Face-to-face vs. Online learning in Engineering Courses

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***Abstract*— After the 2017 earthquake, instruction-at-a-distance was massively adopted at Tecnologico de Monterrey Mexico City Campus (CCM). This tragic experience gave CCM staff, faculty, and students truly online expertise, which is now used due to the pandemic. The pros and cons of in-site classes versus online sessions are presented and discussed for engineering courses. A 25-item survey was designed containing categories such as human interaction, command on oneself, and academic performance, among others. A total sample of 396 engineering students was considered. Most students agree that the face-to-face scenario favors their enthusiasm for class attendance, their learning process as well as teacher and peer-to-peer communication. The lack of human contact, the lack of outdoor activities, and the difficulty in making new friends were also factors against education at a distance. Along the same line, distraction, depression, and stress incremented in the online model. However, from the academic point of view, student performance remained similar in the face-to-face model compared to the online model. The teacher's efforts in order to implement active learning activities through novel apps and simulations in the online model were remarkable.**

Keywords—face-to-face courses, online courses, statistical analysis, educational innovation, higher education

I. INTRODUCTION

Since it was founded, Tecnologico de Monterrey has been a leading international university offering a wide range of courses in several fields. Face-to-face classes had been delivered as usual up to September 2017, when the Mexico City Campus (CCM) suffered the effects of a 7.1 Richter-scale earthquake [1], and classes had to be interrupted for 2 weeks. Fortunately, our Virtual University had already the online transmission expertise and pedagogical staff complemented well-rounded academic training sessions for faculty and students. In the blink of an eye, CCM got back on track. Zoom classrooms were massively adopted and the academic community, without knowing it, prepared itself for what we are living right now.

The COVID-19 dramatically changed the way education is delivered at all levels. At Tecnologico de Monterrey, virtual classes are given mostly via Zoom. All faculty members are assigned a premium license and a wide range of apps complement the academic experience. For example, in the areas of mathematics and computing, *Matlab* licenses are used to program physics simulations and the physical phenomena analysis. Other apps such as *Geogebra*, *Mathematica*, and *Desmos*, to mention just a few, are also used in math and physics courses to expand visual skills. Physics classes are enriched by mainly using the University of Colorado *PhET* simulations. Some teachers complement the instruction with their own *Notability* notes, *Prezi* presentations, *edpuzzle* interactive videos, as well as *Socrative* quizzes. Site apps such as *Classtools*, *Kahoot*, and *Gimkit*, change the pace of the session and keep the flow of student attention. Other tools such as *YouTube*, *Facebook*, *Instagram* and even *TikTok* have also found room in education, so that now more creative sessions are being conducted. Consequently, now online classes include a strong *production* element, which was lacking in some of the traditional instruction. For example, light boards have been constructed by some teachers, several *YouTube* channels have been opened, and closed *Facebook* groups have been organized. Daily academic communication has had an immense support with apps such as *WhatsApp*, *Remind*, *Teams*, *Skype*, *Messenger*, and *Slack.*

The academic transition from face-to-face instruction to online classes has been smooth for Tecnologico de Monterrey. The pandemic lockdown came at a time in which many technological applications have made it possible to migrate to a home schooling in no time at all. Unfortunately, not all Universities and high schools have had the same experience in Mexico. Some of them have really had a very hard time.

On the other hand, at our Institution, a great deal of creativity has been poured into home-made experiments by the chemistry professors. Chemistry is the only area in the Science Department that has not been able to adapt itself 100% to the online instruction. The reason is clear, handling specialized equipment, the enforcement of safety guidelines and some key experiments can only be learnt in the lab. In order to make up for this gap, once it is safe to return to the laboratory, workshops targeting the mentioned weaknesses will be provided on demand.

Under the circumstances being faced there are at least three obliged questions to be asked: *(a)* Are the students taking ownership of their knowledge? *(b)* How has the interaction between the student and the teacher, as well as among

themselves, changed? and *(c)* What types of feelings arise in the students with an off-Campus synchronous online instruction?

In this work, some of the main factors that keep virtual classes at the same level of excellence as the face-to-face ones are analyzed. Obstacles dragging the online sessions must be overcome and key elements that contribute to a memorable experience must be emphasized. A working questionnaire including variables related to human behavior was designed including categories such as (a) academic performance, (b) human interaction (among students, and among students and teachers), and (c) command on oneself (e.g., one's organization, how focused one is, self-discipline, one's health, in one-word, self-wellness).

Therefore, the research questions posed in this work are:

(a) What instructional model do the students prefer, face-to-face or online, and why?

(b) According to students' perceptions, what are the main advantages of the *face-to-face* model regarding academic performance, interaction with teachers and classmates, as well as command on oneself?

(c) According to students' perceptions, what are the main advantages of the *online* model regarding academic performance, interaction with teachers and classmates, as well as command on oneself?

