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RESEARCH ARTICLE

Impact of Electrical Engineering Didactic Videos During Emergency Remote Learning

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ABSTRACT This article demonstrates that didactic videos have the potential to enhance quality perception, performance and interest in engineering education. Emergency Remote Learning (ERL) imposed challenging conditions on education, and its impact was especially noticeable in the Science, Technology, Engineering and Mathematics (STEM) disciplines. This is mainly due to intrinsic cognitive load associated with the high presence of abstract concepts and to difficulties to establish connections among subjects to foster generative processing. Suitable integration of multimedia resources might be beneficial in both regards. The use of didactic videos as pedagogical aid is expected to yield positive results in electrical engineering education, mitigating the impact caused by ERL situations. Using concept maps to identify key concepts in the Electrical Engineering BSc, this article proposes the creation and integration of nine videos to enhance conceptual learning and the creation of links among subjects. This study encompassed three academic years (from 2019 to 2022), covering pre-ERL, ERL and post-ERL scenarios, and considering a total sample of 157 students. By using a Mixed Methods research design, this study has demonstrated how the integration of didactic videos mitigated the negative effects of the unprecedented ERL conditions, with positive impact on students' perception on videos' implications in enhancing their interest and understanding of the subject's concepts.

INDEX TERMS Conceptual learning, distance learning, educational technology, electrical engineering education, emergency remote learning, STEM, videos, YouTube.

I. INTRODUCTION

The Emergency Remote Learning (ERL) entailed by the covid-19 lockdown implied additional challenges for Science, Technology, Engineering and Mathematics (STEM) disciplines, such as concentration issues, reduced interaction, or non-structured pedagogical methods [1]. In this unprecedented situation, Information and Communication Technologies (ICT) were key to ensure the continuity of education, though the improvised nature of ERL prevented the creation of structured designs for a complete online learning experience [1], [2], [3], [4].

Audiovisual resources have proven to be an effective pedagogical tool, and their benefits are directly related to some of the shortcomings produced by ERL. The Cognitive Theory of Multimedia Learning (CTML), based on the Cognitive Load Theory (CLT), offers insights on the impact of multimedia on processing capacity [5], [6], [7]. Extraneous cognitive overload produced by the improvised instructional approach during ERL could be reduced with the use of

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suitable didactic multimedia that allow students to review and to reinforce the explained concepts with well-structured explanations and promote self-paced learning. Essential cognitive load, related to the processing of information to create mental representations in the working memory, can also be reduced with videos given that they increase the number of sensory channels involved in the learning process (visual and auditory).

Moreover, generative processing for the organization of received information and its integration with previous knowledge could be fostered with an organized structure of videos that escalate in level, as well as reinforcing the links among subjects within the degree. This is a specific

challenge of engineering education, where additional difficulties are found for the understanding of connections between subjects, usually delivered in a silo-like fashion [8], [9], [10]. This may lead to a reduction in motivation and confidence, particularly in abstract disciplines, which could be mitigated with an adequate integration of multimedia resources within active learning methodologies, that could also improve academic performance [10], [11], [12], [13], [14], [15], [16], [17].

However, several authors also highlight teachers' difficulties on finding suitable videos for their academic needs [15], [18], [19], [20], as well as students' problems to choose videos for complementary self-directed learning [21]. Additionally, other authors highlight teachers' need to enhance their pedagogical knowledge, as specialization in their STEM discipline might not be enough for a suitable implementation of video-aided learning strategies [17], [22]. Technological Pedagogical Content Knowledge (TPACK), describes the need for this continuous knowledge improvement of lecturers with a view to the successful integration of ICT in educational environments [23], [24], [25], [26], [27].

This article aims to evaluate the mitigating effects of didactic videos on the impact of ERL on education quality perception, performance, and interest in a real electrical engineering classroom environment. For this purpose, concept maps have been used as a helping tool to highlight significant relations among key ideas in order to develop visual schemes that contribute to identify key topics where the benefits of didactic videos could be optimal not only to reinforce a subject's topics of interest, but also their relationship with other subjects of the degree [28], [29]. This analysis helped to design a specific series of didactic videos that were published in a YouTube channel serving both educational and scientific dissemination purposes, which were subsequently distributed among the students of "Electrical Machines I" of the Electrical Engineering BSc from the School of Industrial, Aerospace and Audiovisual Engineering of Terrassa (*Universitat Politècnica de Catalunya*) [30]. The selected channel is *Sígueme la Corriente* [31], which has been studied in previous exploratory research, and has been found potentially suitable for educational use based on users' perception about key metrics related to content and format adequacy [11], [32]. This research extends through three academic years, and addresses the following research questions with a Mixed Methods approach:

- RQ1: Did ERL produce differences in education quality perception and academic performance?
- RQ2: Did didactic videos contribute to mitigate the impact of ERL from the students' perspective?
- RQ3: Did didactic videos contribute to boost motivation and interest in the subject?

After this initial introduction to video integration as pedagogical aid in STEM disciplines, Section II addresses the research design and methodology followed during this study, including relevant aspects of data collection and analysis. Section III presents the most relevant results from both the quantitative and the qualitative phases of the study, showing the impact of didactic videos in students' perception of education quality, performance and motivation for three academic courses covering pre-ERL, ERL and post-ERL scenarios. Section IV analyzes the implications of this study, as well as its contribution to current literature. Finally, Section V highlights the main conclusions of this article, followed by a summary of its limitations and future research in Section VI.

II. METHODOLOGY

This study focuses on the course "Electrical Machines I" (60 hours) taught in the fifth semester of the Electrical Engineering BSc from the School of Industrial, Aerospace and Audiovisual Engineering of Terrassa (*Universitat Politècnica de Catalunya*) [30]. Using concept maps (see Appendix I), it has been detected that both electromagnetism and 3-phase circuits are key concepts for 32.2% of the subjects that make up the electrical engineering degree. Concept maps have been created using CMapTools [33].

There is a specific organizational challenge at *Universitat Politècnica de Catalunya* regarding these selected areas of knowledge. Both electromagnetism and 3-phase circuits are taught as part of three elementary courses, where students from electrical engineering share classroom with students from other engineering branches, which implies that the overall level of instruction received in relation to these concepts is lower than what could be desired for an electrical engineer. Dealing with such key concepts as common topics for diverse engineering branches may be detrimental to the depth of knowledge about said concepts, thus creating a bottleneck for the subsequent subjects of the degree. One of the first subjects affected by this problem in the degree is "Electrical Machines I".

