3 Quality of education	Online activities can undermine the achievement of the expected learning outcomes	✓	✓	Sedaghatjou et al., 2023

Table 1 (continued)

Dimension	Aspect/Construct	Description	Applicable to		Reference
			(S)	(L)	
5. Social dynamics	5.1 Gender diversity	Online activities can for some reason undermine gender equality	✓	✓	González-Gómez et al., 2012
	5.2 Community	Online activities can undermine the sense of belonging to the university community	✓		Fidalgo et al., 2020
	5.3 Academic integrity (honesty, trust, fairness, respect, responsibility)	Extent to which online exams maintain high ethical standards, including anti-fraud measures	✓	✓	Reedy et al., 2021

Some aspects apply to both students (S) and lecturers (L), while others apply to only one of the two respondent parties (see the symbols "✓"). For each aspect/construct, a relevant reference confirming its relevance in the scientific literature is given in the last column.

Table 2 Number of respondents that completed the questionnaires administered at the four European partner universities: Politecnico di Torino (PoliTO), Universitat de Girona (UdG), Universitat Internacional de Catalunya (UIC), and Universidade do Minho (UMinho)

Questionnaire	European universities				Overall
	PoliTO	UdG	UIC	UMinho	
Students (S)	248	137	136	32	**553**
Lecturers (L)	89	18	28	41	**176**

literature. It can be observed that the majority of the aspects are common to both students (S) and lecturers (L), while some are specific to one group or the other.

For each construct, a "triplet" of different *items* (i.e., questions relevant to the construct itself) was formulated (e.g., items 1.1.1, 1.1.2 and 1.1.3 for construct 1.1). This sort of redundancy is intended to provide robustness to the results of the study, as illustrated in greater detail in Sect. "Pre-processing". The responses to each item are expressed on a 7-level scale with increasing direction in terms of gap (the higher the level, the wider the gap). The constructs were developed separately for student and lecturers. Each questionnaire has an initial part of demographic information, which is here omitted for simplicity. Table 7 and Table 8 (in Sect. A.1, in the appendix) show the items of both the questionnaires. Even for the several overlapping aspects/constructs in the two questionnaires (cf. the last two columns of Table 1), the items were customised to suit the respective target populations.

Administration of questionnaires

Both questionnaires were administered to the four partner universities of the REMOTE project and each university identified appropriate samples of lecturers and students. The questionnaires were administered through the LimeSurvey® platform in the month of February 2024. Table 2 shows the number of respondents who completed the relevant questionnaires. Some disparities in participation can be observed, partly commensurate with the size of the universities involved, and partly related to other contingent factors (e.g., dissemination channels used, respondents' sensitivity, etc.). In general, the overall number of respondents can be considered in line with expectations and acceptable for the intended statistical analysis (Franceschini et al., 2022; Ross, 2017). Documents containing the complete responses to the questionnaires are available upon request to the authors.

Results

This section provides a detailed description of the questionnaire results, divided into three subsections. The first subsection outlines the preliminary processing applied to the questionnaire results to enhance their robustness; the second focuses on the results of the student questionnaire, while the third concentrates on the results of the lecturer questionnaire.

Pre-processing

For each of the two questionnaires, the responses provided by individual respondents underwent two preliminary processing steps:

1.Aggregation of the answers (expressed on a discrete rating scale from 1 to 7) of each triplet of items referring to the same aspect/construct, through the median operator.

For example, assuming that a certain respondent gives the following answers to a certain triplet of items:

$$\text{Item } 1.1.1 \rightarrow 6, \text{ Item } 1.1.2 \rightarrow 7, \text{ and Item } 1.1.3 \rightarrow 4, \tag{1}$$

the median associated with aspect/construct 1.1 will be 6. This aggregation gives robustness to the results, filtering out possible outliers. We note that the 7-level rating scale for responses to each item is *ordinal* and should be treated as such when selecting appropriate measures of central tendency and dispersion, avoiding undue scale "promotions", such as those to cardinal scales with *interval* or *ratio* properties (De Vellis, 2017). In this sense, the median is a central tendency indicator compatible with the *ordinal* scale properties of ratings (Franceschini et al., 2022).

This type of aggregation assumes that the items in each triplet represent different interchangeable and redundant variations of the same aspect; therefore, it is expected that the ratings assigned by a respondent will be reasonably close to each other (i.e., concept of low variability *within* triplets). This condition can also be used as an indirect measure of the reliability of an individual questionnaire.[1] To verify this condition, an indicator of dispersion within the respective triplet was determined for each aspect; this indicator is given by the *range* of the ratings of the triplet's items, calculated as the difference between the maximum and minimum values (Ross, 2017). Subsequently, the mean range for each aspect was calculated based on the results obtained from each respondent, as reported in Table 3. It can be seen that the mean ranges of all aspects, with reference to both questionnaires, are relatively low (i.e., always lower than 2 units, except in

[1] High variability *within* triplets could, in fact, indicate that some items were misunderstood or that answers were given without due concentration. Therefore, it is useful to monitor this type of variability.

Table 3 Mean ranges within the triplets of items related to each aspect, for both the student-side (S) and lecturer-side (L) questionnaires

Aspect/Construct	Mean range within triplets	
	(S)	(L)
1.1	1.4	N/A
1.2	1.4	1.7
1.3	1.9	1.3
2.1	1.6	1.5
2.2	1.5	1.6
2.3	1.6	1.4
3.1	N/A	1.2
3.2	N/A	0.9
3.3	N/A	1.2
4.1	1.6	1.2
4.2	1.7	1.4
4.3	1.7	1.7
5.1	2.1	1.2
5.2	1.3	N/A
5.3	1.9	1.8
Grand average	1.6	1.4

Table 4 Example of transforming (median) ratings into ranks

Aspect/construct	(Median) rating	Rank
1.1	2	4
1.2	3	8.5
1.3	1	1
2.1	4	11
2.2	3	8.5
2.3	2	4
4.1	2	4
4.2	3	8.5
4.3	3	8.5
5.1	2	4
5.2	5	12
5.3	2	4

The ranking in Eq. 2 can be converted into the specific ranks reported in the last column

one case), confirming a relatively contained variability within triplets. Additionally, the results of the lecturer questionnaire tend to be less dispersed than those of the student questionnaire (cf. the grand average values of 1.6 and 1.4, respectively, in the lower part of Table 3). This result can be considered as an indirect verification of the reliability of the questionnaire responses collected.

2.Transformation of the (median) ratings for all aspects/constructs of the questionnaire into a single ranking and, subsequently, association of a rank with each aspect/construct.

With reference to the ratings exemplified in the second column of Table 4, the following ranking would be obtained:

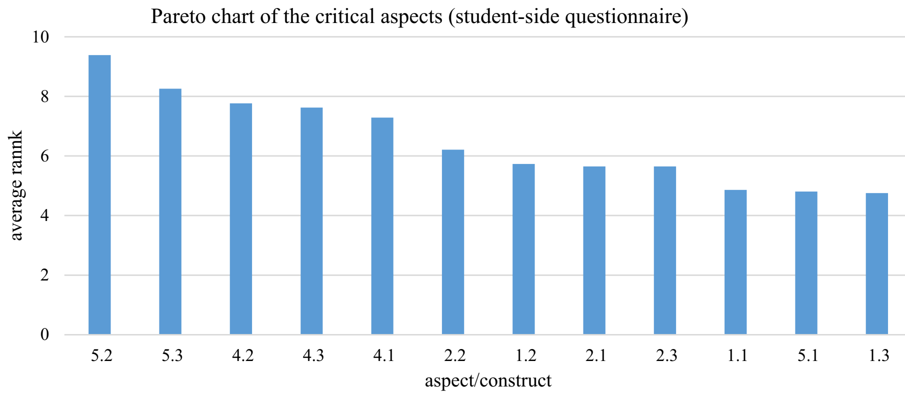


Fig. 1 Pareto chart relating to the results of the student-side questionnaire. The aspects/constructs are sorted in decreasing order in relation to the average values of the response variable (rank) for the aspect/construct of interest. The corresponding numerical values are shown in the "Overall" column of Table 5

$$1.3 \prec (1.1 \sim 2.3 \sim 4.1 \sim 5.1 \sim 5.3) \prec (1.2 \sim 2.2 \sim 4.2 \sim 4.3) \prec 2.1 \prec 5.2, \tag{2}$$

where the symbol "$\prec$" means "*less critical than*", and the symbol "$\sim$" means "*equivalent to*". So, aspects/constructs are ranked in order of increasing *criticality* (understood as the width of the gap).

The rank of the individual aspects/constructs within the ranking is then determined, i.e., their relative position (e.g., 1st, 2nd, 3rd); if several values have the same rank (i.e., they are tied in the ranking), the so-called *mean rank* is conventionally used (Franceschini et al., 2022). The resulting rank of each aspect/construct are used as a variable of interest for subsequent analyses. The transformation of questionnaire ratings into ranks was introduced to facilitate comparability between the results of different questionnaires. [2] Although with some adaptations, this approach is widely used and well-known in the scientific literature as the *Borda's count* (Franceschini et al., 2022). The last column of Table 4 presents the (mean) ranks of the aspects/constructs of interest, ad determined by the ranking defined in Eq. 2.

Student-side questionnaire

Focusing on the results of the student-side questionnaire, Fig. 1 illustrates the Pareto diagram relating the mean values of the variable of interest, i.e., the relative rank of the aspects/constructs of interest, depicting their severity for the respondents (cf. Sect. "Pre-processing").