The outline is as follows. In Sec. II, some aspects of the theoretical framework are presented. Sec. III unveils some representative experiences about the way in which other institutions have dealt with online instruction. Sec. IV describes the methodology followed in this work, while Sec. V presents the data analysis and the results. In the last section, the conclusions and future work are presented.

II. Theoretical Framework

Online learning allows students to have experiences in remote digital environments, based on new technologies and computer networks, taking advantage of the internet and other digital resources and technologies [2]. The materials and environments allow self-directed learning (in which the student decides which resources to use and when), or directed by a teacher (who actively participates in the sessions). On the other hand, the interaction can be synchronous, asynchronous or hybrid (a mixture of synchronous and asynchronous activities). This learning modality requires an intense participation on the teacher´s side. It also requires careful implementation to provide successful learning opportunities. Optimization of the process and the resources is a must.

Although online graduate and undergraduate education-at-a-distance programs have been well established before the COVID-19 crisis, few trust-worthy-research studies have measured the efficiency of licensed online programs in comparison with face-to-face programs [2].

Crick et. al. [3] point out that the overall impact of educational technology and digital learning are still uncertain in the formal academic literature. Their dependence on specific educational settings and the context of Learning, Teaching & Assessment (LT&A) makes a difference in the results. While several international research studies have demonstrated the benefits of the successful application of digital LT&A in a variety of contexts and settings, the widespread adoption, implementation, as well as evaluation of educational technologies has yet to be fully realized [4–7]. Political debate on the efficacy and on the positive impact of educational technology has always been going on. Nevertheless, it has reached an important peak due to the confinement forced by the COVID-19 pandemic. Consequently, academic research on educational technology must be conducted to scientifically support or discard political issues.

Some recurring themes are that learning is caused by methods of instruction rather than by means of instruction, so research should focus on the characteristics that are unique to digital learning environments. Instructional practice should be based on rigorous and on systematic research, including value-added experiments aimed at identifying active ingredients in online instruction. Therefore, online learning research must identify the boundary conditions under which instructional techniques are most effective. It should also test and contribute to a solid learning theory [6].

III. Related Work

Regarding online learning forced by the COVID-19 confinement, there have been interesting studies from different perspectives in several countries. Some of the featured studies are outlined next.

A study made in Hungary to determine the aspects of digital transformation during the pandemic shows that although there are multiple challenges, half of the students liked it and would prefer it in the future [8].

Researchers in Romania reported the use of the *Discord* communication platform to keep teachers and students in touch in real time. With the confinement, they decided to continue developing the platform in order to improve its functionality towards the new educational needs [9]. Based on formal comments of the conducted questionnaires, this research showed that 95% of their students greatly improved the involvement among themselves and with the teachers. On the other hand, through *Discord*, alumni helped students getting jobs in their workplaces [9].

Khanna & Prasad [10] reported a study in India to identify the problems faced during online education forced by the COVID-19 pandemic. They identified that the problems were technical, related to resources, funds and economic issues. They are well aware that the sudden technological adjustment was necessary, but it has lasted more than anyone could have ever imagined. The discipline and the required motivation to keep up with the online instruction is a real challenge, yet to be accomplished. Nowadays, accepting the change and developing new habits according to the needs of the moment are crucial. The art of being tech-friendly is a must. They also suggest that teachers and parents should communicate better with each other to ensure student discipline and performance by relying on technology to track student activities. To maintain continuous interest from students, it is necessary to find increasingly attractive, interactive, and ubiquitous ways to teach and learn.

In the United Kingdom, Barr et. al. [11] reported that the COVID-19 pandemic has caused widespread changes in the way the higher education sector now operates. Their paper discusses the experience of teaching an eight-week undergraduate software engineering course during the mandatory lockdown. They followed well established best practices. For example, through distributing online lectures into smaller pieces, carefully considering group work, and paying close attention to student feedback to inform quick adjustments, it was possible to offer a pedagogically sound experience, even under confined conditions. The authors reported that there are elements of this mandatory distance learning paradigm that we may wish to retain in the post-pandemic era.

Finally, García [12] points out that the pandemic has generated changes and disruptions in broad sectors of human activity. The author maintains that education has been one of the most affected due to the administrative imposition of the full worldwide lockdown of educational centers. The distance education modality, with strong digital support, offered an emergency solution to the crisis.

The foregoing comments lead us to reflect on post-lockdown times, in which hybrid solutions will be certainly found between face-to-face and online teaching, along with mixed, integrated and flexible learning supported by educational emerging technologies.

