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Hybrid Mode: A New Norm for Electrical Engineering Laboratory Education?

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ABSTRACT

CONTEXT

The COVID-19 pandemic has created an incredibly challenging period in which to deliver engineering laboratory exercises. Utilising available digital technologies, the authors converted traditional hands-on laboratory exercises to virtual labs and remote labs. Commencing in Semester 2, 2020, the authors' School has offered a hybrid teaching model which simultaneously delivers laboratory content to an on-campus cohort (who participate in traditional hands-on labs) and a remote-learning cohort (who participate via virtual and/or remote labs). While trying to ensure that the learning experience of both on-campus and remote-learning students were similar, and that teaching outcomes were maintained, the authors observed that the success in adaptation of existing course content to the hybrid teaching model differs between Units of Study (UoS). There is a challenge to understand the basis for these differences and how to optimally design teaching material and manage classes to achieve the best learning outcomes.

PURPOSE

The authors manage and coordinate operation and teaching across six electrical engineering teaching laboratories. This paper aims to report the degree of success of introducing hybrid laboratory education across twelve UoS. Specifically, based on student responses to a survey undertaken in Semester 1, 2021, the authors evaluate the effectiveness of the hybrid model by seeking to answer two questions: (1) Could the students be satisfied with the new hybrid model? (2) Could on-campus and remote-learning students have similar learning experiences?

METHODS

The study covers the School's teaching laboratory programs that span three broad teaching disciplines: power/energy, communications/photonics, and computer/digital electronics. They are organised in either mixed mode (both on-campus and remote cohorts undertake the same exercises) or parallel mode (cohorts complete different exercises that have common learning outcomes). Student survey data across twelve UoS are available, including responses about learning experience, tutor teaching, and additional comments. The method is mainly quantitatively statistical analysis, supplemented by qualitative study.

OUTCOMES

Overall, the hybrid lab program results in a satisfactory learning experience for students. This means that implementing electrical engineering laboratory teaching using a hybrid model is found to be both practical and applicable. However, students on-campus in the mixed mode and both cohorts in the parallel mode tended to adapt more successfully to the hybrid model than those remote students in the mixed mode. It prompts the educators to fine-tune the hybrid program to better accommodate the remote mixed mode students.

CONCLUSIONS

While the hybrid model can deliver effective laboratory education, the degree of success and student experience was found to vary between different cohorts. Further study is warranted to understand the factors behind these differences and to then explore more effective approaches to maximise the students' learning experience. This paper serves as a starting point for the community to discuss the new norm for engineering laboratory education. The pandemic has already had a transformational impact on the delivery of engineering education, and hybrid education may not be transient but instead a future steady state.

KEYWORDS

Engineering Laboratory Education, Hybrid Labs.

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Introduction

The COVID-19 pandemic has created an incredibly challenging period in which to deliver electrical engineering laboratory exercises which are heavily based on acquiring and demonstrating practical skills. At the authors' University, all practical laboratory classes resumed from Semester 2, 2020. However, a considerable percentage (~40%) of the students could only study remotely due to either personal considerations or travel restrictions resulting from the closure of international borders. To continue quality education for the students, the University decided to introduce a hybrid learning model, which allows students flexibility to enrol into either an on-campus stream or a remote-learning stream, depending on their individual circumstances.

The authors manage operations and teaching across six electrical engineering teaching laboratories that span three broad teaching disciplines: power/energy, communications/photonics, and computer/digital electronics (EIE Labs, 2021). To implement the new hybrid learning model for delivery of laboratory education, the authors utilised available digital technologies. They proposed developing new virtual and remote labs that could be as effective as the traditional hands-on labs, as computer-mediated experiments have effectively blurred boundaries between hands-on, virtual and remote laboratories (Ma & Nickerson, 2006). In virtual labs, students use software which mimics the appearance and operation of physical lab equipment or software which performs numerical simulations of circuits or systems. In remote labs, students gain remote access to view and control hardware that is physically located on-campus (Balamuralithara & Woods, 2009; de Jong, Linn, & Zacharia, 2013; Potkonjak et al., 2016). While trying to ensure that the learning experience of both on-campus and remote-learning students were similar, and that teaching outcomes were maintained, the authors observed that success in adaptation of existing course content to the hybrid teaching model differed between Units of Study (UoS). There is a challenge to understand the factors behind these differences and how to best design teaching material and manage classes to achieve the best outcomes.

While there have been many articles appear in the literature which report on aspects of delivering laboratory education during the pandemic (Gamage et al., 2020; Ozadowicz, 2020), to the authors' best knowledge there was no systematic evaluation of students' perception of the new hybrid lab program at a macro (School's) level. To evaluate the effectiveness of the hybrid laboratory program, the authors conducted a joint Teaching Laboratories Survey across twelve UoS at the end of Semester 1, 2021. Those Units were spread across junior years (2 Units), intermediate years (5 Units) and senior years (5 Units). They share the common characteristic of having significant hands-on components which were conducted purely face-to-face in the labs before the pandemic. In this article, the authors first describe their hybrid lab program in detail and then analyse the survey results to evaluate the effectiveness of the hybrid model implemented in their Electrical Engineering laboratories and mainly investigate students' perception of their learning. The research questions to be answered from this study are:

1. Could the students be satisfied with the new hybrid laboratory learning model?
2. Could on-campus and remote-learning students perceive similar learning experiences?

The approach to investigating these results is mainly quantitatively statistical analysis, supplemented by qualitative study.