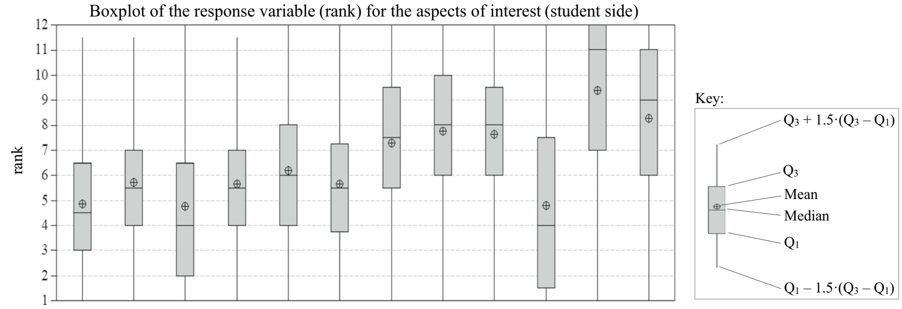
Questionnaire results were statistically analysed to understand the distributions of the variable of interest for each of the twelve aspects/constructs. Figure 2 presents the box plots and a statistical summary of these distributions. Noticeable differences in central tendency emerge among some distributions. For instance, let us consider the

[2] Rating scales may be used subjectively, as there is no absolute reference shared by all respondents. For example, let us consider the seven-level ordinal scale representing the width of a gap: very low, low, moderately low, intermediate, moderately high, high, and very high; "indulgent" respondents tend to assign higher levels whereas "severe" respondents tend to assign lower ones. For this reason, it could be questionable to aggregate ratings by different respondents through indicators of central tendency.

Table 5 Summary of the student-side questionnaire results

Aspect/Construct	European universities				Overall
	PoliTO	UdG	UIC	UMinho	
1.1	4.8	5.0	4.9	4.9	4.9
1.2	5.7	5.6	5.7	6.4	5.7
1.3	4.7	4.6	4.7	6.4	4.8
2.1	5.9	5.3	5.5	6.0	5.6
2.2	6.3	6.1	6.2	6.1	6.2
2.3	5.4	5.6	6.0	6.0	5.6
4.1	7.5	7.2	6.9	7.3	7.3
4.2	7.9	7.9	7.7	6.8	7.8
4.3	7.2	7.9	8.1	7.4	7.6
5.1	4.1	5.3	5.7	4.3	4.8
5.2	10.3	8.9	8.4	8.4	9.4
5.3	8.1	8.6	8.2	7.8	8.3

The table shows average values of the response variable (rank) for the aspects/constructs of interest, both at an overall level and at a university-disaggregated level. "PoliTO" stands for Politecnico di Torino, "UdG" stands for Universitat de Girona, "UIC" stands for Universitat Internacional de Catalunya, and "UMinho" stands for Universidade do Minho. The 553 respondents are allocated to the four university as follows: 248 in "PoliTO" (44.8%), 137 in "UdG" (24.8%), 136 in "UIC" (24.6%), and 32 in "UMinho" (5.8%)



Aspect	1.1	1.2	1.3	2.1	2.2	2.3	4.1	4.2	4.3	5.1	5.2	5.3
Mean	4.9	5.7	4.8	5.6	6.2	5.6	7.3	7.8	7.6	4.8	9.4	8.3
St. dev.	2.6	2.5	3.0	2.4	2.7	2.6	2.8	2.8	2.7	3.5	3.0	2.9
Q_1	3	4	2	4	4	3.75	5.5	6	6	1.5	7	6
Median	4.5	5.5	4	5.5	6	5.5	7.5	8	8	4	11	9
Q_3	6.5	7	6.5	7	8	7.25	9.5	10	9.5	7.5	12	11
Mode	4	6	1.5	6.5	6	6	9.5	9.5	9.5	1	12	11
Min	1	1	1	1	1	1	1	1	1	1	1	1
Max	12	12	12	12	12	12	12	12	12	12	12	12
N	553	553	553	553	553	553	553	553	553	553	553	553

Fig. 2 Boxplot of the response variable (rank) for the aspects/constructs of the student-side questionnaire. Q_1 and Q_3 respectively denote the first and third quartiles of the distributions; N is the total number of respondents. The analysis was carried out using Minitab® statistical software

distributions for aspects 1.1 and 4.2, shown in Fig. 13 (in Sect. A.2, in the appendix). Both distributions are asymmetric: aspect 1.1 is right-skewed with a central tendency shifted to the left (mean value ≈4.9), while aspect 4.2 is left-skewed with a central tendency shifted to the right (mean value ≈7.8). This indicates significant differences in central tendency among (at least some of) the distributions. Therefore, the Pareto diagram in Fig. 1 can be useful in distinguishing between the aspects generally perceived as more critical and those seen as less critical by the respondents. The results of the Mood's test, which examines the equality of medians across various populations, confirm the aforementioned observations (see Sect. A.3, in the appendix).

Based on the above considerations, it seems reasonable to rank the criticality of the analyzed aspects/constructs using central tendency indicators. Returning to the Pareto diagram in Fig. 1, it is helpful in identifying the most critical constructs overall: *community* (5.2), *academic integrity* (5.3), *adequacy of evaluation feedback* (4.2), *quality of education* (4.3), and *adequacy of assessment methods* (4.1).

Further analysis investigated the effect of university affiliation on the questionnaire responses. The data disaggregated by university in Fig. 3 confirm the general trend with minimal variations, suggesting a reasonable level of consensus among respondents, regardless of their institution. This conclusion is supported quantitatively by the relatively high Pearson product-moment correlation coefficients in Fig. 15—(cf. Sect. A.3, in the appendix).

Another factor analysed is the class size (i.e., approximate number of students) that each respondent experienced during their remote learning. Four categories were defined: "< 50", "50 to 100", "101 to 150", and "> 150". The Pareto chart in Fig. 4 disaggregates the overall data by class size, highlighting only minor variations across the categories. There does not appear to be any direct monotonic relationship between class size and the criticality of the aspects (i.e., no consistent increasing or decreasing trend is observed between class size and the responses considered). In Sect. "Interpretation from the students' perspective" a practical interpretation of this result is given.

Besides the fact that remote learning/assessment is not considered critical in terms of gender differences (aspect 5.1), it is interesting to investigate whether there are systematic differences in the responses provided by respondents of different genders. The absence of evidence of a significant gender effect in the responses suggests that remote learning issues may affect all students, regardless of gender (see Fig. 5). Furthermore, for the student-side questionnaire, nearly equal percentages of female and male respondents were recorded, with 46.5% (269 respondents) and 53.5% (284 respondents), respectively. Confirming the high similarity of responses provided by

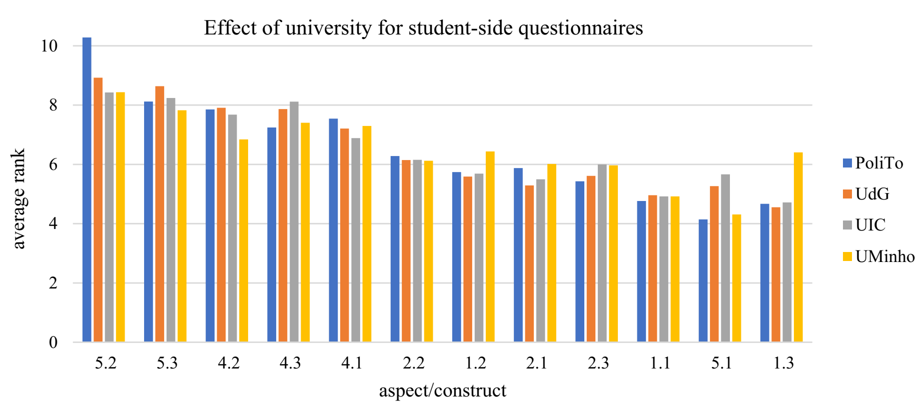


Fig. 3 Pareto chart illustrating the effect of university on the average rank resulting from the student-side questionnaires. Aspects/constructs are ordered in descending order with respect to the "Overall" values in the last column of Table 5. "PoliTO" stands for Politecnico di Torino, "UdG" stands for Universitat de Girona, "UIC" stands for Universitat Internacional de Catalunya, and "UMinho" stands for Universidade do Minho. The 553 respondents are allocated to the four university as follows: 248 in "PoliTO" (44.8%), 137 in "UdG" (24.8%), 136 in "UIC" (24.6%), and 32 in "UMinho" (5.8%)

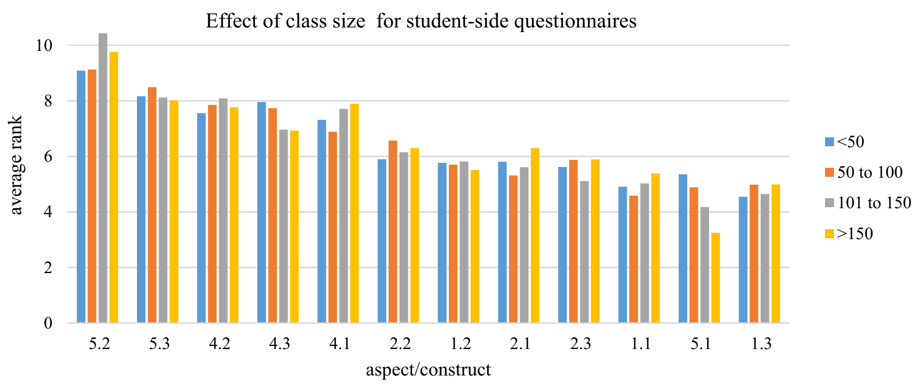


Fig. 4 Pareto chart illustrating the effect of class size on the average rank resulting from the student-side questionnaires. Aspects/constructs are reported in descending order with respect to the "Overall" values in the last column of Table 9 (see Sect. A.2, in the appendix). The 553 respondents are allocated to the four class-size categories as follows: 219 in "< 50" (39.6%), 192 in "50 to 100" (34.7%), 92 in "101 to 150" (16.6%), and 50 in "> 150" (9%)