As means to homogenize the access level in the Electrical Machines I course, and to mitigate some of the negative effects of ERL reported in literature, video-aided reinforcement is proposed as a harmonization strategy, aiming to provide conceptual explanations for students to fill the gaps of previous knowledge and acquire the recommended level in Electromagnetism and 3-Phase Circuits. The objective behind such video-aided harmonization strategy is taking advantage of videos' potential to lower both essential and extraneous cognitive load, as well as promoting generative processing as explained by CTML. A specific series of 9 scientific dissemination videos was created in *Sígueme la Corriente*, considering key metrics from literature on format and content adequacy as guidelines for their creation, such as explanation quality, audiovisual quality, contents' technical level and rhythm, efficient length, voice and language, or interestingness [11], [19], [34], [35], [36]. As inclusion criteria, such videos would cover the main topics of Electromagnetism and 3-Phase Circuits, considered as core knowledge for electrical engineering degree and to a degree of complexity that allows students to reach an appropriate entry level to Electrical Machines I subject.

Additionally, animations and visual explanations played an important role in each one of the videos as a means to enhance essential processing. Videos were distributed to students through Moodle, and they are also collected and available in two playlists of the channel: Electromagnetism [37] and 3-Phase Circuits [38]. This continuous availability of the videos allowed students to review and reinforce concepts at their own pace, which contributes to reduce the extraneous cognitive overload produced by ERL. The organized structure of created videos, escalating in level from introductory chapters to advanced conceptual explanations, is also aimed at fostering generative processing for the suitable organization of new knowledge, and its integration with previous explanations.

A. DESCRIPTION OF THE APPLIED MIXED METHODS STUDY

This study has been carried out during three academic years, where two groups have been distinguished: a control group with students from the 2019/2020 course (pre-ERL) and two experimental groups with students from 2020/2021 year (ERL) and 2021/2022 year (post-ERL). The control group took the classes following a strictly traditional pedagogic approach, with no use of eLearning methodologies or video-based learning, whereas the experimental groups completed the course following a distance-learning approach with complementary video support, starting with ERL during the covid-19 pandemic and continuing with a more normalized distance learning situation. Both situations of distance learning comprised synchronous classes through videoconference services, which were recorded and made available to students, as well as the use of dissemination videos in Moodle to complement base knowledge. No further change in methodology is considered among selected courses. In all courses, laboratory classes remained presential due to its practical component. Additionally, exams were held on-site at the university, and were composed by three parts: theory exam, problems exam and laboratory exam. Throughout the three courses considered in this study, the subject was taught by the same professor and included the same contents, as well as similar evaluation activities.

This research is based on a mixed methods sequential explanatory design, intended to complement quantitative analysis on education quality perceptions and academic performance with a deeper qualitative analysis of the impact of didactic videos in motivation and mitigation of negative ERL effects.

B. STUDY PHASES AND DATA COLLECTION

Data collection has been structured in three phases, starting with a quantitative approach distributed in two stages (phase 1 and 2) of a quasi-experimental post-test design with control group. This analysis is complemented by a case study qualitative approach (phase 3), to further understand the implications of video in an ERL pedagogical environment. Data collected has been made available online through IEEE DataPort [39].

Phase 1 of this study is intended to evaluate the variation of students' perception on education quality for the duration of the experiment. For this purpose, the distributed questionnaire is based on the validated Students' Evaluations of Educational Quality (SEEQ) survey for higher education [40], which is composed of 32 Likert scaled questions organized in nine factors as shown in Appendix II.

Phase 2 aims to quantify the variation in obtained grades. This evaluation is based on a direct comparison of the final grades report between both experimental groups and the control group.

Phase 3 has been designed to evaluate more deeply how the proposed videos may have affected students' motivation and engagement throughout the course, despite the identified negative effects of ERL. This qualitative assessment has been performed through a structured interview with the objective to better understand and cross-check previous results obtained through the SEEQ survey and academic performance. The interview's structure has been based in tensions deducted from research questions:

- Distance education impact on performance.
- Quantity of videos watched (1-9).
- Type of use of the videos (satisfying curiosity, exam preparation, etc.).
- Impact of videos on motivation and interest in the subject
- Relevance of the content creator's identity (professor vs. professional in the field).
- Implications of proposed videos as teaching complement.

Differentiations per age and sex groups were not considered in this study. On the one hand, the population was composed by students of similar age, between 18 and 20 years old for more than the 95% of cases in all years analyzed, as this is a second-year course in the degree. On the other hand, regarding gender, women were underrepresented as there were 5 women out of 47 (10.63%) students in the pre-ERL year, 5 women out of 44 (11.36%) students in the ERL year, and 4 women out of 66 (6.06%) students in the post-ERL year.

Table 1 shows the sample considered in each phase. For phase 1, according to previous evaluations of reliability, validity and usefulness of the instrument performed by Marsh [41], between 10 to 15 or more students show reliable

TABLE 1. Participants in each phase of the study.

ID	Academic year	Phase 1	Phase 2	Phase 3
Pre-ERL	2019/2020	27	47	N/A
ERL	2020/2021	23	44	14
Post-ERL	2021/2022	35	66	7

results through the SEEQ instrument, which is more than doubled in our study for all cases. Class ratings from a sample smaller than 10% of the population should be interpreted carefully, but this is not the case as we are considering in all cases more than 50% of the population. The sample in phase 2 matches the population, as it comes directly from grades reports, whereas in phase 3 several volunteer students from experimental groups participated in the structured qualitative interviews.

Data collection for phase 1 was carried out immediately after the final examinations of the subject both for ERL and post-ERL. The case of pre-ERL students was singular because they were reached between January and March 2021 in order to gather reference information from pre-ERL scenario. Phase 2 source of information are grades reports, and they were collected immediately after the course was finished in each course. Finally, structured interviews constituting phase 3 lasted two weeks for the ERL course and two days for the post-ERL course.

C. DATA ANALYSIS

The statistical analysis shown in the Results section has been performed using SPSS [42] and Jamovi [43], with a confidence level of 95% in all cases. For phases 1 and 2, normality Shapiro-Wilk test confirms the non-normal distribution of data, so non-parametric Mann-Whitney U tests were performed to compare independent samples.

Additionally, for qualitative analysis of the structured interviews during phase 3, all participations were coded following a deductive process after an initial exploratory evaluation. A final number of 40 codes have been defined within the following 6 categories:

- Learning parameters.
- Learning environment.
- Video benefits.
- Subjective valuation.
- Stakeholders.
- Variation in perception.

