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Switching Modalities: An Empirical Study of Learning Outcomes and Learners' Perceptions in a Hybrid Bioengineering Course*

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Online education has the potential to revolutionize the way engineering educators teach fundamental engineering principles and deliver content to engineering students, while increasing access, flexibility, and affordability for both students and academic units. While numerous approaches have been implemented and studied, hybrid teaching approaches, where some portion of the class is online and some is face-to-face, remain a popular approach. Over the past decade, numerous studies have examined hybrid education, but rarely have these studies told us whether students learn equally well in both the online and face-to-face modalities of such courses, nor have they explained how students perceive the online portion of a hybrid course in comparison to the face-to-face portion. Furthermore, studies in engineering education are rare. To address this, we studied a 16-week, hybrid modality, bioengineering course, where we assigned students to one of two groups, with one group beginning the term with the online modality and the other group beginning the term with the face-to-face modality. Mid-term, we then switched the online and face-to-face learning modalities for both groups to inspect how the switch may affect the two groups' learning outcomes and their perceptions of the online portion of the course. The results indicate that (1) overall, both groups had no significant differences in learning outcomes; (2) the group that started from face-to-face learning and ended up with online learning had higher learning satisfaction and course ratings than the group that reversed the order of learning modality; and (3) deliberately switching online/face-to-face modality in the middle of the course may not advisable. Implications are discussed.

Keywords: Engineering education; hybrid learning; switch online/face-to-face; learning outcomes; learners' perceptions; learners' satisfaction

1. Introduction

To address increasingly complex, interdisciplinary problems in a global context, engineering education must cultivate engineers who are well-prepared to adapt to various contexts and cultures, to solve problems flexibly, creatively, and sustainably, and to utilize cutting-edge technology to do so [1]. As industrial technology advances, more and more tools (software, simulations, simulators, remote operations, etc.) are becoming increasingly available online. This technology development, combined with significant advances in Internet access/stability/affordability, and cybersecurity, has made it possible to offer aspects of the engineering curriculum online in a way that would have been unfeasible a decade prior. Indeed, online education has the potential to revolutionize the way engineering educators teach fundamental engineering principles, demonstrate and direct laboratory components, and deliver content to engineering students while increasing scheduling flexibility, accessibility, and affordability for both students and academic units.

However, relatively few engineering educators have fully embraced online learning; this is due to a number of factors, including, but not limited to, lack of time (for learning new pedagogical approaches, learning new technologies, finding and implementing best practices, particularly for educators not already engaged in the scholarship of engineering education, etc.), limited resources and support (including IT support, instructional designers, appropriate learning management system, etc.), and limited enthusiasm [2]. Of these, it is the latter that is often the most difficult to address. Our enthusiasm for adopting new learning modalities is often predicated on our understanding of the success of the approach; for engineering educators, particularly at large, research universi-

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ties, it may not be worth the time to evaluate and update learning modalities unless there is clear data demonstrating that the new approach is, at minimum, equally successful with the current approach. This result is also impacted by our need to ensure that our programs can pass ABET accreditation. Indeed, whether or not an online learning modality leads to the achievement of student learning outcomes remains one of the key questions among engineering educators who have little experience with online learning; many instructors fear that, by changing to an online learning modality, they are producing a lower-quality course with poorer outcomes than their traditional, face-to-face courses [2]. Change, in those circumstances, can be difficult, and our enthusiasm for such change may be low.

In response to these and other pressures, a number of engineering educators have, quite successfully, incorporated aspects of online learning into their face-to-face classes, offering what has become known as a "hybrid" approach [3]. In some cases, this takes the form of online lectures, with in-class time spent working problems and discussing case studies [4, 5]. In others, this may take the form of online assessments, including quizzes, homework, and group projects that can leverage online tools for rapid grading and feedback, or to promote group collaboration [6]. And in still others, it can simply give the instructor the ability to post pre-recorded lectures or to hold office hours remotely while traveling to conferences, so as not to disrupt the continuity of the course during the term [7]. Lastly, hybrid approaches can be used when the class is too large for the space assigned: in these cases, students may rotate between face-to-face and online lectures.

No matter the reason or the form used for the hybrid approach, major questions remain around the *quality* of hybrid learning in engineering education: (1) do students truly have the same experience in the online portion compared to the face-to-face portion? More specifically, (2) how do students perceive the online portion and the face-to-face portion when they have experienced both types of learning in one course? Furthermore, (3) how does the hybrid feature affect students' learning outcomes in the course? Exploring these questions, which are fundamental to our understanding of what leads to a "quality" experience for the student, is critical if we are to successfully engage more engineering educators in utilizing the tools of online learning in their classes.

To address this issue, we conducted a study of the hybrid learning experience in a 16-week, bioengineering course. We assigned students to one of two groups, with one group starting the term in the online learning modality and the other group beginning the term in the face-to-face learning modality. Mid-term (at the beginning of the 9th week of a 16-week semester), we switched the two groups' learning types in the middle of the course; this replicates the experience of students who may be switching learning modalities to address a classroom shortage, for instance). In this way, we studied how the switch affected students' learning outcomes and their perceptions of both the online and the face-to-face portions of this course.

2. Literature Review

The following serves as a literature review and draws heavily from research studies on distance and online learning. Notably, studies in the context of engineering education are rare and seldom go beyond what we list in the introduction of this article.

2.1 Comparative Studies of Online and Face-To-Face Learning

Comparative studies of online and face-to-face learning have been widely conducted. Many researchers, in either systematic literature reviews or empirical studies, have reported from their fields or disciplines that online learning is at least no less effective in ensuring learning performance than face-to-face learning [8–13]. Other researchers studied students' characteristics and preferences toward online and face-to-face learnings [14] and the reasons that help them determine between the two learning methods [15].

2.2 Factors affecting learners' academic performance in online learning

Various factors have been identified that could promote or impede learners' learning performance in online learning. Overall, Lim and Kim [16] indicated that course relevance, emotion, reinforcement, and self-efficacy were motivations that significantly influence learners' perceived learning performance and learning application. An, Kim, & Kim [17] concluded five positive factors to online learning, including self-discipline, team support, social presence, instructional consistency, and clarity of instruction.

Social interaction is an important factor in facilitating online learning. The interaction among students or the instructor-student interaction enhances the online learning performance [18], and synchronous communication enhances participation [19].

As many researchers have argued about the relationship between instructional design and learning effectiveness [20, 21], learning approaches (meaningful learning vs. surface learning) had a significant prediction on learners' academic performance [22]. Flipped class and gamification help online learners produce positive learning outcomes [23]. Other factors related to instructional design include personalization [24], types of learning activities [25], and collaboration [26].

Other factors that contribute to positive online learning performance include self-selection [27], affective learning climate [28], personal commitment [29], and media capabilities (e.g., danmaku videos) [30].

