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Evaluating the Effectiveness of Online, In-Person, and Hybrid Learning: A Case Study of Engineering Disciplines at a Chinese Technical University

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Abstract

The effectiveness of technical education may vary depending on the delivery method. This study compared the effects of online, face-to-face (F2F), and hybrid learning on engineering students' academic performance. The study involved 450 second-year students pursuing an engineering degree at a technical university in China. The pre-test and post-test scores for the five core academic subjects (i.e., computer programming, further mathematics, physics, electrical engineering, and analytical mechanics) revealed a statistically significant improvement in academic performance across all subjects after use of hybrid learning ($p < 0.000$). The average gains were 3.46 points in computer programming, 4.07 points in further mathematics, 3.24 points in physics, 2.5 points in electrical engineering, and 3.06 points in analytical mechanics. The online and F2F delivery groups exhibited a statistically significant improvement with respect to scores for electrical engineering ($p < 0.000$) and physics ($p < 0.002$) only. The one-way ANOVA and Scheffe's test results revealed that the hybrid model had the strongest learning effects compared to online and F2F. A SWOT analysis helped to further explore students' perceptions of the three delivery formats. The present findings, which highlighted the effectiveness of hybrid learning, can be helpful in creating adaptive learning programs for engineering students.

Keywords: education, face-to-face learning, hybrid learning, online learning, students, technical specialties, university

Introduction

Advances in technology have brought new threats and opportunities to education (Lightner & Lightner-Laws, 2024), and technical education is no exception (Iatsyshyn et al., 2020; Li et al., 2024; Sayfullayeva et al., 2021). Recognizing the importance of effective teaching in the 21st century, scholars have looked for the best way to deliver education in universities (Monge et al., 2023). Currently, there is a paucity of empirical evidence on how online, face-to-face (F2F), and hybrid teaching strategies affect the academic outcomes of students in the field of engineering, whereas for other fields, the knowledge base is larger (Singh et al., 2022). The COVID-19 pandemic, which paralyzed the education system in 2020, revealed that educational institutions around the world were able to adapt to the new reality and even reap the benefits of the associated transition (Potra et al., 2021). The active incorporation of digital technologies into teaching sparked interest in different learning formats (Singh et al., 2022; Wahas & Syed, 2024). Researchers have endeavoured to understand how online, F2F, and hybrid instruction can influence academic performance, in order to integrate those that are most effective and beneficial to learners (Meshko et al., 2021; Sayfullayeva et al., 2021). Online learning, despite its advantages of flexibility and virtual presence (Shen et al., 2023), makes live interactions impossible and challenges the ability of students to motivate themselves (Shadiev et al., 2024). The F2F option is centuries old and needs to be updated, even though it has long been considered the gold standard (Valieiev et al., 2021). Hybrid models, which have gained popularity over the past few years, attempt to combine the advantages of these two approaches (Kruchkova & Grigoriev, 2022).

The current study sought to narrow the knowledge gap by comparing the effectiveness of online, F2F, and hybrid delivery within the context of engineering education. The results may be useful to educational institutions and firms in the tech industry that want to optimize learning. The study may help further research on academic performance.

Literature Review

Universities that produce engineering professionals typically offer courses in automation, electronics, computer science, engineering, and other technical fields (Theobald et al., 2020). Technical professionals are expected to possess the skills and knowledge needed to improve existing technologies and develop new ones (Khamidjanovna et al., 2022). In China, due to global and local developments in the technology sector (Wu et al., 2020; Zhang et al., 2022), the most popular technical fields have been electrical engineering, mechanical engineering, and electronics (Lin et al., 2021). To remain competitive in the international market, China has acknowledged the need to enhance the quality of technical education (Ren & Ji, 2021). It is impossible to boost production and develop advanced technologies without properly educated specialists (Kashiramka et al., 2021; Mohammad Shafi et al., 2021). Hence, in countries with high population densities, the quality of technical education has been closely linked to economic growth and quality of life (Lewis, 2020).

From a theoretical standpoint, this study was grounded in the constructivist framework, which posits that knowledge is constructed through learners' active engagement in the educational process (Efgivia et al., 2021). This theory emphasizes the importance of interaction between students and instructors, as well as the necessity of applying acquired knowledge in real-world contexts (Nurhasnah et al., 2024). The hybrid learning format, which integrates both online and face-to-face components, aligns with the core principles of constructivist theory, as it fosters students' active and conscious participation, self-regulation, and the contextual application of knowledge (Niyomves et al., 2024; Wang & Bhagat, 2025). Furthermore, the theory of blended learning—an extension of constructivism—highlights the adaptability of the educational process and the strategic use of digital technologies to enhance learning opportunities (Liu et al., 2024; Singh et al., 2021).