Participations were collected in Spanish, and equivalent English terms for codes have been considered as per the concepts commonly used in literature. Cooccurrence analyses have been performed to detect relevant relations among codes, and Sankey diagrams are presented for their graphic representation. ATLAS.ti software [44] has been used for these purposes.

D. CONFIDENTIALITY

All participants in this study gave informed consent for the scientific use of the data gathered. Answers to the SEEQ questionnaire were completely anonymous, and grades reports were anonymized before analysis. In the case of structured interviews, no personal data was registered.

III. RESULTS

This section presents the results obtained throughout the three phases of the study, aiming to evaluate the variations with respect to traditional education as a control group (pre-ERL), to covid-19 imposed distance learning (ERL) and a more normalized experience of online learning (post-ERL). The objective is to find implications from the integration of didactic videos as a mitigating strategy for the negative effects of ERL.

A. PHASE 1: IMPACT OF METHODOLOGY CHANGE IN PERCEPTION OF EDUCATION QUALITY

The 32 questions proposed by the SEEQ survey are structured according to nine different factors, meant to evaluate the different dimensions to which students' perception of education quality is composed of. Such factors are:

- F1 Learning: understanding, interest in the subject and learning outcomes.
- F2 Enthusiasm: professor's dynamism, enthusiasm, energy, and humor.
- F3 Organization: subject's organization and clarity of teaching.
- F4 Group Interaction: how students were encouraged to interact with the rest of the group during synchronous classes.
- F5 Individual rapport: the individual attention that the professor provided to each student.
- F6 Breadth: subjects' contents contextualization and connection with the broader picture of the discipline.
- F7 Exams: suitability of evaluation activities to fairly assess the students' knowledge on the course's contents.
- F8 Assignments: suitability of texts or other homework and laboratory activities for the subjects' objectives.
- F9 Overall: professor and subject overall evaluation.

Figure 1 shows the mean values for all factors during the whole experiment duration. Additionally, detailed results for each question are shown in Appendix II.

During ERL, it is possible to detect a reduction in students' perception about all factors except group interaction. Afterwards, the post-ERL experimental group shows a recovery of mean scores to values similar to those of the control group.

Table 2 shows the statistical significance of the comparison among groups. Comparing pre-ERL with ERL groups, there is significant reduction in the following factors: Learning, Enthusiasm, Individual rapport, Breadth, Exams and Assignments. The fact that students' perception of professor enthusiasm is affected might be particularly relevant when it comes to the professor's ability to stimulate the interest of students in the subject. On the other hand, comparing pre-ERL with post-ERL we only find significant difference in individual rapport factor, mainly due to a change in the perception of the professor's availability for help or advice.

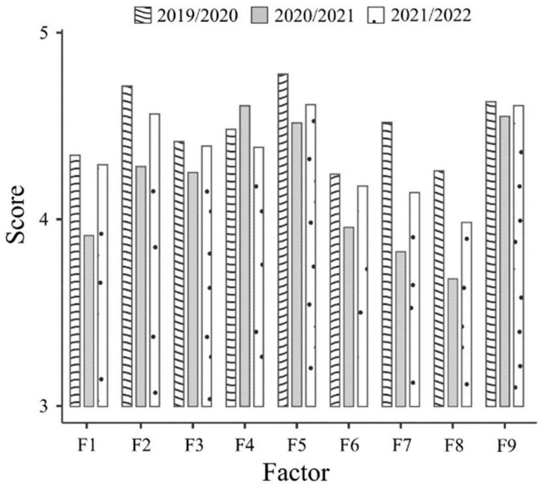

FIGURE 1. Average results per SEEQ survey factors, being F1 Learning, F2 Enthusiasm, F3 Organization, F4 Group Interaction, F5 Individual rapport, F6 Breadth, F7 Exams, F8 Assignments, and F9 Overall.

TABLE 2. Comparison among SEEQ survey factors.

Factors	*p* value		
	Pre-ERL vs ERL	Pre-ERL vs Post-ERL	ERL vs Post-ERL
1. Learning	**0.004**	0.472	**0.019**
2. Enthusiasm	**0.003**	0.283	**0.023**
3. Organization	0.207	0.942	0.238
4. Group interaction	0.469	0.446	0.123
5. Individual rapport	**0.001**	**0.008**	0.371
6. Breadth	**0.045**	0.571	0.112
7. Exams	**0.001**	0.057	0.129
8. Assignments	**0.000**	0.193	0.073
9. Overall	0.173	0.945	0.195

*Mann-Whitney *U* test. Bold values: $p<0.05$.

The rest of parameters are back to normal possibly due to a more normalized experience with online learning.

When comparing the two experimental groups, a significant increase in the Learning and Enthusiasm factors is found as students and professor grow accustomed to distance learning. There are specific enhancements in students' perception of the understanding of the subject's contents and the engagement with professor's style of presentation.

B. PHASE 2: IMPACT OF METHODOLOGY CHANGE IN ACADEMIC PERFORMANCE

As a means to evaluate the changes in academic performance, grades reports have been analyzed. The pre-ERL group shows a mean final grade of 5.27 (SD 2.36), whereas the experimental ERL and post-ERL groups show, respectively, means of 4.25 (SD 2.47) and 4.90 (SD 2.79). Whereas this evolution might seem similar to the one previously seen for SEEQ in subsection A, the Mann-Whitney *U* test finds no significant difference among years.

However, interesting information emerges when comparing separately each one of the evaluation activities.

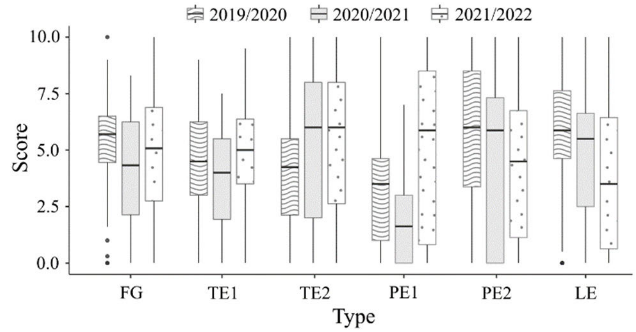

FIGURE 2. Boxplot for Final Grades (FG), Theory Exams (TE), Problems Exams (PE) and Laboratory Exam (LE) in all groups.

TABLE 3. Comparison among SEEQ survey factors.

