Attempts, Successes, and Failures of Distance Learning in the Time of COVID-19

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■ ABSTRACT

Over 1.7 billion students around the world have had their education disrupted by the spread of Coronavirus disease worldwide. Schools and universities have not faced this level of disruption since World War II. The COVID-19 pandemic presented a colossal challenge for teachers to urgently and massively adapt all their classes to distance learning in order to maintain educational continuity with the same quality. Even if some teachers and certain classes were ready to face the situation, a large majority had to adapt their teaching and learning in a very short time without training, with insufficient bandwidth, and with little preparation. This unexpected and rapid transition to online learning has led to a multiplication of teachers' strategies for distance learning in lectures, tutorials, project groups, lab work and assessments. The purpose of this paper is to present the feedback from students and teachers who participated in the lockdown semester of two different groups of a 5-year program in Chemistry, Environment and Chemical Engineering (100 students) at INSA Toulouse (France). The analysis has highlighted some great successes and some failures in the solutions proposed. Consequently, some guidelines can be given to help us all to learn the lessons of such a singular experience in order to face the unexpected future with more knowledge and more successful distance learning. Teachers have shown very strong resilience during this crisis, at the cost of significant personal commitment. They admit that they have learned more about distance education in two months than in the last 10 years.

■ GRAPHICAL ABSTRACT

■ KEYWORDS

General Public < Audience, Distance Learning / Self Instruction < Pedagogy, Inquiry-Based / Discovery Learning < Pedagogy, Collaborative / Cooperative Learning < Pedagogy, Student-Centered Learning < Topics

■ INTRODUCTION

Distance education has been in existence for at least a century. During this time, the medium has changed from pencil and paper correspondence courses by post[1] to real-time Internet courses[2]. Distance education courses were originally developed to involve students[3] who did not have ready access to a School or University, had restricted hours for course participation, or simply disliked the conventional "school" environment. An important foundation of distance education is the theory of independent study[4], which suggests that successful teaching can take place even though teacher and learner are physically separated during the learning process. In this model, the roles of students and teachers are different from those they played in traditional education systems: the teachers are no longer the sole owners of knowledge, and become facilitators to support student learning, while students have to develop their collaborative efforts. The proliferation of the smartphone and videoconferencing systems, with the development of the Internet and the 4G/5G network[5] have provided access to both information and contacts that were previously unavailable. Some works[6] have shown that, on average, students retain 25-60% of the new material presented when learning online, compared to only 8-10% in a traditional classroom and require 40-60% less time to learn.[7] (This could be explained by the fact that students can learn at their own pace, when they want, going back and re-reading, skipping, or accelerating.) It took decades[8,9] to build this model and adapt it to these students (given that each individual has a specific situation: full time employment, high motivation, personal stress, etc.[10,11]). The main barriers associated with such a model were issues of communication between student and institution, isolation[12], tutoring, laboratory work, access to books, and informatics issues, including training of staff and the need for technical support,[2] or even difficulties of access to a sufficiently high-performance Internet connection. The design of specific study materials for distant students has been revealed as a key factor for the success of such a model. Many educators have worked on developing innovative specific tools in the last decade, such as the use of videos,[13,14] the web,[15–17] the creation of real-time experiments,[18] or the development of online games with serious educational objectives[19–

[28]. The latest technological developments, such as Virtual Reality (VR)[26,29–32] or Augmented Reality (AR)[33–41] have emerged as interactive, promising and engaging tools for chemical education that are adaptable for distance learning.

