Technology for Science Education

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The COVID-19 confinement has represented both opportunities and losses for education. Rarely before has any other period moved the human spirit into such discipline or submission—depending on one's personal and emotional points of view. Both extremes have been widely influenced by external factors on each individual's life path. Education in the sciences and engineering has encountered more issues than other disciplines due to specialized mathematical handwriting, experimental demonstrations, abstract complexity, and lab practices.

Keywords: scientific education ; COVID-19 ; educative innovation ; technologies

1. Introduction

Global education has never been tested on the scale of the current COVID-19 pandemic. The health emergency forced massive confinements; overnight, it necessitated technological support to deliver education [1]. This complex experience has been lived differently in Mexico depending on the level and type of education, and was more benign in higher and private education. Even with ten years of development of mobile educational technologies, the diverse mastery of technology among teachers and students resulted in uneven and uncertain outcomes.

In addition, numerous concerns have arisen in the aftermath regarding behavioural issues, orderliness, and cognitive effects [2] resulting from the online educational support imposed by the most viable model to solve the crisis [3]. Other issues, yet unknown, undoubtedly will appear in the upcoming New Normal.

During the COVID-19 lockdown, our knowledge of online technologies and disruptive methodologies increased significantly through experimentation, offering better learning to students in the various educational levels [4]. However, many initiatives were first applied empirically, instead of from a well-planned theoretical framework. Still, not all was lost. In most cases, teachers increased their efforts to measure, assess, and improve their didactic designs to deliver the best possible learning experience. Teachers needed to draw up and devise a proper teaching plan considering the contents and the elements necessary for their students to attain learning.

In addition, in the online versions [5], new creative and flexible methods were developed to supersede the pressure and tedium of single, direct transitions from the face-to-face courses, empirically rediscovering many of the leading contemporary Learning Theories (LT). Thus, new tools and techniques had to be combined to offer more effective learning experiences in the lockdown period to solve urgent learning necessities and deficiencies. Lessons from this experience indicate that education in the New Normal will require a universal learning theory to the cover different needs and interests of learners.

2. Course Design and the Implementation Enrichment Imposed by the COVID-19 Confinement

Every course in March 2020 went through a transition—a redesign process imposing the video class as the primary resource of contact and the institutional CANVAS learning management system for plan adaptations. Each course was unique per the content requirements.

The designs implemented by each teacher included a teaching lab that was continuously modified [6] and followed the CCLT and Online Learning framework as previously established [7][8] but considered some design elements from BLT and HLT [9][10]. To prepare for our first research objective, we classified design decisions, particularly comparing the disruptive features under the hybrid version during the COVID-19 confinement versus traditional face-to-face teaching.

The first transition at the beginning of confinement in March 2020 showed that design categories to be considered should be extended in comparison with the corresponding traditional face-to-face course. Still, it already had some BL elements.

Thus, during the suspension week, all the classes became hybrid to a lesser or greater degree depending on the available electronic resources and activities considered [11] and the videoconferencing presence to which the face-to-face component shifted.

Figure 1 shows graphs exhibiting the transition (left to right), crossing from few elements (red lines) in each category (green lines) for most of the courses in the traditional face-to-face design (left graph) to the more complex design (right side). The transition included additional constructions, including evaluation, mandatory technologies, video classes, and other critical course elements. Methodologies explicitly had to have stimulating variations during the class sessions [7][8] in agreement with CCLT.

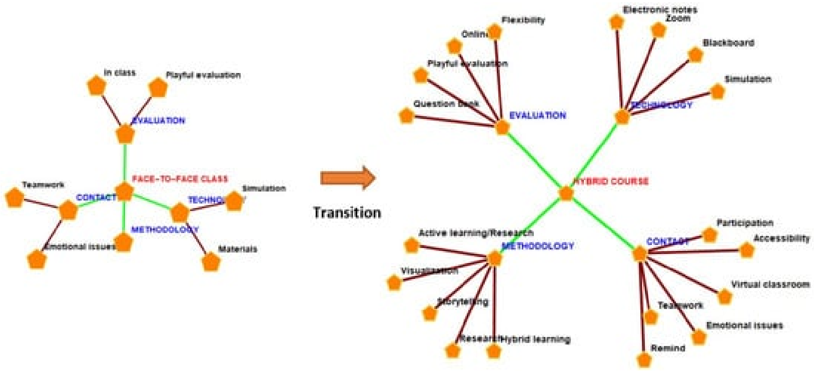

Figure 1. Graphs showing the transition of main design categories (blue) and elements (black) between face-to-face courses (red) and their hybrid versions during the lockdown. Labels are aligned to the left of each vertex.

Finally, designs needed to incorporate contact among the teachers and students to facilitate collaboration and social learning [10][8]. Thus, new focuses were on teaching, stimulus, presence, accompaniment, and assessment compared with face-to-face versions [12] or still hybrid versions with that component (instead of the hybrid approach conducted by videoconferencing).

