Challenge-based learning during the pandemic for engineering courses based on competencies

Víctor Robledo-Rella
School of Engineering and Science
Tecnologico de Monterrey
Cd. de Mexico, Mexico
vrobledo@tec.mx

Luis Neri
School of Engineering and Science
Tecnologico de Monterrey
Cd. de Mexico, Mexico
neri@tec.mx

Rosa M.G. García-Castelán
School of Engineering and Science
Tecnologico de Monterrey
Cd. de Mexico, Mexico
rmggarci@tec.mx

Andres Gonzalez-Nucamendi
School of Engineering and Science
Tecnologico de Monterrey
Cd. de Mexico, Mexico
anucamen@tec.mx

Julieta Noguez
School of Engineering and Science
Tecnologico de Monterrey
Cd. de Mexico, México
jnoguez@tec.mx

Abstract— Full Paper; Innovate Practice. **Challenge-based learning has been a key component of *Tecnologico de Monterrey*'s Tec21 disruptive educational model, which focuses on the development of competencies through working on a solution to a real-life, *ad-hoc* challenge. A brief description of the previous Tec20 and current Tec21 models is presented. The first part of this work presents a comparison of four Tec21 physics courses with 185 students working face-to-face and 205 students working online. The average challenge report score was 5% higher for the online courses than for the face-to-face courses. This difference was significant at $\alpha = 0.05$ level through *t*-tests. Closer monitoring by the instructor to achieve course objectives or less rigorous course evaluation policies might have favored the online courses. The second part of this research compares the average grades of the Tec21 model vs. the Tec20 model, based on traditional Problem-Based Learning (PBL). A comparison of Tec20 PBL reports (372 students) and Tec21 Challenge reports (205 students) taking Electricity and Magnetism courses is presented. Average report grades were 3–7% higher for the Tec21 model than for the Tec20 model. The Tec21 model contains promising features, but a more rigorous evaluation approach is suggested.**

Keywords— Higher Education; Educational Innovation; Challenge-Based learning; Online courses; Pandemic

I. Introduction

The COVID-19 pandemic forced educational institutions all around the world to quickly move from a face-to-face (hereafter *F2F*) model to online instruction to give continuity to students' learning [1–5]. The pandemic imposed a two-year pause which allowed researchers to compare online student performance with F2F interaction. Therefore, there has been an increasing interest in the academic community to assess the effectiveness of online instruction as compared to F2F education [6–10].

F2F instruction allows close and direct contact between instructors and students, as well as students among themselves, coexisting simultaneously in the same physical space, and interaction in the classroom can be easily promoted. Nevertheless, providing a physical space or classroom to accommodate large audiences is not always possible, and splitting large classes into smaller groups requires more instructors, increasing tuition costs.

On the other hand, online technologies allow the possibility to connect people at different locations. Online learning does not require a fixed classroom, allowing students to interact through the internet using remote digital environments, computer networks, and taking advantage of digital resources and digital technologies [8]. In this way, online learning can be cheaper than F2F instruction and more accessible to larger audiences. Its most important shortcoming lies in the lack of direct interaction among instructors and students, which can produce feelings of isolation and depression among students and teachers. This learning modality also requires careful implementation of the learning experience, class-time scheduling, and optimization of resources demanding considerable effort from the teachers [4,8].

For the last few decades, there has been an increasing interest to promote active learning through experiential and inquiry-based methodologies, in which students build their knowledge by acquiring deeper learning competencies by proposing solutions to real-world challenges. These methodologies are centered on the students and not on the teacher, who now becomes a facilitator supporting the students' learning process while they develop their solutions. Problem-based learning (PBL) [11–14], Project-based learning (PjBL) [15], and Challenge-based learning (CBL) [16,17] are examples of suitable inquiry-based experiential learning methodologies.

The Tecnologico de Monterrey introduced in August 2019 its new *Tec21* Educational Model, based on a CBL approach [18,19]. This model replaced the previous *Tec20* model based on traditional content and subjects, including PBL and PjBL techniques.

The Tec21 model is not based on content, but on developing student competencies, both disciplinary and transversal, by working to find suitable solutions to real-life scenarios or *challenges*. This disruptive and dynamic model favors the creation of a learning community in which students collaborate in teams to discuss and find solutions to real-life challenges, guided by their teachers. The acquired knowledge in a given course is immediately applied to *ad-hoc* designed challenges so that students experience for themselves the relevance of different disciplinary areas at once. The emphasis is moved from the memorization of isolated content to the solution of the challenges, thus motivating the students to participate in finding meaningful alternatives. Therefore, a challenge is a real-based project intended to develop student competencies [20,21].