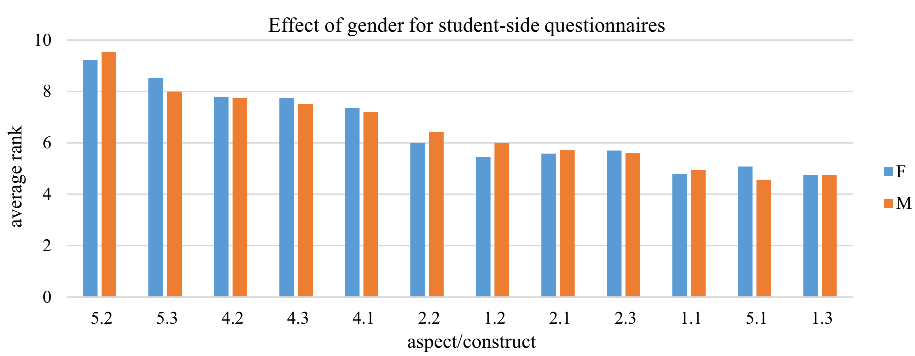


Fig. 5 Pareto chart investigating the effect of gender on the average rank resulting from the student-side questionnaires. Aspects/constructs are reported in descending order with respect to the "Overall" values in the last column of Table 11 (in Sect. A.2, in the appendix). The 553 respondents are allocated to the two gender categories as follows: 269 are female (46.5%) and 284 are male (53.5%)

respondents of different genders, the Pearson product-moment correlation coefficient relative to the mean ranks of each aspect is close to 1 (i.e., 0.975).

Lecturer-side questionnaire

A similar study to the one conducted with the student-side questionnaire was performed with the questionnaire administered to lecturers. Figure 6 illustrates the Pareto diagram, which shows that, on the lecturer side, the aspects perceived as most problematic in general are *student–lecturer interaction* (2.2), *quality of education* (4.3), *preparation for managing the evaluation* (3.2), and *academic integrity* (5.3). Notably, aspect 2.2 has relatively little criticality on the student side (cf. Figure 1); on the other hand, the aspect of *adequacy of evaluation feedback* (4.2), while critical on the student side, is not critical on the lecturer side. Sect. "Interpretation from the lecturers' perspective" revisits these results, offering a discussion and interpretation of the differences observed between the perspectives of students and lecturers.

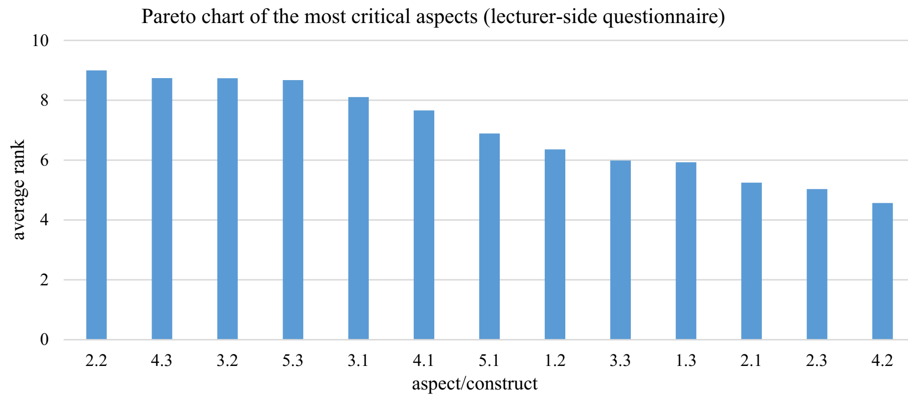


Fig. 6 Pareto chart of the most critical aspects resulting from the lecturer-side questionnaires. Aspects/constructs are ordered in descending order with respect to the "Overall" values in the last column of Table 6

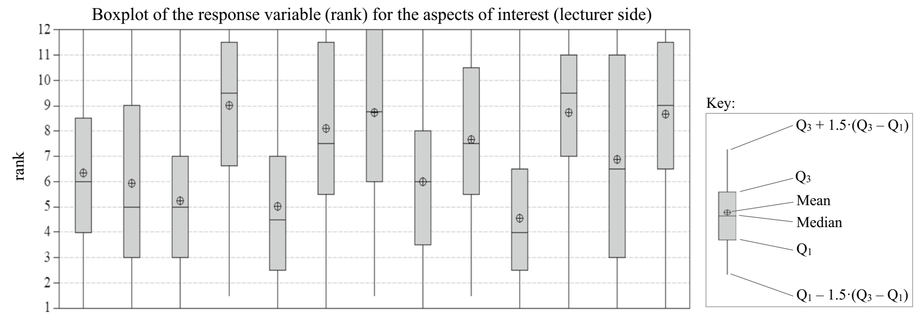
Table 6 Summary of the lecturer-side questionnaire results

Aspect/Construct	European universities				Overall
	PoliTO	UdG	UIC	UMinho	
1.2	6.5	5.1	6.1	6.7	6.4
1.3	5.7	7.1	5.2	6.5	5.9
2.1	5.0	4.8	5.4	5.9	5.2
2.2	9.3	8.1	8.2	9.3	9.0
2.3	4.5	5.4	4.9	6.1	5.0
3.1	8.4	7.5	8.3	7.5	8.1
3.2	8.8	9.1	9.3	8.1	8.7
3.3	5.5	5.6	6.7	6.7	6.0
4.1	8.0	7.9	6.8	7.5	7.7
4.2	4.7	4.7	4.7	4.0	4.6
4.3	9.2	8.4	8.6	8.0	8.7
5.1	7.3	7.5	6.3	6.0	6.9
5.3	8.0	9.9	10.1	8.8	8.7

The table shows average values of the response variable (rank) for the aspects/constructs of interest, both at an overall level and at a university-disaggregated level. "PoliTO" stands for Politecnico di Torino, "UdG" stands for Universitat de Girona, "UIC" stands for Universitat Internacional de Catalunya, and "UMinho" stands for Universidade do Minho. The 176 respondents are allocated to the four university as follows: 89 in "PoliTO" (50.6%), 18 in "UdG" (10.2%), 28 in "UIC" (49.3%), and 41 in "UMinho" (23.3%)

Figure 7 presents the box plots and a statistical summary of the rank distributions for each of the thirteen aspects/constructs of the lecturer-side questionnaire. Significant differences among distributions can be observed, at least in terms of central tendency indicators. For instance, it seems reasonable to state that aspects 2.2 and 4.3 are generally perceived as more critical by the respondents compared to aspects 2.1 and 2.3. These significant differences are confirmed by the results of Mood's median test (see Fig. 18 in Sect. A.2, in the appendix).

Further analysis investigated the effect of university affiliation on the questionnaire responses. The data disaggregated by university seem to confirm the overall trend with only minor variations (in Fig. 8), suggesting a good degree of agreement among respondents, regardless of their university. This conclusion is supported quantitatively



Aspect	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.3
Mean	6.4	5.9	5.2	9.0	5.0	8.1	8.7	6.0	7.7	4.6	8.7	6.9	8.7
St. dev.	3.2	3.4	2.7	3.1	3.0	3.4	3.3	2.9	3.1	2.9	2.8	4.2	3.1
Q_1	4	3	3	6.625	2.5	5.5	6	3.5	5.5	2.5	7	3	6.5
Median	6	5	5	9.5	4.5	7.5	8.75	6	7.5	4	9.5	6.5	9
Q_3	8.5	9	7	11.5	7	11.5	12	8	10.5	6.5	11	11	11.5
Mode	4.5	2.5~3	4.5	13	3	12.5	12.5	2.5~3	7.5	3	11	1.5	11.5
Min	1	1	1	1.5	1	1	1.5	1	1.5	1	1	1	1
Max	13	13	12.5	13	13	13	13	13	13	12.5	13	13	13
N	176	176	176	176	176	176	176	176	176	176	176	176	176

Fig. 7 Boxplot of the response variable (rank) for the aspects/constructs of the lecturer-side questionnaire. Q_1 and Q_3 respectively denote the first and third quartiles of the distributions; N is the total number of respondents. The analysis was carried out using Minitab® statistical software

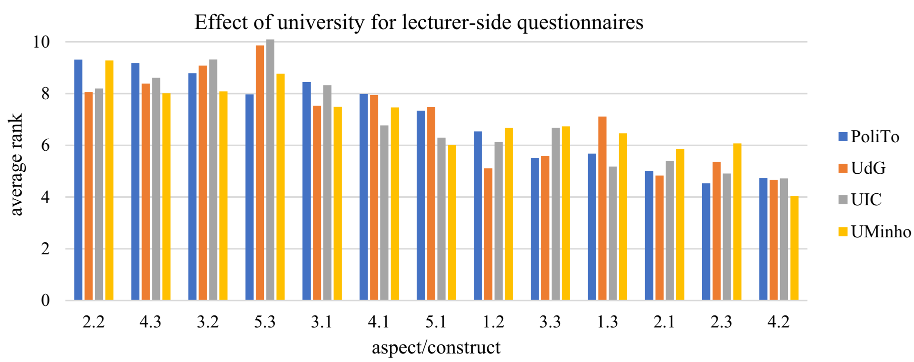


Fig. 8 Pareto chart illustrating the effect of university on the average rank resulting from the lecturer-side questionnaires. Aspects/constructs are ordered in descending order with respect to the "Overall" values in the last column of Table 6. "PoliTO" stands for Politecnico di Torino, "UdG" stands for Universitat de Girona, "UIC" stands for Universitat Internacional de Catalunya, and "UMinho" stands for Universidade do Minho. The 176 respondents are allocated to the four university as follows: 89 in "PoliTO" (50.6%), 18 in "UdG" (10.2%), 28 in "UIC" (49.3%), and 41 in "UMinho" (23.3%)

by the relatively high Pearson product-moment correlation coefficients in Fig. 16 (see Sect. A.3, in the appendix).