Face-to-face designs should consider additional constructions (**Figure 1** on the right). For instance, for evaluation, with some of them as a part of playful evaluations as part of the teaching plan. Question banks should be prepared to avoid fraud despite some required flexibility instead of the direct transition on a face-to-face evaluation sustained through videoconference. Particularly in Math and Physics, the necessity of fluid mathematical writing in technologies involving tablets and electronic pencils substituted for the blackboard.

Some easy tools, such as Excel, Mathematica, and Matlab, supplied the possibility to construct demonstrations and visualizations, or still simulations in the more specialized cases. After the first week of videoconferences, most of the teachers learned that flat classes based on writing as in the face-to-face approach were not very convenient. Thus, they introduced learning methodologies, some of them supported by technology.

Another important aspect was the necessity to promote interactions not only among teacher and student but also among students as partners. Social learning was probably one of the most endangered elements during the pandemic [13], and thus additional effort should be provided to avoid such loss, particularly in some courses where complexity and diversity became extreme [14].

Thus, despite a well-prepared faculty in online technologies [15], a sustained videoconference online class required new distinctions in the design. First, as was previously mentioned, for further analysis, courses were conveniently grouped by affinity in the three academic areas previously mentioned. A design in layers in agreement with the outstanding dimensions in CCLT let to classify most of the elements involved. Such layers are considered in the first level the learning networks in each course.

This included contact as well as activities considering the social learning among partners. The second level considered some adequate learning methodologies fulfiling the necessities of the first layer and concrete course requirements. Such methodologies then implemented social learning but directed to the necessities of each course.

Finally, the third level took account of the technologies and tools required to scaffold the other two first layers as well as the course orientation and specific technologies required by the professional practice. That structure is shown in **Figure 2** where each main technology appoints to elements considered in the design, each one allocated in transverse layers. In addition, each academic area had differentiated elements according to their own necessities [16].

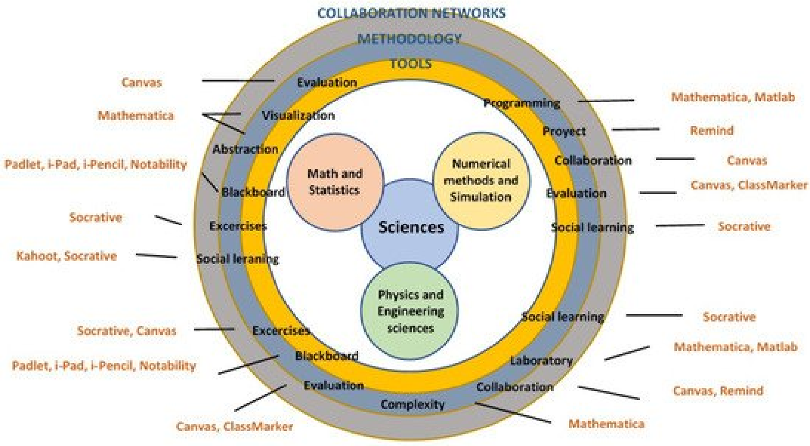

Figure 2. Courses areas in the Sciences department with teaching-learning elements allocated on three layers denoting the necessary tools, methodologies, and collaborative student's networks. Each element points to the technologies supporting them.

At the end of the first semester, the cluster noticed that additional complexity elements should appear. In a first approximation based on an Online Learning framework [8], poor considerations about the extended and sustained videoconferencing learning were made.

Behavioural issues were not originally considered or assumed in the didactic design. Soon, collateral relations among some elements (not shown in the graphs on **Figure 1**) became evident. Some of them are now shown in the graphs depicted in **Figure 3** (gray edges). Thus, for instance, Zoom videoconference system could promote teamwork and participation considering some of its functionalities. A virtual classroom construction was convenient in each course to gather in a single document of the LMS the mobility among activities, class, plans, homework, and supporting resources.

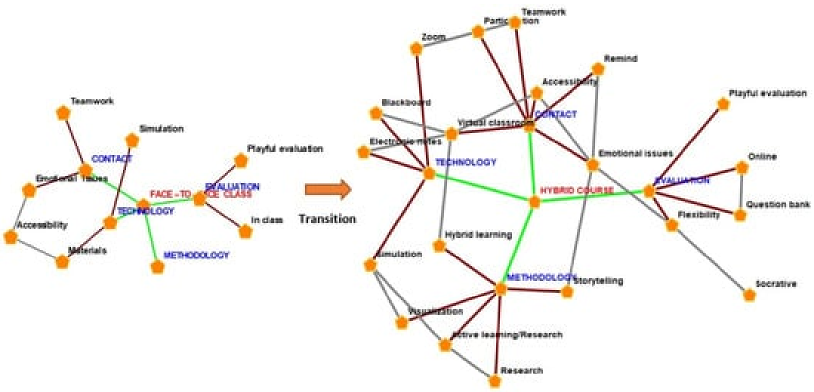

Figure 3. Evolved graphs shown the transition of main design categories (blue), elements (black), and inner associations (gray edges) between face-to-face courses (red) towards their hybrid versions during the lockdown. Labels are aligned on the left on each vertex.