The innovation of this paper comprises two parts: in *Part I*, a comparison of F2F versus online student performance on competencies-based courses is presented, where student performance is measured using (a) final exam grades, (b) final course grades, and (c) challenge report grade. In *Part II*, a comparison of competencies-based courses vs. content-based courses is presented, where results were analyzed for Electricity and Magnetism courses in terms of (a) partial exam grades; (b) final exam grades, (c) final course grades, and (d) challenge report grades.

The organization of this work is as follows: Sections II and III present the Theoretical framework and Related work, respectively. The methodology is included in Section IV. Results are presented and discussed in Section V. Finally, the Conclusions are summarized in Sec. VI.

II. Theoretical Framework

a) Face-to-face vs. online learning models

Although there are several studies in the literature discussing F2F and online affordances to promote student learning, the COVID-19 pandemic has renewed interest to compare the efficiency of these educational models [7-10]. In this regard, the overall impact and effectiveness of educational technology and digital learning are still uncertain, due to their dependence on specific educational settings and the context of Learning, Teaching & Assessment (LT&A) [22]. While several research studies from 2012 up to 2020 have exhibited the benefits of the successful application of digital LT&A in a variety of contexts and settings, the widespread adoption, implementation, and evaluation of educational technologies is still an open field of research [23]. In addition, ongoing research, as well as political debate on the efficacy, utility, and impact of educational technology and digital practice, was renewed by the COVID-19 pandemic from 2020 to 2022. Research in online learning should focus on the identification of those characteristics unique to online environments and identify the boundary conditions under which instructional techniques are most effective to test and contribute to a learning theory [24,25].

The foregoing comments lead us to reflect on post-lockdown times, in which hybrid solutions are being implemented combining F2F and online teaching, along with mixed and flexible learning supported by educational technology and digital learning.

b) Challenge-based, problem-based, and project-based learning

Several learning approaches have been implemented to foster active student learning through experiential and inquiry-based methodologies. In these methodologies, students construct their learning experiences and develop disciplinary and transverse competencies by finding solutions to real-world challenges. In these student-centered methodologies, students usually work in teams at their own pace, supported by their instructors. Active-learning methodologies such as PBL [11–14], PjBL [15], and CBL [16,17] have been successfully applied.

PBL is a constructivist approach in which a scenario describing a problematic situation is proposed. This scenario must be as authentic as possible to promote student motivation and engagement in finding an appropriate solution. Students usually work in teams during a given period while building their knowledge and investigating on their own the topics needed to solve the problem [12]. PjBL is also an active student-centered instruction model characterized by students' autonomy, constructive investigations, goal-setting, collaboration, communication, and reflection while performing real-world practices or larger scope projects [15].

On the other hand, in CBL a real challenge is presented to students in which they develop disciplinary and transverse competencies while finding a solution. The *problematic situation* is usually associated with real companies, communities, or civil organizations, where students engage to propose solutions to these scenarios supported by their teachers and the corresponding *formative clients*. Members of relevant organizations often provide relevant pieces of information to contribute to the solution [16]. In this sense, CBL can be seen as an evolution from PBL and PjBL methodologies [26].

III. Related Work

In a study to determine the aspects of digital transformation during the COVID-19 quarantine [3], it is argued that although there are multiple challenges in implementing an online model of education, half of the students liked it and would prefer it in the future. On the other hand, researchers in Romania reported the use of *Discord* as a communication platform aimed to keep teachers and students in touch in real-time at distance during confinement [27]. Based on formal comments of well-conducted questionnaires, this research showed that 95% of the students commented that the benefit was a greater involvement among themselves and with the teachers.

A study in India found that the main problems faced during online education during the COVID-19 pandemic were technical and economic issues rather than the interaction through the online system [28]. The authors comment that it is necessary to rely on technology to promote better student performance and track student activities. To maintain continuous interest from students, it is necessary to find increasingly attractive, interactive, and ubiquitous ways to teach and learn.

Another work in the United Kingdom [29], reported that the COVID-19 pandemic has caused widespread changes in the way that the higher education sector operates. They discuss the experience of teaching an eight-week undergraduate software engineering course during the pandemic. Following established best practices (such as distributing online lectures into smaller "chunks", carefully considering group work and group composition, and paying close attention to student feedback to make adjustments) it is possible to offer a pedagogically sound experience, even under confined conditions. The authors suggest retaining these elements in the post-pandemic era.