IV. Methodology

A five-section Google-Form survey was distributed via email or Canvas to 475 students of Tecnologico de Monterrey CCM registered in the 2021-Spring term. Students were invited to respond voluntarily; 83.4% of them answered, that is $N = 396$ surveys were completed. Hereafter this number will be regarded as our main sample. The sample contains students from several engineering majors: mechanical, biomedical, electrical, chemical, and civil engineering. A small student sample majoring in business and marketing, which were taking a computing science course, were also included. The surveyed population had a 42% female participation rate. Second-semester, sixth-semester and first-semester students represent 60%, 13.6% and 7.6% of the total sample, respectively. The percentage distribution per semester is shown in Figure 1. Those students were registered in either physics, math, chemistry, or computing science courses.

The survey consisted of a 25-item questionnaire aimed to gather the students' perceptions about the abrupt pandemic change from face-to-face instruction to a completely online model. The survey content was designed based on the authors' face-to-face 25-year teaching experience, as well as on the authors' 3-year online teaching experience. The design of the questions was somehow intuitive to investigate which factors of the study were more important. However, it is consistent with the theoretical model developed by Garrison et. al [13] in terms of an effective online educational community involving the three critical components of cognitive presence, social presence, and teaching presence [13–14]. Also, Motte-Signoret et.al. [15] have designed a survey based on their experience to explore the work effectiveness of their faculty and their students.

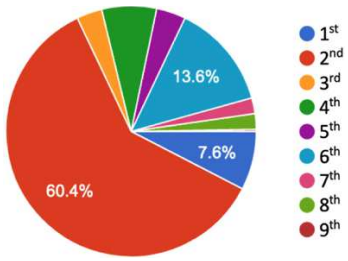


Fig. 1. Sample student distribution by semester.

The questions were grouped in five categories: *(a)* Interaction (5 items), *(b)* Individual (11 items), *(c)* Academic (4 items), *(d)* Support Materials (2 items), and *(e) Learning Experience* (3 items). Interaction questions refer to those items regarding the contact or communication with teachers and classmates. Individual questions include issues that depend on student behavior, feelings, health and attitudes, that is *command on oneself*. Academic questions are meant to explore the academic support given by the teacher. Support material category refers to questions related to proper access to didactic resources. Finally, Learning Experience items refer to the overall learning experience of the student in both models. The survey questions are presented in Table 1. In columns 2, 3, and 4 the question statement, the question abbreviation used hereafter, and the category to which it belongs are included, respectively.

All questions, except *Q*23 and *Q*24, directly compare the students' preference for the online model vs. the face-to-face model. Therefore, they are graded in a 5-step Likert scale ranging from –2 to +2, where –2 refers to total agreement for the *online model* while +2 indicates total agreement with the *face-to-face model*. A 0-value indicates no preference for either model. On the other hand, questions *Q*23 and *Q*24 refer to the face-to-face model and the online model, respectively. They are graded in a 5-step Likert scale ranging from 1 to 5, where 1 = total disagreement, 2 = disagreement, 3 = neutral, 4 = agreement, and 5 = total agreement.

V. Results

A statistical study of the answers given by students was performed, including frequency histograms, principal component analysis (PCA), correlation and regression analysis of variables, as well as clustering. The main results are presented and discussed next.

A. Question Histograms

Figures 2–6 below show the corresponding histograms for each survey question answered by the 396 students.

TABLE 1. 25-ITEM QUESTIONNAIRE

#	Question Description	Abbreviation	Category
Q1	Meeting new people is more favored by	*MeetPpl*	Interaction
Q2	The interaction with my peers is more favored by	*PeerInt*	Interaction
Q3	Extracurricular activities are better suited in	*ExtraAct*	Individual
Q4	The communication with my professors is better in	*ProfComm*	Interaction
Q5	The explanations of my professors are better in	*ProfExpl*	Academic
Q6	The use of support material (videos, apps, simulations, etc.) favors better learning in	*SuppMat*	Support materials
Q7	The coordination of team work schedules is better in	*TeamWkSch*	Interaction
Q8	Team work is more efficient in	*TeamWk*	Interaction
Q9	Student learning is more favored by	*StudLearn*	Academic
Q10	The evaluation used by the professor better reflects my true learning (is more objective) in	*ObjEval*	Academic
Q11	The access to support material is easier in	*AccSuppMat*	Support materials
Q12	My doubts are resolved faster in	*DbtSolv*	Academic
Q13	During class sessions, I pay more attention in	*PayAttn*	Individual
Q14	I organize my work better in	*SelfOrg*	Individual
Q15	During my evaluations I am more honest in	*HonEval*	Individual
Q16	I tend to get more distracted in	*Distracted*	Individual
Q17	I tend to get more depressed in	*Depressed*	Individual
Q18	I tend to get more stressed in	*Stressed*	Individual
Q19	I am more motivated in	*Motivated*	Individual
Q20	My physical discomfort (back, head, eyes pain, etc.) is greater in	*PhysDiscom*	Individual
Q21	My diet in general is healthier in	*HealthyDiet*	Individual
Q22	My overall health (weight, physical condition, etc.) is better in	*Health*	Individual
Q23	My learning experience in the face-to-face model has been (*)	*FFLrnExp*	Learning experience
Q24	My learning experience in the online model has been (*)	*OnlineLrnExp*	Learning experience
Q25	To take a subject I prefer	*FFvsOnline*	Learning experience

(*) In these questions the scale goes from 1 to 5. In all other questions the scale goes from –2 to + 2.