As done for the student-side analysis, the Pareto chart in Fig. 9 disaggregates the overall data by class size, highlighting only minor variations across the categories. The impression of the class-size factor having no significant effect is further supported quantitatively by the relatively high Pearson product-moment correlation coefficients in Fig. 19 (see Sect. A.3, in the appendix), which indicate a strong agreement in the responses across different class-size categories of respondents.

Similarly to the student-side analysis, the results for lecturers show no significant gender effect, although the percentages of female and male respondents differ to a greater extent (34.1% and 65.9%, respectively). The Pareto diagram in Fig. 10

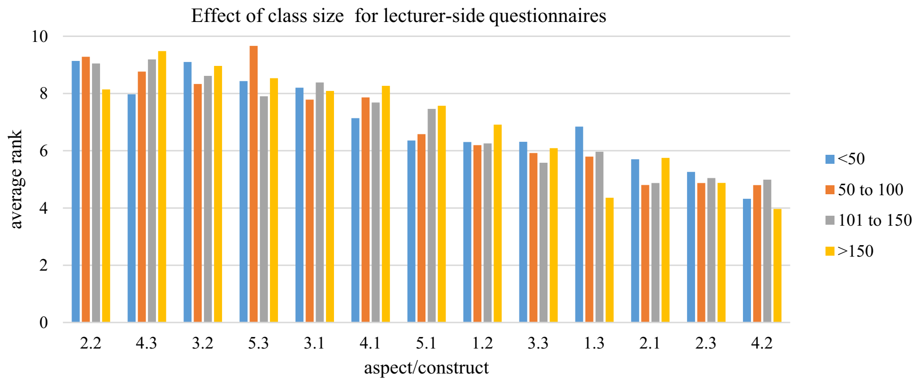


Fig. 9 Pareto chart illustrating the effect of class size on the average rank resulting from the lecturer-side questionnaires. Aspects/constructs are ordered in descending order with respect to the "Overall" values in the last column of Table 10. The 176 respondents are allocated to the four class-size categories as follows: 54 in "< 50" (30.7%), 51 in "50 to 100" (29.0%), 43 in "101 to 150" (24.4%), and 28 in "> 150" (15.9%)

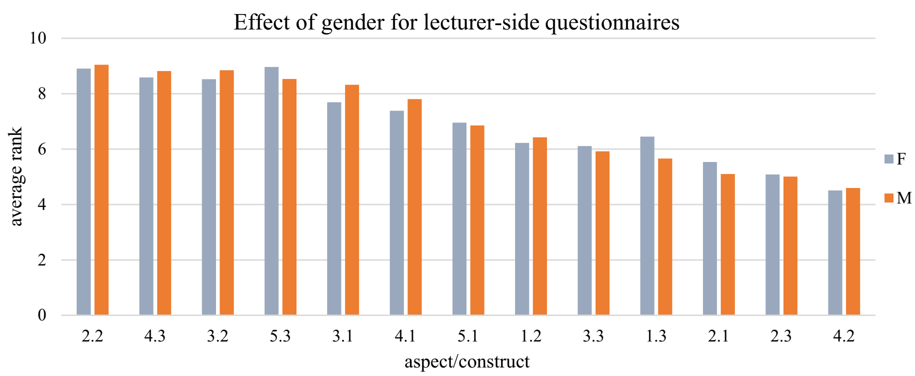


Fig. 10 Pareto chart illustrating the effect of gender on the average rank resulting from the lecturer-side questionnaires. Aspects/constructs are ordered in descending order with respect to the "Overall" values in the last column of Table 12 (in Sect. A.2, in the appendix). The 176 respondents are allocated to the two gender categories as follows: 60 are female (34.1%) and 116 are male (65.9%)

illustrates the results, which are confirmed by the relatively high Pearson product-moment correlation coefficient (0.973) relative to the gender-disaggregated mean ranks (see Sect. A.2, in the appendix).

An additional factor analysed is the academic position of the respondents, for which three categories are defined: "assistant professor", "associate professor", and "full professor". The Pareto diagram in Fig. 11, which disaggregates the data by academic title, shows relatively contained fluctuations in terms of mean rank for the thirteen aspects of interest. This general similarity by respondents from the three categories is also confirmed by the relatively high Pearson product-moment correlation coefficients in Fig. 20 (see Sect. A.3, in the appendix).

Discussion

This section expands on and interprets the previous results (see Sect. "Results") and is structured in three subsections concerning: (i) the interpretation of the most relevant findings from the students' perspective, (ii) the interpretation of the most relevant

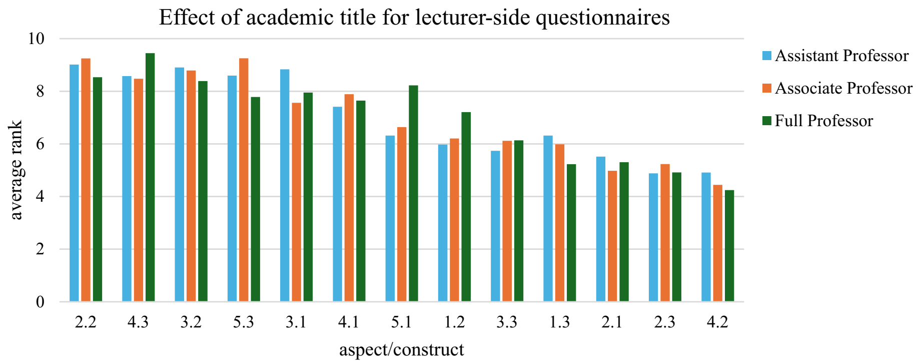
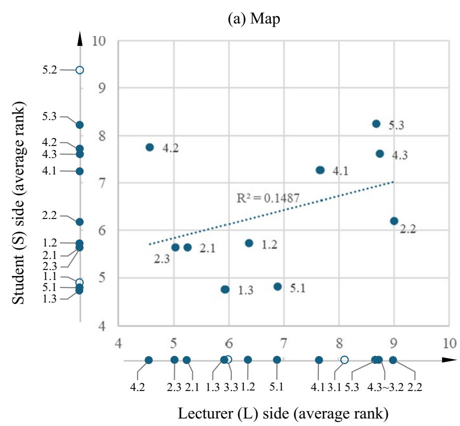


Fig. 11 Pareto chart illustrating the effect of academic title on the average rank resulting from the lecturer-side questionnaires. Aspects/constructs are ordered in descending order with respect to the "Overall" values in the last column of Table 13. The 176 respondents are allocated to the three academic-title categories as follows: 63 in "assistant professor" (35.8%), 72 in "associate professor" (40.9%), and 41 in "full professor" (23.3%)



(b) Data

Aspect / Construct	(Average) Rank S	L
1.1 Accessibility to materials	4.9	N/A
1.2 Accessibility to evaluation resources	5.7	6.4
1.3 Access equity	4.8	5.9
2.1 Connection and web platform adequacy	5.6	5.2
2.2 Student-lecturer interaction	6.2	9.0
2.3 Technical problem solving	5.6	5.0
3.1 Preparation and training for managing lectures	N/A	8.1
3.2 Preparation for managing the evaluation	N/A	8.7
3.3 Institutional support to lecturers	N/A	6.0
4.1 Adequacy of assessment methods	7.3	7.7
4.2 Adequacy of evaluation feedback	7.8	4.6
4.3 Quality of education	7.6	8.7
5.1 Gender diversity	4.8	6.9
5.2 Community	9.4	N/A
5.3 Academic integrity (honesty)	8.3	8.7

● Aspects/constructs applicable to both S and L sides
○ S/L side-specific aspects/constructs

Fig. 12 Map of the positioning of the aspects/constructs analysed, from the dual perspective of students (vertical axis) and lecturers (horizontal axis). Only the aspects/constructs applicable to both respondent counterparts are considered in the map, while all are considered in the relative axes (cf. Table 1). The numerical values are the "Overall" ones from Table 5 and Table 6 respectively, which represent the average values of the response variable (i.e., rank) for the aspects/constructs of interest

findings from the lecturers' perspective, and (iii) the analysis of commonalities and differences in the perceptions of remote STEM education between students and lecturers, highlighting potential practical implications.

Before addressing the discussion, the two-dimensional map in Fig. 12 is presented, offering a quick and intuitive visualisation of the questionnaire results from the perspective of the students (vertical axis) and the lecturers (horizontal axis).

Interpretation from the students' perspective

Analyzing the results from the students' perspective (vertical axis of Fig. 12), five aspects are considered particularly critical, with average rank values higher than 7 (cf. RQ#1 "*What are the current challenges of remote STEM education, as perceived by students and lecturers?*").

Among these, two belong to the *social dynamics* (5) dimension: sense of *community* (5.2) and *academic integrity* (5.3). The pandemic experience seems to have left a certain sense of isolation among the students, not only because of the lack of interaction with teachers but especially with peers. Interactions are in fact essential for both personal and academic growth during university, which extends beyond mere "passive" dissemination of knowledge and skills (Fidalgo et al., 2020; Wilcox et al., 2005). Moreover, academic integrity remains a common concern in the context of online exams (Reedy et al., 2021).