In December 2019, a new strain of coronavirus caused a cluster of cases of a respiratory disease, which has been referred to as coronavirus disease 2019 (COVID-19). According to media reports,[42] more than 200 countries and territories have been affected by COVID-19, with major outbreaks occurring in Central China, Iran, Western Europe, Brazil and the United States, and the disease was characterized as pandemic by the World Health Organization on March 11th, 2020[43]. The COVID-19 pandemic has affected educational systems worldwide, leading to the near-total closures of schools, universities and colleges. Most governments around the world have temporarily closed educational institutions to contain the spread of COVID-19. Approximately 1.725 billion learners were affected by university closures in response to the pandemic. In response, UNESCO recommended the use of distance learning programs.[44,45] The COVID-19 pandemic presented a colossal challenge to educators to adapt all their classes urgently and massively to distance learning in order to maintain educational continuity with the same level of quality. In the context of the health crisis linked to the COVID-19 epidemic, a plan for educational continuity was set up in France by the Ministry of Higher Education, aiming at maintaining the continuity of teaching by guaranteeing that institutions offer their teaching modules in e-learning form to enable students to follow their courses at home. Within this framework, national tools are made available (FUN MOOC, thematic digital universities, etc.) and are available for educators. Even though some educators and some classes were ready to face the situation, a large majority had to adapt their teaching and learning in a short time, with no training, insufficient bandwidth, and little preparation. Moreover, the existing distance courses were not created for conventional students or for the Y/Z generation[46]. This population was born into a world of information technology and is therefore much more connected to the world[47–49]. They prefer to work in groups with hands-on experience[50,51]. They have few time constraints and many more sources of entertainment. They did not choose this way of learning, and so they may not be as motivated as the students that chose distance learning in the past. In the case of COVID-19, the sudden decision to impose lockdown obliged educators and students to stay at home, thus inducing inequalities, ominous for both students and educators. For students, the family support for logistics (shopping, preparation of meals, etc.) is different between students who have returned to their families and those who remain isolated in their small rooms close to the campus. The former have more comfortable and social conditions, and can be supported by their family. However, some of these students have to share their computer or connection time with other family members, which reduces their working time for real-time on-line learning, and leads them to work on courses on demand or to often have group meetings at night. Similarly, teachers' working conditions are variable, depending on their personal accommodation, their access to the home network, the composition and constraints of their family unit (children, other persons working at home, need to support vulnerable people), and the means available to them at home. They often have to mobilize their own means (apart from a laptop), without dedicated equipment and without institutional help concerning their working conditions. This unplanned, unprepared and rapid move to online learning led to a multiplication of strategies by educators for distance learning to be able to replace, within a short period, classes, tutorials, project groups, lab works and assessments with different, recently acquired technologies. The purpose of this paper is first to present some attempts and the corresponding feedback from users in order to enable lessons to be learnt from this unique experience of education in the time of the COVID-19. Secondly, this work aims at helping the academic educational community to learn from the experience and prioritize a forward-thinking and scholarly approach to the practical solutions implemented.

■ METHOD & CONTEXT

The lockdown occurred in the middle of the semester, on March 16th (semester started on January 27th, 2020 and ended on June 5th, 2020) and obliged the educators to adopt different strategies to ensure the continuity and the content of the teaching program without loss of quality. The study focuses on a the semester organized for 3rd- and 4thyear students following a 5-year program in Chemistry, Environment and Chemical Engineering (a total of 104 students in the 2019/2020 academic year) in the Chemical Engineering Department at INSA Toulouse (National Institute of Science and Technology of Toulouse), France. These students were part of a highly motivated, concerned group, who had already acquired working methods, and were able to work autonomously. The usual teaching method before lockdown comprised lectures, tutorials and lab work that occupied similar proportions of their time. This study is based on an inventory of the many different strategies imagined, set up and applied by educators during the semester. A sixteen-question online survey in French was carried out at the end of the semester to evaluate the feedback from students on each strategy proposed, with responses based on a Likert[52] scale (Figures 1&2). The survey also included 8 open-ended questions on the main parts (classes, tutorials, lab work, projects, assessments, distance learning, proposal, educator involvement) that were asked after a series of 3-6 questions on each topic. Participants were approached twice by Email and the response rate was 85%. All the students were in France in the same time zone (Central European Time, CET) during the semester. Teachers were also consulted by means of a 10 question online survey (N =15, response rate was 75%). The data from the online surveys were entered into a Microsoft Excel spreadsheet and were collated. All responses were analyzed and the results are presented in the next section.