[30] points out that the COVID-19 pandemic has generated changes and disruptions in broad sectors of human activity, including Education, due to the administrative imposition of the total closure of educational centers in large part of different countries around the world. The modality of isolated education, with strong digital support, came to offer timely emergency solutions to this crisis.

In a survey of 396 students to investigate their perception of F2F vs. online courses, [4] found that most of the students prefer F2F better to online classes. They also found that depression and stress increased during the online experience. However, student performance and course perception remained about the same in both instruction models.

In preliminary comparisons between F2F and online student performance in Tec21 Model courses, [4] and [8] report that although students prefer the F2F model due to the interactions with their classmates and professors, the students' performance is similar in both models.

Many technological applications and software have been developed to provide support to the students, and adaptive learning techniques such as CBL have been used during the last decade [31]. In this sense, [20, 21, 32] reported their experience in evaluating the implementation of CBL in Mechatronics, Biotechnology, and Sustainable Development engineering areas with a competency-based approach. Results indicate that students were motivated and acquired practical technical knowledge as well as soft skills. The inclusion of external training partners to foster students' learning and engagement during the challenge development, as well as the use of digital tools to promote students' competencies were found to be very important.

Regarding the use of CBL in undergraduate programs, [36] have discussed the development of competencies by students working with CBL in short Introductory Physics courses for freshmen engineering students. These authors found that it is necessary to reinforce the development of higher-level reasoning and thinking competencies during the course.

IV. METHODOLOGY

In *Part I* of this study, a comparison of face-to-face (F2F) vs. online student performance in Tec21 courses is presented, with 15 groups of four short physics courses taught between August 2019 to June 2021 at the Tecnologico de Monterrey. A student sample of $N = 390$ undergraduate engineering students was considered. Seven courses were taught F2F before the COVID-19 pandemic (185 students), and eight courses were taught online during the pandemic (205 students). Student performance was measured and compared using the average of (a) final *argumentative* exam grade, (b) final course grade, and (c) challenge report grade.

In *Part II* of this study, a comparison of Tec21 vs. Tec20 model courses is presented. 15 groups of the Tec21 Educational model (372 students) and 10 groups of the Tec20 Educational model (205 students) were selected. These courses were lectured by three of the authors, for a total of 25 groups with a total sample of $N = 577$ students. Grades were analyzed for both Tec21 and Tec20 models for Electricity and Magnetism courses in terms of (a) partial exam grades; (b) final exam grades, (c) final course grades, and (d) challenge/project report grades. For the challenge/project report, 15 groups for the Tec21 model (372 students) and 20 groups for the Tec20 courses (410 students) were considered.

Description of Tec20 and Tec21 Electricity and Magnetism Courses

In this section, the Electricity and Magnetism Courses in the Tec20 and Tec21 models are described and compared.

a) Tec20 Electricity and Magnetism Courses

In the Tec20 Model, the Electricity and Magnetism course lasted 16 weeks. The course syllabus included, for the electric part: electric charges, electric forces and fields, Gauss law, electric potential, capacitance, current and electric circuits. The magnetic part included: magnetic forces and torques, sources of magnetic field, Biot-Savart's law, Ampere's law, Faraday's law, a brief description of inductance, and Maxwell's equations. About two-thirds of the syllabus was dedicated to electricity and one-third to magnetism. One professor directed the entire course, and a lab instructor was responsible for the Lab sessions. Two partial exams and one final evaluation were administered during the semester. Weekly homework, in-class quizzes, and weekly lab sessions rounded up the instruction. From time to time, interactive *Kahoot*, *Socrative* questionnaires, as well as *Phet* simulations, enriched the lectures.

The 16 weeks were divided into three periods. Typically, two projects were assigned to the students during the semester. They had to work it out in teams comprised of 4-5 members. In general, the project followed the known PBL format. The research and the ongoing feedback between the students and the professors had place for about 4-5 weeks. Once the project was done, a written report had to be submitted and the students had an oral presentation to all their classmates. Some of the research projects were more theoretical while others required the implementation of an experiment.

Table 1 below presents the grading percentages for a typical Tec20 course, including the relative weights of the mid-term and final exams (66% of total grade), weekly assignments (9%), PBL projects (10%), and final Lab grade (15%).