Other critical aspects also stand out, particularly those related to the *online assessment* (4) dimension: *adequacy of assessment methods* (4.1), *adequacy of evaluation feedback* (4.2), and *quality of education* (4.3). These results are consistent with the literature, which emphasizes that students view assessment and feedback as weaknesses in remote learning, especially in technical and scientific contexts (Jeong et al., 2020; Sedaghatjou et al., 2023). The increased autonomy required in these environments may generate uncertainty among students, particularly when assessment methods are not clearly adapted to the online setting.

At more granular levels of aggregation, where the results were analysed, no substantial differences were observed for any of the three factors analysed: university affiliation, class size or gender of the respondents (cf. RQ#3 "*Are there factors—such as university affiliation, class size, and gender of respondents—that significantly influence the answers to the questionnaire?*"). One possible explanation for the uniformity across university institutions could be the relative similarity in approaches and platforms used for online teaching and assessment (e.g., MS Teams, Google Classroom, Zoom, Moodle, Respondus, etc.). Similarly, online education does not appear to negatively impact large classes in terms of *student–lecturer interaction* (2.2). This may be due to the interaction tools available on remote-learning platforms (e.g., public/private chats for student discussions, dedicated Q/A sessions, etc.), which paradoxically mitigate some of the inherent limitations of traditional in-person teaching in large classes (Capone & Lepore, 2022; Maisano et al., 2023). In general, the impression that class size has no significant effect is further supported by the relatively high Pearson product-moment correlation coefficients shown in Fig. 15 (Sect. A.3, in the appendix), indicating a strong alignment in responses across different class-size categories.

Additional insights emerge from the analysis of optional comments provided by students. Many highlighted the absence of a perceived gender disparity in remote teaching and assessment, suggesting that *gender diversity* (5.1) is not particularly relevant in this context. Furthermore, several students confirmed the critical role of social aspects, lamenting the reduction in student interactions and the sense of belonging to the university *community* (5.2). Technical issues related to new technologies and online platforms were perceived as temporary and isolated inconveniences, confirming the relatively low impact of the *technical responsiveness* (2) dimension, which includes aspects such as *connection and web platform adequacy* (2.1), *student–lecturer interaction* (2.2), and *technical problem-solving* (2.3). These observations reinforce the quantitative findings of this study. Paradoxically, some students expressed dissatisfaction with the return to fully in-person teaching, preferring a hybrid model with asynchronous access to video lectures. Finally, concerns were raised regarding the adaptation of technical-scientific teaching in laboratory settings, with mixed opinions about the feasibility of conducting practical activities remotely.

Interpretation from the lecturers' perspective

From the lecturers' perspective (horizontal axis of Fig. 12), five aspects are perceived as highly critical, with average ranks exceeding 8 (cf. RQ#1 "*What are the current challenges of remote STEM education, as perceived by students and lecturers?*"). The most problematic one is *student–lecturer interaction* (2.2). One possible explanation for this concern is that lecturers often assess the effectiveness of their teaching based on immediate student feedback, adjusting their approach in real time according to questions and doubts raised during lessons. While online platforms allow for some degree of interaction, real-time feedback tends to diminish in remote teaching environments, leaving a gap compared to in-person teaching (Capone & Lepore, 2022).

Other problematic aspects include *academic integrity* (5.3), *quality of education* (4.3), and *adequacy of assessment methods* (4.1), which were also considered critical by students. Additionally, lecturers highlighted concerns regarding their *preparation for managing the evaluation* (3.2), reporting difficulties in mastering remote assessment techniques. This could be attributed to the fact that, during the pandemic, universities primarily focused on ensuring the continuity of teaching, leaving assessment methods largely to the discretion of individual lecturers (Rapanta et al., 2020).

At more granular levels of aggregation where the results were analyzed, no substantial differences were observed for any of the three factors: university affiliation, class size, or gender of respondents. However, it is noteworthy that some senior lecturers (*full professors*) tend to differ slightly from their junior counterparts, suggesting a possible generational effect on perceptions. This observation aligns with previous studies, which have identified greater resistance to adopting new technologies among older lecturers (King & Boyatt, 2015).

Free-form comments from lecturers reinforce some of these points: many expressed a preference for a hybrid model that includes asynchronous video lectures, emphasizing their usefulness in emergency situations. Additionally, several lecturers highlighted the need for greater technological support from universities, particularly regarding hardware. The challenges of teaching and assessing group-based technical and practical activities were also frequently noted, especially in remote teaching contexts (cf. aspect 3.2).

Similarities and differences between students and lecturers: practical implications

Comparing the results from students and lecturers using the map in Fig. 12 (cf. RQ#2 "*What are the main discrepancies between students' and lecturers' perceptions regarding the effectiveness of remote learning and assessment?*"), no significant correlation ($R^2 \approx 15\%$) emerges between the two respondent groups, indicating that the two populations perceive remote teaching in complementary ways, reflecting their distinct responsibilities and modes of interaction. Both groups agree on the importance of *quality of education* (4.3) and *academic integrity* (5.3), sharing concerns about the management of online exams and the overall effectiveness of remote teaching, particularly in STEM fields. However, significant differences arise in two areas: the *adequacy of evaluation* *feedback* (4.2) and *student–lecturer interaction* (2.2). While students place great emphasis on detailed and timely feedback, lecturers are more focused on direct interaction with students. This reflects the different perspectives of the two groups: students, in a more autonomous learning environment, heavily depend on clear feedback to track their progress, while lecturers see the lack of interaction as a barrier to effective teaching.

These divergences suggest that educational institutions should strengthen mechanisms for timely and detailed feedback, potentially by implementing automated tools or ensuring regular points of contact between lecturers and students. At the same time, there is a need to improve student–lecturer interaction, perhaps by integrating interactive sessions, live Q&A, or virtual office hours. Additionally, enhancing online assessment procedures is crucial, both by providing targeted training for lecturers to increase their proficiency and by implementing methods that ensure clearer, more efficient evaluation processes for students. In the subsequent phases of the REMOTE project, the results of this questionnaire-based analysis will be submitted to educational experts from the participating universities to gather more targeted suggestions for further improvement initiatives.

Conclusions

This research was conducted under the EU-funded project REMOTE, exploring the most significant challenges currently facing remote teaching and assessment, from the dual perspectives of students and lecturers. The initial phase of the analysis involved the design of two questionnaires to probe potentially critical aspects of remote education, identified through an extensive review of the scientific literature. With the collaboration of all project partners (i.e., universities and agencies for quality assurance), these aspects were pinpointed, leading to the implementation of the questionnaire via the LimeSurvey® online platform. Subsequently, questionnaires were distributed across the four European universities involved in the project. Respondent samples varied in size due to inevitable differences in the number of faculty and students and other contingent factors (e.g., promotional activities, questionnaires issued during vacation periods, exam sessions, or other potentially challenging times for respondents, etc.). Nevertheless, an acceptable overall sample size was achieved, including more than five hundred students and nearly two hundred faculty members. In addition, it is worth noting that the questionnaire ratings were transformed into corresponding ranks, which were then used as response variables; this approach prevented (i) inappropriate *promotions* of scale properties (from *ordinal* to *cardinal*) of data, and (ii) questionable comparisons between respondents using somewhat heterogeneous rating scales (Franceschini et al., 2022).

The analysis of the questionnaire results revealed that the most problematic aspects of online teaching and assessment for students include *sense of belonging to the university community* (5.2), *academic integrity* (5.3), *adequacy of evaluation feedback* (4.2), *quality of education* (4.3), and *adequacy of assessment methods* (4.1). On the other hand, the most critical issues for lecturers are *student–lecturer interaction* (2.2), *quality of education* (4.3), *preparation for managing the evaluation* (3.2), and *academic integrity* (5.3) (cf. RQ#1 "*What are the current challenges of remote STEM education, as perceived by students and lecturers?*"). Interestingly, both students and lecturers identified *quality of education* (4.3) and *academic integrity* (5.3) as among the most critical aspects. However, discrepancies between the two groups were noted: students considered *adequacy of evaluation feedback* (4.2) more relevant, while lecturers found it less critical; conversely, lecturers perceived *student–lecturer interaction* (2.2) as more critical than students (cf. RQ#2 "*What are the main discrepancies between perceptions of students and lecturers regarding the effectiveness of remote learning and assessment?*").

A relevant aspect of the analysis is the general agreement found among the partner universities involved in the questionnaires, which span diverse geographic and cultural realities; this lends a certain generality to the results obtained. Furthermore, a substantial absence of gender bias was observed in the questionnaire responses, both among students and lecturers. Additionally, no substantial differences were noted by the respondents regarding other factors, such as class size (in terms of the average number of students), for both student and lecturer respondents, and academic position, for lecturer respondents (cf. RQ#3 "*Are there factors—such as university affiliation, class size and gender of the respondents—that significantly influence the answers to the questionnaire?*").

The results of the quantitative analysis of the questionnaires were supported by the open-ended comments from respondents. Notably, both students and lecturers expressed a significant reluctance to return to 100% in-person teaching, preferring not to forgo the typical tools of remote teaching and assessment (e.g., video lectures, online assessment platforms, etc.). They instead wish for some tools to remain available as needed for both lecturers and students. Another interesting aspect that emerged from the lecturer-side questionnaires is the ambivalent relationship with remote learning when applied to technical laboratories: while some respondents view it as a valuable additional resource, others find it challenging, if not impossible, to conduct practical activities that are usually done in person.