Academic outcomes (e.g., grades and performance on various tests, exams, thesis presentations) are qualitative and quantitative indicators of academic success (Kaya & Erdem, 2021; Miller et al., 2021). They serve as markers that help judge the quality of education, the effectiveness of the teaching strategies employed, and the extent to which learners have engaged with the course (Demir et al., 2021). Higher academic results indicate more effective teaching (Rafiola et al., 2020), and more effective teaching raises students' chances of future success in their profession (Hayat et al., 2020). From a practical standpoint, academic results can be helpful in adapting the teaching strategy to the needs of students and teachers (Reis et al., 2021).

Seminars, lectures, and practical sessions can be delivered in different ways. The online approach implies that the learning activities occur within a virtual space (Nambiar, 2020). Online platforms have allowed teachers and students to communicate with each other via the Internet, thereby enabling learning without physical presence in the classroom (Farrell & Brunton, 2020; Kadhim et al., 2023). Online education has offered access to a wide range of educational resources, which have become abundant since the onset of the COVID-19 pandemic, and enhanced flexibility (Cramarenco et al., 2023). Traditional F2F delivery requires the presence of both the teacher and student in a physical location (Stevens et al., 2021) with knowledge exchanged through live interaction, which helps to build and maintain social connections (Gherheș et al., 2021; Louis-Jean & Cenat, 2020). The hybrid format, as the name suggests, combines the best of both online and F2F instructional methods (Singh et al., 2021). Hybrid learning can be implemented in different ways. For example, laboratory and practical sessions can take place in an online environment, while discussions can be traditionally styled. In this case, the learning materials may be posted online (Haningsih & Rohmi, 2022). There is a need to identify which of these three formats is most effective in improving students' grades in engineering education (DeChenne-Peters et al., 2022; Owston et al., 2020). It is also important to understand their strengths and weaknesses and the opportunities and threats they bring.

Problem Statement

This study compared the effectiveness of different delivery formats used in university courses (i.e., face-to-face, online, hybrid) to determine which worked best with engineering students. Hypothetically, hybrid learning will be the most effective method as it combines the best of both face-to-face and online instructional methods. The insights provided here may be useful in education reform efforts and help boost the quality of technical education. The current study explored the pros and cons of each delivery format through the lens of a strengths, weaknesses, opportunities, and threats (SWOT) framework using data derived from student interviews. The objectives of the study were to (a) compare the pre-test and post-test scores for academic performance across three study groups; (b) determine whether the results of these groups were different (ANOVA analysis); (c) determine which group was significantly different compared to others (Scheffe's post-hoc analysis); and (d) identify strengths, weaknesses, opportunities, and threats associated with each delivery format under consideration (SWOT analysis).

Materials and Methods

In this study, student performance was assessed across five academic subjects (i.e., computer programming, further mathematics, physics, electrical engineering, and analytical mechanics) using final course grades ranging from 0 to 100 as measures of academic performance. The five academic disciplines in question are extremely important as a source of in-demand technical professionals. The final course grades were derived from the anonymized academic performance report provided by the university.

Participants

The study involved 450 second-year students pursuing an engineering degree at a technical university in China. The potential participants entered the degree course a year prior to the intervention; hence, they were familiar with the five academic subjects under consideration and possessed some amount of knowledge in the field. All students were randomly divided into three equal groups: online, traditional F2F, and hybrid (for more details, see Table 1).

Table 1

Data on Student Participants

Group	Number	Male	Female	Mean age	SD
Online delivery	150	109	41	19.27	0.87
F2F delivery	150	110	40	19.58	0.71
Hybrid delivery	150	114	36	19.17	0.83
Total	450	333	117	-	-
Overall mean	-	-	-	19.34	0.80

As shown in the table above, male students were overrepresented in each group, most likely because in China, males dominate in technical specialties. The students were all roughly the same age, which meant the groups were compatible with each other in terms of age. The homogeneity of each group was also tested with respect to pre-test subject scores. For this, a t-test was employed.

Study Design

The intervention was conducted from September 2022 to July 2023. During the preparatory phase, participants were selected, and informed consent was obtained. Students were randomly assigned to one of three groups (online, face-to-face, and hybrid learning). The homogeneity of the groups was verified based on initial academic performance, using final grades from the first year in the same five engineering courses. These academic results served as a reliable baseline or pre-test for the study.