■ CLASSES AND TUTORIALS

Different strategies were attempted for distance classes. In the urgency of the first two weeks of the situation, many classes were transformed into sessions in which the students worked alone, reading the class documents (slideshow, book, etc.) or specific documents sent by the educators. A majority of students (76.1%) did not enjoy using this technique (Fig 1.a Q1) and thought the presence of an educator who gave explanations when necessary was beneficial to help them to deeply understand the courses. Nevertheless, some students (9.1%) appreciated this way of learning, which could be done on demand (e.g. when the student was most available, and repeated as many times as necessary) and also helped them to develop their autonomy skills. Another approach that was developed early in the beginning of the pandemic was the use of videos of slideshows blended with an explanation by the educators (Fig 1.a Q2) and completed with videos from the Internet to flesh out specific points. All the material was available on a free, open-source learning management system (Moodle) and was also available on paper at the request of students. This technique was much more appreciated by students (51.8 vs 29.4%). Providing a video support made it possible for students to watch it several times, which helped them to organize their own time and also to concentrate for a long period. For students, this represented an opportunity to develop their own skills, and their sense of creativity and adaptation. After a week, some educators proposed a commented slideshow (free option in Microsoft PowerPoint software – audio is triggered on each slide - Fig 1.a Q3). This led to large files being shared via the file transfer service or the video hosting platform of the University (https://prismes.univ-toulouse.fr). This last option had the advantage of allowing the video capsule to be embedded directly in the teaching web platform (such as Moodle), thus avoiding losing students who were inevitably attracted by other supports when they were on commercial video platforms (commentary section, other videos, advertising, etc.). A similar number of students agreed that the use of these commented slideshows was useful as a course (51.8%) and fewer disagreed (16.9%). This solution seemed to be more efficient for educators as the audio recording was faster and seemed to be less refused by the students than the reading approach. In both cases, students appreciated being able to work at their own pace and to listen to the explanations as many times as necessary to understand the course. Nevertheless, the students pointed out the advantage of keeping a form of direct interaction with the teacher and gradually progressing in the course to have an experience that was as close as possible to the face-to-face classes. Some students also said that the video lectures were better than the audio ones. Indeed, the video format attracts more attention than an audio lecture. However, technically speaking, it should be noted that video files should not be shared by file transfer in their original format, as these video files exceed several gigabits and they must be shared on online video-sharing platforms to alleviate the storage burden.

After two weeks of distance learning, all educators were granted a license for video telephony and online chat services through a cloud-based peer-to-peer software platform (Zoom Video Communications – Fig 1.a Q4). It is worth noting that a large majority thought this solution was helpful for distance learning (79.3%) and was the best way to mimic traditional classes closely, allowing the educators to give live answers to students' questions. However, some students (6.9%) encountered difficulties with this system. Class rhythm could sometimes be too fast, shy students did not dare to ask the educators to explain, other students had difficulty in paying attention to a screen for more than an hour (inattention could lead to a breakup in the classes and a decrease in motivation) and not all students had a calm place to study. A positive benefit was obtained with the chat, which allowed many questions to be collected during the lesson and groups of questions to be answered at a defined frequency. It clearly helped to collect questions from students who had never asked such questions in a conventional lecture. It is interesting to note that the use of video communications forced students to discipline themselves by cutting off their microphones when they were not speaking, and by respecting the speech of other classmates. The main drawback was that exchanges between students were limited.

Moreover, a large number of students reported an increase of the time needed to work on the classes after the videoconferences, which slightly increased the work load. 61.9% thought they were less effective than learning with the educator in presence. Regarding the content of the courses, 43.5% of the students thought they covered an amount of knowledge that was equivalent to that in the face-to-face sessions, but 44.7% thought it was smaller (11.8% bigger).

Tutorials had a similar duration to lessons, were classically more interactive and specific than a lecture, and sought to teach by example/application. They were firstly organized in autonomy without any synchronous input from educators (Fig 1.b – Q5). This approach was massively rejected by the students: 94.4% of the panel judged it ineffective. The second approach tested was the diffusion of a correct version of the answers to exercises by mail or on a web platform (such as Moodle – Fig 1.b – Q6). This approach was considered useful by almost 29.1% of the student panel and useless by 45.3%. As an alternative, some educators proposed to answer the students' questions in online forums or using chatting apps like WhatsApp (Fig 1.b – Q7) as a support.