Regarding the outcomes of this research, the debate will continue within the REMOTE project, involving experts and high-profile individuals from the academic world. It will also be interesting to consider the perspective of the agencies for quality assurance, to understand their interpretation of the results. The focus may also broaden to include collateral phenomena such as the rise of private remote universities, which, often driven by opportunistic reasons, do not always provide educational services at the level of traditional universities, despite seeking accreditation for an increasing number of courses of questionable quality (Cunha et al., 2020).

Appendix

Questionnaires

This subsection contains the complete questionnaires, administered to students and lecturers, respectively.

See Tables 7, 8, 9, 10, 11, 12 and 13.

Table 7 Student-side questionnaire, entitled "Challenges in remote learning: your experience as a student"

Dimension	Aspect/Construct	Item	Scale
1. Resource availability and accessibility	1.1 Accessibility to materials	1.1.1 How often do technical issues prevent you from accessing online teaching materials?	1—Never … 7—Always
		1.1.2 Assess the likelihood of facing challenges in accessing teaching materials due to compatibility issues with your devices or software	1—Very unlikely … 7—Very likely
		1.1.3 To what extent do the available teaching materials meet your diverse learning needs?	1—Fully meets needs … 7—Not at all
	1.2 Accessibility to evaluation resources	1.2.1 How frequently do you encounter technical issues with software or platforms during online assessments?	1—Never … 7—Always
		1.2.2 Rate the adequacy of the resources (like software, hardware) provided for conducting online evaluations	1—Fully adequate … 7—Completely inadequate
		1.2.3 Assess the likelihood of encountering insufficient or outdated evaluation resources in future online assessments	1—Very unlikely … 7—Very likely
	1.3 Access equity	1.3.1 How often do you perceive disparities in access to online learning resources among different student groups?	1—Never … 7—Always
		1.3.2 Rate the extent to which you believe your own access to technological resources for online learning is equal to that of your peers	1—Completely equal … 7—Not equal at all
		1.3.3 To what extent do you think the problem of the "digital divide" (e.g. unequal levels of Internet connectivity) hinders equal access to online education?	1—Not at all … 7—To a great extent
2. Technical responsiveness	2.1 Connection and web platform adequacy	2.1.1 Rate the reliability of the online platforms used for lectures and exams in terms of uptime and accessibility	1—Very reliable … 7—Very unreliable
		2.1.2 How adequate do you find the user interface and overall user experience of the online learning platforms?	1—Very adequate … 7—Very inadequate
		2.1.3 Evaluate the impact of technical issues on the online platforms on your overall learning experience	1—No impact … 7—Major impact
	2.2 Student–lecturer interaction	2.2.1 How often do you experience difficulties in reaching out to lecturers for assistance in an online setting?	1—Never … 7—Always
		2.2.2 Rate the effectiveness of the communication channels used for interacting with lecturers online	1—Very effective … 7—Very ineffective

Table 7 (continued)

Dimension	Aspect/Construct	Item	Scale
		2.2.3 Evaluate how supported you feel by your lecturers in the online learning context	1—Fully supported … 7—Not supported at all
	2.3 Technical problem solving	2.3.1 How frequently do you encounter technical issues that disrupt your participation in online classes or exams?	1—Never … 7—Always
		2.3.2 Rate the effectiveness of the support provided when encountering technical issues during online learning	1—Very effective … 7—Very ineffective
		2.3.3 How often do technical issues remain unresolved for prolonged periods, affecting your learning experience?	1—Never … 7—Always
4. Online assessment	4.1 Adequacy of assessment methods	4.1.1 Rate the level of fairness of the online assessment methods in comparison to traditional in-person exams	1—Just as fair … 7—Much less fair
		4.1.2 How often do the online assessment methods fail to accurately evaluate your understanding of the course material?	1—Never … 7—Always
		4.1.3 Rate the extent to which the online assessments encourage critical thinking and problem-solving skills	1—To a great extent … 7—Not at all
	4.2 Adequacy of evaluation feedback	4.2.1 Rate the timeliness of the feedback provided after completing online assessments	1—Very prompt … 7—Extremely delayed
		4.2.2 Evaluate the extent to which feedback on online assessments helps you understand your mistakes and learn from them	1—Extremely helpful … 7—Not helpful at all
		4.2.3 Rate the level of detail provided in the feedback for understanding your performance in online assessments	1—Highly detailed … 7—Very superficial
	4.3 Quality of education	4.3.1 Rate the effectiveness of the online course format in facilitating deep understanding of the subject matter	1—Highly effective … 7—Not effective at all
		4.3.2 How often do you feel that online courses fail to provide the same level of education quality as in-person courses?	1—Never … 7—Always
		4.3.3 Assess the adequacy of resources (like libraries, laboratories) available to you in an online learning format	1—Fully adequate … 7—Completely inadequate
5. Social dynamics	5.1 Gender diversity	5.1.1 To what extent do you believe that online activities promote gender equality?	1—To a great extent … 7—Not at all
		5.1.2 Evaluate the extent to which gender biases affect the learning experience in your online courses	1—Not at all … 7—To a great extent

Table 7 (continued)

Dimension	Aspect/Construct	Item	Scale
		5.1.3 How inclusive do you find the online learning environment in terms of gender representation?	1—Very inclusive … 7—Not inclusive at all
	5.2 Community	5.2.1 Rate the effectiveness of online platforms in facilitating a sense of community among students	1—Highly effective … 7—Not effective at all
		5.2.2 Rate the sense of belonging to the university or academic community you experience in an online learning setting	1—Feel a strong sense of belonging … 7—Do not feel a sense of belonging at all
		5.2.3 To what extent do you feel connected to your peers in the online learning environment?	1—Very connected … 7—Not connected at all
	5.3 Academic integrity (honesty)	5.3.1 How frequently do you encounter situations in online exams where academic integrity is compromised?	1—Never … 7—Always
		5.3.2 Assess the likelihood of students engaging in dishonest behaviors due to the perceived ease of cheating in online environments	1—Very unlikely … 7—Very likely
		5.3.3 Evaluate the extent to which you believe online exams maintain principles of ethical conduct (e.g., faireness, honesty, integrity, etc.)	1—To a great extent … 7—Not at all

Table 8 Lecturer-side questionnaire, entitled "Challenges in remote teaching and assessment: your experience as a faculty member"

Dimension	Aspect/Construct	Item	Scale
1. Resource availability and accessibility	1.2 Accessibility to evaluation resources	1.2.1 How much do hardware/software limitations affect your ability to conduct effective online evaluations?	1—Not at all … 7—Extremely
		1.2.2 How often do you have to compromise on evaluation quality due to resource accessibility issues?	1—Never … 7—Always
		1.2.3 How adequate are the evaluation tools provided to you for assessing students online (e.g., Moodle, Google Classroom, Zoom, Survey Monkey, etc.)?	1—Perfectly adequate … 7—Completely inadequate
	1.3 Access equity	1.3.1 Considering students' personal financial constraints, how fair do you find the availability/accessibility of digital tools and resources at your university, on campus?	1—Very equitable … 7—Not equitable at all
		1.3.2 How equitable do you believe the distribution of digital tools and resources is for students, when accessing them from outside your university (e.g., from home or other external locations)?	1—Very equitable … 7—Not equitable at all
		1.3.3 To what extent do you perceive a disparity in technological resource access among students, which affects their ability to participate in online learning?	1—No perceived disparity … 7—Extreme perceived disparity
2. Technical responsiveness	2.1 Connection and web platform adequacy	2.1.1 How would you rate the quality of audio and video streaming on your current online platform?	1—Excellent … 7—Very poor
		2.1.2 How often do you find that the web platform's features limit the types of remote teaching/assessments you can perform?	1—Never … 7—Always
		2.1.3 How frequently do you experience interruptions due to connectivity issues in online teaching?	1—Never … 7—Always
	2.2 Student–lecturer interaction	2.2.1 How would you rate the overall quality of interaction you have with students in an online teaching environment?	1—Excellent … 7—Very poor

Table 8 (continued)

Dimension	Aspect/Construct	Item	Scale
		2.2.2 How often do you feel that the online platform hinders meaningful dialogue with students?	1—Never … 7—Always
		2.2.3 How frequently do you encounter barriers to providing immediate feedback to students during online assessment?	1—Never … 7—Always
	2.3 Technical problem solving	2.3.1 In instances of technical difficulties, how promptly do you receive support from the IT department?	1—Very promptly … 7—Not promptly at all
		2.3.2 How often do you encounter technical problems that disrupt online teaching or assessment?	1—Never … 7—Always
		2.3.3 How effectively can you communicate technical issues to the relevant support team to get them resolved?	1—Very effectively … 7—Not effectively at all
3. Training	3.1 Preparation and training for managing lectures	3.1.1 How adequate do you find the provided training for conducting online lectures? (If no training was provided at all, answer "Completely inadequate")	1—Very adequate … 7—Completely inadequate
		3.1.2 How relevant do you find the training content to your actual teaching needs? (If no training was provided at all, answer "Not relevant")	1—Highly relevant … 7—Not relevant
		3.1.3 How much do you feel that the training enhances your effectiveness as an online lecturer? (If no training was provided at all, answer "Does not enhance")	1—Greatly enhances … 7—Does not enhance
	3.2 Preparation for managing the evaluation	3.2.1 How effectively does the training prepare you for creating online assessment materials? (If no training was provided at all, answer "Not effectively at all")	1—Very effectively … 7—Not effectively at all
		3.2.2 How sufficient do you find the training for using online tools and technologies in assessments? (If no training was provided at all, answer "Insufficient")	1—Very sufficient … 7—Insufficient