It is observed from Figs. 2-6 that in most questions the students tend to favor face-to-face interactions, in accordance to what has been published by Motte-Signoret et al. [15]. Issues related to the level of stress, depression, and physical discomfort appear more frequently in the online classes. Wang et al. [16] reported that nowadays students at different learning stages face worrisome due to higher pressure to adapt to current learning conditions. In the present study, it is found that students tend to get more distracted in the online model. Similar results are reported in Wang et al. [16] and Mukhtar et al. [17] works. On the other hand, one positive aspect of online classes is that the students get much healthier meals at home, which in the long run may benefit their academic performance: a balanced food intake helps keeping a healthy mind in a healthy body. Baczek et al. [18] also report that the ability to stay at home, continuous access to online resources, learning at your own pace, and comfortable surroundings can be considered as advantages of online learning for medical students. The questions related to the usage of apps in order to comply with class activities, teamwork dynamics, and self-organization came almost even in the face-to-face and in the online sessions. Nevertheless, the study by Wang et al. shows that in general, students had insufficient self-learning abilities, therefore it was hard to be organized and participate in the sessions [16].

It is interesting to note the fact that students report that they tend to be less honest in their online assessments than in the face-to-face ones, as also noted by Mukhtar et.al. [17]. This can be explained by the fact that, in the face-to-face model, the assessments are performed in the classroom under the direct supervision of the teacher, while in the online model students can communicate more easily with each other and have access to a wide range of materials that are not necessarily always allowed in onsite sessions. The vast online information outside of scrutiny of the instructors is just a click away. This is an important issue to be addressed by teachers and academic authorities when adopting online instructional models.