2.3 Factors affecting Students' Preference for Online vs. Face-to-Face Learning

In their study, Butler & Pinto-Zipp [31] found that convenience and online interaction were the main reasons why students chose an online course. Findings by Paechter & Maier [32] revealed that self-pacing, clear and cohesive course structure, the ways of information distribution, and learning objectives of "remembering" or "applying" levels [33] determined learners' choice on online learning, while the needs for in-person interaction and skills in self-regulated learning had them advocate face-to-face learning. Tichavsky, Hunt, Driscoll, & Jicha [34] indicated that learners preferred face-to-face learning because of social interaction in, motivations in, and familiarity with face-to-face learning and that learners who had previous online learning experience were more likely to take online courses compared to those who had no online learning experience. Additionally, Ellis and Han [35] pointed out that an inappropriate integration of an online learning environment with the course design, heavy course workload, and a lack of enough benefits might deter learners from enrolling in an online course.

2.4 Factors Affecting Motivation and Satisfaction in Online Learning

As stated by Artino and Stephens [36], the configurations of learners' motivations and emotions influenced their learning experience and satisfaction. Leong [37] found that social presence had an indirect impact on learners' satisfaction through the mediation of cognitive absorption, and learning interest impacts learners' satisfaction both directly and indirectly (through the mediation of social presence and cognitive absorption). Cheng & Chau [38] indicated that online participation promoted not only learning outcomes but also learning satisfaction. Bray, Aoki, & Dlugosh [39] reported that predictors of higher online learning satisfaction included learners' perseverance, more advanced computer skills, more interaction with instructors, and less interaction with other learners, among which the last predictor conflicted with other researchers' findings such as Swan's [40].

2.5 Theoretical Framework

Kats [41] studied how four factors in online learning (level of control, independence, satisfaction, and study motivations) affected learners' preferences for different types of online learning. Later, Luo et al. [42] found that if one factor among the level of control, independence, and satisfaction increases, the other two will increase as well.

Lim and Kim [16] studied how learner characteristics (e.g., gender, age, marital status, employment, etc.) and five learning motivation types (i.e., course relevancy, course interest, affect/emotion, reinforcement, and self-efficacy) affected learner's online learning performance and application.

Roblyer [43] studied different factors that might affect learners' choices on different learning types (online vs face-to-face) and found that pace and timing control was most influential to online learning, while the interaction with the instructors and other learners was key to face-to-face learning that was similarly reported specifically in engineering education as well [44].

Additionally, Artino [45] studied factors, including task value, self-efficacy, and instructional quality, to examine their relationship to motivations and satisfaction in online learning.

In this study, we combined different factors studied or discussed in previous research studies and generated a seven-factor frame as our theoretical framework. The seven factors are:

- level of control,
- independence,
- satisfaction,
- instructor's role and support,
- students' interaction,
- instructional design, and
- knowledge transfer and application.

We used this framework to guide our data collection, data analysis, and result discussion.

3. Research Questions

Though numerous researchers have conducted comparative studies of online and face-to-face learning as well as factors that affect the learning performance, motivations, and satisfaction in both types of learning, few researchers have ever had the experimental group and the control group experience both online and face-to-face learning in one course.

In this study, our goal was to understand differences in learning outcomes and learners' motivation and satisfaction of online courses, particularly when encountering online learning the context of a switch between online and face-to-face learning in the middle of a hybrid learning course. Specific research questions include:

- RQ1: Given a 7-factor model affecting learning, do students switching from face-to-face to online score higher on motivation and satisfaction than students switching from online to face-to-face?
- RQ2: For students' learning performance,
  - a: Overall, do students switching from face-to-face to online score higher than students switching from online to face-to-face (based on homework, discussion, quiz, exam, and final scores)?
  - b: Does the online-first group perform higher or lower than the face-to-face-first group before the switch (based on homework and discussion scores)?
  - c: Does the online-first group perform higher or lower than the face-to-face-first group after the switch (based on homework and discussion scores)?
- RQ3: What is the relationship between students' scoring on the seven factors of motivation and satisfaction and their course grades?

4. Methodology

4.1 Participants

Seventeen students from a biochemical engineering course offered by a mid-west university in the United States participated in the study. In the 16-week semester, nine of them took the course in a face-to-face modality for the first eight weeks and then an online learning modality for the second 8 weeks; the other eight students reversed the order. All 17 students had previous online course learning experiences in addition to the course in this study. Among them, six had 1–2 online course experience; ten had 3–4, and one indicated five or more. 15 out of 17 participants felt satisfied with their Internet skills, compared with one feeling "neutral" and one feeling "very dissatisfied". Tabulated results can be found in Table 1.

4.2 Data Collection

We created a survey in Qualtrics.com and distributed it to the 17 participants at the end of the semester. The survey contained 18 questions, with Questions 1–6 collecting learners' demographic information and Questions 7–18 focusing on the online part of the course. Types of survey questions included multiple-choice, checkbox, Likert-scale rating, and open-ended questions. In Likert-scale rating questions, learners were asked to rate their learning preferences and learning experience in online learning on a scale from 1 to 6, with 6 being the highest. The items from Questions 7–18 were adapted from the questionnaires developed by Pintrich et al. [46], Johnson et al. [10], and Artino and Stephens [36]. The frame of the seven factors was adapted from previous studies on motivation and satisfaction affecting online learning [16, 31, 41–43]. The study was approved by human subject research, and learners' consent to participate in the survey was obtained.

We collected learners' course scores from Canvas, the learning management system (LMS) in use at the institution. These data include learners' scores in homework, discussion, overall performance, quizzes, and exams through weeks 1–8, weeks 9–16, and the entire semester. Learners' consent to provide these data was obtained in advance.

4.3 Data Analysis

The collected data included the analysis of survey responses and that of course grades derived from Canvas.

For survey responses, we conducted a descriptive analysis using frequency and percentage calculation for closed-ended questions. The survey constructs were clustered based on 58 items as following:

- Level of control in online learning (8 items, Cronbach's $\alpha = 0.82$).
- Independence in online learning (8 items, Cronbach's $\alpha = 0.84$).
- Satisfaction in online learning (8 items, Cronbach's $\alpha = 0.70$).

Table 1. Demographic information of survey participants

Survey question	Number of participants ($N = 17$)
Learning group assigned	
Face-to-face first and online second	9
Online first and face-to-face second	8
Previous online learning experience	
Yes	17
No	0
Previous online courses enrolled	
1–2 courses	6
3–4 courses	10
5 or more	1
Satisfaction with personal Internet skills	
Very dissatisfied	1
Dissatisfied	0
Somewhat dissatisfied	0
Neutral	1
Somewhat satisfied	1
Satisfied	14

- Instructor's role and support (13 items, Cronbach's $\alpha = 0.95$).
- Students' interaction (10 items, Cronbach's $\alpha = 0.85$).
- Instructional design (8 items, Cronbach's $\alpha = 0.80$).
- Knowledge transfer and application (3 items, Cronbach's $\alpha = 0.55$).

Appendix 1 exhibits the seven factors and their source question items. Except for the value of Cronbach's α of the factor "Knowledge transfer and application", all others' values of Cronbach's α indicate good or acceptable reliability. We continued including all constructs to preserve the integrity of the instrument.

