Academic and emotional effects of online learning during the COVID-19 pandemic on engineering students

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Abstract

The unprecedented situation of the COVID-19 pandemic has caused the closure of universities worldwide and has forced the transition to online learning. This exceptional context compels us to understand students' experience with online learning. Previous literature identifies relevant factors that intervene in the online education experience and can affect students' academic development. One of the main concerns is the students' mental health, given the lockdown restrictions under which classes have been conducted. Furthermore, the impact of the prolonged lockdown and the pandemic fatigue on university students and their academic experience is still unclear. This study delves into engineering undergraduate students' online education experience during the COVID-19 pandemic and its emotional impact across time. With this aim, a questionnaire was distributed to second, third, and fourth-year engineering undergraduate students at two time points, approximately six months apart. The results show significant differences in students' connection with other students and teachers, workspace conditions, and boredom between time points. Besides, the findings indicate significant correlations between academic development and quality of online classes, adaptation of the course, workspace conditions, and connection with other students and teachers, and also between students' emotions and connection with other students and teachers. Finally, the study identifies best practices carried out during online teaching that will be of value for future courses and engineering education beyond the pandemic situation, amongst which those related to effective communication with teachers stand out.

Keywords Engineering education · Online learning · COVID-19 pandemic · Mental health · Academic development · Pandemic fatigue

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1 Introduction

The COVID-19 pandemic has posed an unprecedented challenge in education, leading to the suspension of face-to-face teaching (UNESCO, 2020). This change has been particularly challenging in university undergraduate engineering degrees since much of the learning process is based on practical applications, laboratory classes, and direct contact with teachers and other students. Being an exceptional and novel situation, the potential impact of the health crisis and the prolonged lockdown on students' academic development and emotional state is still unknown.

Recent work has identified some variables that intervene in the online education process, such as the correct adaptation of teaching to the online format, including classes, assessment methods, and teacher support (Alnusairat et al., 2020; Linh & Trang, 2020); the quality of the classes received (Al-Balas et al., 2020; Amir et al., 2020); the conditions of students' workspace (Gelles et al., 2020; Son et al., 2020); and the connection with other students and teachers (Elmer et al., 2020; Radu et al., 2020). However, there is a knowledge gap in how these variables are related to students' academic development and whether having been in a prolonged lockdown might have affected them.

Furthermore, educational and psychological research has raised concerns about students' mental health as they have had to suddenly switch to online learning systems and follow classes under lockdown restrictions. Investigations pointed out that students have experienced an increase in stress, anxiety, and depression (Aslan et al., 2020; Odriozola-González et al., 2020; Saravanan et al., 2020; Son et al., 2020), and have felt some negative feelings intensified, such as fear, worry, or boredom (Aristovnik et al., 2020; Son et al., 2020). Several studies have highlighted the protective effect that the connection with the rest of the academic community can have on anxiety, depression, and stress (Elmer et al., 2020; Magson et al., 2021; Procentese et al., 2020). Although mental health during the COVID-19 pandemic has received much attention in the academic field, studies have focused on analyzing adverse mental states such as depression, stress, or anxiety, but a broader perspective on the emotional state of the students, including a wider range of emotions and considering positive emotions such as calm or trust, is still missing.

Within this context, the present study carried out at the Polytechnic University of Catalonia (UPC), Spain, investigates how the COVID-19 pandemic and the lockdown has affected the academic experience of students and their emotional state across time. Two measurements taken six months apart were compared to detect changes potentially caused by a prolonged public health crisis and lockdown, providing new knowledge about pandemic fatigue in university students. Moreover, we assessed the correlations between the variables related to online education and the academic development of students to understand how the change to online teaching may have affected the performance of engineering students. Also, based on Plutchik's theoretical framework on emotions (Plutchik, 1994), a study has been carried out to understand the impact of the pandemic on students' emotional state and how the connection with other students and teachers

can help not only to reduce adverse emotions, but also to enhance positive emotions such as calm or confidence. To the best of our knowledge, no prior studies on the impact of the COVID-19 pandemic on engineering university students have considered such a wide spectrum of emotions and have observed the impact of being in contact with the rest of the academic community on these emotions. Furthermore, our research is novel as it encompasses the different variables involved in online education identified in previous studies, and conducts a longitudinal study to understand the impact of time and pandemic fatigue on these variables and students' academic development. Finally, this investigation identifies best practices carried out during distance teaching that can help improve the online learning experience in engineering studies beyond the pandemic situation.

Understanding the academic and emotional effects of the pandemic on engineering students is essential for several reasons. There is a growing trend for universities to offer online courses. However, in engineering, this transition is still a challenge since traditional engineering studies are based fundamentally on the practical application of scientific and technological principles. The unexpected situation generated by COVID-19 has forced engineering universities to offer their studies online, even for students who would not have proactively chosen to learn online. Therefore, it is an opportunity to analyze students' academic experience in distance engineering studies since they are rarely offered online. This information will contribute to the design of remote engineering courses to make them more accessible. On the other hand, the pandemic's scope during the next few years is unclear, so it is essential to understand its impact on learning to develop support actions for students. Also, all these lessons will be relevant if we face a similar situation that requires the confinement of the population in the coming years.

1.1 Impact of COVID-19 on students' learning experience

The COVID-19 pandemic caused by the SARS-CoV-2 virus began in late 2019 and spread around the world rapidly within months (Du Toit, 2020; Zhou et al., 2020). On March 11th, 2020, The World Health Organization (WHO) declared the public health emergency caused by the new coronavirus an international pandemic. Due to the high transmission rate of SARS-CoV-2, most countries took measures to stop the spread, including the blockade of cities, strict implementation of contact isolation, and strict medical system precaution (World Health Organization, 2021). This reduction in population mobility caused higher education institutions to cancel in-person classes and move towards remote learning (UNESCO, 2020). In the case of traditional engineering studies, this posed a significant challenge since it is a field in which a large part of the curriculum is based on the practical application of knowledge and relies heavily on face-to-face practical and laboratory classes (Jacques et al., 2020). This unexpected change in the teaching format has forced engineering students to adapt to new ways of learning under the conditions of the health crisis, potentially affecting their academic development. Furthermore, while previous research has revealed the impact of online education on those students who proactively chose distance learning, the current pandemic situation allows studying the

impact on all students and in degrees that are generally not available online, as it is the case for engineering studies. Due to the exceptional nature of the situation, the effect of online classes derived from the emergence of COVID-19 on students is yet unknown, so work providing empirical data is crucial to understand the scope of its impact and to be able to propose support actions for students.

Although literature is still limited in this regard, several studies have tried to explain the impact of the rapid transition to online models during COVID-19 on students' academic development. However, the results of these investigations are not homogeneous and show remarkable differences in the results. These variations may be due to the start and end dates of the academic years and school holidays, the timing and impact of the pandemic in each country, and the corresponding measures implemented to manage the health crisis. For example, in some countries face-to-face classes were suspended from the beginning of the pandemic while others were less restrictive and just reduced face-to-face teaching or postponed the beginning of the semester (Gonzalez et al., 2020). These contrasts can also be related to other factors like the differences between academic fields, the resources available for students, and the methodologies implemented by teachers during online teaching, among others. This lack of consistency opens the door to new studies that provide complementary evidence which might allow for a better understanding of the impact of online teaching during the COVID-19 pandemic on university students from different countries and academic fields.