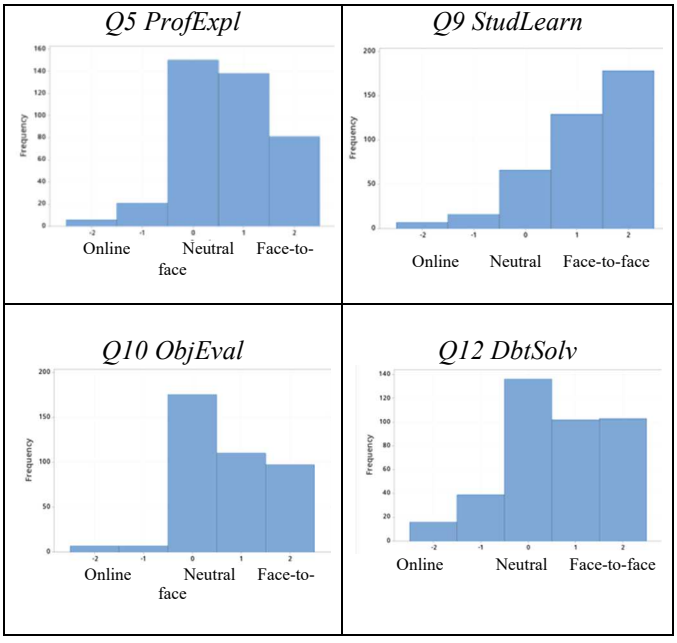


Fig. 2. ACADEMIC CATEGORY

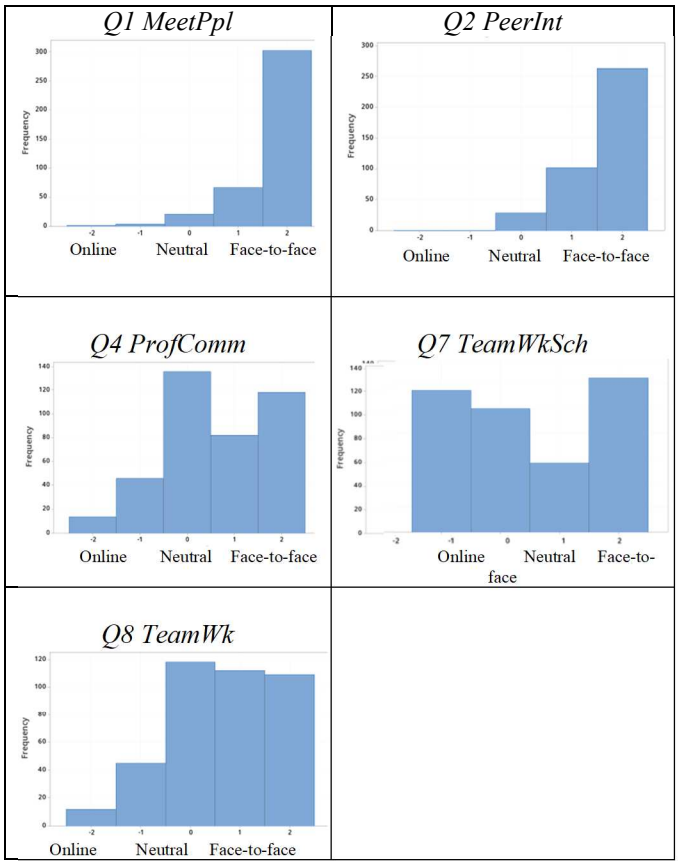
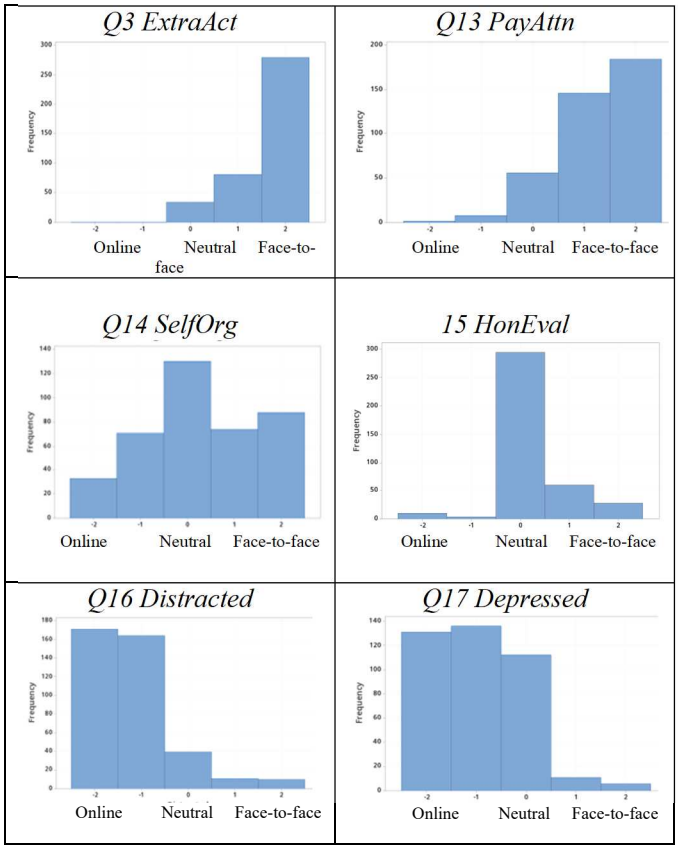