Table 8 (continued)

Dimension	Aspect/Construct	Item	Scale
		3.2.3 How relevant is the training content to the specific types of assessments you administer? (If no training was provided at all, answer "Not relevant")	1—Highly relevant … 7—Not relevant
	3.3 Institutional support to lecturers	3.3.1 How responsive is the institution to your needs and challenges in online teaching?	1—Very responsive … 7—Not responsive at all
		3.3.2 How effectively does the institution facilitate access to necessary online teaching resources?	1—Very effectively … 7—Not effectively at all
		3.3.3 To what extent do you feel supported by the institution in developing your online teaching skills?	1—Fully supported … 7—Not supported at all
4. Online assessment	4.1 Adequacy of assessment methods	4.1.1 How effective do you find the current online assessment methods in accurately evaluating student knowledge?	1—Very effective … 7—Not effective at all
		4.1.2 How confident are you in the reliability of the results obtained through online assessments?	1—Very confident … 7—Not confident at all
		4.1.3 How well do the assessment methods align with the learning objectives of your courses?	1—Perfectly align … 7—Do not align at all
	4.2 Adequacy of evaluation feedback	4.2.1 How timely do you provide feedback to students following online assessments?	1—Very timely … 7—Extremely delayed
		4.2.2 How clear and understandable do you believe your feedback is to students?	1—Very clear … 7—Not clear at all
		4.2.3 How effective is the feedback you provide in enhancing student learning and understanding?	1—Very effective … 7—Not effective at all
	4.3 Quality of education	4.3.1 To what extent do you believe online teaching methods engage students as effectively as in-person methods?	1—To a great extent … 7—Not at all
		4.3.2 How effective do you find online activities in achieving the expected learning outcomes?	1—Very effective … 7—Not effective at all
		4.3.3 How adequate do you find the online course materials in covering the course curriculum comprehensively?	1—Very adequate … 7—Completely inadequate

Table 8 (continued)

Dimension	Aspect/Construct	Item	Scale
5. Social dynamics	5.1 Gender diversity	5.1.1 How effective do you think online platforms are in fostering an environment of gender equality?	1—Very effective … 7—Not effective at all
		5.1.2 To what extent do you believe that online education addresses the specific needs and perspectives of all genders?	1—Fully addresses … 7—Does not address at all
		5.1.3 To what extent do you think online learning environments can contribute to reducing gender disparities in education?	1—Greatly contribute … 7—Do not contribute at all
	5.3 Academic integrity (honesty)	5.3.1 How prevalent do you believe cheating or dishonest practices are in online assessments?	1—Not prevalent … 7—Very prevalent
		5.3.2 How effective are the current measures implemented to ensure academic integrity in online exams?	1—Very effective … 7—Not effective at all
		5.3.3 How sufficient do you find the institutional policies and support in addressing academic integrity issues in online learning?	1—Very sufficient … 7—Insufficient

Table 9 Student-side questionnaire results, presenting average rank values for the aspects/constructs of interest, disaggregated by class size

Aspect/Construct	Class-size categories				Overall
	< 50	50 to 100	101 to 150	> 150	
1.1	4.9	4.6	5.0	5.4	4.9
1.2	5.8	5.7	5.8	5.5	5.7
1.3	4.5	5.0	4.6	5.0	4.8
2.1	5.8	5.3	5.6	6.3	5.6
2.2	5.9	6.6	6.1	6.3	6.2
2.3	5.6	5.9	5.1	5.9	5.6
4.1	7.3	6.9	7.7	7.9	7.3
4.2	7.6	7.9	8.1	7.8	7.8
4.3	8.0	7.7	7.0	6.9	7.6
5.1	5.4	4.9	4.2	3.3	4.8
5.2	9.1	9.1	10.4	9.8	9.4
5.3	8.2	8.5	8.1	8.0	8.3

Class-size categories are respectively "< 50", "50 to 100", "101 to 150", and "> 150". The 553 respondents are allocated to the four class-size categories as follows: 219 in "< 50" (39.6%), 192 in "50 to 100" (34.7%), 92 in "101 to 150" (16.6%), and 50 in "> 150" (9%)

Table 10 Lecturer-side questionnaire results, presenting average rank values for the aspects/constructs of interest, disaggregated by class size

Aspect/Construct	Class-size categories				Overall
	< 50	50 to 100	101 to 150	> 150	
1.2	6.3	6.2	6.3	6.9	6.4
1.3	6.8	5.8	6.0	4.4	5.9
2.1	5.7	4.8	4.9	5.8	5.2
2.2	9.1	9.3	9.0	8.1	9.0
2.3	5.3	4.9	5.0	4.9	5.0
3.1	8.2	7.8	8.4	8.1	8.1
3.2	9.1	8.3	8.6	9.0	8.7
3.3	6.3	5.9	5.6	6.1	6.0
4.1	7.1	7.9	7.7	8.3	7.7
4.2	4.3	4.8	5.0	4.0	4.6
4.3	8.0	8.8	9.2	9.5	8.7
5.1	6.4	6.6	7.5	7.6	6.9
5.3	8.4	9.7	7.9	8.5	8.7

Class-size categories are respectively " < 50", "50 to 100", "101 to 150", and " > 150". The 176 respondents are allocated to the four class-size categories as follows: 54 in " < 50" (30.7%), 51 in "50 to 100" (29.0%), 43 in "101 to 150" (24.4%), and 28 in " > 150" (15.9%)

Table 11 Student-side questionnaire results, presenting average rank values for the aspects/constructs of interest, disaggregated by gender ("Female" and "Male")

Aspect/Construct	Gender		Overall
	Female	Male	
1.1	4.8	4.9	4.9
1.2	5.4	6.0	5.7
1.3	4.8	4.8	4.8
2.1	5.6	5.7	5.6
2.2	6.0	6.4	6.2
2.3	5.7	5.6	5.6
4.1	7.4	7.2	7.3
4.2	7.8	7.7	7.8
4.3	7.7	7.5	7.6
5.1	5.1	4.6	4.8
5.2	9.2	9.5	9.4
5.3	8.5	8.0	8.3

The 553 respondents are allocated to the two gender categories as follows: 269 are female (46.5%) and 284 are male (53.5%)

Table 12 Lecturer-side questionnaire results, presenting average rank values for the aspects/constructs of interest, disaggregated by gender ("Female" and "Male")

Aspect/Construct	Gender		Overall
	Female	Male	
1.2	6.2	6.4	6.4
1.3	6.5	5.7	5.9
2.1	5.5	5.1	5.2
2.2	8.9	9.0	9.0
2.3	5.1	5.0	5.0
3.1	7.7	8.3	8.1
3.2	8.5	8.8	8.7
3.3	6.1	5.9	6.0
4.1	7.4	7.8	7.7
4.2	4.5	4.6	4.6
4.3	8.6	8.8	8.7
5.1	7.0	6.9	6.9
5.3	9.0	8.5	8.7

The 176 respondents are allocated to the two gender categories as follows: 60 are female (34.1%) and 116 are male (65.9%)

Table 13 Lecturer-side questionnaire results, presenting average rank values for the aspects/constructs of interest, disaggregated by academic title

Aspect/Construct	Academic-title categories			Overall
	Assistant Prof	Associate Prof	Full Prof	
1.2	6	6.2	7.2	6.4
1.3	6.3	6	5.2	5.9
2.1	5.5	5	5.3	5.2
2.2	9	9.3	8.5	9.0
2.3	4.9	5.2	4.9	5.0
3.1	8.8	7.6	8	8.1
3.2	8.9	8.8	8.4	8.7
3.3	5.7	6.1	6.1	6.0
4.1	7.4	7.9	7.6	7.7
4.2	4.9	4.4	4.2	4.6
4.3	8.6	8.5	9.5	8.7
5.1	6.3	6.6	8.2	6.9
5.3	8.6	9.3	7.8	8.7

Academic-title categories are respectively "Assistant Professor", "Associate Professor", and "Full Professor". The 176 respondents are allocated to the three academic-title categories as follows: 63 in "Assistant Professor" (35.8%), 72 in "Associate Professor" (40.9%), and 41 in "Full Professor" (23.3%)

Additional disaggregated results

This subsection contains additional tables with results disaggregated by various factors: class size, gender (for both student-side and lecturer-side questionnaires), and academic title (for lecturer-side questionnaire only).

Supplementary information on statistical tests

See Figs. 13, 14, 15, 16, 17, 18, 19 and 20.