In addition, we used coding, theme clustering, and frequency count for the open-ended questions. Answers to the open-ended questions were carefully reviewed and categorized into different themes. Sample themes are such as "group", "immediate feedback", "ask questions" or "explanation from professor". After that, we conducted a second round of theme clustering and concluded seven categories: (1) Face-to-face communication, (2) Immediate feedback, (3) Group work, (4) In-class activities, (5) Extra credit, (6) Coursework reminder, and (7) Real-life examples. The frequency of each category was then counted and recorded.

For data exported from the campus LMS, both non-parametric and parametric analysis methods were adopted. First, we tested the assumption for data normalization. The results showed that both assumptions were violated. Therefore, a standardized transformation was used to normalize the data. A descriptive analysis for means, standard deviations, medians, and skewness was then carried out. To verify any potential differences before and after the online/face-to-face switch, we conducted a Dependent Sample t-test with the standardized data and examined the assumption of normality again. To find out any potential differences between the online first and face-to-face second group (hereinafter referred to as "Online-F2F" group) and the face-to-face first and online second group (hereinafter referred to as "F2F-Online" group), we used one-way ANOVA test, and once more, we examined the assumptions of normality and homogeneity of variances (HOV).

Besides, we also conducted a non-parametric analysis because the normality assumption of the raw data was violated. Descriptive analysis for medians and ranges of the data was conducted, followed by a Wilcoxon signed-rank test to examine any potential differences before and after the online/face-to-face switch and by a Kruskal-Wallis H test for any potential differences between the Online-F2F group and the F2F-Online group.

Finally, to test any potential relationships existing between the survey data and the course scores, we created a correlation matrix and examined the Pearson's correlation coefficients. Among the 13 variables, 91 correlation coefficients were calculated, and 28 of them were significant ($\alpha = 0.05$) with the correlation coefficients ranging from 0.49 to 0.99. The power for the significant coefficients ranged from 0.58 to 1.00 according to a two-tailed posthoc power analysis under a Correlation: Point Biserial Model by using G*Power 3.1.9.2. [47, 48].

5. Results and Discussion

In this section, we present the results and discussion of the data analysis.

5.1 Factors Influencing Choices of an Online Course

As is displayed in Table 2, participants chose an online course to avoid "conflict between class time and work commitments" (9 out of 17 participants), to avoid "course scheduling conflict" (11 out of 17), to "reduce time commuting to class" (12 out of 17) and to get "flexibility in setting pace and time for studying" (14 out of 17). Only one participant found the conflict between taking a class and taking care of children. Also, one participant commented that "No missing notes or quizzes due to missing class" and indicated "Strongly agree".

Our results replicated the findings that learners who choose an online course may want to save time,

Table 2. Number of participants indicating factors in making their choices of an online course

Factors (N = 17)	**Strongly disagree**	**Disagree**	**Agree**	**Strongly agree**
Conflict between class time and work commitments	3	5	7	2
Conflict between class time and childcare commitments	14	2	1	0
Course scheduling conflict	3	3	7	4
Reduce time commuting to class	0	5	6	6
Flexibility in setting pace and time for studying	0	3	6	8
Other	0	0	0	1

Table 3. Number of participants indicating beneficial online learning activities

Factors (N = 17)	Strongly disagree	Disagree	Agree	Strongly agree
Asynchronous discussion with fellow students	3	8	4	2
Dialogues with fellow students in synchronous chat	4	9	2	2
Weekly mandatory readings	1	5	10	1
Videotaped lectures	0	0	5	12
Posting a mandatory number of writing assignments per week	1	6	10	0
Group assignments and activities	4	1	8	4

avoid commuting to the campus, avoid class conflict, or balance work commitments [9, 15].

5.1.1 *Activities Benefitting Online Learning*

As Table 3 exhibits, all participants found recorded lectures were beneficial to their online learning. Twelve participants believed that group work was beneficial, but 11 found synchronous discussion not beneficial, and 13 believed asynchronous discussion not beneficial either. Besides, 11 participants indicated that they benefited from mandatory readings, and that number for mandatory writing assignments was 10.

From the results, it seems that more than half of the participants believed that the group work during face-to-face time was beneficial to their learning, while fewer than half of participants favor either synchronous or asynchronous online discussion with fellow students. Our interpretation is that students found that the online synchronous or an asynchronous discussion was less effective to their learning success, while face-to-face tasks in the form of active learning prompts gave them a better opportunity to engage and a better "complete" experience. Additionally, though the online discussion might expand students' thinking, they might still believe that the discussion was not exclusively directly helpful to knowledge absorption or skills building, while the face-to-face active learning group tasks were more directly about knowledge application or skills practices. As a result, students might consider the face-to-face group tasks more helpful to their online learning through discussions.

5.1.2 *Ratings on Seven Factors*

Participants were asked to rate their online learning regarding seven factors: level of control, independence, satisfaction, instructor, interaction, course design, and knowledge transfer on a 1–6 scale with 6 being the highest. A rating of 4, 5 or 6 was considered as a high score, which we understood as that participants had a strong belief in or felt satisfied with the proposed statement; and a rating of 1, 2 or 3 was considered as a low score, indicating that participants did not agree with or felt unsatisfied with the proposed statement.

As is indicated in Figs. 1–7, the F2F-Online group had higher overall and average ratings on all factors than the Online-F2F group did. A one-way ANOVA test indicated that the F2F-Online group rated the satisfaction in online learning significantly higher (M = 5.17, p < 0.05) than the Online-F2F

Figs. 1–7. *Note:* Participants' ratings on seven factors in online learning (Rated on a 1–6 scale with 6 being the highest; italic numbers are the mean for each group.)

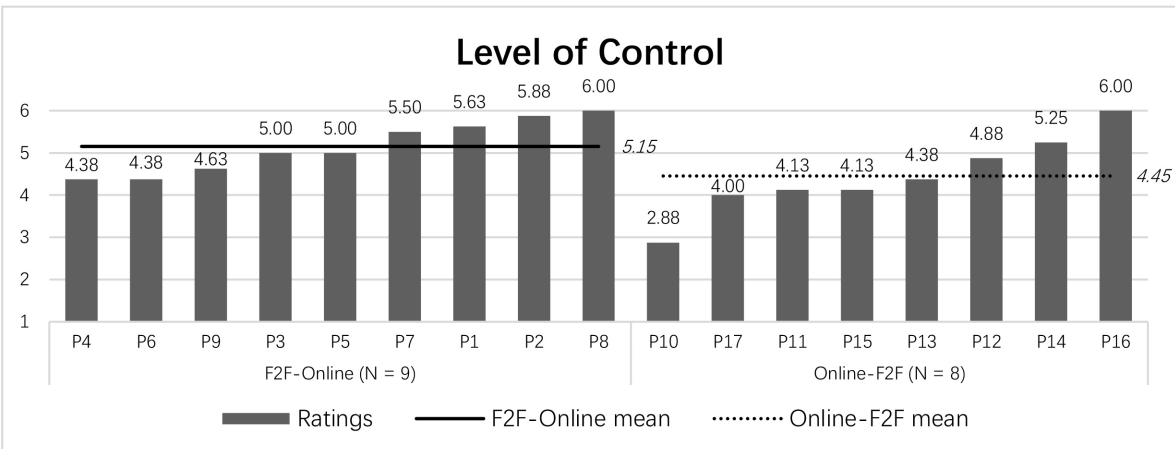

Fig. 1. Ratings on level of control.