During the main phase of the research, which began in late September 2022, each group received instruction in one of the three designated formats. In the online group, all lectures and practical sessions were delivered remotely via DingTalk and MOOC platforms. The F2F group attended all instructional activities in traditional classroom settings. The hybrid group participated in a combination of online and face-to-face lectures and practical classes. Additionally, both the online and hybrid groups engaged in in-person sessions for consultations, group work, and demonstration-based instruction that required physical presence. These face-to-face components were integrated to enhance the educational impact of the primary delivery format.

The total instructional load (in hours) was equal across all three groups. Final academic results (i.e., post-tests) were collected at the end of the academic year and served to assess students' learning outcomes following instruction in their respective formats. Furthermore, between June and July 2023, interviews with students were conducted to inform a SWOT analysis based on their experiences and feedback.

Online Delivery Group

Students in this group studied the learning material online using the DingTalk app and the MOOC platform. DingTalk, a video conferencing platform, has been widely used in China (DingTalk, 2023). In this study, DingTalk served as a tool to distribute course materials, submit homework, and receive feedback from teachers.

The MOOC platform has hosted various courses, including those in technical disciplines (MOOC China, 2023). It enables learners to participate in discussion forums, communicate with their classmates and teachers, complete online assignments and tests, and study independently.

F2F Delivery Group

Students in this group received F2F instructions only. Lectures, practical lessons, seminars, and discussions were traditionally styled, and no computer programs or digital platforms were used. One exception was the professional software that students were expected to cover as part of their training program.

Hybrid Delivery Group

Students in this group took both online and F2F classes. The digital resources used to support online interactions were the MOOC platform and the DingTalk app.

Data Analysis

All data regarding student performance were transferred to an SPSS v26 file for analysis. The results were presented as descriptive statistics (i.e., means, standard errors of the mean, standard deviations, skewness, and kurtosis). The means were then compared using the following statistical methods: student's t-test, one-way analysis of variance (ANOVA), and Scheffé's method. Data for the SWOT analysis were derived from student interviews.

Ethical Issues

The ethics committee of the participating university approved the study procedures. All students who participated in the project did so voluntarily. The subjects were informed about the nature of the study and gave written consent to participate. Confidentiality and anonymity were guaranteed.

Results

Table 2 presents the descriptive statistics for student performance across five different subject areas before (pre-test) and after (post-test) the intervention. Students in the hybrid delivery group improved significantly from the pre-test, with average gains of 3.46 points in computer programming, 4.07 points in further mathematics, 3.24 points in physics, 2.5 points in electrical engineering, and 3.06 points in analytical mechanics. Improvements in the online and F2F delivery groups were less significant; the average gains there ranged from 0.25 to 1.69 points.

Table 2

Descriptive Statistics of Pre-Test and Post-Test Subject Scores: Online, F2F, and Hybrid Delivery

Group	Measure	Computer programming (pre-test)	Computer programming (post-test)	Further mathematics (pre-test)	Further mathematics (post-test)	Physics (pre-test)	Physics (post-test)	Electrical engineering (pre-test)	Electrical engineering (post-test)	Analytical mechanics (pre-test)	Analytical mechanics (post-test)
Online	*M*	75.70	76.54	71.18	72.17	76.56	77.17	75.28	76.48	70.32	70.57
	SD	4.084	4.129	4.183	3.879	4.411	4.279	3.307	2.991	4.455	4.052
	SEM	.332	.336	.340	.316	.359	.348	.269	.243	.363	.330
	Skewness	.159	-.052	.142	-.093	-.186	-.101	.157	-.209	-.166	.060
	Kurtosis	-1.044	-1.260	-1.252	-1.244	-1.011	-1.383	-1.090	-1.030	-1.197	-1.219
F2F	*M*	75.83	76.68	71.88	72.17	76.19	77.88	74.95	75.97	70.12	70.70
	SD	4.341	4.061	4.049	3.823	4.549	3.980	3.475	3.299	4.047	4.130
	SEM	.356	.333	.332	.313	.373	.326	.285	.270	.332	.338
	Skewness	-.053	-.006	-.088	-.006	.025	-.182	.268	.023	-.130	-.094
	Kurtosis	-1.352	-1.241	-1.220	-1.206	-1.257	-1.099	-1.156	-1.336	-1.122	-1.279
Hybrid	*M*	76.01	79.47	70.99	75.06	76.27	79.51	74.87	77.37	70.35	73.41
	SD	4.343	2.388	3.865	2.017	4.711	3.036	3.492	2.914	4.334	2.335
	SEM	.355	.195	.316	.165	.385	.248	.285	.238	.354	.191
	Skewness	-.021	-.012	.125	-.028	.135	.013	.169	-.033	.021	-.059
	Kurtosis	-1.238	-1.355	-1.105	-1.304	-1.242	-1.298	-1.182	-1.298	-1.249	-1.244