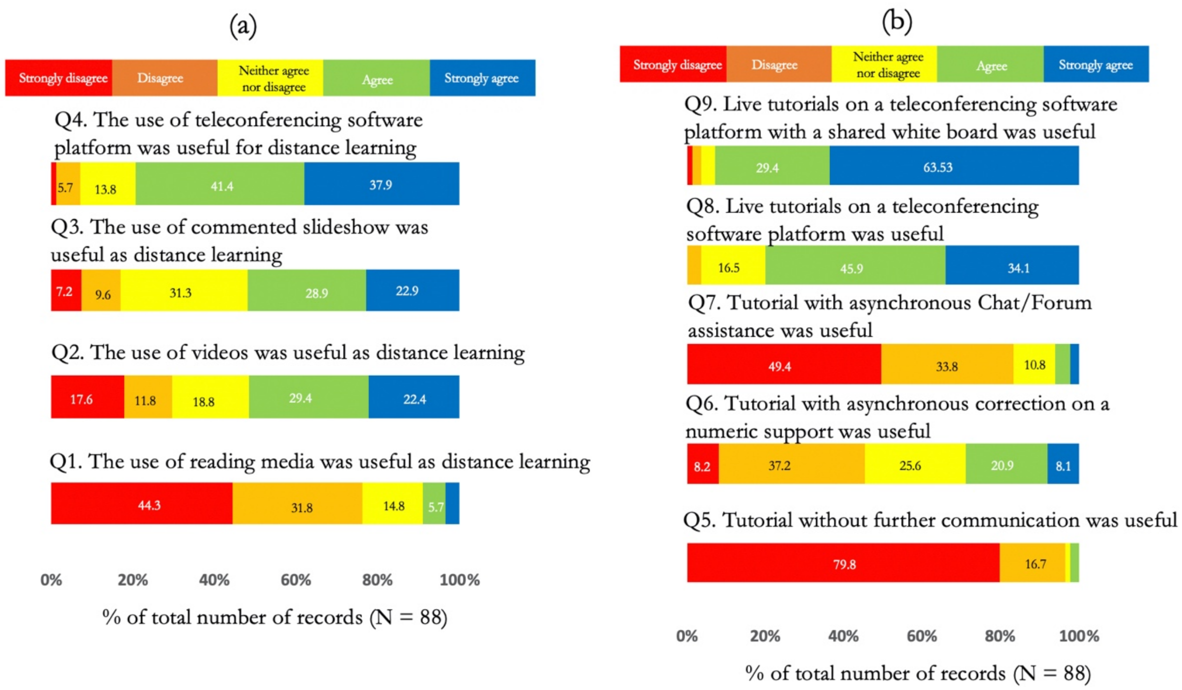

Figure 1. *Student responses relating to the pedagogy attempted for distance learning for classes (a) and tutorials (b) in time of COVID19. Total number of respondents = 88 (academic years 2019/2020).*

Unfortunately, due to the long response time needed to type the answer and the lack of readability, this approach was ultimately widely rejected by students (83.1%). The use of videoconference software was much better received by the users (Fig 1.b – Q8), with an 80% satisfaction rate. The students emphasized the dynamics during the tutorials and that the exchanges with the teacher helped them not to drop out of the session. Nevertheless, some students pointed out that, during distance tutorials, the rhythm was often imposed by the best students and they therefore suggested organizing small groups and even randomly dividing the group into sub-rooms to favor collaboration between students' (more than face-to-face tutorials). As the videoconference software was equipped with a whiteboard option where all annotations could be displayed to all the users (Fig 1.b – Q9), this option was tested first by educators equipped with tablets/pencils but then rapidly extended to other possibilities. In the absence of specific equipment, various alternatives were implemented with similar degrees of effectiveness: (i) sharing a correct version prepared before the session and showing the elements of correction as and when appropriate, (ii) sharing the video stream of a smartphone filming the hand writing in real time, (iii) using a Microsoft Excel spreadsheet that was displayed step by step and sent to the students after the session. These interactive approaches were the most useful according to our student panel (92.9%) and also according to educators (100%), as this allowed the educator to advance at the same pace as the students. It also provided the possibility to refine the explanation with more details for students that were experiencing difficulty. For all these tutorial approaches, 49.4% of the student panel perceived a decrease in the effectiveness of the tutorials relative to a face-to-face one and 22.4% thought they were more effective. Regarding the content of the courses, 48.8% of the student panel thought they covered an equivalent or greater amount of knowledge but 51.2% thought they covered a smaller amount than the face-to-face sessions. Another aspect was the adaptability of the taught content to the communication tools and vice versa. Content that needed deeper explanations and argumentation, for example the logical development of a theory in physical-chemical science, were better perceived in face-to-face or videoconference sessions than in autonomy. The possibility to interact with the educator until they achieved full comprehension reassured the students. Autonomous documentation and commented slideshow methods performed better than face-to-face for story-like contents, as, for example, in the lecture on “waste management strategies”. These (partially) self-taught methods were more attractive and prevented students from dropping out.