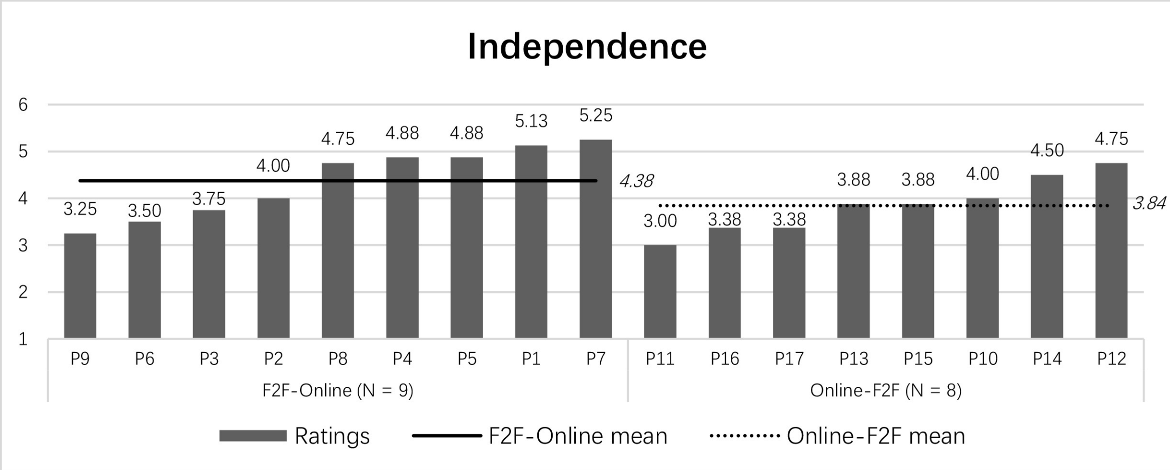

Fig. 2. Ratings on independence.

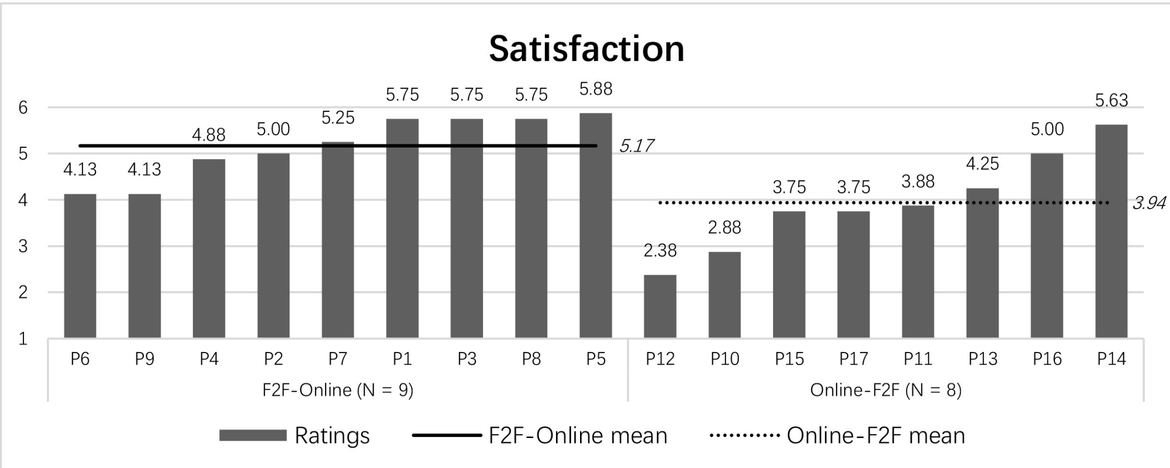

Fig. 3. Ratings on satisfaction.

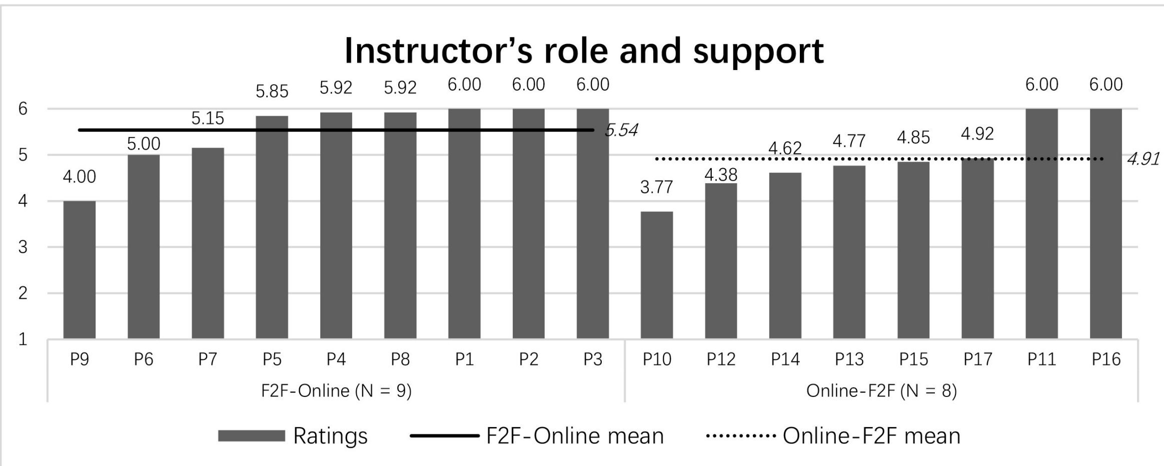

Fig. 4. Ratings on the instructor's role and support.

group did (M = 3.94) (Fig. 3), and rated the interaction in online learning significantly higher (M = 4.93, $p < 0.05$) than the other group did (M = 4.10) (Fig. 5). The assumptions of the normality and homogeneity of variances (HOV) were both met. Details of the ANOVA results can be found in Table 4.

Previous researchers found that familiarity

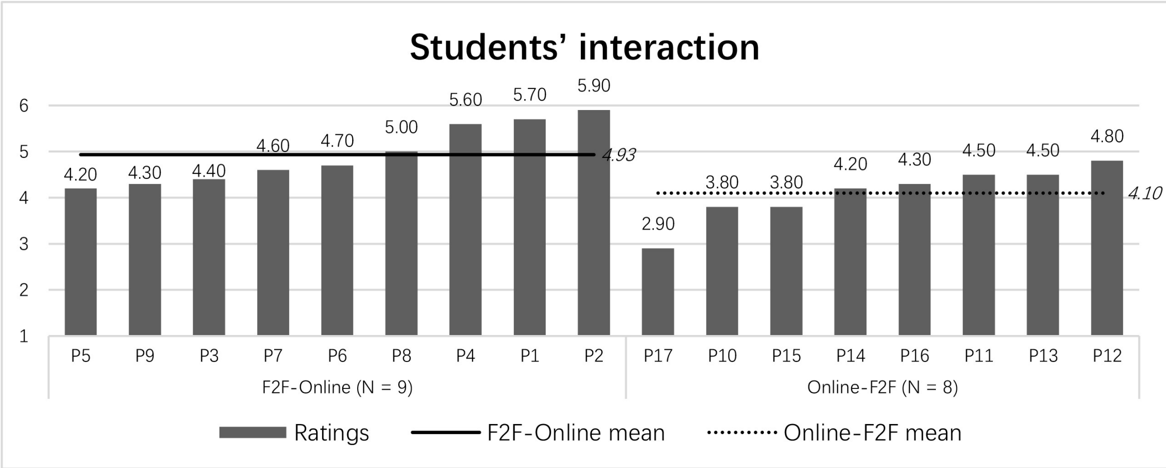

Fig. 5. Ratings on students' interaction.