To study the way in which the lockdown and distance teaching have affected engineering students during the COVID-19 pandemic, it is necessary to identify the variables that intervene in the online educational experience. Previous research in psychology and education has identified four relevant constructs in distance education, which have also received attention in studies on remote education in the context of the COVID-19 pandemic.

First, previous research on online teaching highlighted the courses' quality as a significant factor in students' satisfaction and learning (Piccoli et al., 2001; Sun et al., 2008) and pointed out that the effective switch toward online teaching models is influenced by the perceived quality of the classes (Ibrahim et al., 2013). When designing online courses, classes cannot simply be transferred from a face-to-face to an online environment. Content, pedagogy, methodology, and technology need to be adapted for successful online teaching (Aristovnik et al., 2020). The quality of online teaching has received considerable attention in studies on the effects of COVID-19 on higher education. In some of the studies conducted during the lockdown, university students reported low satisfaction with the quality of online teaching (Al-Balas et al., 2020; Alnusairat et al., 2020) and higher learning satisfaction in face-to-face learning than in distance learning (Amir et al., 2020; Linh & Trang, 2020). According to the UNESCO (2020), this disaffection with the online classes stems from the fact that the content offered was never designed within the framework of a distance course but instead tried to make up for the absence of face-to-face classes with virtual classes without sufficient preparation. However, the results of other studies showed that students were satisfied with the overall e-learning provided thus far in their university studies (Aristovnik et al., 2020; Jacques et al., 2020; Puljak et al., 2020). More specifically, in a study with a sample that included

engineering students, 85% of the respondents indicated that online teaching quality during the COVID-19 pandemic was good or very good (Radu et al., 2020). Since the quality of teaching is one of the main constructs in the evaluation of distance teaching, it has been included in this research as a study variable. Also, as there is a lack of consistency in the results of previous studies regarding the satisfaction with the online course's quality during COVID-19, it is necessary to provide more data from samples of engineering students.

Second, there are considerable differences in results among research regarding specific aspects, such as classes, exams, or teachers' support, in adaptation to distance learning during the COVID-19 pandemic. Nevertheless, the results differ across the investigations. On the one hand, previous research reported students' low satisfaction with the support received from their teachers (Alnusairat et al., 2020) and less satisfaction with the classes and assessment methods in distance education compared to classroom learning (Linh & Trang, 2020). This low satisfaction with how teaching was adapted to the online format is associated with an increase in the perceived workload (Alnusairat et al., 2020; Gelles et al., 2020; Son et al., 2020). Furthermore, Khalil et al. (2020) pointed out that the issues related to the implementation and quality of online courses can become barriers to the engagement and acquisition of knowledge. On the other hand, there are studies in university settings in which students were satisfied with the teacher support received and the content of their online classes during the COVID-19 pandemic (Jacques et al., 2020; Rodríguez-Rodríguez et al., 2020). Also, in Puljak et al.'s (2020) investigation, students reported that the assessment methods and materials used in their classes during the lockdown were tailored to e-learning. Similar to the courses' quality, current studies show contradictory results regarding student satisfaction on how their courses were adapted to the remote format. Moreover, adaptation to online teaching was a highly discussed construct during the COVID-19 health crisis due to the short time in which classes, evaluation methods, and teachers' support and guidance had to be readjusted to the online format (UNESCO, 2020).

Third, another major challenge on distance education are the feelings of isolation and disconnection in online courses due to lack of face-to-face contact with other students and teachers (Mcinnerney & Roberts, 2004). Numerous studies prior to the COVID-19 pandemic indicated that interactions with other students and teachers were essential for student satisfaction and played a decisive role in academic development and students' achievements (Arbaugh, 2000; Hong, 2002; Mcinnerney & Roberts, 2004; Piccoli et al., 2001; Sun et al., 2008). Hence, when designing online courses, the interaction mechanisms must be considered to offer enriching and thriving learning environments. Concerning the perceived connection with other students and teachers during the lockdown, previous research indicated that students felt less connected with fellow students and teachers than in face-to-face education (Al-Balas et al., 2020; Puljak et al., 2020; Son et al., 2020). Overall, university students indicated that they have missed in-person contact with other students and professors during the lockdown (Puljak et al., 2020) and that communication has been more complicated than in face-to-face education (Alnusairat et al., 2020; Amir et al., 2020; Radu et al., 2020). In Elmer et al. (2020) investigation on students enrolled in engineering and natural science programs, students reported fewer study partners and felt significantly more socially isolated. Also, in the

study by Tang et al. (2020) on undergraduate students from engineering majors, almost 70% thought that they had not communicated often with their teachers from the online courses during the pandemic. This lack of contact is worrisome since social contact and socialization routines are part of the daily experience of higher education students and can affect their academic development (UNESCO, 2020). In the context of online classes during the pandemic, a greater connection with the community has been related to greater self-efficacy and engagement and lower academic stress (Luan et al., 2020; Procentese et al., 2020). Connection with fellow students and teachers is one of the variables that has received the most attention in the academic community concerning the experience in online education. Social isolation of students during the pandemic has further increased the importance of this factor and hence, we have included connection with other students and teachers as a variable in this study.

Finally, although it had not received much attention in distance education literature before the pandemic, learning environment conditions, its ergonomics, and access to a quality internet connection are additional and indeed important variables to consider in distance learning. A workspace that does not offer the appropriate conditions represents a risk factor for comfort, well-being, and students' academic performance (Braat-Eggen et al., 2017; Hviid et al., 2020; Parvez et al., 2019; Zhong et al., 2019). The unexpected change to online education due to the COVID-19 pandemic has made researchers and academic staff wonder whether students were prepared to take classes from their home and whether they had an adequate workspace, equipment, and facilities for effective learning. In addition, the lockdown situation has prevented students from going to libraries or study halls and, in many cases, has forced family members to share the spaces of their houses, which might have worsened student workplace conditions by increasing noise and distractions (Driessen et al., 2020). In several studies, university students reported that their home has been a distractive environment and mentioned that they were more prone to be interrupted by roommates or family members (Gelles et al., 2020; Kyne & Thompson, 2020; Son et al., 2020). Moreover, Realyvásquez-Vargas et al. (2020) pointed out that environmental factors such as noise, temperature, and lighting had a significant effect on university students' academic performance during online classes in the pandemic context. These issues were associated with more difficulties in focusing and concentrating while learning (Amir et al., 2020; Son et al., 2020) and can become a barrier to the acquisition of knowledge through online courses (Khalil et al., 2020). Another drawback identified in online classes during the pandemic has been inadequate internet access (Al-Balas et al., 2020; Alnusairat et al., 2020; Amir et al., 2020; Aristovnik et al., 2020; Kyne & Thompson, 2020). Several studies have reported that a significant percentage of university students, especially those from disadvantaged families, have had problems accessing internet services (Aristovnik et al., 2020). Due to the unexpected lockdown situation and the rapid transition to online learning, students did not have time to adapt their workspace, which may have had an impact on their academic development. Thus, we included workspace conditions as a variable for this study.