■ LAB WORK, PROJECTS AND ASSESSMENTS

Group projects were organized in parallel with the lectures and tutorials in several domains (bibliographic research, initiation to research, experimental project, etc.) in groups of 3 to 6 students for a duration of 2-4 months (Fig 2.a – Q10).

According to the results of the survey, 51.2% of students found it difficult to participate in group projects with distant project members, i.e. without the possibility of face-to-face with each other. The shared result can be explained in two ways. First, it can be hard to work remotely within a group especially when it is necessary to collectively use and work on software related to the subject of their project. In addition, the absence or lack of active participation of certain members can degrade all teamwork. The students also encountered difficulties in distributing tasks and in interacting. It was observed that groups of more than 3 students made these tasks impossible to carry out. It should also be noted that the students' participation and motivation in the group work were more unequal than in pre-lockdown projects. The absence of synergy due to the distance can partly explain this lack of motivation. In contrast, other students thought that using the videoconference application made it easier to work in a group. The students notably pointed out the need to allow extra time in the timetable that was reserved for the projects, so as to help the organization of supplementary meetings.

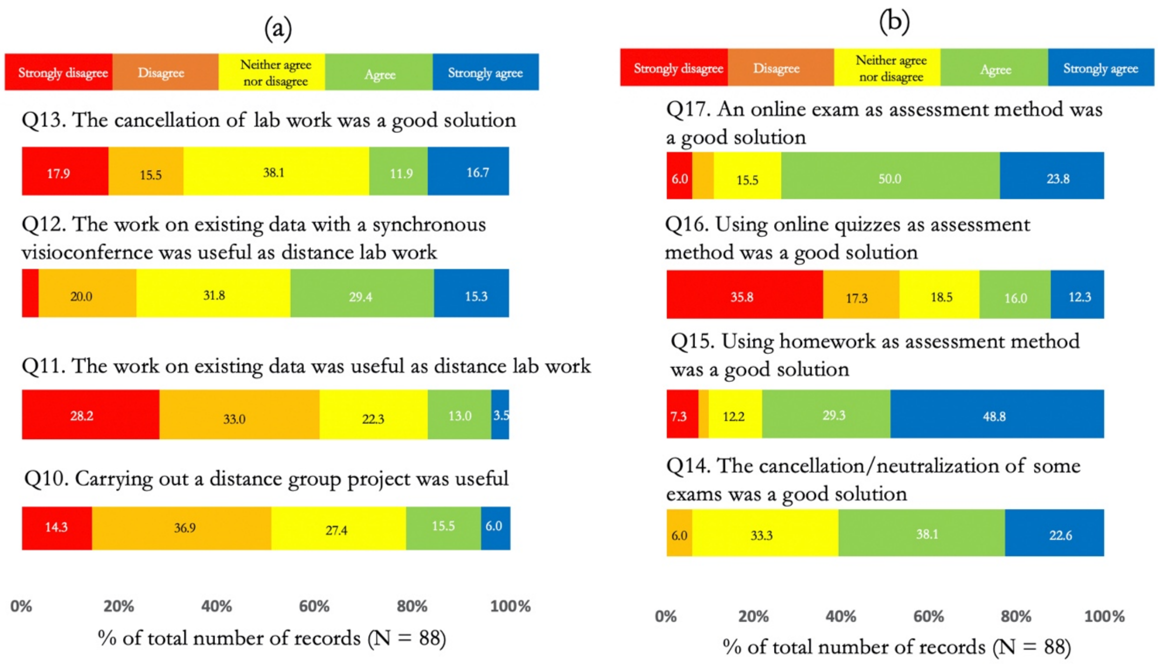

Figure 2. *Student responses relating to the attempts in pedagogy concerning distance learning for project and lab work (a) and assessments (b) in time of COVID19. Total number of respondents = 88 (academic years 2019/2020).*

In the end, 51.3% of the students did not see an increase in the effectiveness of the projects and only 15.9% thought they were more effective than a face-to-face project. Regarding the interest of working in a group, 52.9% of the students thought that maintaining group projects at distance was useful. It is worth noting this remark was valid for long-term projects, as working in small group for tutorials was much more appreciated.