TABLE 1. COURSE EVALUATION PERCENTAGES IN **TEC20** MODEL

Period	Exams	Homework and quizzes	Project	Lab	Total
First Period	17%	3%			20%
Second Period	19%	3%	5%		27%
Third Period	30%	3%	5%	15%	53%
Total	**66%**	**9%**	**10%**	**15%**	**100%**

The final exam had two sections. The first section was a theoretical part with five multiple-choice items, in which students had to justify their choice. The second section consisted of 4-5 typical end-of-chapter numerical problems. Usually, three of them were related to the electric content and two of them to the magnetic topics. The final exam weighted 30% of the total grade (Table 1).

As for the lab reports, they were typically submitted every other week based on traditional lab experiments. Occasionally, students played a more active role in providing ideas for experiments that could clarify or deepen their understanding of course concepts. When planned, the lab instructor could also provide the students with a variety of project ideas to choose from, so that not all teams worked on the same project simultaneously.

b) Tec21 Electricity and Magnetism courses

An important change between the Tec21 and Tec20 models is that in Tec21, each semester is now divided into three, 5-week long courses, currently called *formation units*. The Electricity and Magnetism syllabus content was divided into two short courses, one covering Electricity and the other Magnetism.

Another relevant difference is that some of the Tec21 courses, called *blocks* are taught by a team of 2-4 professors, experts in their respective fields: physics, maths, computing (Matlab), and "challenge". The block lasts 60 hours (12 hours per week) and consists of *modules* in which the academic content is studied: a math module, a computing module, and two physics modules. The core of each block is an *ad-hoc* designed challenge, i.e., a project in which the student immediately applies what has been taught in each module. The proposed challenge was designed in advance at an institutional level by several professors. All academic approach during the course supports the development and solution of the challenge, and the team of professors guides the students throughout the process.

Yet another difference between the Tec20 and Tec21 models is that Tec20 courses were mainly based on academic content while Tec21 courses are based mainly on developing competencies. Of course, the academic content is still at the core, but the competencies are formally evaluated. The fifth and last week of the course focused on the competencies' evaluation through a team oral presentation, the challenge prototype and report solution, and an argumentative exam. Targeted questions are asked to each team member during the oral presentation to finish the individual competencies evaluation. The *argumentative* exam must show the overall understanding of the challenge and the academic soundness acquired during the 5 weeks. During the exam, specific questions related to the core-challenge concepts have to be answered correctly by the students using sound reasoning and physics concepts and arguments.

The grading percentages for the Tec21 physics courses are presented in Table 2 below, where the assignments used to evaluate student competencies are also indicated.

The Tec21 challenge solutions can be compared with the PBLs worked out in the Tec20 model. The outcome and the quality of both are practically the same. The main difference is that in the Tec21 approach, the course content and knowledge are intentionally blended with the challenge, and competencies are also evaluated. The team of professors in the Tec21 model introduces different points of view to the project, thus enriching the student's learning experience. The flexibility in the process adds another component that was not necessarily present in previous the Tec20 model.

TABLE 2. COURSE EVALUATION PERCENTAGES IN **TEC21** MODEL

	Weekly Assignments	**Competencies**
Module 1	10%	
Module 2	10%	
Module 3	10%	
Module 4	10%	
Challenge solution		15%
Oral Presentation		15%
Argumentative exam		30%
Subtotal	40%	60%
Total		**100%**

Our Engineering and Science School is divided into 4 *entry avenues*: (1) Applied Sciences, (2) Computing Sciences, (3) Biotechnology, and (4) Innovation and Transformation. Each avenue has its own designed challenges, even though the academic modules deal with the same syllabus and the same competencies. The idea is to foster the students' interest depending on their initial professional choice.

The Tec21 model was fully deployed during the 2019-II (Fall) semester, with only one-semester experience of F2F instruction before the pandemic arose in México in March 2020. The 2020-I (Spring) semester began in February, but after the first period of five weeks of organized F2F instruction, everything had to continue online since mid-March. While the pandemic, the Tec21 challenges had to depend more on simulations and the creativity of the professors. Due to the nature of the associated challenge, some subjects were more difficult than others for online instruction. The Electric and Magnetic blocks fell into this category, since part of the academic contents is abstract and hard to grasp at first, and specialized equipment was not available for experiments. Nevertheless, the commitment of the professors, the vast teaching experience, and the use of suited apps, smoothed the transition. Students were also part of the model's success, trying to make the best out of this experience. As the pandemic persisted, we had to make every moment count. The homemade challenges turned out to be better than expected. On the downside, what was greatly missed, of course, was human interaction as well as the benefit of enjoying the Campus's facilities, as reported by [4,8].