All these factors should be considered when designing online courses to avoid detrimental effects on students' academic development (Braat-Eggen et al., 2017;

Hviid et al., 2020; Mcinnerney & Roberts, 2004; Piccoli et al., 2001; Sun et al., 2008; Zhong et al., 2019). Numerous studies predicted that the change in teaching methods during the pandemic affected students' academic development and their outcomes, although the results are inconsistent. Some of the studies have shown that confinement had positively affected students' academic performance and their learning efficiency (Gonzalez et al., 2020; Khalil et al., 2020). The study by Jacques et al. (2020) carried out with engineering students showed that distance learning did not reduce students' performance and that the grades obtained were similar to those expected in face-to-face teaching. Contrarily, previous research revealed that students perceived worse performance upon face-to-face classes being canceled (Aristovnik et al., 2020) and showed concerns about the negative impact that the pandemic situation will have on their academic outcomes (Nassr et al., 2020; Son et al., 2020). The study by Hamann et al. (2020) suggested that students who followed the course entirely online were significantly less likely to be successful than students who also, or exclusively, attended face-to-face courses during the pandemic. Furthermore, Tang et al. (2020) indicated in their study during the COVID-19 lockdown that students felt generally dissatisfied with the effects of online engineering courses on their learning.

Based on these assumptions, we expect to find a positive correlation between students' academic development with the variables of quality of teaching, adaptation of the classes to the online format, connection with other students and professors, and workspace conditions (Hypothesis 1). Since many of the studies done so far in the context of the pandemic have identified these variables separately, few correlational studies have analyzed their associations and identified the factors that may have had the greatest impact on students' academic development during COVID-19. Knowing how the variables related to the online experience have affected the performance of the students will allow us to identify relevant points that should be considered in the design of online courses. To complement this information, we also identified the best practices carried out by instructors in online teaching during the pandemic that have helped students transition to this new learning environment. This information can help instructors and institutions improve online teaching beyond the pandemic situation. This approach is aligned with the conclusions of Anderson et al. (2011), which showed that receiving feedback from students about the online lessons is vital to improve the courses offered.

1.2 Emotional effects of COVID-19

Studies before the COVID-19 pandemic already reported the negative psychological effects that lockdown can cause on people (Blendon et al., 2004). Quarantine is often described as an unpleasant experience for those who suffer it, and can involve uncertainty about the situation and boredom (Brooks et al., 2020; Cava et al., 2005). It is also associated with significant psychological distress, depressive symptoms, post-traumatic stress, and aversive emotional states such as anger, confusion, anguish, disgust, fear, or nervousness, among others (Brooks et al., 2020; Hawryluck et al., 2004). In the studies carried out during the COVID-19 lockdown, university students reported negative effects on their mental health and emotions. Generally, students

have experienced an increase in their stress, anxiety, and depression during the COVID-19 pandemic (Aslan et al., 2020; Odriozola-González et al., 2020; Saravanan et al., 2020; Son et al., 2020). Besides, they reported feeling some negative emotions intensified, such as fear, worry, or boredom (Aristovnik et al., 2020; Son et al., 2020).

Despite the proven adverse effects that lockdown can have on people, in cases like a public health emergency due to an infectious disease, imposing measures on the population to stop the spread of such disease is needed. Studying which elements can minimize the negative impact and aversive feelings during isolation are of great importance in this context. Some studies have indicated that contact with the academic community can act as a protector and decrease the negative impact of lockdown on students' mental health (Elmer et al., 2020; Magson et al., 2021; Procentese et al., 2020). Others have shown that the lack of relationships and connection with other students and teachers is associated with an increase in academic stress (Zurlo et al., 2020).

Most studies during the COVID-19 pandemic on the emotional state of university students have only analyzed negative emotional states such as anxiety, stress, or depression. However, there is a lack of research with a more global perspective on the emotional state of university students that also includes positive emotions to study whether these have decreased during the pandemic. In the study of emotions, psychological theories have proposed some dimensions to measure people's emotional state, although they have hardly been contemplated in studies on the emotional impact of the COVID-19 pandemic. One of the best known and widely used is Plutchik's (1994) theory, which presents eight emotional dimensions in opposite pairs. Compared with other theories such as Ekman (1992) or Parrot (2001), Plutchik's framework is well-founded in psychological studies, presents a good balance between positive and negative emotions, and offers a broader subset of emotional dimensions (Wang et al., 2019), the aforementioned reasons being why it has been used as a reference to measure the emotions of the students in this study.

Based on the results of the previous literature, we hypothesize that there is an association between the perceived connection with other students and teachers and the emotional state of the students, so a greater connection with other students and teachers will be associated with a decrease in negative emotions and an increase in positive emotions (Hypothesis 2).

1.3 Effects of pandemic fatigue

One of the great unknowns related to the impact of the COVID-19 pandemic are the effects of a prolonged lockdown situation. The entire world population has been exposed to a state of exceptionality generated by the COVID-19 pandemic that has required the implementation of invasive measures with unprecedented impact on daily lives. When these measures are prolonged for an extended period of time, it can cause what is known as pandemic fatigue, which is the mental exhaustion caused by a public health crisis and the restrictions derived from it. This state can affect the mental health of those who suffer it, causing boredom, demotivation, alienation, and hopelessness (World Health Organization & Regional Office for Europe, 2020).

Given the unusual nature of the situation, the literature on the impact of the pandemic and the lockdown implemented is still limited, and there is little evidence to indicate whether the academic and psychological effects of lockdown are greater at the beginning of the pandemic because of the uncertainty of the situation or may become more significant as the pandemic continues due to the feeling of burnout during the prolonged lockdown (Canet-Juric et al., 2020). Additionally, most longitudinal studies in the context of the COVID-19 pandemic in university students assessed only the psychological impact, so more research is required to analyze the academic impact. As Odriozola-González et al. (2020) pointed out, more longitudinal studies are needed to analyze the long-term impact of the COVID-19 pandemic and to draw conclusions about the cause and effect relationships between the variables involved.

In the current literature there is substantial debate about the detrimental effects of pandemic fatigue. In particular, there are two major views: some longitudinal studies supported the theory that adverse effects have intensified as time in lockdown increased and showed significant increments in negative symptoms such as depression, anxiety, or stress (Ausín et al., 2021; Cecchini et al., 2021; Gopal et al., 2020). In contrast, other studies argued that the effects did not increase over time and, in any case, were are greater at the beginning of the pandemic due to uncertainty and fear of the unknown situation (Canet-Juric et al., 2020). Regarding this theory, the study by Ramos-Morcillo et al. (2020) identified two phases as a pandemic progresses. The first is the so-called shock phase, which occurs during the first weeks, and disorientation and mental performance decreases, along with the ability to concentrate. The second is the normalization phase, in which conditions of confinement start to be assimilated, and the new everyday life is normalized. Thus, based on this second theory, we hypothesize that there is an association between time in lockdown and academic experience, and students will have a worst online learning experience at the beginning of lockdown (Hypothesis 3). We also expect an association between the time in lockdown and students' emotional state, and we hypothesize that negative feelings will be greater at the beginning of lockdown, and positive feelings will be greater as time progresses (Hypothesis 4). Knowing when the impact of a confinement situation or health crisis is greater and which feelings increase over time will help to develop support plans for students and plan corrective measures in similar situations like climate, political, or security crises that can restrict people's movement and prevent regular university access.