Practical lab works (laboratories) are considered as an application (and a measure made by the students) of scientific methodology, based on proposing an initial hypothesis, designing an experimental protocol from it, performing the experiments, interpreting the results and possibly refining the initial hypotheses. At the time of distance learning, this pedagogical method was one of the most difficult to maintain. Firstly, educators proposed replacing the lab work by an analysis of data provided by them (Fig 2.b – Q11). This approach, which consisted solely of the numerical application of the lab work in autonomy, was rejected by the students (61.2%). The same approach using the presence of the educator with videoconference in small groups (Fig 2.a Q12) was appreciated by the students (44.7%). Some students appeared frustrated to lose the practical aspect of the lab work, which was probably exacerbated because the student panel questioned was composed of students of disciplines relating to Engineering Science where the "hands-on" dimension is particularly important. In contrast, some others underlined the fact that the theoretical aspect was treated in much greater depth and this helped them to understand the courses. Because of the circumstances, some of the practical lab work was cancelled (Fig 2.a – Q13). This solution divided the student panel: 33.3% found it a good solution, 28.6% disagreed, and 38.1% were neutral on the question. The students stated that attempts at maintaining the lab work was more time consuming for them and more exhausting (even without experiments). These results should be put into perspective. The practical work proposed for distance learning was not fully appropriate to replace laboratory sessions. The restricted access to the experiments, due to the lockdown, did not permit this type of teaching to be adapted in good conditions. Pictures and videos would have enabled a better understanding of the experimental work and allowed the operation of the devices in real conditions to be visualized. As for the distance project, students encountered many issues in terms of organization and interactions (planning, connection, sharing data, motivation of some members, etc.) and pointed out that writing a report on each session was a strong constraint, requiring more time and several visual resources (videos, 360° photography, AR, VR) that were not designed before the lockdown and could not be produced in time. Finally, 72.0% of the student panel observed a decrease in the effectiveness of the lab work at distance and only 6.1% thought it was more effective than learning in presence. Regarding the content of the lab work session, 81.9% of the student panel thought they had done less than in presence sessions and a small majority (53.7%) of the student panel thought the distance did not alter the work in groups.

Concerning assessment, various forms were tried out. As for the lab work, first, some intermediate exams or project presentations were cancelled or neutralized in order to release time for students and to give time for educators to find a solution (Fig 2.b –

Q14). This approach was appreciated by 60.7% of the panel but some students pointed out the risks of cancelling intermediate exams as (i) they would have helped them to evaluate gaps in their knowledge or difficulties in a topic and (ii) such cancellations dangerously reinforced the need to succeed in the final exam. Some other exams were replaced by homework over a long period (Fig 2.b – Q15). This system was much appreciated by students, with 78 % expressing satisfaction and appreciating having time to reflect on a given problem. Online quizzes (multiple choice or open choice) were implemented (Fig 2.b – Q16) but a large majority (53.1%) did not find them satisfactory. This was because the quizzes, as proposed, did not allow the method of thinking, the analysis, the writing or the understanding of a problem to be evaluated and this created considerable stress for the students. Many students were worried about not completing the test in time. Finally, the last system to be tested was for the student to download the exam question(s) online and upload his/her answers to a server (Fig 2.b - Q17). This system was the most appreciated, with 73.8% of approval from the students, because it was the one that came closest to the usual exam conditions. However, some students pointed out the stress caused by downloading/uploading files in the event of technical problems, and concentration problems that would not have occurred in the exam room. They asked for clear rules to be defined before the exam and more time than usual to complete the exam. This last request may seem contradictory to the feelings of some of the students who denounced illicit communication between learners during the assessments.