The student’s t-test showed that differences between the pre-test and post-test subject scores in the hybrid delivery group were statistically significant ($p < 0.000$). This finding pointed to the effectiveness of the hybrid instructional format. In contrast, the only statistically significant improvements observed in the online and F2F delivery groups after the intervention were found with respect to the final scores for electrical engineering (p <0.000) and physics (p <0.002). For more details, see Table 3. Even though using online and F2F teaching strategies ensured the academic growth of students in just one subject, no downward trends were detected. Therefore, both instructional approaches were equally compatible.

Table 3

Student's t-Test Results: Performance Levels of the Online, F2F, and Hybrid Delivery

Group	Subject	Paired differences					*t*	*Dfdf*	Sig. (2-tailed)
		M	*Std. DeviationSD*	*SEM*	95% CI				
					Lower	Upper			
Online	Computer programming	-.813	5.934	.485	-1.771	.144	-1.679	149	.095
	Further mathematics	-.953	5.632	.460	-1.862	-.045	-2.073	149	.040
	Physics	-.680	5.704	.466	-1.600	.240	-1.460	149	.146
	Electrical engineering	-1.227	4.065	.332	-1.883	-.571	-3.696	149	.000
	Analytical mechanics	-.220	5.546	.453	-1.115	.675	-.486	149	.628
F2F	Computer programming	-.873	5.701	.465	-1.793	.046	-1.876	149	.063
	Further mathematics	-.340	5.623	.459	-1.247	.567	-.741	149	.460
	Physics	-1.607	6.132	.501	-2.596	-.617	-3.209	149	.002
	Electrical engineering	-1.000	5.194	.424	-1.838	-.162	-2.358	149	.020
	Analytical mechanics	-.607	5.956	.486	-1.568	.354	-1.247	149	.214
Hybrid	Computer programming	-3.460	4.832	.395	-4.240	-2.680	-8.769	149	.000
	Further mathematics	-4.073	4.448	.363	-4.791	-3.356	-11.215	149	.000
	Physics	-3.247	5.703	.466	-4.167	-2.327	-6.973	149	.000
	Electrical engineering	-2.507	4.517	.369	-3.235	-1.778	-6.797	149	.000
	Analytical mechanics	-3.060	4.912	.401	-3.852	-2.268	-7.630	149	.000

There were no statistically significant differences in pre-test subject scores between groups as determined by one-way ANOVA (Table 4). At the same time, differences between the post-test scores were statistically significant across all subjects (p < 0.000), indicating that not all delivery formats are highly effective delivery formats.

Table 4

Performance Variance in the Three Comparison Groups (One-Way ANOVA Findings)

Subjects	Comparison Groups	*Sum of SquaresSS*	*df*	*Mean SquareMS*	*F*	Sig.
Computer programming (pre-test)	Between groups	7.032	2	3.516	.194	.824
	Within groups	8101.388	447	18.124		
	Total	8108.420	449			
Computer programming (post-test)	Between groups	817.417	2	408.709	31.244	.000
	Within groups	5847.340	447	13.081		
	Total	6664.758	449			
Further mathematics (pre-test)	Between groups	65.949	2	32.974	2.026	.133
	Within groups	7275.971	447	16.277		
	Total	7341.920	449			
Further mathematics (post-test)	Between groups	833.285	2	416.642	37.044	.000
	Within groups	5027.446	447	11.247		
	Total	5860.731	449			
Physics (pre-test)	Between groups	11.756	2	5.878	.283	.754
	Within groups	9289.224	447	20.781		
	Total	9300.980	449			
Physics (post-test)	Between groups	435.531	2	217.766	15.059	.000
	Within groups	6464.160	447	14.461		
	Total	6899.691	449			
Electrical engineering (pre-test)	Between groups	14.343	2	7.171	.611	.543
	Within groups	5245.222	447	11.734		
	Total	5259.564	449			
Electrical engineering (post-test)	Between groups	151.530	2	75.765	8.030	.000
	Within groups	4217.634	447	9.435		
	Total	4369.164	449			
Analytical mechanics (pre-test)	Between groups	4.802	2	2.401	.131	.877
	Within groups	8199.198	447	18.343		
	Total	8204.000	449			
Analytical mechanics (post-test)	Between groups	772.358	2	386.179	29.760	.000
	Within groups	5800.400	447	12.976		
	Total	6572.758	449			

The results of Scheffe's post-hoc test analysis revealed significant differences between hybrid delivery and the other two formats across all subjects ($p < 0.001$). This finding suggested that the hybrid instructional format was the most effective option among the three formats. For more details, see Table 5. The significant differences between online and F2F formats were not present for every subject, indicating that these two delivery strategies had similar levels of impact on learning.