1.4 Context of the current study

In the current study carried out at the UPC, we made two measurements at different time points and compared data collected in spring and fall semesters, 2020, to evaluate the effects of prolonged lockdown and pandemic fatigue on the educational experience and emotional state of engineering students. Regarding the restrictions derived from the pandemic in Spain, the first state of alarm was decreed on March 14th, and the free movement of citizens was limited to essential activities resulting in the confinement of the population in their places of residence and the suspension

of face-to-face education. Consequently, educational institutions had to switch the teaching to the online format, and many held the classes and academic activities remotely until the end of the course in June 2020. Due to the increase in cases, on October 16th, all face-to-face activity in universities was suspended again, although many higher education institutions had already started the academic year online after the summer. On October 25th, after exceeding half a million infected county-wide, the second state of alarm was established to face the pandemic's second wave. In this case, a curfew was imposed between 10 p.m. and 6 a.m., and later the population was confined again in their municipalities and social gatherings were restricted.

2 Method

2.1 Participants

The participants of this study were students enrolled in the second, third, and fourth-year of the Bachelor's Degree in Industrial Design and Product Development Engineering. First-year students were excluded from the sample due to the short time they had been in engineering studies and the inability to compare the impact of the lockdown on their academic activity with previous courses. All students enrolled in the other three courses were invited to participate, that is, a total of 339 students, 168 at Time 1 (T1) and 171 at Time 2 (T2). The required sample size calculated based on a confidence level of 95% and a margin of error of 5% was 181 students for the total sample, 119 for each measurement. Finally, a total of 254 students participated in the study, 122 at T1 and 132 at T2, so the study sample meets the intended size. Participants were self-selected and no incentive was given to students to participate in the study. The protection of personal data was duly taken into account, ensuring that all recipients agreed to receive communications. Both anonymity of the participants and confidentiality of the data to be collected were guaranteed. Data did not include personal characteristics of the students. Table 1 shows the academic year and the conditions in which the participants took the online classes during the pandemic, type of residence and workspace conditions.

2.2 Measures

Due to the exceptional nature of the situation a questionnaire was designed for this study with measures derived from previous literature and adapted to fit the research context. In previous investigations on the impact of online teaching on students' academic experience during the COVID-19 pandemic, these constructs were measured using questionnaires addressed to students. In these questionnaires, students were asked about their perception of the quality of teaching (Al-Balas et al., 2020; Alnusairat et al., 2020; Amir et al., 2020; Aristovnik et al., 2020; Linh & Trang, 2020; Puljak et al., 2020; Radu et al., 2020), the adaptation of classes to the online format (Al-Balas et al., 2020; Alnusairat et al., 2020; Aristovnik et al., 2020; Linh & Trang, 2020; Puljak et al., 2020; Rodríguez-Rodríguez et al., 2020), the perceived connection with other students and teachers

Table 1 Academic course and lockdown conditions of the participants

Baseline characteristic	Time 1[a]		Time 2[b]	
	n	*%*	*n*	*%*
Academic course				
Second-year	22	18.0	41	31.1
Third-year	62	50.8	52	39.4
Fourth-year	38	31.1	39	29.5
Residence				
Family home	119	97.5	112	85
Student flat	3	2.5	12	9
University residence	0	0	8	6
Workspace				
Personal bedroom	79	64.8	92	69.7
Home office	25	20.5	18	13.6
Common area	18	14.8	22	16.7

$N = 254$

[a] $n = 122$

[b] $n = 132$

(Al-Balas et al., 2020; Alnusairat et al., 2020; Amir et al., 2020; Linh & Trang, 2020; Puljak et al., 2020; Radu et al., 2020; Tang et al., 2020), their workspace conditions (Al-Balas et al., 2020; Amir et al., 2020; Driessen et al., 2020; Kyne & Thompson, 2020; Linh & Trang, 2020; Realyvásquez-Vargas et al., 2020), and the impact on students' academic development (Al-Balas et al., 2020; Aristovnik et al., 2020; Linh & Trang, 2020; Realyvásquez-Vargas et al., 2020; Tang et al., 2020). These investigations have been used as a foundation to build the measuring instrument for this study.

The quality of the online classes that students received during the lockdown was assessed with a 4-point scale (1 = Very bad to 4 = Very good). To measure students' perceptions about the adaptation of the course to the online format, a set of 4 items was designed ($\alpha = .76$) rated on a 4-point scale (1 = Strongly disagree to 4 = Strongly agree). Students were asked to indicate if the classes and the assessment methods had been adapted correctly to the online format, if they had been able to follow the course correctly, and if they had received the necessary support from teachers. To assess the level of connection that students felt with other students and teachers a set of 4 items was designed ($\alpha = .65$) rated on a 4-point scale (1 = Strongly disagree to 4 = Strongly agree). Students were asked to indicate if they felt connected with other students and teachers and if they had missed having contact with fellow students and teachers. To measure the workspace conditions, students were asked about the place and the type of room from where they followed the online classes with two multiple-choice questions of three options each (e.g., from a student flat) and an open field. Students also had to indicate if their workspace conditions had been suitable on a 4-point scale (1 = Strongly disagree to 4 = Strongly agree). To determine how students perceived the impact of the switch to online classes on their academic development, they were asked to rate on a 3-point

scale (1 = It has worsened to 3 = It has improved) if they believed that their academic development had been affected by online teaching.

To measure the emotions students felt during online classes while they were in lockdown, a measure based on Plutchik's (1994) wheel of emotions was designed using a multiple-choice question. Students were asked to select their feelings during the lockdown from 8 options adapted from Plutchik's classification.

Finally, an optional open question was added in which students could share if there was something that teachers did during the online teaching that helped them especially.

2.3 Procedure

For the present study, students completed the exact same questionnaire at two points, approximately six months apart. The first time the questionnaire was distributed was on June 3rd, 2020 (T1), during the spring semester and almost three months after the first lockdown was established and all classes went online. Consequently, students had a reasonable exposure to the online learning experience and the lockdown to answer the questionnaire. The second measurement was made in the fall semester on November 18th, 2020 (T2), approximately one month after the second state of alarm was decreed and the new lockdown was applied to face the second COVID-19 outbreak. Therefore, both measurements were made while students were taking classes online.

The questionnaire, which was anonymous and drawn up using Google Forms, was sent by email together with a motivational letter explaining the purpose of the study. Both times, students had up to 1 week to complete it, and took approximately fifteen minutes to finish. Participants were recruited via email messages sent by the authors of this research and faculty members, and were encouraged to answer all the questions accordingly to their opinions. Before being sent, the questionnaire was submitted to a validation process to identify whether it omitted some question areas, determine whether the questions were clear and well-formulated, and detect possible errors in its preparation.