The online assessments introduced strong biases between the students, as some worked online with others (serval teachers have observed identical answers to exam) and especially for calculation exams, as it worked fine in writing/redaction exams, and some students try to save time by pretexting connection problems. Some solutions to avoid cheating have been considered in France, such as monitoring exams via videoconferencing, or by installing software on the student's computer, which allows monitoring through facial recognition but also prevents access to other documents on the computer (TestWe [53]). However, these solutions are perceived by students as an intrusion into their privacy. In addition, this system is a source of discrimination for students who do not have a computer or a high-performance Internet connection. And, finally, these software are expensive and complicated to set up. In some disciplines, solutions to avoid cheating have been considered. For example, students did not have to answer the same questions. Also, sometimes, the content or the order of the exams has been modified and, to avoid the student going on the Internet, the questions have required more reflection from the candidate[54]. The methods of testing have changed in some disciplines, giving priority to homework on subjects for reflection and oral examinations, allowing exchanges and a better understanding of the student's personal work and achievements. Skills assessments in "project" have made it possible to carry out distance learning support and allow for personalized contact with the students. These online exam sessions may be an opportunity to put cooperation and mutual aid above the excessive individualism that universities normally display. The time of collective intelligence is perhaps the future of a post-coronavirus.

Globally, and despite some failures in our attempts, the panel of students voiced a good percentage (60.0%) of satisfaction with the implementation of full distance learning and 65.8% appreciated all the measures taken to adapt the planning of learning. 76.7% also appreciated the technical tools provided during the semester and a large majority of 87.2% appreciated the involvement of educators during the distance semester. Nevertheless, only 38.5% of the panel were satisfied with their work. It is important to note that, in our study, the students already knew their teachers and the working methods of the institute. It must have been less easy for 1st year students who are less used to working independently. Teachers observed an increase in students' marks in exams (1 to 2 points more out of 20) but it is still too early to know the real effectiveness / success of this teaching method.

Concerning the teachers' feedback, we would like to point out that a large majority of them had not prepared supports for distance teaching before the crisis. However, they quickly managed to organize and implement sharing sessions for (i) their corrections via platforms such as Moodle, (ii) good practices using collective videoconferencing or, (iii) mutual aid in learning these massive videoconferencing software packages. This solidarity permitted many teachers to progress collectively in facing the rapid adaptation of distance education. 19% of the teacher panel encountered some issues in using the distance learning tools and 21% faced problems to adapt their teaching. 85% of the educators spent more time preparing what was to be learned (64% - a much longer time) and 85% encountered issues for distance assessments. Nevertheless, 67% of the panel was convinced of the need to maintain individual assessment for distance learning. 100% of the panel thought the distance learning changed the relationship between educators and students. 50% of the panel recognize they have acquired a new vision of distance learning, 65% think it will impact their way of teaching and 53% will conserve some approaches when presence learning is restored. Several educators reported some health consequences of spending most of the daytime focusing on screens during videoconferences, such as headaches, which may also be experienced by students. This may affect concentration and the ability to react promptly during distance classes. Overall, 75% of the panel was satisfied by the distance learning provided. These results should nevertheless be balanced with respect to the audience and students' profiles. They are not transposable to all levels or domains of higher education.

■ DISCUSSION

The COVID-19 pandemic has created significant challenges for the global Higher Education community. The first was to adapt distance learning tools[55] to the current generation of students. Initially, the distance learning tools were developed for motivated students with strong time constraints who had chosen this method but, in the current situation, it has been imposed on the Y/Z generation who have fewer time constraints but many sources of distraction and stress. Many existing approaches were therefore not suitable and new ones had to be adapted to the context. In the event that the pandemic continues to disrupt traditional teaching platforms, the lessons learned from this experience might help us prepare. Special attention should be paid to:

(i) working on the ethics of student assessment and its real purpose;

(ii) remaining flexible towards students, whose social life has been disrupted to a large extent, in order to regain a certain balance. Particular attention must be paid to the well-being of students, for example by setting up a support system for students with psychological difficulties;

(iii) breaking the monotony of distance learning by bringing back motivation/conviviality,[56] establishing distance gamification[19,34,56–58], and restoring the pleasure of learning[59];

(iv) assisting students who do not have reliable Internet access and/or who are struggling with technology; the digital fracture between students must be narrowed. According to UNESCO,[60] 826 million students in the world do not have a computer and 706 million do not have Internet access at home (around 1% in our institution);

(v) working with international students, who were more isolated[61] and less equipped[62] than most other students;

(vi) paying more attention to the working conditions of teachers at home, with regard to their equipment and tools, but also the ergonomics of their working environment (health safeguards), their connection time and respect of disconnection between private life and working time, and

(vii) favoring a variety of supports, whether for teachers, who must be free to select the tools suited to the subject and their technicality, or for students, in order to avoid weariness when using single format supports.