Evaluation Activity		*p* value		
		Pre-ERL vs ERL	Pre-ERL vs Post-ERL	ERL vs Post-ERL
TE1	Theory Exam 1	0.060	0.487	**0.014**
TE2	Theory Exam 2	0.148	**0.023**	0.778
PE1	Problems Exam 1	**0.036**	**0.016**	**0.000**
PE2	Problems Exam 2	0.426	0.063	0.419
LE	Laboratory Exam	0.179	**0.000**	0.087
FG	Final Grades	0.064	0.400	0.254

*Mann-Whitney *U* test. Bold values: $p<0.05$.

Table 2 shows the grades distribution in all courses split by the different theory, problems and laboratory exams that were held. Additionally, Mann-Whitney *U* tests have been performed to establish comparisons among courses (see Table 3).

As presented in Table 2, during mid-semester, both Theory Exam 1 (TE1) and Problems Exam 1 (PE1) took place. It can be observed how grades distribution decreased during ERL, with a subsequent rise where post-ERL performance could even overcome pre-ERL levels. Though there is no significant difference between pre-ERL and ERL scenarios in the case of TE1, a significant recovery is registered during post-ERL, recovering the grades levels from pre-ERL course. Additionally, there is a significant reduction for PE1 in the ERL scenario, as well as significant improvement in post-ERL scenario when compared to both pre-ERL and ERL.

End-semester examinations consisted of Theory Exam 2, Problems Exam 2, and Laboratory Exam. TE2 shows a significant grade increase in the post-ERL scenario, while PE2 grades stay stable during both ERL and post-ERL. Finally, LE shows a similar grades profile to PE2, where there are no significant differences between the pre-ERL and the ERL scenarios, but a significant decrease is found when comparing pre-ERL and post-ERL scenarios.

C. PHASE 3: IMPLICATIONS OF THE USE OF DIDACTIC VIDEOS

Previous quantitative results show the impact of ERL in the perception of education quality and academic performance.

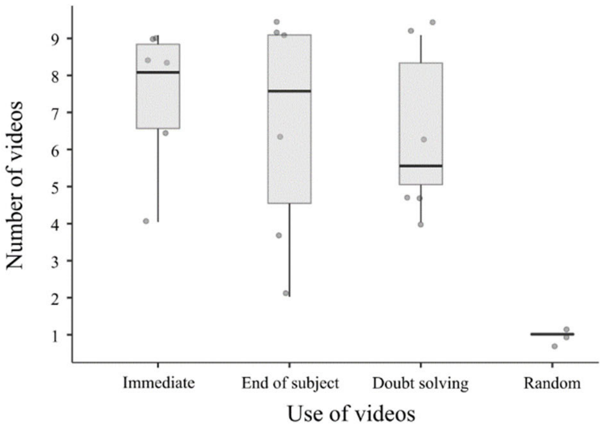

FIGURE 3. Number of videos watched related to their use.

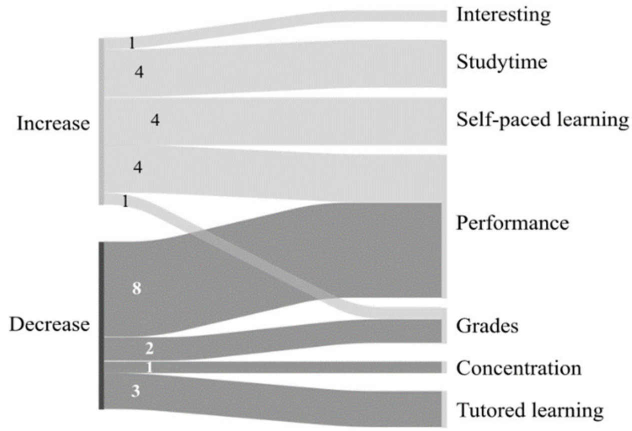

FIGURE 4. Sankey diagram for the subjective perception of ERL effects in performance and learning related parameters.

However, the implications of the integration of didactic videos during this experience could be better appreciated through a qualitative approach that allows to understand to which extent they were helpful in mitigating the negative effects of ERL, by helping conceptual learning and raising interest among students.

First, participants in the qualitative assessment were asked to declare whether they used videos as soon as they were available, at the end of the course, as conceptual aid for clearing doubts, or randomly. Table 3 shows the number of videos watched related to declared use. Out of the nine videos provided, a mean of 7.33 (SD 1.97) were watched immediately after release. Other students decided to use all videos together once the course finishes, in order to prepare their final examinations. In this case, a mean of 6.5 (SD 3.02) videos are watched. When referring to clarify doubts, a mean of 6.33 (SD 2.16) videos are watched at a variable pace depending on when the conceptual aid is needed. Finally, random use is declared by three students, and it refers to the reproduction of a randomly chosen video for curiosity, but without further use of these resources.

After collecting the 21 participations in the structured interview, the resulting text was coded following a deductive process as described in the Methodology section. In order to analyze the codependency of the main ideas transmitted by participants, a cooccurrence analysis has been developed, and its results are presented through Sankey diagrams to visually understand those connections. These kinds of representations allow us to visualize the relations between the concepts on the left and the concepts on the right, through the number of cooccurrences between them found during the interview. This number is indicated on the left side of the graphic and, additionally, the more cooccurrences are found in students' participations the thicker the flow lines will be.

ERL impact in academic performance and other learning descriptors is represented in Table 4, where 8 cooccurrences declare a decrease in performance. This is also related with a perceived decrease of tutored learning and concentration. However, up to 4 cooccurrences from other participants are found indicating an increase in this same descriptor, related to an increase of self-paced learning options, study time and interest in the subject.

As regards the videos' specific impact, Figure 5 shows the main learning-related parameters related to the specific benefit extracted from videos.

In terms of facilitating conceptual learning, videos are found to be useful to understand subject's concepts mainly because they can be viewed several times and allow to clarify doubts through self-paced learning. Additionally, the available videos are considered a positive complement to the professor's explanations due to their didactic value, as well as individual learning descriptors previously mentioned. Some participants also highlight their specific value to visualize abstract ideas present in STEM.

Regarding videos' impact on the enhancement of motivation and interest in the subject, the main highlighted metric refers to their didactic value. Other participants see a connection between this aspect and their added value for the visualization of abstract ideas, as well as their practical and direct explanation style. As for this practical focus of videos, some students consider it relevant that the contents are created by a professional in electrical engineering, as it helps them to discover professional applications and integrate the studied concepts into the big picture of the degree.

IV. DISCUSSION

The ERL unprecedented conditions imposed by the covid-19 lockdown had several implications, and our results show interesting insights in this regard. This section intends to answer the proposed research questions as per our findings.