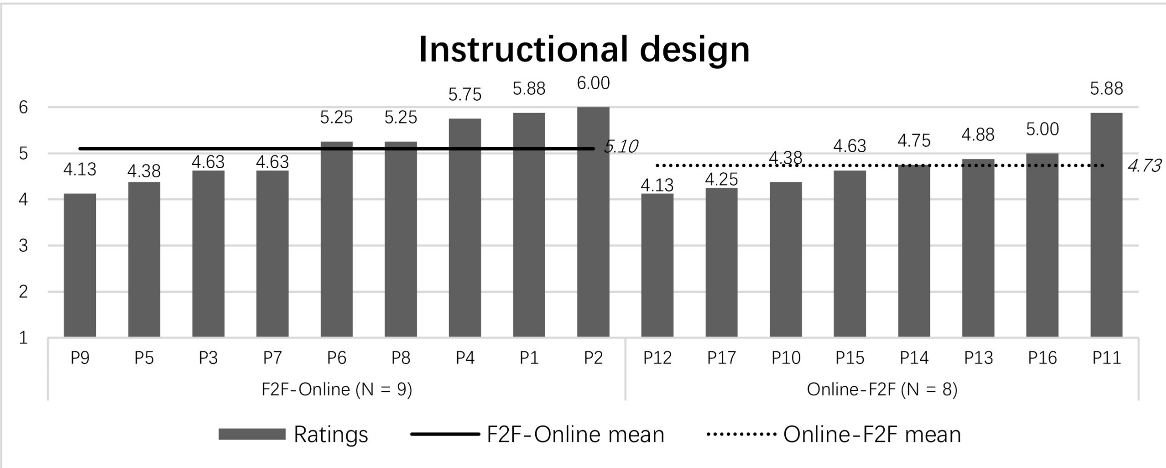

Fig. 6. Ratings on instructional design.

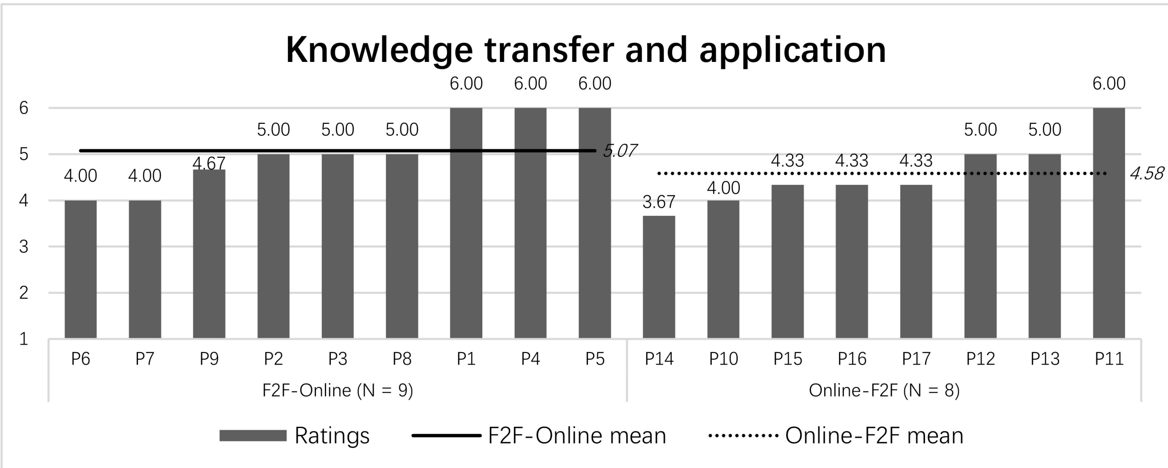

Fig. 7. Ratings on knowledge transfer and application.

among group members would increase the satisfaction of group work in computer-mediated learning [49]. Another study pointed out that the potential effects of the group member familiarity poses on online learning should be emphasized to promote better learning performance through appropriate

Table 4. One-way ANOVA test for the survey data

Factors	Group	*M*	*SD*	*df*	*F* value	*p*-value
Level of control in online learning (8 items)	F2F-Online (N = 9)	5.15	0.62	1, 15	3.37	0.09
	Online-F2F (N = 8)	4.45	0.94			
Independence in online learning (8 items)	F2F-Online (N = 9)	4.38	0.75	1, 15	2.58	0.13
	Online-F2F (N = 8)	3.84	0.59			
Satisfaction in online learning (8 items)	F2F-Online (N = 9)	5.17	0.69	1, 15	8.32	0.01*
	Online-F2F (N = 8)	3.94	1.05			
Instructor's role and support (13 items)	F2F-Online (N = 9)	5.54	0.69	1, 15	3.14	0.10
	Online-F2F (N = 8)	4.91	0.76			
Students' interaction (10 items)	F2F-Online (N = 9)	4.93	0.65	1, 15	7.55	0.01*
	Online-F2F (N = 8)	4.10	0.60			
Instructional design (8 items)	F2F-Online (N = 9)	5.10	0.69	1, 15	1.41	0.25
	Online-F2F (N = 8)	4.73	0.55			
Knowledge transfer and application (3 items)	F2F-Online (N = 9)	5.07	0.80	1, 15	1.74	0.21
	Online-F2F (N = 8)	4.58	0.73			

* Significant at alpha = 0.05.

Table 5. Number of participants' preference for the types of online learning

Online Learning Type	Frequency (N = 17)
Self-paced online learning	4
Interaction-based online learning	9
Others, please specify:	4
1. Self-paced is harder to keep up with if you are busy. Also, it can become more of a crammed style of learning.	1
2. I have never taken a completely "self-paced" course. If it's a subject not in my degree field, I would rather take self-paced. If it's a course with material that is relevant to me, I would prefer an interaction-based online learning.	1
3. Minimal interaction structured course.	1
4. Not a lot of interaction with other people in terms of participation points. Interaction with the professor through recorded lectures, answering questions, etc.	1

learning design [50]. During an online learning, instructors or instructional designers should consider various ways to promote active social presence and meaningful online interaction – such as the required online "introduce yourself" component in this class [18].