However, this was not only convenient, this also allowed the flexibility and affordability of the entire course to support each student. As well, some other tools or technologies could play multiple roles in the course: visualization, Active Learning, etc. [6][17].

With those distinctions on the design, which were common elements of classification inside the cluster, no matter if courses belong to any of each one of the academic areas, each course was evolving through the three periods, considering a growing or a better group of methodologies and technologies [17]. In the following section, a quantitative analysis of the general implementations is given. Implementations were recovered from the daily course' documentation. This was followed by an analysis of the students' outcomes compared with their perceptions about the teaching-learning plan.

3. Implementation Chronology, Development, and Categorization by Academic Area and Didactic Group

To fulfil the first objective of the research, we begin our analysis depicting the global process of inclusion of methodologies and technologies in the current subsection. At the beginning of lockdown, some methodologies and technologies were suggested by the training program in technologies approximately in terms of **Figure 1** in agreement with the activity records in CANVAS. In general terms, apart from Zoom and CANVAS, other technologies were suggested for sciences and engineering: Remind as contact media and software like Mathematica, Matlab, and Geogebra for visualization.

While the semester advanced, some other technologies and methodologies were shared and introduced by teachers. In the teachers' cluster being depicted here, a near collaboration in terms of procedures, outcomes, necessities, and implementation recommendations was permanently sustained, thus, conforming to a learning community. Thus, through the three semesters, different methodologies appeared in the different courses to fulfil certain requirements or necessities demanded by each one in the different academic areas to provide increased opportunities for success in learning.

Figure 4 shows a detailed analysis and depiction of those methodologies and technologies as they were introduced for the first time in each area. Then, each technology permeated in other curses and inclusively areas, through the dissemination in the teachers' cluster. The plot depicts the months from February 2020 (the month when the first period of lockdown began) to June 2021 (the end of the third period, before the writing of the current report and the advent of New Normal for education in Mexico).

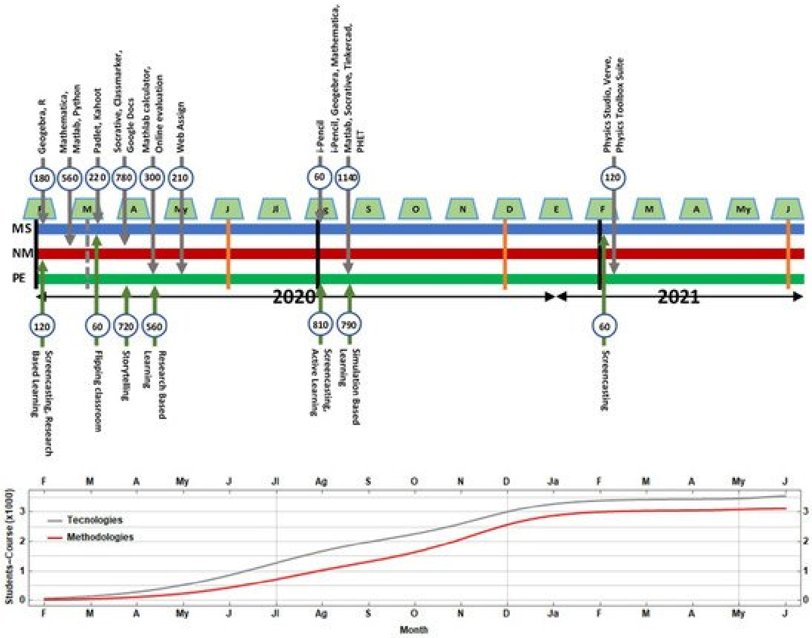

Figure 4. Chronology of the technologies and methodologies implementation in each area. Each arrow sets the beginning with each technology or methodology in some course, and thus transferred into others in the same period of another after. Numbers depict the total number of students/course impacted. The plot in the bottom reflects a softened curve of estimation for the entire technologies and methodologies during the lockdown period covered by this report.

Orange lines state the end of each semester while black lines state the beginnings. Each academic area is depicted with different colours: MD in blue, NM in red, and PE in green. There, technologies implemented for the first time are remarked above and methodologies below. Each group of methodologies and technologies are grouped by affinity and they appoint to each academic area when they were first introduced.