A. RQ1: DID ERL PRODUCE DIFFERENCES IN EDUCATION QUALITY PERCEPTION AND ACADEMIC PERFORMANCE?

Through SEEQ survey (see Appendix II for detailed results), we were able to quantify a significant reduction in Learning and Enthusiasm factors, mainly because of a reduction in understanding of the subject's contents, and a decrease of interest in professor's presentations. The ERL improvised

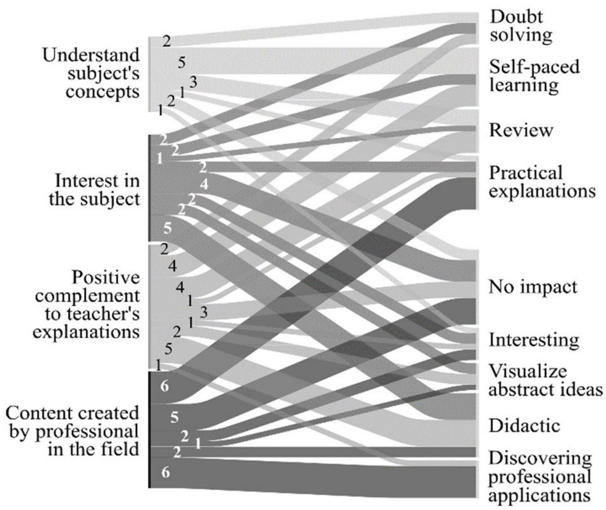

FIGURE 5. Sankey diagram for videos' implications in conceptual learning, interest, and value from the professional perspective.

environment might have affected the professor's comfort, conditioning his ability to deliver engaging presentations of the subject's contents and also incorporating the use of humor. This is particularly relevant, as it shows how ERL did not only affect students' perception of their learning outcomes, but also of their professors' ability to contribute to students' motivation and interest in the subject through engaging presentations. These findings are consistent with Tulaskar and Turunen's, after conducting their research based on surveys, semi-structured interviews and diary studies [1]. Through a survey with 138 participants, 61% reported a negative experience with ERL, mainly related to an uninteresting presentation and a non-interactive way of teaching. Additionally, they measured a moderate satisfaction perception of learning quality (3.42 score on a 5-point Likert scale).

Performance in evaluation activities differed slightly, but there are not significant differences between pre-ERL and ERL situations excepting PE1. This fact is consistent with the initial difficulties of ERL, which in this case study has had a higher impact in procedural learning. Tulaskar and Turunen's measures of students' adjustment, and acceptance of the situation during the progress of the course, are also consistent with the improvement in performance from mid-semester to end-semester examinations measured in our study for ERL [1].

Regarding active participation during synchronous classes, SEEQ survey unveiled an increase from pre-ERL to ERL, mainly associated to professors' increased proactivity towards students' expressing their ideas, asking questions, and participating in class discussions. This is common practice in Electrical Machines I subject at this university, which is consistently taught with high students' participation component, but isolation and the new learning environment imposed by ERL conditioned the professor to further insist on the importance of group interaction.

However, despite this is true for synchronous classes, it might not be representative of the whole learning experience. Other negative effects of ERL quantified by the qualitative assessment are related with a perceived decrease in tutored learning and concentration, also reported by Tulaskar and Turunen [1]. A reduction in professor's accessibility was also significant as per SEEQ's results, in keeping with qualitative findings of a perceived decrease in tutored learning. This is also related to the grades and performance decrease reported by some students, as shown in Table 4. Feedback on graded assignments, as well as instructor's emphasis on key concepts for evaluation also decreased during ERL. However, overall assessment of the degree's professors performed by the Electrical Engineering Department confirms that "Electrical Machines I" professor is among the most valued professors of the degree during the pre-ERL, the ERL and the post-ERL scenario, specifically due to the pedagogical tools used for online teaching. A similar case study performed in other subjects might unveil higher impact among scenarios. Concerning these aspects, Gopal et al. [4] measured that instructor's quality is the main factor affecting student's satisfaction during online classes, followed by students' expectations and feedback. They concluded that instructors need to be more creative in designing and delivering course contents to improve overall satisfaction.

This appreciation might be related to results in the perception of the course's assignments. Measured impact through the SEEQ mainly refers to proposed reading and homework, whose value for students was significantly reduced. However, the didactic videos made available during the course did have a remarkable impact on students, as reported through qualitative assessment.

B. RQ2: DID DIDACTIC VIDEOS CONTRIBUTE TO MITIGATE THE IMPACT OF ERL FROM THE STUDENTS' PERSPECTIVE?

Quantitative approach in this article has intended to evaluate ERL impact on students' perception on education quality and performance, but with only that information it is not possible to isolate the effect of videos in such scenario. However, despite previously mentioned negative impacts of ERL, nuances extracted from qualitative assessment indicates that there are also positive impacts for students that participated in this study, mainly related to an increase in autonomous study fostered by video-aided active learning. Table 4 shows that some participants declared an increase in performance and interest during ERL thanks to the new possibilities for self-paced learning, as well as study time increase promoted by provided video resources. Self-paced learning is also highlighted by Shoufan, as a consequence of his experience with fully active learning [10]. Additionally, in Kim and Ahn experience with video-aided flipped classroom learning, an increase of 25% in class time was quantified, as well as an engagement increase from students in the learning process by the possibility to self-regulate their study pace, and the option of repeatedly watching proposed video clips [17].

This repeatability factor is also highlighted by Tiernan and O'Kelly [15].

Participants stated that videos contributed to understand the subject's concepts, and they were a positive complement to professor's explanations, mainly because they allowed to repeatedly watch conceptual explanations and solving doubts at a self-paced rhythm with didactic explanations. As unveiled during the initial stage of qualitative assessment, a mean of 6.33 (SD 2.16) videos were watched for doubt-solving purposes, at a variable pace depending on needs for conceptual aid. In the framework of CLT, Tani et al. concluded that multimedia presentations such as video might increase academic performance, specifically in procedural and evaluative knowledge [14]. There is wide evidence that video integration in education with procedural learning fosters problem-solving activities [21], [34], [45]. However, related to conceptual learning, Song and Kapur have also highlighted positive results of video integration with prior concept discussion and problem resolution in tutored activities during class, which is consistent with our findings [46]. This backs up the differences on Theory Exams and Problems Exams, where conceptual learning promoted by video integration is found to be useful to mitigate ERL impact for both TE1 and TE2. The main detected impact of ERL in academic performance relates to problems and laboratory tests, where in theory examinations videos might have acted as a mitigating tool by supporting conceptual learning. It is worth mentioning that end-semester theory examinations normally show better results than mid-semester ones, because students incorporate and assimilate concepts during the whole course, hinting at an intrinsic enhancement in performance.