No outliers were identified, and no missing values were found either since all the questions in the questionnaire were mandatory. Descriptive statistics and frequency analyses were applied to characterize the sample. Spearman's rank correlation coefficient was used to test the first hypothesis on how the variables related to the online academic experience affected students' academic development. Although the intercorrelations were calculated between all the variables of the online academic experience, the analysis was done using academic development as the independent variable and the variables of connection with other students and teachers, workspace conditions, quality of online classes, and adaptation of the course as dependent variables. To evaluate our second hypothesis about whether the connection with other students and teachers can affect students' emotional state, a Chi-Square Test for Independence was performed using connection with other students and teachers as the independent variable and emotions as the dependent variables. To fulfill the assumption concerning the minimum expected cell frequency, the measure

of connection with other students and teachers was transformed into a dichotomous variable combining the negative and positive values, respectively. To assess our third hypothesis on how the time in lockdown affected the academic experience of the students, we performed a Mann-Whitney U Test using the time in which the measurements were made as the independent variable and the variables of academic development, connection with other students and teachers, workspace conditions, quality of online classes, and adaptation of the course as dependent variables. Since the emotion variables were dichotomous, for the fourth hypothesis about how time in lockdown affected the emotional state of the students, a Chi-Square Test for Independence was carried out using the time in which the measurements were taken as the independent variable and the different emotions as dependent variables. In the analyzes, $p < 0.05$ was considered statistically significant, and the effect size was assessed using Cohen's (1988) criteria. For the qualitative data, an abductive methodology was used to identify the codes. First, half of the dataset was analyzed, and a preliminary code list was obtained. Next, the entire dataset was processed with the identified codes, and the rest of the codes emerged from the data iteratively, adding new codes if practices not identified in the preliminary list were found.

3 Results

Descriptive analyses indicated that about half of the students reported that the quality of the online classes received during the pandemic was bad or very bad (T1 = 54.1%, T2 = 46.2%), and more than a half thought that their academic development worsened during online classes compared to face-to-face classes (T1 = 66.4%, T2 = 68.9%). Also, more than half of the students indicated that their workspace conditions had been adequate, especially at T2 (T1 = 58.2%, T2 = 73.5%). Regarding the single items that compose the variable adaptation of the course variable, over half of the students reported that classes were correctly adapted to the online format (T1 = 57.4%, T2 = 68.2%) and that the evaluation methods were also properly adapted (T1 = 56.6%, T2 = 54.5%). Furthermore, the majority indicated that they had been able to follow the course correctly (T1 = 63.9%, T2 = 78.8%) and had the necessary support from teachers (T1 = 57.4%, T2 = 67.4%). Remarkable differences can be observed between the two time points regarding the 4-items that compose the variable connection with other students and teachers. Students felt less connected to other students and teachers in T2 than in T1 (T1 = 67.2%, T2 = 27.3%; and T1 = 51.6%, T2 = 40.1%; respectively) and the vast majority missed having contact with other students and teachers (T1 = 82.0%, T2 = 95.5%; and T1 = 81.1%, T2 = 91.7%; respectively).

As shown in Table 2, the workspace conditions in which students took the online classes improved significantly from T1 to T2 with a small effect size. On the other hand, the perceived connection with fellow students and teachers worsened significantly from T1 to T2 with a medium effect size, so that in T2 they felt less connected with other students and teachers. Although the quality of online classes and the adaptation of the course improved at T2 compared with T1, no significant differences were found.

Table 2 Descriptive Statistics and Mann-Whitney Test at Time 1 and Time 2

Variables	No. of items	Range	Time 1[a]		Time 2[b]		U	z	p
			M	SD	M	SD			
Quality of online classes	1	1-4	2.5	0.7	2.5	0.7	7540	0.97	.334
Academic development	1	1-3	1.4	0.6	1.4	0.6	7909	-0.30	.765
Workspace conditions	1	1-4	2.7	0.8	2.9	0.7	6864	2.23	.026
Adaptation of the course	4	1-4	2.6	0.6	2.7	0.5	7146	1.57	.116
Connection with other students and teachers	4	1-4	2.2	0.5	1.8	0.5	4361	-6.38	.000

$N = 254$

[a]$n = 122$

[b]$n = 132$

At both times, correlations between academic development and quality of online classes and adaptation to the course were relatively high and positive with a medium effect size (see Table 3). Also, the workspace conditions had a positive significant correlation with academic development with a small effect at T1 and T2. Therefore, those students who perceived a better quality and adaptation of the online classes and had better workspace conditions were those who reported a better academic development. On the other hand, academic development had a significant positive correlation with connection with other students and teachers with a small effect size at T2, the time point when they felt more disconnected with fellow students and teachers.

As illustrated in Fig. 1, the emotions that students felt the most during the lockdown were discouragement (22.6% T1, 23.0% T2), boredom (T1 = 17.5%, T2 = 21.8%), confusion (T1 = 18.3%, T2 = 15.7%), worry (T1 = 15.4%, T2 = 14.3%), and annoyance (T1 = 10.8%, T2 = 10.3%). Contrary, the least common were vigilance (T1 = 8.2%, T2 = 7.3%), calm (T1 = 5.7%, T2 = 6.1%), and trust (T1 = 1.5%, T2 = 1.6%). Regarding the differences between T1 and T2, students felt slightly less worried and confused at T2, although no statistically significant

Table 3 Intercorrelations for Study Variables at Time 1 and Time 2

Variable	1	2	3	4	5
1. Academic development	-	.176	.403***	.358***	.237**
2. Connection with other students and teachers	.282**	-	.274**	.340***	.118
3. Quality of online classes	.496***	.265**	-	.409***	.258**
4. Adaptation of the course	.435***	.298**	.571***	-	.313***
5. Workspace conditions	.243**	.188*	.423***	.393***	-