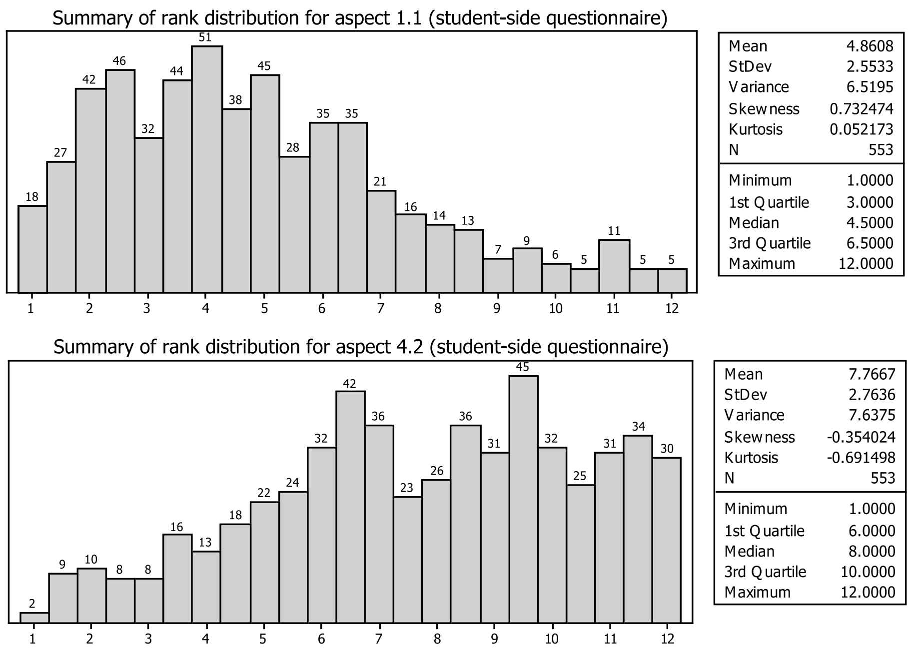


Fig. 13 Histograms and descriptive statistics related to the distributions of the response variable (rank) for the aspects/constructs 1.1. and 4.2 of the student-side questionnaires; the frequency values are shown above the respective bars. The analysis was carried out using Minitab® statistical software

Mood median test: rank vs. aspect/construct of student-side questionnaires

```
Mood median test for Rank
Chi-Square = 939.06    DF = 11    P = 0.000
                                   Individual 95.0% CIs
Aspect  N<=   N>  Median  Q3-Q1   ------+---------+---------+---------+
1.1     441  112    4.50   3.50     (-*-)
1.2     382  171    5.50   3.00         (-*-)
1.3     417  136    4.00   4.50   (-*-)
2.1     392  161    5.50   3.00         (-*-)
2.2     324  229    6.00   4.00           (-*-)
2.3     387  166    5.50   3.50         (-*-)
4.1     243  310    7.50   4.00                 (-*-)
4.2     204  349    8.00   4.00                   (-*-)
4.3     211  342    8.00   3.50                   (-*-)
5.1     386  165    4.00   6.00   (-*-)
5.2     129  420   11.00   5.00                               (-*-)
5.3     172  371    9.00   5.00                       (-*-)
                                  ------+---------+---------+---------+
                                      5.0       7.5      10.0      12.5

Overall median = 6.50
```

Fig. 14 Results of the Mood's test of the populations consisting of the rank values related to the individual aspects, in the student-side questionnaire. The null hypothesis (H_0) is that population medians are all equal, while the alternative hypothesis (H_1) is that they are not equal. For each aspect/construct, "N < = " and "N > " denote respectively rank values lower than or equal and those greater than the overall median (i.e., 6.5). A graphical representation of the 95% confidence intervals (CIs) around the medians is shown on the right-hand side. The analysis was carried out using Minitab® statistical software

(Student-side) correlations: PoliTO; UdG; UIC; UMinho

	PoliTO	UdG	UIC
UdG	0.938 (0.000)		
UIC	0.897 (0.000)	0.987 (0.000)	
UMinho	0.901 (0.000)	0.834 (0.001)	0.801 (0.002)

Fig. 15 Pearson product-moment-correlation coefficients (and relevant *p*-values in brackets), related to the university-disaggregated data in Table 5 (student-side analysis) (Ross, 2017). "PoliTO" stands for Politecnico di Torino, "UdG" stands for Universitat de Girona, "UIC" stands for Universitat Internacional de Catalunya, and "UMinho" stands for Universidade do Minho. The analysis was conducted using Minitab® statistical software

(Lecturer-side) correlations: PoliTO; UdG; UIC; UMinho

	PoliTO	UdG	UIC
UdG	0.840 (0.000)		
UIC	0.852 (0.000)	0.863 (0.000)	
UMinho	0.836 (0.000)	0.808 (0.001)	0.859 (0.000)

Fig. 16 Pearson product-moment-correlation coefficients (and relevant *p*-values in brackets), related to the university-disaggregated data in Table 6 (lecturer-side analysis) (Ross, 2017). "PoliTO" stands for Politecnico di Torino, "UdG" stands for Universitat de Girona, "UIC" stands for Universitat Internacional de Catalunya, and "UMinho" stands for Universidade do Minho. The analysis was conducted using Minitab® statistical software

(Student-side) correlations: <50; 50 to 100; 101 to 150; >150

	<50	50 to 100	101 to 150
50 to 100	0.962 (0.000)		
101 to 150	0.941 (0.000)	0.938 (0.000)	
>150	0.873 (0.000)	0.889 (0.000)	0.960 (0.000)

Fig. 17 Pearson product-moment-correlation coefficients for each pair of class-size categories (i.e., "< 50", "50 to 100", "101 to 150" and "> 150"), in the case of student-side questionnaires (see numerical data in Table 6). In brackets are the corresponding *p*-values for the significance test of the correlation coefficient being zero (i.e., null hypothesis of absence of correlation) (Ross, 2017)

This subsection contains supplementary material regarding some examples of the distribution of questionnaire responses and the statistical tests mentioned in Sect. "Results", divided according to the student-side and lecturer-side analyses, i.e., Mood's

Mood median test: rank vs. aspect/construct of lecturer-side questionnaires

```
Mood median test for Rank
Chi-Square = 339.59    DF = 12    P = 0.000
                                  Individual 95.0% CIs
Aspect  N<=   N>  Median  Q3-Q1  ---+---------+---------+---------+---
1.2     112   64    6.00   4.50             (-*----)
1.3     119   57    5.00   6.00        (-*----)
2.1     139   37    5.00   4.00        (-*--)
2.2      49  127    9.50   4.88                              (--*--)
2.3     139   37    4.50   4.50    (----*-)
3.1      79   97    7.50   6.00                  (--*------)
3.2      63  113    8.75   6.00                       (---*-----)
3.3     119   57    6.00   4.50          (----*--)
4.1      78   98    7.50   5.00                  (--*----)
4.2     143   31    4.00   4.00    (-*--)
4.3      49  123    9.50   4.00                              (--*-)
5.1      92   80    6.50   8.00               (--*------)
5.3      55  116    9.00   5.00                            (-*----)
                                  ---+---------+---------+---------+---
                                   4.0       6.0       8.0      10.0
Overall median = 7.00
```

Fig. 18 Results of the Mood's test of the populations consisting of the rank values related to the individual aspects, in the lecturer-side questionnaire. The null hypothesis (H_0) is that population medians are all equal, while the alternative hypothesis (H_1) is that they are not equal. For each aspect/construct, "N < = " and "N > " denote respectively rank values lower than or equal and those greater than the overall median (i.e., 7.0). A graphical representation of the 95% confidence intervals (CIs) around the medians is shown on the right-hand side. The analysis was carried out using Minitab® statistical software

(Lecturer-side) correlations: <50; 50 to 100; 101 to 150; >150

	<50	50 to 100	101 to 150
50 to 100	0.916 (0.000)		
101 to 150	0.898 (0.000)	0.931 (0.000)	
>150	0.822 (0.001)	0.884 (0.000)	0.909 (0.000)

Fig. 19 Pearson product-moment-correlation coefficients for each pair of class-size categories (i.e., " < 50", "50 to 100", "101 to 150" and " > 150"), in the case of lecturer-side questionnaires. In brackets are the corresponding *p*-values for the significance test of the correlation coefficient being zero (i.e., null hypothesis of absence of correlation) (Ross, 2017)

(Lecturer-side) correlations: Assistant Prof.; Associate Prof.; Full Prof.

	Assistant Prof.	Associate Prof.
Associate Prof.	0.947 (0.000)	
Full Prof.	0.847 (0.000)	0.873 (0.000)

Fig. 20 Pearson product-moment-correlation coefficients for each pair of academic-title categories (i.e., "Assistant Professor", "Associate Professor", and "Full Professor"), in the case of lecturer-side questionnaires. In brackets are the corresponding *p*-values for the significance test of the correlation coefficient being zero (i.e., null hypothesis of absence of correlation) (Ross, 2017)

test, Pearson product-moment correlation coefficients related to the questionnaire results, disaggregated by various factors.

It is important to note that Mood's test is a non-parametric test, meaning it does not require specific assumptions about the underlying distributions of the populations being compared, except that they should be roughly similar in shape. However, it remains relatively robust even when small variations in shape are present (Ross, 2017). The results, shown in Fig. 14, with a χ^2 value of 939.06 and a p-value close to 0, provide sufficient evidence to reject the *null hypothesis* (H_0) that all population medians are equal, in favour of the *alternative hypothesis* (H_1) that at least some medians are not equal, at commonly used α levels. The graphical representation of the confidence intervals on the right-hand side of the same figure (obtained using Minitab® statistical software) also helps identify pairs of aspects/constructs with statistically significant differences in central tendency (median in this case) as indicated by non-overlapping confidence intervals. For example, aspects 4.2 and 4.3 are statistically equivalent to each other (as their confidence intervals overlap), but significantly more critical than aspect 2.2, for the student-side analysis.

Abbreviations

ANVUR	Agenzia nazionale di valutazione del sistema universitario e della ricerca
AQU	Agència per a la Qualitat del Sistema Universitari de Catalunya
A3ES	Agência de Avaliação e Acreditação do Ensino Superior
COVID	Corona virus disease
PoliTO	Politecnico di Torino
RQ	Research question
STEM	Science, technology, engineering, and mathematics
UdG	Universitat de Girona
UIC	Universitat Internacional de Catalunya
UMinho	Universidade do Minho

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Not applicable.

Declarations

Competing interests
The authors do not have conflict of interest.

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