Students highlighted the fact that proposed didactic videos allowed them to visualize more clearly abstract concepts, which enhanced the didactic experience. This is supported by CTML, as the dual channel (visual and auditory) reduces the cognitive load the student is exposed, and visual animations help understanding abstract ideas [5], [6], [7]. Additionally, this is consistent with findings from Asef and Kalyvas [47], quantifying the central role of animations in promoting conceptual learning through videos, with rates of 68% of positive responses from undergraduate students (including very significant and significant), and 86% from postgraduate students. Moreover, the same study highlights that respectively 75% and 82% of undergraduate and postgraduate students indicate that they prefer animated videos instead of traditional video recordings to understand real-world technology. Tiernan and O'Kelly [15] also highlight students' feedback of videos' specific value to visualize information, as well as to provide practical explanations, concluding to a generalized agreement from students that the learning value of video is higher than compared to books alone.

Our findings from qualitative assessment, and their match with observations from quantitative assessment and literature, suggest that didactic videos could present a mitigating effect for some of the negative effects of ERL, mainly due to their support to conceptual learning, and their contribution to increasing study time and self-paced learning. However, they were not enough to fully compensate such an unprecedented change of paradigm, but instead act as a cushioning measure.

C. RQ3: DID DIDACTIC VIDEOS CONTRIBUTE TO BOOST MOTIVATION AND INTEREST IN THE SUBJECT?

As previously discussed, though ERL had a substantial impact in students' perception of education quality, didactic videos played a mitigating role, especially regarding conceptual support during the course. This had a specific effect in academic performance of theory exams. But, when focusing on motivation and the interest on the subject, didactic videos' implications are even more noticeable.

Though finding suitable videos online for education is usually challenging from teachers' perspective, Pattier highlights that the most frequent selection criterion is a video's potential to generate motivation in students, followed by its relevance for the objectives of the subject and its expositive clarity [18]. The aspect of the motivational value of videos as a main driver is also highlighted by Tiernan and O'Kelly [15], after quantifying in their qualitative study how a wide majority of their students and teachers reported that videos helped to increase attention during classes, as well as to raise of the interest in the subject. They also highlight that it is essential to ensure that videos are relevant for students, and their contents are not only interesting, but also show an adequate difficulty level. This aspect is confirmed for videos created by the *Sígueme la Corriente* channel, including those considered in this study, where positive perception has been quantified for both content and format adequacy, as well as the engaging style of the presenter and the usefulness of the contents to understand topics of interest [11]. Global positive evaluation of *Sígueme la Corriente* educational value is also consistent with Shoufan's findings [36], that highlight a set of 6 reasoning clusters determinant for students to like or dislike educational videos: explanation quality, audiovisual quality, content, efficient length, voice and language, and interestingness.

Didactic video integration was also able to raise the interest in the subject, as highlighted by participants in qualitative assessment. This is mainly related to video support to visualize abstract concepts, widely present in STEM disciplines and, particularly, in electrical engineering. Previous studies by Horta-Bernus and Casals-Rosas explain how phasor diagrams are helpful for students to understand abstract concepts in electrical engineering, due to the complex mathematics involved in this field [48]. Additionally, Wu et al. concluded that drawing prompts are useful tools for problem-solving strategies in engineering. [49]. These aspects are consistent with our study's premise, where developed videos included an enhanced version of phasor diagrams due to the possibility of including animated drawings.

Additionally, the fact that videos were created by an active professional was also valued from students, as they included interesting practical explanations that allowed them to discover the professional applications of electrical engineering. This contributes to create a global perception of the degree's contents, as well as connecting key concepts among subjects that would otherwise be presented separately and unlinked. Conclusions from Cabrera-Peña et al. are aligned in this regard, highlighting the need to connect concepts belonging to different engineering courses [9]. Moreover, Maciejewsky et al. also support this perspective, with a specific focus in those disciplines more abstract such as electrical engineering [8]. This practical use of videos to enhance a complete understanding of the degree's implications and applications also contributes to influence some of the main reasons for dropout rates in engineering studies, which are additionally increased by online learning modality [50], [51].

Overall, qualitative participations show that didactic videos had a positive impact in both motivation and a raise of interest in the subject's contents. According to Soufan's experience with fully active learning [10], successful integration of multimedia resources promotes a high level of perceived interest in students, as well as a reduction in boredom levels. Additionally, Gordillo et al. experience with video-based learning measured a positive perception from students on video integration for online software engineering education [52], where most students stated that video-based methodology helped them learn (with a mean of 4 in a 5-point Likert scale).

V. CONCLUSION

Didactic video integration has proven to provide an overall positive impact in this study, with beneficial implications in conceptual learning and performance, as well as interest and motivation. They have also shown a positive mitigating effect on some of the most impacting challenges of ERL during covid-19 lockdown, as well as a positive contribution during post-ERL scenario. Additionally, this study shows how an adequate selection of topics through conceptual mapping of subjects is able to promote video-aided reinforcement for the global perspective of the degree through conceptual connections. The practical perspective of provided videos has also been beneficial to provide first-hand prospects of the professional applications of the degree. The challenge remains in professor's acceptance and integration of these resources and active methodologies, which could be fostered by an enhancement on their pedagogical knowledge as complementary to the normal specialization in their respective STEM discipline, based on TPACK model and its particularized ICT-TPACK.