V. RESULTS AND DISCUSSION

A. Part I: Face-to-face vs. online comparison for Tec21 courses

a) Student sample

A total student sample of N = 390 students from 15 groups of four short physics courses was selected (Table 3). Seven courses were taught F2F before the COVID-19 pandemic, and eight courses were taught online during the pandemic. Student performance was measured and compared using the average of (a) final argumentative exam grade, (b) final course grade, and (c) challenge report grade.

TABLE 3. STUDENT SAMPLE (TEC 21 MODEL)

	Number of students
Face-to-face	185
Online	205
Total	**390**

Table 4 shows the student population for each of the four Tec21 physics courses (with their corresponding Avenue) considered from 2019-II to 2021-I, where CTI stands for Computation and Technology Information, and IIT stands for Innovation and Transformation Engineering. A preliminary analysis of these data was presented by [8].

TABLE 4. STUDENT POPULATION

Course Code/ Avenue	Course Name	Mod	Term	Number of groups	Number of students
F1004B/ CTI	Computational modeling of movement	F2F	2019-II	1	28
		Online	2020-II	2	29
F1005B/ CTI	Computational modeling using energy conservation laws	F2F	2019-II	1	31
		Online	2020-II	1	18
F1006B/ CTI	Movement modeling in engineering	F2F	2019-II	3	90
		Online	2020-I	1	35
			2021-I	1	33
F1015B/ ITE	Thermodynamics application in engineering systems	F2F	2020-I	2	36
		Online	2021-I	3	90

b) Exam grades, final grades, and challenge report grades

Figs. 1*a* – 1*c*, show the histogram comparison of the four physics courses taught online and F2F during the considered two-year timespan, for (a) final exam grade, (b) final course grade, and (c) challenge report grade, respectively.

c) Face-to-face vs Online Discussion

As shown in Figs. 1*a* – 1*c*, online grades are higher than F2F grades by up to 8–12 points. It was found that the final exam and the final course grades are 9.1 and 7.1 points (about 12% and 8%) higher in online courses as compared to F2F courses, respectively. For the challenge solution report, this difference is only 4.5 points (about 5%) higher. *t*-tests were applied and these differences were found to be significant at $\alpha = 0.05$ level [8]. Possible causes of this behavior include: (i) closer professor guidance to fulfill the course goals, (ii) limited surveillance of student work during exams, and/or (iii) relaxation of evaluation policies for online courses.

Closer teacher guidance to student work and interaction in the online model was provided to compensate for the lack of F2F interaction and to properly fulfill suitable academic standards similar to those of the F2F model. Therefore, frequent additional tutoring sessions to online classes were organized to give more support and feedback to student work. These additional online sessions were attended by larger student audiences as compared to typical tutoring F2F sessions, so this may contribute also to higher online grades.

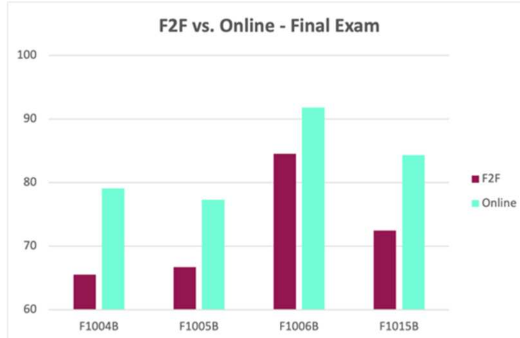

Fig. 1*a*. Final exam comparison of four physics F2F vs. online courses for Tec21 model as given in Table 4

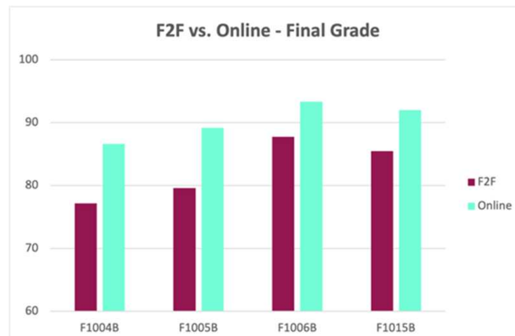

Fig. 1*b*. Final grade comparison of four physics F2F vs. online courses for Tec21 model as given in Table 4