The results for the Time 1 sample ($n = 122$) are shown above the diagonal. The results for the Time 2 sample ($n = 132$) are shown below the diagonal
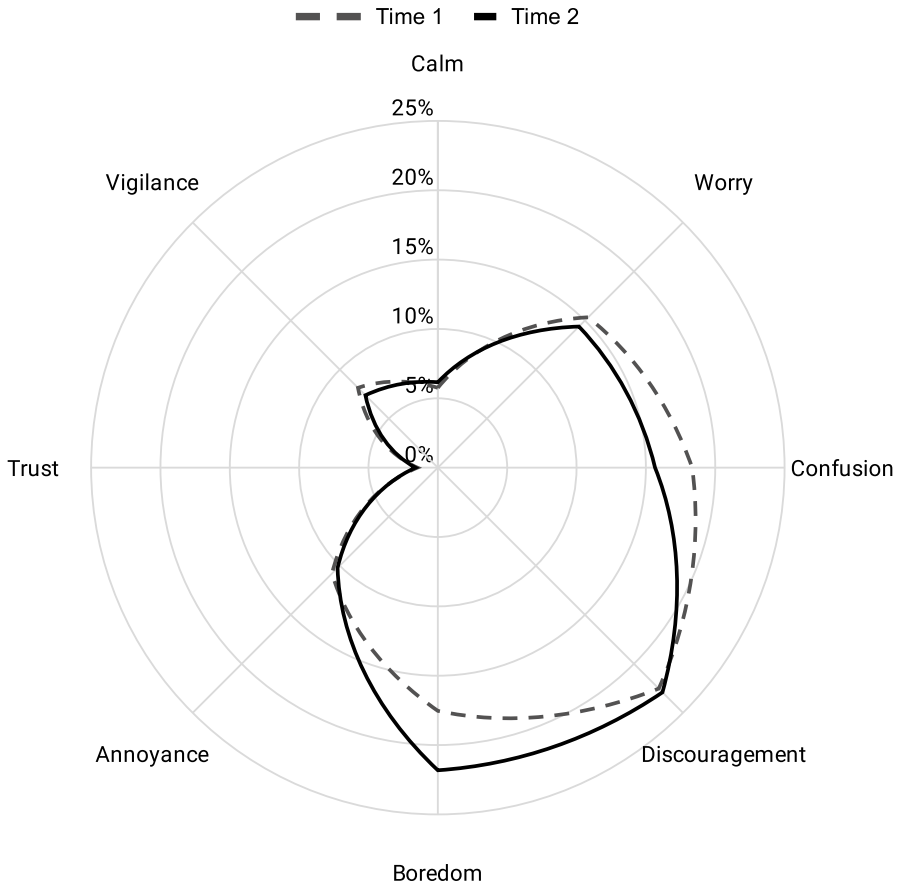
$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$

Fig. 1 Changes in Students' Emotions between Time 1 and Time 2

difference was found (X2 (1, $N = 254$) = 0.12, $p = .728$, *phi* = -.030; and X2 (1, $N = 254$) = 1.13, $p = .288$, *phi* = -.075; respectively). Besides, they felt more bored at T2 than T1, with a statistically significant difference (X2 (1, $N = 254$) = 5.30, $p = .021$, *phi* = .153) with a small effect.

As shown in Table 4, a significant association with small effect was found between the connection with other students and teachers and the emotions felt by the students, with the exception of boredom, which did not present significant differences. Those students who felt more connected with other students and teachers were more likely to feel calm and trust. Otherwise, those students who felt more disconnected were the ones who felt more worry, confusion, discouragement, annoyance, and vigilance.

The open question regarding best practices carried out during the online teaching received 117 responses, 63 from T1 and 54 from T2. From these responses, 21 best practices were identified, plus the "other practices" code (Table 5). As some answers referred to more than one code, the total number of best practices identified (*n =*

Table 4 Chi-Square Results for Connection with Other Students and Teachers in Students' Emotions

Variable	Disconnected[a]		Connected[b]		X^2	p	phi
	n	%	n	%			
Calm	30	15.3%	18	31.0%	6.23	.013	.169
Worry	101	51.5%	20	34.5%	4.55	.033	-.143
Confusion	115	58.7%	23	39.7%	5.78	.016	-.160
Discouragement	153	78.1%	33	56.9%	9.18	.002	-.201
Boredom	127	64.8%	34	58.6%	0.49	.482	-.054
Annoyance	74	37.8%	12	20.7%	5.08	.024	-.151
Trust	5	2.6%	8	13.8%	9.45	.002	.214
Vigilance	55	28.1%	8	13.8%	4.15	.042	-.139

$N = 254$

[a]$n = 196$

[b]$n = 58$

182) is greater than the total number of responses. The codes were classified into four categories: communication, classes, course adaptation to the online format, and teachers.

4 Discussion

The COVID-19 pandemic has brought a global change in educational systems, forcing the transition from face-to-face to online learning due to the restrictions and lockdowns imposed in most countries. This study has examined university engineering students' academic experience and the emotional impact of online education during the COVID-19 pandemic using a longitudinal approach. The results provide novel information and extend prior research on the impact of distance education during the COVID-19 lockdown on engineering students.

4.1 Effects of the prolonged lockdown on students' learning experience

The majority of students in our sample reported that their academic development worsened during online learning, and a high percentage considered that the online teaching they received was of a bad quality. Therefore, students have perceived a negative impact regarding the change to online teaching during COVID-19 in their academic experience, especially in their academic development and the quality of the teaching they have received. These findings are consistent with some studies on university students during the COVID-19 pandemic regarding the quality of teaching received (Al-Balas et al., 2020; Alnusairat et al., 2020; Amir et al., 2020; Linh & Trang, 2020) and the impact on students' learning outcomes (Aristovnik et al., 2020; Nassr et al., 2020; Son et al., 2020; Tang et al., 2020). As UNESCO (2020) has pointed out, this may be because the change towards online learning has been

Table 5 Best Practices in Online Teaching During COVID-19 Lockdown

Category	Code	n	%
Communication	Instant messaging	10	5.3
	E-mail	9	4.8
	Forum	2	1.1
	Social networks	2	1.1
Classes	Record and share classes	37	19.6
	Individual or small group tutoring	18	9.5
	Sessions to resolve doubts	9	4.8
	Live problem solving	3	1.6
	Synchronous learning	3	1.6
	Asynchronous learning	3	1.6
Course adaptation to the online format	Provide solved problems	10	5.3
	Provide support videos	10	5.3
	Adapt the statement of the projects	5	2.6
	Provide extra support documentation	5	2.6
	Make assignment deadlines more flexible	4	2.1
	Small workgroups	4	2.1
	Adapt evaluation methods	4	2.1
	Follow-up activities (as questionnaires or discussions)	3	1.6
Teachers	Fast answers	20	10.6
	Supportive attitude	19	10.1
	Frequent contact	2	1.1
Other practices		7	3.7
Total		189	100

sudden and consequently the content offered in the classes was not designed to be taught in an online course and online classes were given with limited preparation.

Contrary to our hypothesis (Hypothesis 3), there are no significant differences between T1 and T2 regarding the quality of online classes, the adaptation of teaching to the online format, and the academic development of students. However, we observed a slight increase in the perception of the online classes' quality and the adaptation of the course, though this difference is not statistically significant. These results suggest that although there may have been an improvement in some aspects of teaching, probably due to enhancements introduced by teachers in the subjects after the first months of the pandemic, these have not been enough to make a significant change in students' perception. On the other hand, our data show significant differences between T1 and T2 on the workspace conditions and the perceived contact with fellow students and professors. The conditions of the workspace have significantly improved as time progressed in lockdown. This result suggests that students, foreseeing that the new course would also be online, prepared their workspace conditions to suit their needs. As UNESCO (2020) argues, student's expectations differ if they

expect to enroll from the beginning in a distance course or a regular course. So, it is relevant that academic institutions inform students in advance on possible changes in teaching, so that they can adapt their expectations and prepare properly. Contrary to what was expected, the perception of connection with other students and teachers is significantly lower at T2, so the feeling of isolation worsens significantly as the time in lockdown passes and online classes become regular. Students who reported having missed the contact with other students at T2 reach 95.5% and with teachers 91.7%. Similarly, previous studies have highlighted the lack of social contact and the feelings of isolation and disconnection during the COVID-19 lockdown (Al-Balas et al., 2020; Elmer et al., 2020; Puljak et al., 2020; Radu et al., 2020; Son et al., 2020). These studies indicate that students have felt less connected to the academic community than in face-to-face teaching (Al-Balas et al., 2020; Puljak et al., 2020; Son et al., 2020). Our findings reveal that not only do students feel less connected to their peers and teachers in online learning compared to face-to-face classes, but also that this feeling increases as time in lockdown lengthens. This finding reaffirms the importance of social contact and communication mechanisms in online education and suggests that if these mechanisms are not properly implemented in the online education systems, the lack of social contact and its negative effects on students' educational experience may get worse (Luan et al., 2020; Procentese et al., 2020).