Fig. 3. INTERACTION CATEGORY



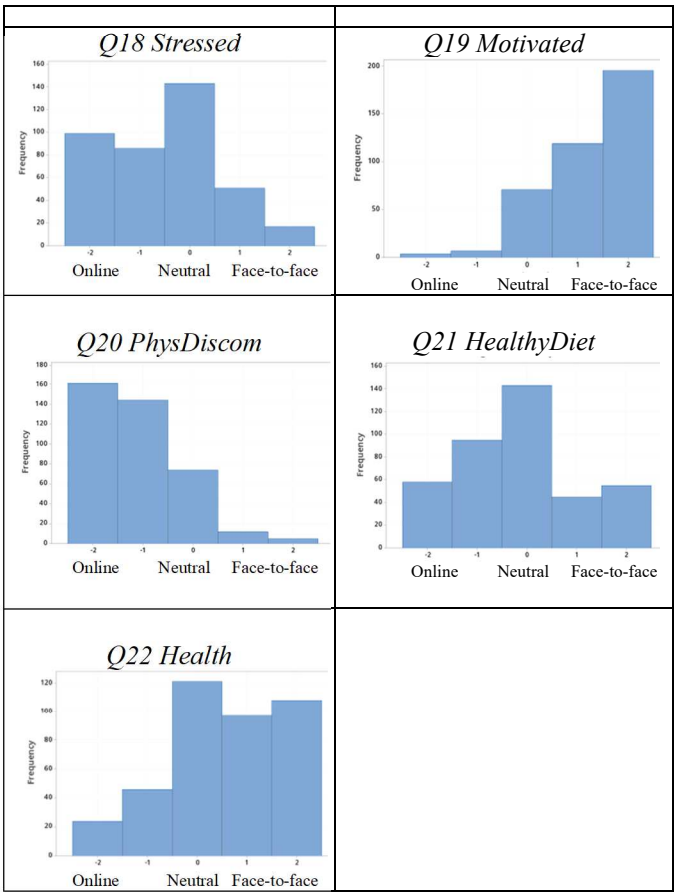


Fig. 4. INDIDUAL CATEGORY

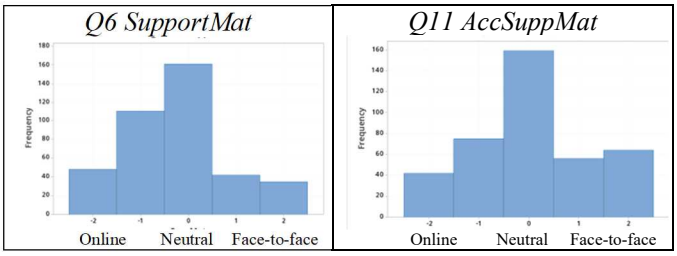


Fig. 5. SUPPORT MATERIAL CATEGORY

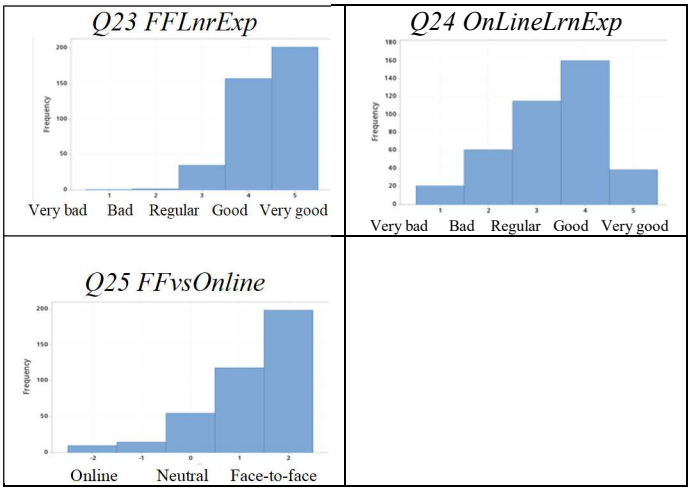


Fig. 6. LEARNING EXPERIENCES CATEGORY

Despite of the fact that the adverse variables mentioned before were present, the global academic performance of the students in the online model was successful in the sense that the model could be implemented without any major inconvenience. This means that overall, a great effort was made by both students and teachers. Most limitations of the online model were overcome and a satisfactory academic performance in the online model was achieved.

B. *Principal Component Analysis (PCA)*

A PCA analysis was performed to investigate possible correlations between the different questions. A biplot of the main components of the analysis is presented in Figure 7. In the diagram, 22 dimensions (*Q*1 to *Q*22) are studied. It is found that physical discomfort, depression, stress, and class distraction dimensions are highly correlated. It can also be seen that health and a well-balanced healthy diet variables are also linked. These two findings are expected.

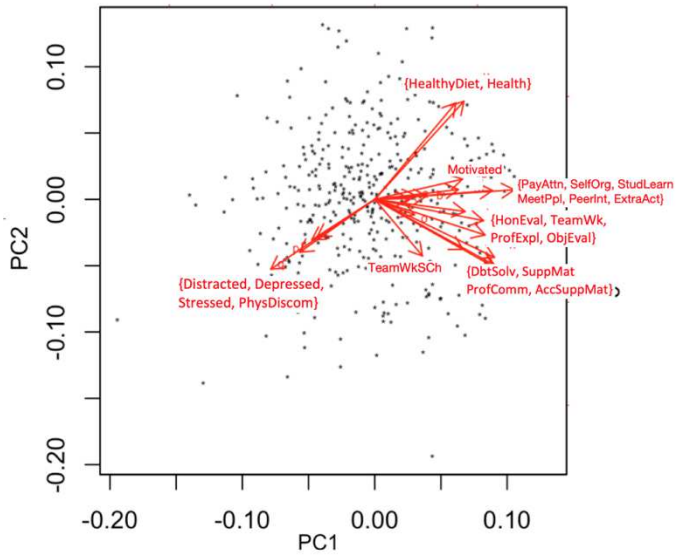


Fig. 7 Biplot of the PCA analysis.

C. *Correlation Analysis*

A correlation analysis among the variables was also performed. On the one hand, it was found that the variables that were more interrelated are: *(a)* student learning (*Q9*) and professor explanation (*Q5*) (0.574), *(b)* professor communication (*Q4*) and doubt solving (*Q12*) (0.572), *(c)* professor communication (*Q4*) and professor explanation (*Q5*) (0.542), *(d)* student learning (*Q9*) and self-organization (*Q14*) (0.536), *(e)* healthy diet (*Q21*) and health well-being (*Q22*) (0.498), and *(f)* depression (*Q17*) and stress (*Q18*) (0.491). All these correlations are somehow expected.