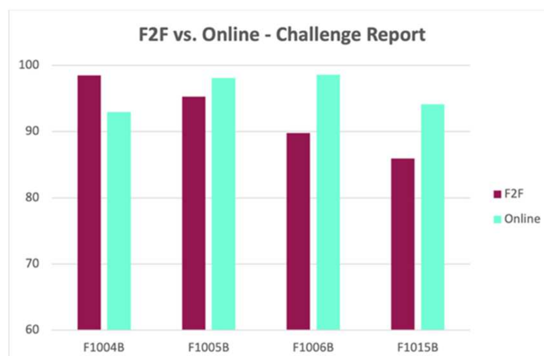

Fig. 1*c*. Challenge report comparison of four physics F2F vs online courses for Tec21 model as given in Table 4

On the other hand, in the online model, it was not possible to properly watch over students' work during exams, as in the F2F model. It is quite possible that some students dishonestly communicated among them with their smartphones or consulted online resources. Moreover, some instructors may have relaxed their grading policies during online courses to compensate for student stress due to the COVID lockdown and to prevent student dropout. Unfortunately, a limitation of the present research is that, at this point, it is not possible to distinguish between these three causes.

B. Part II: Tec20 vs. Tec21 comparison for Electricity and Magnetism courses

Table 5 shows the student population, course modality (F2F vs. Online), average mid-term exam grades, average final exam grades, final course grades, and challenge report grades for Tec20 and Tec21 Electricity and Magnetism individual courses from 2018-I to 2021-1. For Tec20 courses, there are two mid-term exams (P1 and P2), and the final exam. For Tec21 courses, there is the *physics* argumentative exam (including only the physics part) and the *total* argumentative exam (including also the math and computing parts of the block).

TABLE 5. PARTIAL EXAM, FINAL EXAM, COURSE, AND CHALLENGE REPORT GRADES FOR INDIVIDUAL TEC20 AND TEC21 COURSES

Course Code	Term	Group	Mod	*N*	P1/ Phys Arg Exa	P2	Fin Ex/ Total Arg Ex	Course grade	PBL/ Challenge
Tec20 Elec & Mag									
F1005	2018-I	F1005.5	F2F	**18**	44.5	70.2	59.8	73.5	88.9
F1005	2018-I	F1005.11	F2F	**20**	81.3	80.6	55.4	75.9	95.5
F1005	2018-I	F1005.12	F2F	**15**	90.4	85.6	43.8	81.7	94.0
F1005	2018-I	F1005.13	F2F	**30**	93.9	88.4	60.2	88.9	94.0
F1005	2018-I	F1005.20	F2F	**29**	88.2	85.4	70.3	85.5	92.5
F1005	2018-II	F1005.10	F2F	**15**	93.7	77.3	61.3	90.5	97.8
F1005	2018-II	F1005.20	F2F	**27**	95.6	73.6	60.8	90.8	98.0
F1005	2018-II	F1005.21	F2F	**15**	91.5	88.5	77.3	90.4	96.7
F1005	2019-I	F1005.1	F2F	**26**	60.0	79.9	58.2	81.5	94.0
F1005	2018-II	F1005.11	F2F	**10**	95.3	79.7	65.8	90.4	98.1
Tot				**205**	**83.4**	**80.9**	**61.3**	**84.9**	**94.9**
Tec21 Elec									
F1013B	2020-I	F1013B.12	Online	**29**	85.5		88.1	93.1	96.1
F1013B	2020-I	F1013B.13	Online	**17**	78.6		83.7	92.4	97.1
F1013B	2020-I	F1013B.15	Online	**11**	47.7		51.9	75.7	97.4
F1016B	2020-I	F1016B.4	Online	**30**	83.0		85.1	87.1	88.7
F1019B	2020-I	F1019B.6	Online	**22**	89.5		89.1	89.2	92.6
F1013B	2021-I	F1013B.33	Online	**24**	77.5		82.7	89.9	90.8
F1016B	2021-I	F1016B.29	Online	**29**	91.4		89.7	92.0	97.6
F1016B	2021-I	F1016B.27	Online	**30**	86.0		77.3	89.0	88.8
Tot Elec				**192**	**79.9**		**81.0**	**88.6**	**93.6**
Tec21 Mag									
F1014B	2020-I	F1014B.12	Online	**30**	91.9		89.1	93.2	96.3
F1014B	2020-I	F1014B.13	Online	**23**	91.6		91.3	93.0	87.8
F1014B	2020-I	F1014B.15	Online	**5**	86.5		85.1	91.9	83.2
F1017B	2020-I	F1017B.4	Online	**30**	79.1		93.6	89.2	87.2
F1012B	2021-I	F1012B.22	Online	**30**	77.8		74.4	83.7	89.8
F1014B	2021-I	F1014B.33	Online	**26**	82.9		83.3	90.1	95.1
F1017B	2021-I	F1017B.27	Online	**36**	81.9		90.7	93.4	95.2
Tot Mag				**180**	**84.5**		**86.8**	**90.6**	**90.7**
Tot E&M				**372**	**82.1**		**83.7**	**89.5**	**92.2**