Per our results, one implication is that even with the same instructor, instructional design, and instructional delivery methods, it might still be better to have students take face-to-face learning first and then online learning. Reversing this order may lead to a worse learning experience. Students and the instructor need to become acquainted in a face-to-face environment at first, and the group member familiarity will positively affect their learning experience in the follow-up online learning. Our results do not support the positive effect of the group member familiarity formed in online learning first and face-to-face learning later.

Another implication is that online learning may afford more levels of control than face-to-face learning may. It may explain why the F2F-Online group had higher ratings on all factors (either significant or not) because students would gain more freedom to control their learning when switching from face-to-face to online and would lose more when reversing the order. It is always hard to let people lose something when they have already had it. According to findings by Luo et al. [42], there is a threefold correlation among learners' level of control, independence, and satisfaction in online learning: whenever one factor increases, the other two will increase simultaneously. Though the mean difference in the level of control between the two groups was not significant, since the mean difference of the satisfaction between the two groups was significant, we do believe that the F2F-Online group gained more freedom to control the class when they switched the learning from face-to-face to online.

5.1.3 Participants' Preference for Online Learning Types

Among the 17 participants, four chose "Self-paced online learning" and nine preferred "Interaction-based online learning" (Table 5). Another four participants indicated "Others" and made comments, among which two participants discussed their preferences on different conditions, one indicated "Minimal interaction structured course," and the other one preferred more interaction with the instructor instead of with other learners in the course.

Course interaction might be an important consideration for participants in this study to decide the types of online learning. Some of them preferred interaction with other learners, while some others preferred more interaction with the instructor. Therefore, we may infer that effective interaction may bring these learners a better learning experience, which aligns with research findings from almost 20 years ago that interaction with either instructors or students in asynchronous online courses had a significant influence on learners' satisfaction with the course [40, 51]. On the other hand, a more recent study found that social interaction in online learning benefits students more than independent online learning [38]. Considering that some participants chose self-paced online learning and that self-regulated efforts would contribute to the level of social interaction in online learning [29], a successful online course may need to provide learners with options for both types of online learning, but instructors or instructional designers should encourage more course interaction even in a self-paced online learning.

5.1.4 Participants' Comments on Online and Face-to-Face Learning

Two open-ended questions were asked for participants' comments on both face-to-face learning and online learning. The first question started with "One thing that was good about doing the activities in class, not online was . . ." and the second question reversed the order of "in class" and "online". All 17 participants answered both questions.

As Table 6 shows, for participants, face-to-face communication is the most attractive feature that face-to-face learning can provide. Meanwhile, immediate feedback is also what participants highly expect from face-to-face learning. While in an online learning setting, learning flexibility is most attractive to participants.

The results showed that, though all participants had a previous online learning experience and had very positive ratings on the online learning session of this course, they still believed that in-person communication and immediate feedback were delivered better in class. The advancement of technology may have brought online learners a better sense of social presence [52]. Since a good social presence may not predict a sound learning outcome [53] or may not be a direct predictor of learner satisfaction [37], the survey results may have revealed a potential gap between the existing online course (or the existing online learning system) and learners' expectation of an online learning (as well as its system) that the online learning should be better designed to support more effective interaction and more instant communication or feedback as they are in a face-to-face learning environment.

In addition, the result that 9 participants favored "face-to-face communication" and 5 favored "immediate feedback" and as a contrast, only 2 favored "group work" may imply that learners would prefer a teacher-student interaction rather

Table 6. Participants' comments on face-to-face learning and online learning

Clustered themes	Frequency
One thing that is good about doing the activities in class, not online was ($N = 17$)	
Face-to-face communication	9
Immediate feedback	5
Group work	2
In-class activities	1
Extra credit	1
Coursework reminder	1
Real-life examples	1
One thing that is good about doing the activities online, not in class was ($N = 17$)	
Flexibility/self-pacing	15
Review lectures	2
More thorough notes	2
More activities	1
Independent thinking	1
Search online	1

Table 7. Participants' overall preference for online or face-to-face learning

Preferred learning type	Frequency (N = 17)
F2F-Online group (N = 9)	
Face-to-face	5
Online	2
No preference	2
Online-F2F group (N = 8)	
Face-to-face	6
Online	1
No preference	1

than a student-student interaction when they are in a face-to-face learning environment.

What is more, since 15 out of 17 participants believed that "flexibility/self-pacing" is good about doing a learning activity online, which confirms earlier studies [54], and few of them had the same belief in "review lectures" and "more thorough notes", we may get the implication that participants might fail to see the value of these online learning materials in blended learning and, therefore, course designers may need to help learners understand the significance of learning resources in the online settings [35].

5.1.5 Participants' Overall Preference for Online or Face-to-Face Learning

When inquiring about their preference for online or face-to-face learning, we learn that learners from both groups prefer face-to-face learning (Table 7). Probable reasons for this included less in-person communications, less physical teaching presence despite regularly scheduled, in-person office hours for both groups, and less immediate, in-person feedback. This finding and the inferred reasons are consistent with previous findings [14, 34]. In the future, online learning should focus more on providing better interaction and faster communication and feedback from multiple aspects, including instructional design, system design, and usability design.

5.2 Analysis of Course Grades

A parametric analysis and a non-parametric analysis were conducted to study if any significant differences in course grades existed due to the switch between online learning and face-to-face learning and within both the Online-F2F and the F2F-Online groups. Quantitative results are presented in this subsection.

5.2.1 Parametric Analysis

We tested the assumption of normality on all differences between each set of paired variables. We conducted a Shapiro-Wilk test [55], and the results indicated that all normality assumptions were met ($p > 0.05$).

Meanwhile, we tested the assumption of normality and HOV on the 16-week homework score, the 16-week discussion score, the 16-week overall score, the quiz score, the exam score, and the final score. The assumption of normality was violated for the first three variables ($p < 0.05$), indicating that caution should be taken when we discuss these results. The normality assumptions for the quiz, exam, and final scores were met. We also conducted a Levene's test for the assumption of HOV, and the results indicated that the assumptions were all met ($p > 0.05$).

5.2.1.1 Dependent Sample t-test

A Dependent Sample t-test was used to examine any differences in scores of homework, discussion, and overall before and after the switch. Results indicated that there were significant differences ($p < 0.05$) in homework scores for both groups and the overall score for the Online-F2F group only, and the effect sizes (Cohen's d) ranged from medium to large (see Table 8).

Table 8. A Dependent Sample t-test for score differences between online/face-to-face switch

Variable	*M*		*SD*		*t*	*df*	*p*	Cohen's *d*
	Week 1–8	Week 9–16	Week 1–8	Week 9–16				
Online-F2F group (N = 8)								
Homework score	47.00	42.35	6.82	3.79	2.57	7	<0.05*	0.91
Discussion score	8.69	8.42	0.52	1.90	0.48	7	>0.05	0.17
Overall score[1]	27.84	25.38	3.39	2.18	2.66	7	<0.05*	0.94
F2F-Online group (N = 9)								
Homework score	48.41	45.08	5.24	1.24	2.31	8	<0.05*	0.77
Discussion score	8.26	8.00	1.23	1.35	0.63	8	>0.05	0.21
Overall score	28.34	26.54	2.97	0.98	2.21	8	>0.05	0.74

* Significant at alpha 0.05.
[1] Overall score is the weighted sum of homework score and discussion score.