VI. LIMITATIONS AND FUTURE WORKS

The main limitation of this study is related to the irruption of ERL and the required change in learning methodologies, which implies difficulties for the proper isolation of either

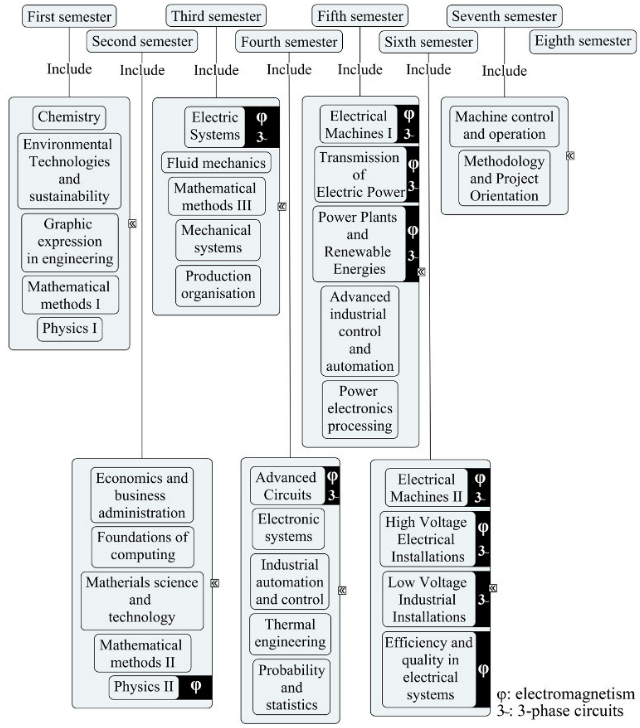

FIGURE 6. **Concept map of compulsory subjects in BSc in Electrical Engineering, marking those related to electromagnetism (ϕ symbol) and 3-phase circuits (3L4 symbol).**

videos or ERL effects on education quality perception and performance parameters through a quantitative approach. It is not possible to isolate one effect from the other, as both coexisted in time and had mixed implications. Therefore, qualitative assessment has allowed to collect specific information on video impact, which has been beneficial for the interpretation of perceived videos' benefits for above mentioned parameters, as well as their additional benefits for students' motivation and interest. Additionally, this study has been conducted during three academic years, and has focused on a specific course of the electrical engineering degree in only one university. Its results are representative of the specific case of electrical engineering studies in a public university. More case studies in similar environments might provide additional evidence of videos implications in electrical engineering education during ERL, as well as to further extend the findings of this article and extrapolate them to other learning situations.

With a view to overcoming the main limitation of this study, proposed future works include the extent of a similar case study in future academic years, once presential learning is fully reinstated. This will allow to evaluate the specific impact of didactic videos by means of a direct comparison with the pre-ERL scenario, as well as contrasting obtained results for the main factors where videos acted as mitigating resource for ERL negative impacts during ERL scenario. Additionally, other sources of didactic videos will be evaluated to further explore the educational use of scientific dissemination in a wider variety of STEM disciplines.

TABLE 4. Students' Evaluation of Educational Quality survey results, distinguishing between factors: F1 Learning, F2 Enthusiasm, F3 Organization, F4 Group Interaction, F5 Individual rapport, F6 Breadth, F7 Exams, F8 Assignments, and F9 Overall.

Factors		Questions	Control		Experimental				*p* value*		
			2019/2020		2020/2021		2021/2022		'19/'20 vs '20/'21	'19/'20 vs '21/'22	'20/'21 vs '21/'22
			Mean	SD	Mean	SD	Mean	SD			
F1	1	I have found the subject intellectually challenging and stimulating	4.44	0.847	4.22	0.671	4.43	0.698	0.111	0.723	0.179
	2	I have learned something which I consider valuable	4.56	0.892	4.39	0.583	4.49	0.742	0.098	0.439	0.337
	3	My interest in the theme has increased because of this subject	4.26	0.944	3.74	1.210	4.23	0.877	0.112	0.811	0.132
	4	I have learned and understood the contents of this course	4.11	0.847	3.30	1.260	4.03	0.857	**0.009**	0.646	**0.026**
F2	5	The professor was enthusiastic about teaching the subject	4.89	0.320	4.87	0.344	4.71	0.789	0.836	0.465	0.622
	6	The professor was dynamic and energetic in conducting the subject	4.78	0.641	4.57	0.662	4.66	0.684	0.111	0.312	0.467
	7	The professor enhanced presentations with the use of humor	4.70	0.609	4.17	0.984	4.57	0.739	**0.016**	0.440	0.061
	8	Professor's style of presentation held my interest during class	4.48	0.753	3.52	1.160	4.31	0.832	**0.001**	0.418	**0.006**
F3	9	Professor's explanations were clear	4.67	0.480	4.35	0.647	4.37	0.843	0.071	0.162	0.614
	10	Subject materials were well prepared and carefully explained	4.30	0.869	4.30	0.822	4.40	0.812	0.983	0.534	0.584
	11	Proposed objectives agreed with those actually taught so I knew where the subject was going	4.44	0.801	4.09	0.848	4.46	0.780	0.090	0.961	0.065
	12	The professor gave lectures that facilitated taking notes	4.26	0.903	4.26	0.864	4.34	0.802	0.992	0.726	0.741
F4	13	Students were encouraged to participate in class discussions	4.48	0.753	4.65	0.647	4.37	0.731	0.333	0.474	0.106
	14	Students were invited to share their ideas and knowledge	4.33	1.040	4.61	0.722	4.40	0.695	0.307	0.739	0.160
	15	Students were encouraged to ask questions and were given meaningful answers	4.67	0.480	4.70	0.470	4.54	0.611	0.828	0.496	0.389
	16	Students were encouraged to express their own ideas	4.44	0.698	4.48	0.790	4.23	0.942	0.689	0.439	0.281
F5	17	The professor was friendly towards individual students	4.74	0.813	4.35	0.832	4.57	0.558	**0.014**	**0.042**	0.389
	18	The professor made students feel welcome in seeking help/advice in or outside of class	4.93	0.267	4.52	0.947	4.57	0.778	**0.032**	**0.012**	0.885
	19	The professor had a genuine interest in individual students	4.74	0.813	4.70	0.470	4.69	0.583	0.223	0.317	0.806
	20	The professor was adequately accessible to students during office hours of after class	4.70	0.823	4.50	0.512	4.63	0.547	**0.030**	0.198	0.291
F6	21	The professor contrasted the implications of various theories	4.08	0.935	3.87	0.920	4.00	0.874	0.368	0.634	0.665
	22	The professor presented the background or origin of ideas/concepts in or outside of class	4.44	0.577	4.00	0.853	4.31	0.796	0.053	0.700	0.133
	23	The professor presented points of view other than his/her own when appropriate	4.11	0.934	3.83	0.834	3.94	0.851	0.140	0.334	0.490
	24	The professor adequately discussed current developments in the field	4.33	0.920	4.13	0.757	4.46	0.741	0.188	0.649	0.063
F7	25	Feedback on examinations/graded materials was valuable	4.37	0.884	3.70	1.220	4.06	1.030	**0.034**	0.227	0.267
	26	Methods of evaluating student work were fair and appropriate	4.48	0.849	3.57	0.992	4.00	1.080	**0.000**	0.061	0.071
	27	Examinations/graded materials tested course content as emphasized by the instructor	4.70	0.823	4.22	1.130	4.37	0.910	**0.045**	**0.046**	0.748
F8	28	Required readings/texts were valuable	4.07	0.958	3.67	0.557	3.82	0.999	**0.032**	0.267	0.395
	29	Reading, homework, laboratories contributed to appreciation and understanding of subject	4.44	0.847	3.70	0.876	4.14	0.974	**0.001**	0.165	**0.038**
F9	30	Compared with other subjects I have had at the university, I would say this one is:	4.52	0.849	4.26	0.689	4.49	0.702	0.079	0.633	0.159
	31	Compared with other professors I have had at the university, I would say this one is:	4.70	0.542	4.74	0.449	4.71	0.572	0.949	0.827	0.881
	32	As an overall rating, I would say the professor is:	4.67	0.555	4.65	0.487	4.63	0.690	0.774	0.979	0.738