Table 6 shows average mid-term exams (Tec20) or physics argumentative exam (Tec21) grades, final exam (Tec20) or final (total) argumentative exam (Tec21) grades, and final course grade separated by *topic*: Electricity and/or Magnetism.

Finally, Table 7 compares the average mid-term grades, final exam grades, and challenge report grades for all Tec20 vs. Tec21 Electricity and Magnetism courses.

TABLE 6. PARTIAL EXAM, FINAL EXAM, FINAL COURSE, AND CHALLENGE REPORT GRADES FOR TEC20 AND TEC21 BY **TOPIC** FOR ELECTRICITY AND MAGNETISM COURSES

	Topic	Activity	Number of Groups	Number of Students	Grade
Tec20	Elec	P1, P2	18	366	**85.4**
Tec21	Elec	Exam Argum Phys	10	258	**79.9**
Tec20	Mag	P1, P2	4	88	**63.7**
Tec21	Mag	Exam Argum Phys	5	144	**86.4**
Tec20	Elec & Mag	Final Exam	10	205	**61.3**
Tec21	Elec & Mag	Exam Argum Tot	15	372	**83.7**
Tec20	Elec & Mag	Final Grade	10	205	**84.9**
Tec21	Elec & Mag	Final Grade	15	372	**89.5**

TABLE 7. MID-TERM EXAM, FINAL EXAM, FINAL COURSE, AND CHALLENGE REPORT GRADES FOR **TEC20** AND **TEC21** ELECTRICITY AND MAGNETISM COURSES

	Topic	Number of Groups	Number of Students	Mid-term/ Phys Exam	Final Exam	Final Grade	Challenge Rep Grade
Tec20	Elec & Mag	10	205	83.4	61.3	84.9	94.9
Tec21	Elec & Mag	8 (Elec) 7 (Mag)	372	82.1	83.7	89.5	92.2

(a) Mid-term exams

Fig. 2 shows the Mid-term exam grades for Tec20 and Tec21 Electricity and Magnetism courses.

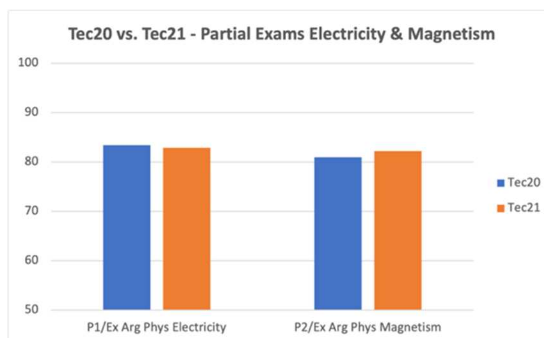

Fig. 2. Comparison of Mid-term exam and Argumentative exam for Tec20 and Tec 21 courses

(b) Final exam and final course grades

Fig. 3 compares student performance for mid-term physics exams for Tec20 vs. Tec21 Electricity and Magnetism courses.

Fig. 4 presents a comparison by topic: Electricity or Magnetism.

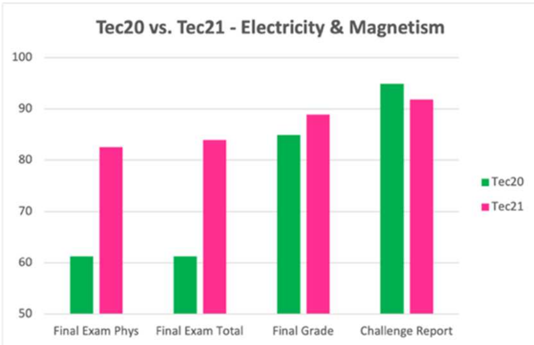

Fig. 3. Final exam, final grade, and challenge report grade for Tec20 and Tec21 courses