Table 5

Scheffe's Post-Hoc Test Findings

Subject	(I)	(J)	Mean difference (I - J)	*Std. ErrorSE*	Sig.	99.9% CI Lower	99.9% CI Upper
Computer programming	Online	F2F	-.135	.418	.949	-1.70	1.43
		Hybrid	-2.924*	.417	.000	-4.49	-1.36
	F2F	Online	.135	.418	.949	-1.43	1.70
		Hybrid	-2.789*	.418	.000	-4.36	-1.22
	Hybrid	Online	2.924*	.417	.000	1.36	4.49
		F2F	2.789*	.418	.000	1.22	4.36
Further mathematics	Online	F2F	-.002	.387	1.000	-1.45	1.45
		Hybrid	-2.888*	.387	.000	-4.34	-1.44
	F2F	Online	.002	.387	1.000	-1.45	1.45
		Hybrid	-2.886*	.388	.000	-4.34	-1.43
	Hybrid	Online	2.888*	.387	.000	1.44	4.34
		F2F	2.886*	.388	.000	1.43	4.34
Physics	Online	F2F	-.714	.439	.268	-2.36	.93
		Hybrid	-2.348*	.438	.000	-3.99	-.71
	F2F	Online	.714	.439	.268	-.93	2.36
		Hybrid	-1.634	.440	.001	-3.28	.01
	Hybrid	Online	2.348*	.438	.000	.71	3.99
		F2F	1.634	.440	.001	-.01	3.28
Electrical engineering	Online	F2F	.517	.355	.347	-.81	1.85
		Hybrid	-.890	.354	.043	-2.22	.44
	F2F	Online	-.517	.355	.347	-1.85	.81
		Hybrid	-1.407*	.355	.000	-2.74	-.08
	Hybrid	Online	.890	.354	.043	-.44	2.22
		F2F	1.407*	.355	.000	.08	2.74
Analytical mechanics	Online	F2F	-.135	.416	.949	-1.69	1.42
		Hybrid	-2.844*	.415	.000	-4.40	-1.29
	F2F	Online	.135	.416	.949	-1.42	1.69
		Hybrid	-2.709*	.417	.000	-4.27	-1.15
	Hybrid	Online	2.844*	.415	.000	1.29	4.40
		F2F	2.709*	.417	.000	1.15	4.27

Note. *Correlation is significant at the 0.001 level.

In terms of advantages (Table 6), delivering courses online means that (a) more materials can be made available to students, (b) students get more autonomy in deciding their own schedule, and (c) these courses can be completed anywhere. At the same time, learning online leads to a lack of interpersonal communication and creates a need for self-regulation. The F2F delivery format fosters direct interaction and allows teachers to structure classes in a way that makes it easy to follow the curriculum. The downsides of this strategy are that you can only study in a physical classroom and that learning feels monotonous and outdated. The hybrid format combines the advantages of both methods (i.e., interactivity and hands-on experience), but technological compatibility may be a challenge.

Table 6

SWOT Analysis of Online, F2F, and Hybrid Modalities

Category	Online	F2F	Hybrid
Strength	Wide access to educational resources, no geographical constrains, customized learning schedule	Clarity, structured learning and management, in-person contact with teacher and peers	Combines the advantages of online and F2F methods (i.e., interactivity + practical and live experience)
Weakness	Lack of in-person interaction, difficulty focusing without teacher's supervision, poor learning effectiveness of some digital platforms	Inability to learn outside of campus, monotony, outdated training methods	Difficulty adjusting, incompatibility of digital technologies, forced alternation between online and F2F contexts
Opportunity	Adaptation of existing courses, freedom of distribution, technological progress	Deep student-teacher interaction, socialization, living the life of a university student	Higher academic performance, geographical flexibility, access to learning in time of crisis (e.g., during the COVID-19 pandemic)
Threat	Isolation, slow Internet, technical problems with audio and video materials, technological incompetence	Less time saved, dependence on physical presence, no access to learning in time of crisis (e.g., during the COVID-19 pandemic)	High optimization effort required, technological incompetence