On the other hand, the correlation analysis showed that the least interrelated variables were: *(a)* permanent class attention (*Q13*) and getting distracted in class (*Q16*) (–0.558), *(b)* student learning (*Q9*) and stress (*Q18*) (–0.42), *(c)* motivation (*Q19*) and depression (*Q17*) (–0.415), and *(d)* motivation (*Q19*) and stress (*Q18*) (–0.392). These findings are also expected from everyday experience.

It seems from the previous results that being among your peers in a classroom in a face-to-face session, that is, human interaction, plays a key role in the learning process. If the student pays attention and if the student is motivated, the rest will follow. Couching one another in a nearby environment, cheering each other, eye-contact, and even body language are subtle expressions of non-verbal communication that are all present in a regular classroom.

D. *Regression Analysis*

A regression analysis was made in order to evaluate the main variables that influenced the student's preferences in the face-to-face model versus the online model. *Minitab* was used in order to find the most relevant variables. Form the survey answers, the following regression was obtained, with an R^2 = 0.53.

$$FFvsOnline = -0.08\ (0.418) + 0.51\ (0.000)\ StudLearn + 0.27\ (0.000)\ MeetPpl - 0.12\ (0.001)\ Stressed + 0.15\ (0.002)\ Motivated$$

The coefficients represent the probability that the chosen variable *does not* influence the face-to-face classes versus the online sessions. The numbers in parenthesis to the right of the coefficients are the *p*-values of each coefficient.

According to the *Stepwise* method, it is observed that the most important variables that incline the students' preference towards the face-to-face classes are: *(a)* how much they learn (*Q9*), *(b)* the chance to meet new people (*Q1*), *(c)* the tendency to get more stressed (*Q18*) and, *(d)* the tendency to be more motivated (*Q19*). In general, students appreciate when they perceive themselves advancing in their learning framework. As mentioned above, meeting new people is at the core of the face-to-face preference. According to the students' perception, no online session can fully capture the human interaction in order to get to know someone, especially if it is the first encounter. If a key concept is missed, one gets frustrated and more stressed. On the contrary, if one gets distracted in a regular classroom environment, either the professor or a classmate can quickly help regain the focus. The students get encouraged when peers are helping, and even teasing one another in a face-to-face environment.

E. Clustering

In order to identify groups of students having similar overall perceptions on the two models, a clustering study was also performed. Four main clusters were identified with populations 114 (cluster 1), 74 (cluster 2), 101 (cluster 3), and 107 (cluster 4), respectively.

Figure 8 presents a normalized radar of 22 *dimensions*, from 0 (center of the radar) to 1 (perimeter of the radar), where 0 and 1 represent the lowest and the highest preference for the face-to-face model, respectively. Differences among clusters are clearly differentiated. Students of Cluster 3 reflect a clear preference for the face-to-face model for almost all dimensions,

compared to the other clusters, except those related with physical discomfort, stress, distraction, and depression. On the other hand, Cluster 1 presents the lowest preference for the face-to-face model in most dimensions. Finally, clusters 2 and 4 show values intermediate between those of Clusters 1 and 3.

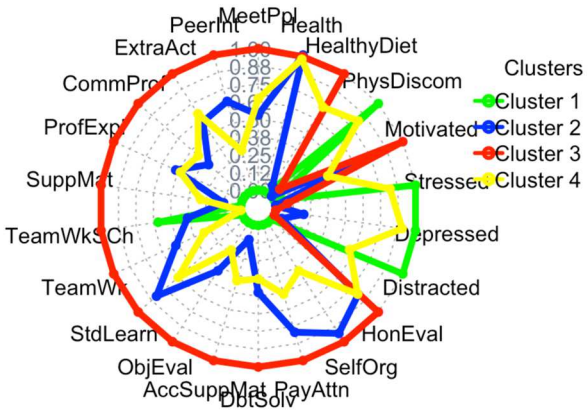


Fig. 8. Clusters Comparison

The average evaluation of the students' learning experience (*Q*23 and *Q*24) in each cluster is shown in two-bar graphs (Figure 9), the blue bar corresponding to face-to-face instruction and the orange bar to the online sessions. The vertical scale here ranges from 1 to 5, where 1 stands for "poor experience" and 5 for "best experience". Students of Clusters 2, 3 and 4 clearly prefer the face-to-face model, while students of Cluster 1 (about 25% of the sample) express a similarly good experience for both modes of instruction. These results agree with those obtained from the radar diagram above.

Finally, Figure 10 shows the results for question *Q*25, which summarizes the overall preference for taking a subject either in the face-to-face or in the online model. Again, the same tendency is obtained, with all groups showing a clear preference for the face-to-face model: Cluster 3 showing the largest one, followed by Clusters 2 and 4, while Cluster 1 presents the lowest value but still favoring the face-to-face model.