The numbers in circles report the total number of estimated students in each group of methodologies and technologies impacted using them (such estimation was consistently obtained from the posterior register of such methodology or technology in CANVAS). The lower plot summarizes the softened continuous implementation process by a gradual model of increasing by monthly periods, which provides a perspective of the real progressive impact.

ME required a fluent way to present and share mathematical writing and diagrams, which were neither easy nor convenient to present on pre-built slides. Thus, tools, such as Padlet or i-Pencil, were gradually integrated; however, they did not arrive before going through more traditional experiences of physical writing on traditional whiteboards, handwriting, or inverted writing in transparent crystals during the first weeks of videoconferencing (some of them affordable in Zoom).

Otherwise, the Screencasting resources also allowed to extend the number of exercises seen in class. Additionally, tools such Excel, R, Mathematica, and Geogebra were included to support visualization in Math. Individual and continuous practices were given through tools, such as Kahoot and Socrative additionally promoting social learning as well as motivation. Those tools supported mainly the Flipping classroom methodology, a technique to allow a more recurrent social practice of learning during the class.

For MN, although there were courses that, by their nature, previously had a greater digital development (due to their BL focus) before the existence of the Hyperflex model versions, the concept of the virtual classroom was still implemented as in other areas (the concentrator map of activities guiding the entire course activities and their navigation). The students appreciated this type of space as easier to understand those procedural and methodological aspects expected in the transition.

There, tools, such as Phyton, Mathematica, and Matlab, settled the basic support, and the slideshow facilitated the concentration of the specific theoretical developments before each numerical or technical method was reviewed in the courses. Support for the programming component continued being delivered through Screencasting in addition to the videoclass, which already existed in many of the previous courses.

FE represents most of the courses that were analysed in the current report. They faced two aspects: experimentation and complexity. For the first aspect, some experiments with homemade materials and directions given through Screencasting were implemented. Additionally, different simulation tools ranging from Geogebra, Physics Studio, Tinkercad, and Verve were used, and even programming to connect the real experience of the phenomena with the theoretical components of the courses [18].

Tools, such as the Physics Toolbox Suite allowed experimental measurements of motion, acceleration, magnetic field, etc., by using the mobiles of students [19]. This app supplied some measuring devices or provided alternatives for measurement. The aspects of complexity were partly addressed first with a planned visualization using Mathematica and Matlab, and then with the realization of a simulation project. The use of Mathlab calculator, a useful app for mobiles, made it possible to effectively resume the use of the scientific calculator with editing, thus supporting students in its use with a minimum of mistakes and waste of time during the videoclass.

Methodologies, such as Flipping classroom, Active learning, and Exercise solving, were implemented through tools, such as Socrative to generate playful spaces of collaboration on which social learning was reached. This practice became useful to bring closer to the students into the formal summative evaluations. As in MS, Screencasting also allowed to extend the number of exercises seen in class, this practice was inherited from experiences in NM. The use of Storytelling and its combination with animated slideshows or including demonstrative videos were useful to capture the attention in those courses.

As a general practice, in some courses, the advisory was recorded to increase the flexibility and the broadcasting to other students. A large bank of questions, to sustain remote evaluation letting several attempts, was implemented in tools, such as ClassMarker and Canvas. This allowed students complete their learning while obtaining improved grades. To summarize specific technologies and methodologies used in each academic area in terms of the main use, **Table 1** presents that information.

Table 1. Technologies and methodologies compilation with their main use.

Resources	Videoconferencing	Advisory	Contact	Visualization	Writing	Evaluation	Social learning	Demonstration	Practicing	Experimentation	Calculation
Methodologies											
Flipping classroom						×	×				
Active learning							×	×		×	
Exercise solving						×	×		×		×
Research based learning					×		×				
Storytelling	×			×		×			×		
Simulation based learning				×		×	×	×	×	×	
Screencasting		×		×		×		×			×
Technologies											
Zoom	×	×					×		×		

Resources	Videoconferencing	Advisory	Contact	Visualization	Writing	Evaluation	Social learning	Demonstration	Practicing	Experimentation	Calculation
Remind		×	×				×				
CANVAS	×	×	×			×	×				
Mathematica	×	×		×	×	×	×	×	×		×
Excel	×	×		×		×	×	×	×	×	×
Matlab	×			×		×	×	×	×	×	
Geogebra	×	×		×		×	×	×	×		×
R				×		×	×	×	×	×	
Python				×		×	×	×	×	×	
Kahoot	×	×				×	×		×		×
Padlet	×	×			×			×	×		×
i-Pencil/Notability	×	×	×	×	×			×	×		×
Classmarker						×	×	×			×
Mathlab calculator	×	×		×	×	×		×			×
Web assign						×					
Tinkercad				×		×	×	×		×	
PHET	×	×		×			×	×		×	
Physics studio	×			×			×	×		×	×
Verbe	×	×		×			×	×		×	
Physics toolbox suite	×			×			×	×		×	

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