Table 9. A one-way ANOVA test for score differences between the two groups

Score items	Group	*M*	*SD*	*df*	*F*	*p*	η^2
16-week homework score	F2F-Online (N = 9)	47.13	3.61	1, 15	0.78	>0.05	0.05
	Online-F2F (N = 8)	45.21	5.29				
16-week discussion score	F2F-Online (N = 9)	8.15	1.12	1, 15	0.63	>0.05	0.04
	Online-F2F (N = 8)	8.57	1.04				
16-week overall score	F2F-Online (N = 9)	87.99	6.68	1, 15	0.55	>0.05	0.04
	Online-F2F (N = 8)	85.15	9.10				
Quiz score	F2F-Online (N = 9)	83.20	15.27	1, 15	0.18	>0.05	0.01
	Online-F2F (N = 8)	79.24	22.55				
Exam score	F2F-Online (N = 9)	86.83	8.83	1, 15	1.61	>0.05	0.10
	Online-F2F (N = 8)	81.57	8.19				
Final score	F2F-Online (N = 9)	87.80	6.75	1, 15	1.62	>0.05	0.10
	Online-F2F (N = 8)	83.53	7.05				

5.2.1.2 One-way ANOVA Test

We conducted a one-way ANOVA test to examine any group differences in 16-week homework, discussion, and overall scores and in quiz, exam, and final scores. Results indicated that there was no significant difference in all these scores between the two groups ($p > 0.05$ for all), and the effect sizes (η^2) varied from small to medium (see Table 9).

5.2.2 Non-Parametric Analysis

We conducted a non-parametric analysis since the normality assumption of the raw data was violated.

5.2.2.1 Wilcoxon Signed-Rank Test

A Wilcoxon signed-rank test was conducted to examine any differences in scores of homework, discussion, and overall before and after the switch. Results indicated that there were significant differences ($p < 0.05$) in homework and overall scores in the Online-F2F group and in the discussion score in the F2F-Online group. The effect sizes (r) ranged from small to large (see Table 10).

5.2.2.2 Kruskal-Wallis H Test

We adopted a Kruskal-Wallis H test to analyze any group differences in course scores between the two groups. Results indicated that there were significant differences ($p < 0.05$) in the 16-week discussion score and the overall score between the two groups. Effect sizes (η^2) varied from small to medium (see Table 11).

5.2.3 Discussion of Analysis Results

From the results of the Dependent Sample t-test and the Wilcoxon signed-rank test, students in both groups experienced a score decrease in homework, discussion, or overall scores towards the end of the term that might be caused by the online-f2f switch, indicating that this kind of switch in learning mode might impose some negative influence on students' learning outcomes. Another possible cause might be a difficulty increase in the learning activities during weeks 9–16, which might explain the score decrease experienced by both groups after the switch.

Although we found significant score differences in

Table 10. A Wilcoxon signed-rank test for score differences between online/face-to-face switch

Variable	*MDN*		*Range*		*p*	*r*
	Week 1–8	Week 9–16	Week 1–8	Week 9–16		
Online-F2F group (N = 8)						
Homework score	50.41	42.90	20.06	12.60	<0.05*	0.69
Discussion score	8.75	9.00	1.62	5.50	>0.05	0.10
Overall score[2]	29.55	25.94	9.41	6.88	<0.05*	0.69
F2F-Online group (N = 9)						
Homework score	48.62	45.40	13.56	4.40	>0.05	0.61
Discussion score	8.38	8.50	3.50	3.67	<0.05*	0.26
Overall score	28.94	26.83	8.16	2.78	>0.05	0.61

* Significant at alpha 0.05.
[1] Overall score is the weighted sum of homework score and discussion score.

Table 11. A Kruskal-Wallis H test for score differences between the two groups

Score items	MDN		*df*	*p*	η^2
	Online-F2F group (N = 8)	F2F-Online group (N = 9)			
16-week homework score	47.63	47.38	1	>0.05	0.03
16-week discussion score	8.82	8.71	1	<0.05*	0.03
16-week overall score	88.41	91.28	1	<0.05*	0.03
Quiz score	81.54	89.29	1	>0.05	0.004
Exam score	81.91	86.58	1	>0.05	0.07
Final score	85.32	86.29	1	>0.05	0.08

some scoring items, the results from both the one-way ANOVA test and the Kruskal Wallis H test showed that there was no significant difference between online learning and face-to-face learning in terms of learning outcomes. This conclusion has been found in numerous previous studies [10, 56, 57].

Additional finding in this study was that in a blended learning environment, the order of online learning and face-to-face learning does not significantly affect students' final *learning outcomes*, although they may have a better *learning experience* in the F2F-Online group. Worse, switching the two learning modes may decrease learners' learning outcomes during the second half of the semester. Consequently, it might be better to keep the learning mode consistent throughout the entire semester. If it is an online course at the beginning, then keep it online until the end of the course, and vice versa. To improve the learning outcomes in a blended learning setting, instructional designers or teachers may need to consider other factors such as learning content, learning activities, or practices.

5.2.4 Correlations across the Survey Data and Course Grades

We created a correlation matrix with Pearson's correlation coefficient to examine any potential correlations between the survey items and the course grades that students achieved.

As is exhibited in Table 12, some variables for course scores were significantly correlated with each other, such as the 16-week homework score and the 16-week overall score, the 16-week homework score and the final score, and the quiz score and the final

Table 12. Correlation Matrix between survey data and course scores

Pearson's r	hw16	dis16	over16	quiz	exam	final	level	indep	satis	instr	inter	id	kw
hw16	1												
dis16	0.13	1											
over16	0.95***	0.36	1										
quiz	0.59*	0.27	0.67**	1									
exam	0.14	0.22	0.19	0.06	1								
final	0.75***	0.37	0.83***	0.71**	0.63**	1							
level	0.44	-0.03	0.4	0.28	0.01	0.33	1						
indep	0.16	0.22	0.09	0.08	0.31	0.19	0.37	1					
satis	0.21	-0.23	0.13	-0.01	0.01	0.08	0.69**	0.39	1				
instr	0.28	-0.25	0.19	0	0.34	0.26	0.59*	0.15	0.67**	1			
inter	0.51*	0.23	**0.53***	**0.52***	0.32	**0.57***	0.53*	0.45	0.36	0.5*	1		
id	0.45	0.03	0.44	0.25	0.24	0.38	0.32	0.06	0.36	0.69**	0.74***	1	
kw	0.33	0.11	0.3	0.11	**0.72****	**0.55***	0.12	0.22	0.24	0.6*	0.5*	0.48	1

* Significant at alpha 0.05, ** significant at alpha 0.01, *** significant at alpha 0.001. **Bold numbers** indicate correlations between survey items and course scores.