Discussion

Integrating online learning models with hands-on activities was reported to be beneficial to STEM education (Shen et al., 2023), which resonates with the current study. Yet, this process has presented challenges for teachers and students unfamiliar with the new technology (Wahas & Syed, 2024). The present study revealed similar obstacles. Our results highlighted the need to create effective teaching strategies and prepare educators to implement new technology. This study was not the first attempt at using distance technologies to teach engineering students. Previous research supported the present findings regarding the importance of innovative teaching methods (Meshko et al., 2021; Sayfullayeva et al., 2021). Blended learning has been associated with higher levels of student satisfaction when compared to F2F and distance modes (Valieiev et al., 2021). In this study, hybrid learning had a superior boosting effect on academic performance. Similarly, other researchers have argued that a hybrid delivery format can significantly improve the quality of education (Kruchkova & Grigoriev, 2022).

Some scholars have pointed out the growing need for skilled technical professionals and the current education system's shortcomings in producing such specialists through traditional routes (Lewis, 2020). Furthermore, other researchers have acknowledged the need to adapt curricula to the current demands of the labor market and facilitate collaboration between educational institutions and employers (Mohammad Shafi et al., 2021). Some researchers offered an automated assessment system as a possible solution (Kadhim et al., 2023). Their system was designed using Internet of Things technology, which supported the idea that innovation makes learning more effective. Previous research has shown that online training can be as effective as F2F (Stevens et al., 2021), which aligned with the results of the current study. Developing education programs that combine the best aspects of traditional and online learning can offer effective solutions to challenges associated with online transition (Singh et al., 2021).

Online learning has proven effective during the COVID-19 pandemic, highlighting the need to develop hybrid educational models (Haningsih & Rohmi, 2022). This finding, consistent with the current study, showed that hybrid models not only enhanced learning but also ensured greater access to learning while meeting the diverse needs of students. Some researchers provided an interesting perspective on STEM students' preferences and perceptions towards blended learning (Owston et al., 2020). Significant academic gains were reported, despite a relatively low level of satisfaction with blended courses (Owston et al., 2020). This finding pointed out the need to further adapt and individualize learning approaches to satisfy students' needs. There is evidence that course-based research experiences can be adapted to online or hybrid modality with minimal impact on student performance (DeChenne-Peters et al., 2022), which is especially important in light of online transition. Hybrid learning can be more effective than online and F2F formats as demonstrated by both previous research (Felder, 2021) and our current study. This is especially true in the field of engineering. Thanks to a combination of interactive and flexible learning experiences, hybrid courses can meet student needs better than can other modalities.

Conclusions

Our results showed a statistically significant effect of hybrid learning on academic performance across all five subjects ($p < 0.000$). The average gains were 3.46 points in computer programming, 4.07 points in further mathematics, 3.24 points in physics, 2.5 points in electrical engineering, and 3.06 points in analytical mechanics. Online and F2F learning resulted in a statistically significant improvement of final grades in electrical engineering (p <0.000) and physics (p <0.002). The one-way ANOVA and Scheffe's test findings revealed that hybrid format had the strongest learning effects compared to online and F2F. Based on the results of the SWOT analysis, the strengths of the online format were accessibility and flexibility, while the strengths of the F2F format were live interaction between teacher and learner and structured learning. The hybrid format combines these advantages.

The present study contributes to the growing body of empirical research on the effectiveness of hybrid learning, particularly within the context of technical education. However, its findings may also be relevant to other academic disciplines where the integration of theoretical knowledge and practical skills is essential. Further exploration of the adaptability of hybrid learning formats across diverse educational contexts may support the enhancement of university curricula and vocational training systems. The present findings can be used by other researchers in the field and by educational institutions that seek to integrate hybrid courses into their programs. Future research may also examine the role of student motivation and preferred learning styles within the context of online, in-person, and hybrid learning formats. Such investigations would offer deeper insights into the underlying mechanisms that influence the effectiveness of each instructional approach.

Limitations

This study focused on just five technical disciplines, which may have limited the generalizability of the findings. There were just two learning platforms used throughout the courses, so more studies may be needed to explore the effects of other commonly as well as less frequently used digital tools. Despite the large sample size, all participants were recruited from the same university, making extrapolation of the data difficult. In addition, the study did not examine the longitudinal effects, which may be an interesting topic for future research.

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