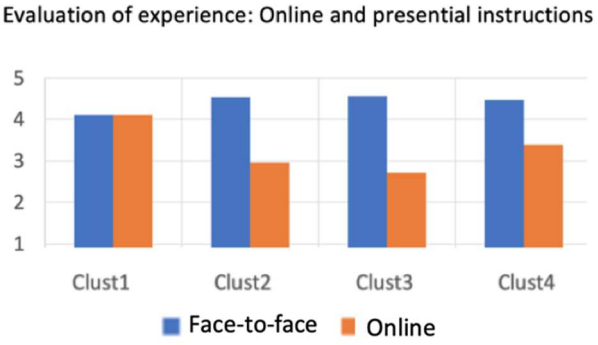


Fig. 9. Online and face-to-face learning experience.

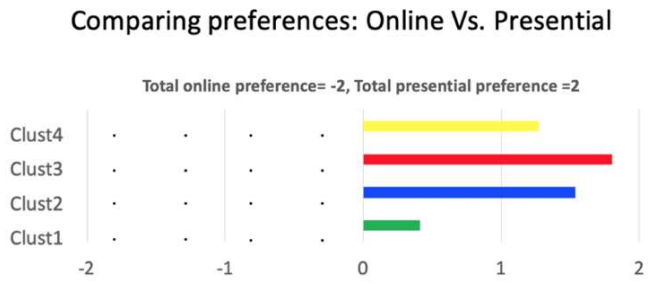


Fig. 10. Cluster preferences Face-to-Face vs. Online models

VI. Conclusions and Future Work

Regarding the research questions, from the results of the present survey it can be stated that students clearly prefer the face-to-face model over the online one, as mainly stated in the summarizing questions Q9, Q23, Q24 and Q25. The main reason is related to the personal and closer interaction they can have with their classmates and the support received from their teachers in the face-to-face model. Although the online model also allows communication with teachers and peers through platforms such as Zoom, students state that this cannot entirely replace the human contact present in the face-to-face model.

According to students' perceptions, the main advantages of the face-to-face model as compared to the online one are: *(a)* a closer interaction with classmates and teachers (Q2, Q4, Q1), *(b)* feeling more motivated (Q19), therefore less depressed (Q17) or stressed (Q18) due to home isolation, *(c)* paying more attention to classes (Q13) and being less distracted (Q16), *(d)* having better explanations (Q5), a more objective evaluation (Q10) and their doubts resolved faster (Q12), *(e)* favoring better organization of both individual (Q9, Q14) and collaborative work (Q7, Q8) , *(f)* having the possibility of participating in extracurricular activities as cultural and sporting events (Q3), as well as access to campus facilities such as libraries, cafeterias, labs and gyms. Finally *(g)* avoiding physical discomfort (back, head, eyes pain, etc.) due to long periods of time in front of the screen sitting on inappropriate furniture (Q20).

On the other hand, the advantages of the online model as compared to the face-to-face one, according to students' perceptions, include: *(a)* having a healthier diet because students are more likely to eat homemade food with their family members (Q21, Q22), and *(b)* the fact that they are encouraged to use more frequently online multimedia support material (simulators, online labs, videos, apps, etc.) that favors their learning (Q6, Q11).

In general, a very important result of this study is that students did not reject the online classes completely, even though the human interaction in the face-to-face model was greatly missed. The enormous effort made by the professors in preparing the online sessions, keeping student attention, and implementing new apps, was greatly appreciated by the students. Clear and concise explanations were also important. All faculty members did their best when conveying the gist of the scientific concepts. Even though a pressing challenge lies on

the grading process as well as on the time invested in it, for sure new high technology-based ideas will come up in the future in order to make this path smoother. Online evaluation still deserves further research.

Theoretical courses did not suffer as much as the lab sessions in the remote experience. Physics, math and computing science classes were carried on rather successfully complementing each other, with some simple but ingenious home-made experiments. The usage of simulations and engaging apps gave a tremendous boost to all courses. In the Science Department, chemistry was the area that suffered the most since safety regulations and complex compound mixtures could not be fully replaced even by state-of-the-art simulations.

Despite the general preference of students for the face-to-face model, there are several practices driven by the online model that will survive and enrich the teaching-learning process when academic institutions finally return to the face-to-face model. The increasing incorporation of various online resources and tools (interactive applications, simulations, virtual labs, etc.) is expected to reinforce and nurture the sessions. In addition, the use of online platforms to communicate with students at a distance will be more common when face-to-face interaction is not possible. Undoubtedly, the use of hybrid models that combine distance sessions with online classes will also be more frequent, increasing the flexibility of academic instruction models. Ultimately, the most important consequence of the pandemic regarding instructional practices will be the inclusion of mixed or hybrid models to enrich student learning.

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