(Codes: "hw16" = 16-week homework score, "dis16" = 16-week discussion score, "over16" = 16-week overall score, "quiz" = overall quiz score, "exam" = overall exam score, "final" = final score, "level" = learners' levels of control in online learning, "indep" = learners' independence in online learning, "satis" = learners' satisfaction in online learning, "instr" = learners' ratings on instructor's role and support in online learning, "inter" = learners' ratings on students' interaction in online learning, "id" = learners' ratings on instructional design in online learning, "kw" = learners' ratings on knowledge transfer and application in online learning) score. The correlation coefficients range from 0.59 to 0.95, with p values ranging from < 0.05 to < 0.001.

As for survey items, some variables were also significantly correlated, such as learners' levels of control and their satisfaction in online learning, the levels of control and their ratings on students' interaction, and students' ratings on instructor's role and their ratings on the instructional design. The correlation coefficients range from 0.50 to 0.74, with p values ranging from < 0.05 to < 0.001.

More importantly, students' ratings on interaction was significantly correlated with their 16-week homework scores (r = 0.51, p < 0.05), 16-week overall scores (r = 0.52, p < 0.05), quiz scores (r = 0.53, p < 0.05), and final scores (r = 0.57, p < 0.05) respectively. In addition, students' ratings on knowledge transfer and application was significantly correlated with their exam scores (r = 0.72, p < 0.01) and final scores (r = 0.55, p < 0.05).

These results support the finding from the analysis of the survey data that learners like the interaction with the instructor and would like to receive more feedback from the instructor. The more support the instructor provides, the higher satisfaction learners will feel in online learning. Therefore, instructional designers should pay attention to the role and support of the instructor to provide a higher quality of online learning for learners. These results may also imply that interaction in a course might be important to learners' learning outcomes. Either in a face-to-face course or in an online course, more interaction with peer learners or with the instructor should be emphasized.

6. Limitations and Future Work

The sample size of this study was small. A sample of 17 participants was very hard to obtain powerful results. This limitation may affect the validity of this study. Besides, one of the seven (7) factors we studied did not load as strong in its reliability coefficient, which might very well be due to the small sample size. Future researchers and instructors should be cautious about conducting studies with a similar research design since switching between face-to-face and online learning may impede learners' learning outcomes. Future studies may involve more participants and see if a larger sample size may yield different results.

7. Conclusion

This is one of the first studies in engineering education to demonstrate that learning outcomes can be equally achieved in both the face-to-face and the online learning modalities in a hybrid course; this is significant in that a common roadblock to the adoption of online learning strategies by engineering educators is the worry that students will have worse learning outcomes when engaged in online learning versus face-to-face learning. In this study, we cross-compared learners' learning experience and outcomes between two groups with different course settings in a 16-week blended learning course. In this study, although the achievement of learning outcomes may be stable between the modalities, switching between modalities negatively impacted students' learning satisfaction. In general, the results of this study suggest that, if educators are attempting to maintain learning outcomes and demonstrate high student learning satisfaction while taking advantage of the benefits of online learning, a fully online learning modality, or a hybrid course where modalities are not switched (for instance, a flipped classroom), might be more successful. The comparison of the learning experience and outcomes between face-to-face learning and online learning is a widely studied and discussed research topic in the field of educational technology. Based on this study, we recommend engineering instructors who want to switch to a 100% online modality to particularly focus on how to provide meaningful interaction between students and faculty and students. For a better blended learning experience, we recommend using a face-to-face learning at first to help increase the familiarity among learners and with the instructors and then starting the online learning.

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Appendices

Appendix 1

The seven factors and corresponding survey items under each factor

Level of Control in Online Learning

1. I am allowed to work at my own pace in online learning.
2. I am able to follow the syllabus of online courses according to my schedule.
3. Asynchronous online learning activities allow me to actively participate in the class according to my schedule.
4. Online courses save me a lot of time for other engagements.
5. I am allowed to select my time of the day to log onto online courses.
6. I am allowed to select time to communicate with my instructors of online courses.
7. I am allowed to select time to discuss the course materials with my classmates.
8. I am allowed to select time to do readings and assignments.

Independence in Online Learning

1. I am confident I can learn without the presence of an instructor to assist me.
2. I am certain I can understand even the most difficult material presented in an online course.
3. I am self-disciplined in online learning.
4. I try to determine which concepts I don't understand well.
5. If I get confused during online learning, I make sure I'll sort it out before proceeding on to the next section.
6. I keep track of how much I understand.
7. I make sure I keep up with the weekly readings and assignments of an online course.
8. If I have trouble in an online course, I try to figure it out by myself.

Satisfaction in Online Learning

1. I am satisfied with online learning because I am able to do things according to my schedule.

2. I am satisfied with online learning because I save a lot of time traveling to school.
3. I am satisfied with online learning because I am able to select my time of the day to study.
4. I am satisfied with online learning because I can work part-time/full-time.
5. I am satisfied with online learning because I can study in a place where I can be concentrated.
6. I am satisfied with online learning because I can select time to meet my instructors and classmates online.
7. I am satisfied with online learning because I am able to manage my study time effectively.
8. Overall, I am satisfied with online learning.

Instructor's role and support

1. The instructor clearly communicated important course topics.
2. The instructor clearly communicated important course goals.
3. The instructor provided clear instructions on how to participate in course learning activities.
4. The instructor clearly communicated important due dates/time frames for learning activities.
5. The instructor was helpful in identifying areas of agreement and disagreement on course topics that helped me to learn.
6. The instructor was helpful in guiding the class towards understanding course topics in a way that helped me clarify my thinking.
7. The instructor helped to keep course participants engaged and participating in productive dialogue.
8. The instructor helped keep the course participants on task in a way that helped me to learn.
9. The instructor encouraged course participants to explore new concepts in this course.
10. Instructor actions reinforced the development of a sense of community among course participants.
11. The instructor helped to focus discussion on relevant issues in a way that helped me to learn.
12. The instructor provided feedback that helped me understand my strengths and weaknesses relative to the course's goals and objectives.
13. The instructor provided feedback in a timely fashion.

Students' interaction

1. Getting to know other course participants gave me a sense of belonging in the course.
2. I was able to form distinct impressions of some course participants.
3. Online or web-based communication is an excellent medium for social interaction.
4. I felt comfortable conversing through the online medium.
5. I felt comfortable participating in the course discussions.
6. I felt comfortable interacting with other course participants.
7. I felt comfortable disagreeing with other course participants while still maintaining a sense of trust.
8. I felt that my point of view was acknowledged by other course participants.
9. Online discussions help me to develop a sense of collaboration.
10. Problems posed increased my interest in course issues.

Instructional design

1. Course activities piqued my curiosity.
2. I felt motivated to explore content-related questions.
3. I utilized a variety of information sources to explore the problems posed in this course.
4. Brainstorming and finding relevant information helped me resolve content-related questions.
5. Online discussions were valuable in helping me appreciate different perspectives.
6. Combining new information helped me answer questions raised in course activities.
7. Learning activities helped me construct explanations/solutions.
8. Reflection on course content and discussions helped me understand fundamental concepts in this class.

Knowledge transfer and application

1. I can describe ways to test and apply the knowledge created in this course.
2. I have developed solutions to course problems that can be applied in practice.
3. I can apply the knowledge created in this course to my work or other non-class related activities.

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