The results of this study indicate that the effects of the prolonged lockdown may impact differently on the variables involved in the online educational experience, and raise new hypotheses regarding the impact of a prolonged lockdown. On the one hand, the impact on variables related to pedagogical aspects of online teaching, such as quality and adaptation of the course, may be more negative at the beginning of the pandemic due to the uncertainty of the situation (Canet-Juric et al., 2020; Ramos-Morcillo et al., 2020). However, these aspects may improve as time passes due to teaching improvements on the online practices and students' preparation of their workspace environment foreseeing that they will continue the classes remotely (Scull et al., 2020). This hypothesis is supported by studies such as Van Nuland et al. (2020), which indicates that many teachers have been asked, almost overnight, to implement classes remotely in response to the consequences of the COVID-19 pandemic. Many of these teachers had no or little prior experience in online teaching and that they lacked the pedagogical content knowledge needed for online teaching. As the pandemic has progressed, teachers and universities have been adapting and have implemented several innovations to improve the online teaching experience of students (Scull et al., 2020). On the other hand, the variables related to the social aspects of the academic experience, such as the contact with other students and teachers, may be negatively affected by the feeling of burnout as time in lockdown passes (Ausín et al., 2021; Cecchini et al., 2021; Gopal et al., 2020). As other studies have reported, the lockdown situation has triggered the feeling of isolation and disconnection of students (Al-Balas et al., 2020; Puljak et al., 2020; Son et al., 2020), feelings already identified in pedagogical research on the challenges of e-learning (Mcinnerney & Roberts, 2004). Understandably, this feeling strengthens while students remain locked in their homes, and as the time without seeing their classmates and teachers increases. Therefore, it will be crucial for academic institutions and faculty members to put mechanisms in place that help students feel connected to each

other and to their teachers, such as discussion forums or instant messaging channels (Moorhouse, 2020; Rosenberg & Asterhan, 2018). The study by Scull et al. (2020) shares some learnings from universities and teachers that might help strengthen the connection and communication with students during the pandemic, such as providing channels through which they can ask for help or by opening the debate to more personal day-to-day issues to relax the atmosphere and enhance engagement.

In line with what was predicted in our first hypothesis (Hypothesis 1), we find significant relationships between academic development and the rest of the variables related to the online academic experience of students. Specifically, students' academic development is associated with the quality of the classes received, the adaptation of the courses to the distance format, and the workspace conditions. Also, a positive correlation was found in T2 between students' academic development and contact with other students and teachers. Previous literature already pointed out the relationship between the variables studied and the academic development of students (Braat-Eggen et al., 2017; Hviid et al., 2020; Mcinnerney & Roberts, 2004; Piccoli et al., 2001; Sun et al., 2008; Zhong et al., 2019). In this line, our results confirm these relationships between the variables under the conditions of a pandemic and lockdown in engineering students. Considering the direction of the correlations, offering students classes of high quality, adapting the class contents, assessing teaching methods properly, and giving support from teachers to the online format relate to a better academic development. Therefore, it is important to offer teachers training and pedagogical tools needed to provide adequate distance teaching (Van Nuland et al., 2020). Moreover, having better workspace conditions can enhance students' academic development. In this regard, academic institutions can ask students about their conditions and offer support, for example, temporarily borrowing computers from the university or granting access to online learning platforms through mobile phones (UNESCO et al., 2020).

Furthermore, previous literature has focused on the positive effects that contact with teachers and other students can have on academic development, such as greater self-efficacy and learning engagement, and less academic stress (Luan et al., 2020; Procentese et al., 2020). Our study suggests that having good connections with other students and teachers is not necessarily associated with academic development (as observed at T1), but if this lack of contact is extended in time (as observed at T2), it may negatively impact students' academic development. This new finding supports the previous observation that it is necessary to work on the relationships between students themselves and with their teachers in online learning; otherwise, if these connections are lacking, it may have a negative effect on the educational experience and students' outcomes.

4.2 Emotional impact of prolonged lockdown

Students' most-reported emotions during the lockdown are discouragement, boredom, confusion, and worry, all of them negative emotions. On the contrary, those less prevalent are the positive emotions of calm and trust. Despite previous articles

mainly focusing on negative emotions (Aslan et al., 2020; Odriozola-González et al., 2020; Saravanan et al., 2020; Son et al., 2020), future studies on students' mental health should also include positive feelings to understand to what extent these decrease due to the pandemic situation. Assessing positive feelings during a public health crisis is essential as it has been shown that positive emotions can help maintain and improve human mental health (Yamaguchi et al., 2020). Thus, using a theoretical framework as Plutchik's (1994), which includes a broad subset of emotional dimensions, can give a more detailed picture of the emotional state of students and can help detect which feelings teachers and academic institutions need to reinforce, such as students' confidence and calm. Based on this information, institutions can work on messages and communications towards their students to counteract the emotional impact and enhance these positive emotions (Heffner et al., 2021).

Contrary to what was expected regarding the differences in the emotional state of the students as the lockdown elapses (Hypothesis 2), most emotions do not show significant changes from T1 to T2. However, worry and confusion are less reported in T2. The fact that students feel more concerned and confused at the beginning of confinement is aligned with the phases of the pandemic identified by Ramos-Morcillo et al. (2020), in which there is a first phase when disorientation prevails due to the novelty of the situation and a second phase as time progresses when the situation is assimilated and normalized. The only emotion that shows a significant increase from T1 to T2 is boredom, a feeling also present in other studies in the context of the COVID-19 pandemic (Aristovnik et al., 2020; Son et al., 2020). Although this result is not consistent with our hypothesis, it is aligned with the effect of mental exhaustion and demotivation the WHO (2020) claims that pandemic fatigue can cause. These results suggest that burnout does not affect all emotional states in the same way, and while some may not increase as time progresses or even decrease, such as worry or confusion, others such as boredom may increase (Canet-Juric et al., 2020). This information is relevant for teachers and academic institutions to understand how their students feel in each phase of the pandemic and to adapt the type of support provided at each moment.

In line with hypothesis 4 and the results of prior research (Elmer et al., 2020; Magson et al., 2021; Procentese et al., 2020), the connection with other students and teachers is correlated with students' emotions. As expected, connection with others acts as a protector and, as the perception of contact with the academic community increases, the negative feelings of worry, confusion, discouragement, annoyance, and vigilance decrease. Besides, it has also been found that contact with fellow students and teachers is positively associated with the feelings of calm and trust, which suggests that social contact is not only a protector against negative emotions, but that it can also enhance positive emotions. Since positive emotions are the least reported by students during the lockdown, it is essential to identify which actions can enhance these emotions to improve students' mood. This finding reinforces the need to create alternative ways to stay in contact, so students can feel more connected with their classmates and teachers. Fostering social contact and communication will improve students' mental health during online learning in the public health crisis and, as indicated by other studies, even beyond the pandemic situation (Holen et al., 2018).