*Mann-Whitney *U* test. Bold values: $p<0.05$.

From professors' perspective, future works will include specific evaluations of their ICT acceptance, including specific training programs on digital competencies intended to improve professors' predisposition to foster ICT-aided active methodologies.

APPENDIX I. CONCEPT MAPS

Concept maps have been used as a helping tool to confirm our hypothesis that Electromagnetism and 3-phase circuits are key concepts to implement video-aided reinforcement. As a first step, we have analyzed the itinerary that all students will follow in the degree for our experimental case [30]. To provide a broad picture of the context, Figure 6 shows each compulsory subject within the different semesters of the degree, highlighting those that are related to electromagnetism (φ symbol) and 3-phase circuits (3~symbol) as our target concepts. It can be appreciated how these concepts are of relevance for the electrical engineering curriculum,

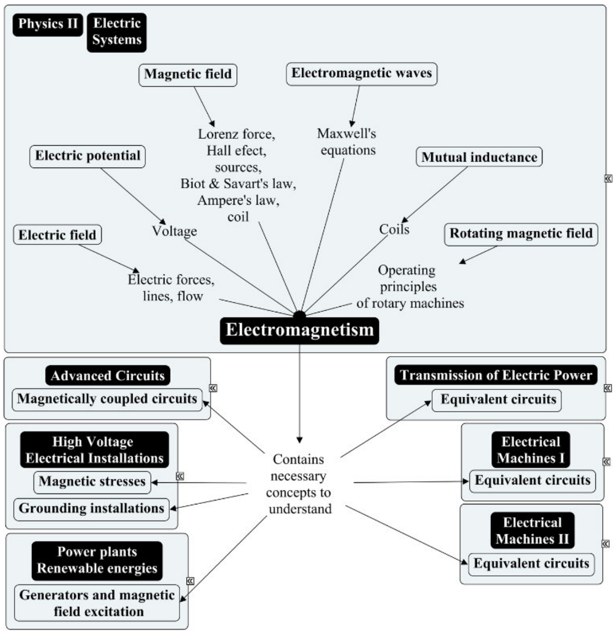

FIGURE 7. Concept map detailing both the concepts preceding electromagnetism and the concepts to which electromagnetism understanding is needed.

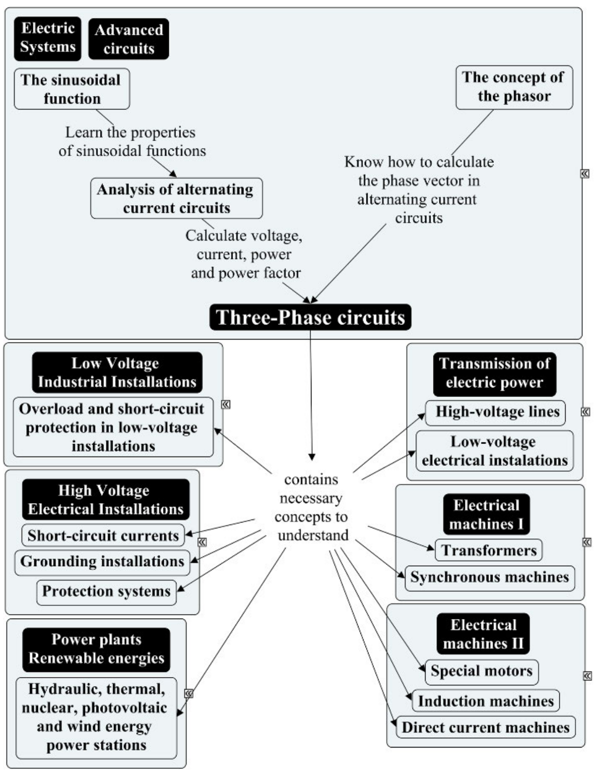

FIGURE 8. Concept map detailing both the concepts preceding 3-phase circuits and the concepts to which 3-phase circuits understanding is needed.

since they are directly related to 10 subjects (32.2% of all compulsory subjects).

However, what is the nature of the relation among those subjects from the perspective of both concepts? Figure 7 and Figure 8 present a detailed view showing the selected concepts. Above them, previous base concepts needed for their understanding are detailed. Below, additional concepts that need to be mastered are developed, in order to properly understand each subject.

After an analysis of the contents included in these 10 highlighted subjects and the time dedication foreseen in their study [30], it is observed that electromagnetism and 3-phase circuits are necessary concepts to understand from 20% to 80% of each one of these subjects. Therefore, this concept can be considered as a bottleneck for 32.2% of the courses that make up the electrical engineering degree, starting with "Electrical Machines I" as one of the first specialization subjects that students will face (taught in parallel to Transmission of Electric Power, and Power Plants and Renewable Energies).

APPENDIX II. SEEQ SURVEY

This appendix shows the results for each question in the SEEQ survey, detailing in Table 4 which are the specific questions grouped in each factor, as well as mean scores and standard deviation for each year comprising the study. The 9 factors considered in this questionnaire are: F1 Learning, F2 Enthusiasm, F3 Organization, F4 Group Interaction, F5 Individual rapport, F6 Breadth, F7 Exams, F8 Assignments, and F9 Overall. Additionally, the courses included are 2019/2020 (pre-ERL), 2020/2021 (ERL) and 2021/2022 (post-ERL). Additionally, p values are shown for statistical significance of the comparison among academic years.

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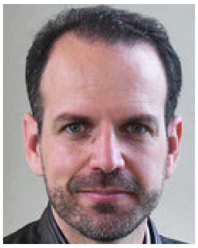

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