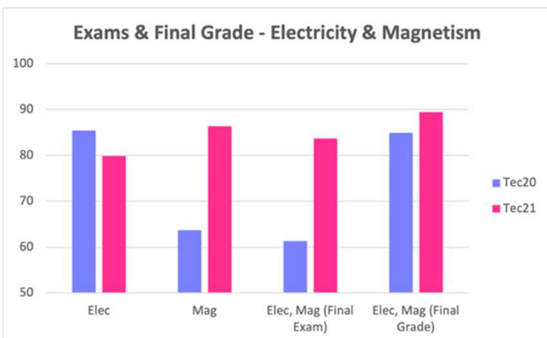

Fig. 4. Grades by **topic**: Electricity; Magnetism; Final Exam grade, and Final course grade for Tec20 and Tec 21 courses

(c) Challenge Report grades

Fig. 5 shows the Tec20 PBL projects vs. the Tec21 challenge-based learning reports grades for the Electricity and Magnetism courses.

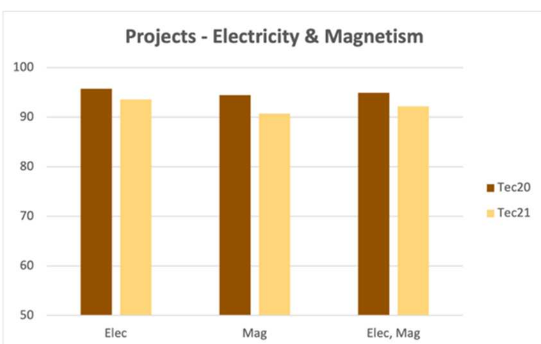

Fig. 5. Challenge report grades by topic for Tec20 (PBL) and Tec21 (Challenge) Reports for Electricity and Magnetism courses

(d) Tec20 vs. Tec21 discussion

From Tables 5–7 and Figs. 3–5, it can be seen that the average mid-term exam grades for Tec20 and Tec21 are very similar. Nevertheless, comparing the final physics exam (Tec20) and final argumentative exam (Tec21), it can be seen that Tec21 grades are higher, by as much as 15–20 points than Tec20 grades. This may be because the Tec20 final exam assessed the whole 16-week period of the Tec20 courses, asking rather isolated questions for physics topics only, while the Tec21 final argumentative exam evaluates only the 5 weeks of the course, and it also integrates the contribution from the computing and math modules covered by the challenge of Tec21 courses, aiding students to better remember and connect the concepts included in the challenge.

It was found that the Tec21 final course grade is only 3–5 points higher than the Tec20 final course grades (Figs. 3 and 4). This can be explained in part by the higher weights given to collaborative activities in the Tec21 model. For example, in the Tec21 model, the final challenge solution weights 15 points and the final oral presentation counts another 15 points (Table 2).

Regarding the challenge reports, both Tec20 and Tec21 grades are about the same, with Tec20 grades somewhat higher that Tec21 grades. This could be explained because, by design, the Tec21 challenges are more complex and involve math and computation concepts besides physics topics, while Tec20 projects were shorter and focused only on isolated physics concepts. Nevertheless, further analysis is needed to determine if this difference is significant.

An important limitation of this research is the fact that all Tec20 courses were given in the F2F model, while all Tec21 courses were given in online. As discussed above, grading in the online model may have been more relaxed than in the F2F model, making this comparison somewhat unfair. In this research, it was not possible to eliminate said bias.

VI. CONCLUSIONS

In this research, it was shown that online models can provide similar or better results than F2F models, regarding student performance, if a careful implementation of the online model is provided. In fact, for the Physics courses considered, student outcomes were better in the online model as compared to the F2F model. Possible causes of this behavior include closer professor guidance to fulfill the course goals, limited surveillance of student work during exams, and/or relaxation of evaluation policies for online courses. It was not possible to distinguish among these alternatives.

Considering the comparison between Tec20 and Tec21 educational models for Electricity and Magnetism courses, it was found that the new Tec21 model favors larger grades by as much as 5% as compared to the previous Tec20 model. This can be explained by the fact that, in the Tec21 model, Physics, Mathematics, and Computation concepts are integrated around a real-life challenge where students can apply concepts in a more meaningful way than in the Tec20 model, based mainly on concepts. As a result, in the Tec 21 model, higher weights are given to collaborative activities while developing a solution for the proposed challenge, as compared to the Tec20 model, where exams have a greater weight in the final course grade. Nevertheless, it is recognized that this comparison could not be completely valid because all Tec20 courses were taught in the F2F model, while most of the Tec21 courses were given in the online model. Further research has to be performed in this direction.

This research is part of a larger ongoing study considering also Tec20 and Tec21 Thermodynamics and Mechanic courses to be published elsewhere.

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