4.3 Best practices in online teaching

In addition to validating the hypotheses raised, this study explores best practices carried out by the teaching staff during distance classes that have helped engineering students during online teaching. Although these practices have been identified in the context of the COVID-19 pandemic during the lockdown, they can also be initiatives of interest for regular teaching in university studies or in the design of online courses beyond the pandemic. Concerning the communication between students and teachers, the two most mentioned communication channels are instant messages and emails. Students have highly appreciated those teachers who have opened instant messaging channels such as WhatsApp to communicate with them in a faster and more accessible way. During the classes, the practice that helped students the most was the recording of the online classes allowing students to review them later. Besides, individual or small group video calls with the professor to clarify doubts more closely and in a more comfortable environment were also highly appreciated. Regarding the course adaptation, the two most relevant initiatives have been sharing problems already solved so students have guidelines to self-correct their exercises and sharing support videos with complementary explanations to the subjects' content. Finally, it was highly appreciated that teachers gave quick answers to students' questions and that they had a supportive attitude and were attentive to students' needs. Some students reported on teachers having asked them for feedback to know how they were doing and improve their classes accordingly. Previous research has already highlighted the importance for teachers of receiving feedback from students in order to improve teaching (Anderson et al., 2011). The results of our study suggest that the benefits of the feedback are bi-directional, and it is not only helpful for teachers, but also makes students feel heard and valued. Previous research indicates that communication between students and teachers can be more complicated online than in face-to-face teaching (Alnusairat et al., 2020; Amir et al., 2020; Radu et al., 2020). Our study supports this claim, showing that most of the outstanding initiatives have been those practices that allowed students to solve their doubts more efficiently, such as faster communication methods, individual or small group tutoring sessions or having problems already solved in order to self-solve possible doubts autonomously. Although other studies already identified some of the initiatives undertaken by teachers to improve the experience during online teaching (Scull et al., 2020), our work collects those practices most valued from the students' perspective and the ones that have been most helpful for them.

4.4 Limitations and future directions

The results of this study should be interpreted in the context of some limitations, which can be addressed in future research.

The study was conducted during an exceptional public health crisis, so it is not easily replicable. Also, the results of this study are influenced by the actions to face

the COVID-19 pandemic taken by both the state and local governments and the academic institution in which the study was carried out. The measures adopted by the different countries and universities have differed, adapting them to the possibilities and characteristics of each case (Gonzalez et al., 2020). These differences may make the results of this study difficult to extrapolate to other countries or university degrees in which different solutions to the COVID-19 crisis have been implemented. For this reason, while it is expected that some of the results may be of value beyond the pandemic situation, it will be necessary to validate their applicability in other contexts.

Participants of this research were recruited from second, third and fourth year from a specific engineering degree, so the lack of random sampling and the representation of a student population limited to one engineering degree seem to be a limitation in generalizing the results to all engineering studies or all academic courses. As the field of engineering is vast and there are many different specializations, it would be interesting to expand the study and validate the results in other engineering degrees and in other courses. For example, the academic experience of first-year students who have started their studies in a pandemic situation may be different from those students from second, third and fourth year. It would also be interesting to extend the sample to other universities and countries since the impact of the COVID-19 pandemic has not been the same everywhere. Furthermore, we have only included students in the study sample and not teachers. Perspectives of teachers regarding the switch to online learning would be valuable and should be explored in future studies. The samples of this study have been treated as independent. However, since it is a longitudinal study, it would be interesting to validate the observations with paired samples to compare the changes between time points on an individual basis.

Regarding the instruments used in the research, one limitation is that we created a new questionnaire for this study. Although the questions are based on previous studies, we could not find a similar questionnaire in the literature that incorporated all the measurements. Also, the reliability value of the scale used to measure the contact with other students and teachers is a bit low ($\alpha = 0.65$) although Cronbach's alpha is quite sensitive to the number of items in the scale, and short scales often have low Cronbach alpha values. Future research should validate these results and the instrument used and expand the number of items of the proposed scales to improve the scale's reliability. Moreover, we did not collect participants' personal data, such as gender or demographic information to preserve participants' anonymity and favor the predisposition of students to answer the questionnaire.

As the study was conducted using a questionnaire, the results studied are based on students' perceptions. However, perceptions do not always match reality. For example, while in our study students indicated that their academic development worsened during online teaching, the study of Jacques et al. (2020) found no differences between the grades of engineering students in online education and those expected in a face-to-face teaching. Thus, it would be interesting for future research to compare students' perceptions regarding their academic development with their academic qualifications to validate the impact of the lockdown and distance classes on students' outcomes. Also, we phrased the questions to collect the opinion of students

regarding the majority of teachers and courses. We acknowledge that they may be differences between different teachers and courses that may impact individual experiences. However, we were interested in analyzing overall collective students' opinion towards the online learning experience.

Despite these limitations, the results of this study offer valuable information on the academic and emotional effects that online learning during the COVID-19 pandemic had on engineering students and raises new hypotheses which can be examined in more detail in subsequent work. Moreover, a more specific analysis can be carried out to know how much of the variance in academic development can be explained by the quality of the classes, the adaptation of the teaching to the online format, the conditions of students' workspace and the connection with other students and teachers.

5 Conclusions

The findings of this study highlight that the majority of students were not satisfied with the quality of their online education enforced during the lockdown due to the COVID-19 pandemic, and that they believe that it has negatively affected their academic performance. Moreover, students' academic development is correlated with the quality of the teaching, the adaptation of the assignments, workspace conditions, and the contact with other students and professors. Regarding their emotional state, students reported feeling discouragement, boredom, confusion, and worry to a greater extent, and calm and trust to a lesser extent. Except for boredom, all emotions are associated with the connection with classmates and teachers perceived by students, hence the students who have perceived a higher level of connection are those who reported more positive emotions and less negative ones. Additionally, we find significant improvements as time in lockdown elapsed regarding the students' workspace conditions, while perceived contact with other students and teachers and boredom worsened significantly as the pandemic progressed. These results indicate that it is necessary to consider how the courses should be adapted to the online format since their quality and their correct adaptation will have an impact on the students' academic development. Furthermore, it is essential to work on connection and communication mechanisms among students and between students and teachers since these can improve students' emotional state. These conclusions, along with the good practices that teachers have carried out during online classes in the pandemic and that we have identified in this study, will hopefully help in the design of future online courses and in the implementation of support plans to improve the student learning experience and their emotional state.

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and A.-I.R.-D.; Writing—review and editing, R.B.-S, N.O.-T., M.P. and A.-I.R.-D.; Supervision, R.B.-S., N.O.-T. and M.P. All authors have read and agreed to the published version of the manuscript.

Availability of data and material The data and materials that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

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

Consent for publication The participants have consented to the submission of the case report to the journal.

Conflicts of interest The authors declare no conflict of interest.

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