The COVID-19 crisis has changed our world, and it has also taught us that the education system must be renewed to better prepare the current student generation for an unexpected future. This includes:

- preparing our students to become citizens of a sustainable world [63,64], to work collaboratively on a global level, to be prepared for a change in the economic markets[65–71] (although energy, water and environmental sectors seem to have been little impacted by the crisis - placement rate of students in last years of 50% before graduation in our department),
- redefining the role of educators[72], who should no longer be the sole owners of knowledge but become mentors or facilitators, in particular to encourage students to find sustainable solutions to complex problems, based on a critical analysis of existing data and their own knowledge, which they need to develop,
- teaching life skills[73,74] necessary for the post-crisis world, such as creativity[75], innovation, autonomy, resilience, adaptability, communication and collaboration, empathy and emotional intelligence, and
- unlocking new technologies to offer engaging and motivating education programs.

This last aspect was targeted during this semester, but more interactions are necessary. Examples worthy of mention are the development of quizzes during videoconferences to motivate students, the establishment of regular question/answer sessions to guide students or give and receive feedback, the implementation of more support materials such as video, AR, VR, filmed visual experiments[76–84] or 360° laboratory visits[85,86], and more distant measurements.[87,88] It is also important to vary the media for access to learning, and to hybridize the teaching methods, so that each student can find his or her way in access to knowledge. During a learning session, it is essential to give students the opportunity to apply their knowledge before the final assessment. This allows the teacher and the student to verify that the concepts learned are well understood. This experience opens up many perspectives, based on the experience acquired during the COVID-19 pandemic, such as the possibility of removing large classes in lecture halls by offering distance learning courses and by promoting remedial work in small groups of students.

The University will have to invest sustainably in distance equipment (tablets/pencils) for teachers or virtual laboratories to provide the students with the most pleasant and engaging experiences. Hybrid education requires time and investment: teacher training, recruitment of pedagogical advisers, studio design, information material, etc. Contact with teachers remains central and cannot be removed, so certain means of communication, such as meetings by videoconference or the use of distance whiteboards, should be preserved even after the crisis. Face-to-face communication helps to motivate students, better capture their attention, and set the right pace for those who go too fast (partially acquired skills), so as to help reduce school dropout while not frustrating the engaged and proactive students. Distance learning involves a profound change in the role of the teacher and in the teacher-student relationship.

Overall, this experience was generally beneficial, pushing our students to work on their flexibility and benevolence but, more importantly, it is our hope that, for the Z/Y generation,[48,50] these experiences of isolation and distance learning away from the campus or their peers /educators will serve as a reminder of our strong human need for face-to-face social interaction. The President of the Sorbonne University confirmed this[89]: "Distance learning alone is useless, it is not the solution. It must be a complementary element to face-to-face teaching. You never learn better than in a group. We need contact and exchanges with students. Teaching must be hybrid".

■ CONCLUSION

The COVID-19 crisis has resulted in the closure of schools and universities across the world. Globally, over 1.7 billion students were out of school. As a result, higher education had to adapt quickly and to change radically, with a massive rise of e-learning, with teaching being provided on digital platforms or in live classes online. The teachers at INSA Toulouse have accomplished so much in such a short time with impressive commitment. This unexpected, rapid shift to online learning has led to a multiplication of teachers' strategies for distance learning, tutorials, project groups, lab work and assessments in a dozen teaching units concerning chemistry, chemical engineering and environment at INSA Toulouse, France. The purpose of this paper was to collect the experience of these challenging days, with feedback from students. The analysis showed great successes and some failures in the solutions proposed. Some guidelines have been put forward and remaining challenges addressed in order to learn from such a singular experience, and to face the future with more knowledge about distance learning. The main outcome has clearly been to trust human creativity and to allow teachers the flexibility to creatively develop their own pedagogy, especially with the support provided by their institutions. While some believed that the unexpected, rapid transition to online learning – without training, with insufficient bandwidth, and with little preparation – would result in poor transmission, our analyses showed a blend of success and failure when the experience was reviewed. Teachers recognize that they have learned more about distance education in these two months than in the past ten years, and this was the result of their constant commitment and dedication to education during this crisis. As one university head claimed[90], "The coronavirus will have done more for e-learning and online training than all the plans and strategies of states and institutions of higher education!" .

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