Hybrid Labs

The School's laboratory programs span three broad teaching disciplines: power/energy, communications/photonics, and computer/digital electronics. Under the hybrid labs model, students elected to enrol into a UoS in either the on-campus cohort or remote-learning cohort. Depending on the course-specific content, the hybrid labs were delivered in either mixed-mode or parallel-mode.

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(a) Mixed-mode

Considering that modern Electrical Engineering lab equipment can be mediated by computers, physical colocation of students and equipment becomes less critical. Most of our modern instruments had an in-built interface that computers could control. This meant that as long as the remote-learning students could remotely access the lab computers and the lab could provide a video/web camera, these students could effectively work on experiments with the computers as their "hands" and the cameras as their "eyes" and obtain a similar learning experience as if they were on campus. So, the lab instructors provided one camera for each workbench and used Zoom Remote Control to enable online students to access on-campus computers (therefore instruments). Another hurdle was that some operations still required physical adjustments to be made to hardware (i.e. changing component placement on a breadboard circuit). To overcome this limitation, the authors paired remote and on-campus students, often in groups of 2-5, and structured the activities so that students were required to work on the lab tasks together. On-campus students can operate it physically, while remote-learning students could access them by remote-controlling the computers that connect the hardware. In addition, this approach also provided an opportunity to promote collaboration between on-campus and remote-learning students and to provide the remote-learning students with a sense of connection to the classroom. The mixed-mode arrangement is illustrated as shown in Fig. 1.

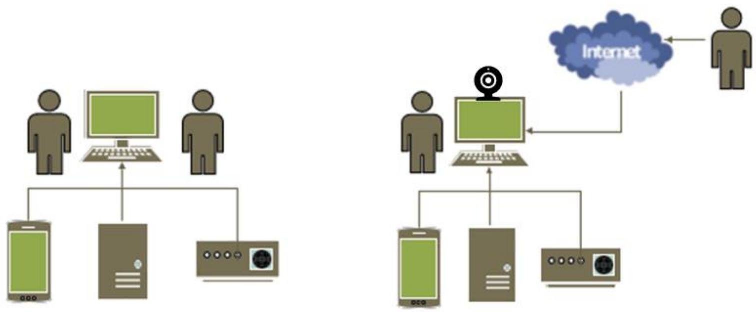

Figure 1: Lab arrangement (Left) the purely on-campus mode arrangement in 2019 before the pandemic and (Right) Mixed-mode collaboration from 2020.

(b) Parallel-mode

In the parallel mode, the authors have designed two sets of lab activities for both on-campus and remote students. On-campus students work in the traditional hands-on labs, while remote-learning students attended virtual simulation labs with learning outcomes derived from the hands-on labs. The classes were conducted simultaneously. The University has implemented UniConnect Cloud (UniConnect, 2017), in which the laboratory simulation software can be moved from the University physical computers to the Cloud. Students can access them through any web browser, making virtual labs accessible to anyone, anytime.

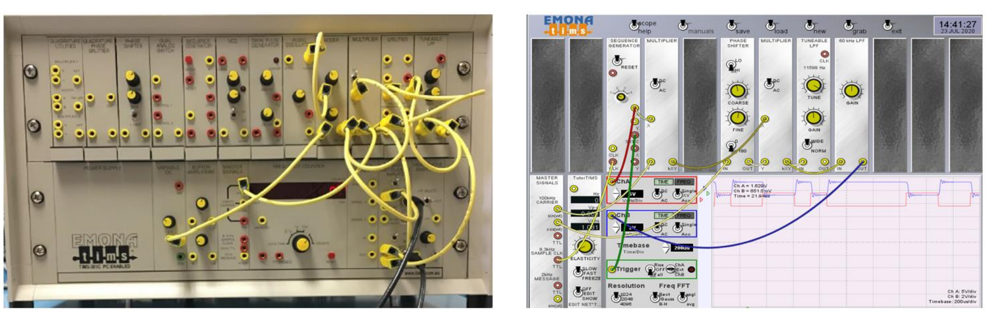

Figure 2: Lab arrangement (Left) TIMS physical setup on campus and (Right) TutorTims Virtual Lab on Uniconnect Cloud.

In the example shown in Fig. 2, Telecommunication Instructional Modelling System (TIMS) labs are set up and conducted using the physical TIMS equipment for students on campus

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(EMONA TIMS, 2021), while corresponding virtual simulation labs using TutorTIMS software are hosted on Uniconnect Cloud for remote-learning students to complete lab exercises. These two options are considered to be nearly identical in delivering the same learning outcomes. Students can choose either approach to complete the lab tasks/exercises through either hardware or software interfaces. This mode provided more flexibility and independence to students, however it also required more resources to prepare and support the classes.

Methods

(A) Participation

The setting of this study was undergraduate and postgraduate coursework students who enrolled in a UoS which was delivered under a hybrid lab program in Semester 1 2021. To evaluate the effectiveness of hybrid laboratory education, the authors conducted a Teaching Laboratories Survey across 12 UoS at the end of Semester 1 2021. Those Units have significant hands-on components that were conducted face-to-face in the labs before the pandemic, and they were distributed across junior years (2 Units), intermediate years (5 Units) and senior years (5 Units). The underlying population size of the survey exercise was 1300 in total. Among them, 775 students were on-campus students, while 525 students chose the remote-learning option. In another dimension, among the entire population, 952 students were enrolled in Units delivered using the mixed mode of the hybrid labs, while 348 were in Units delivered using the parallel mode. Based on the above two hybrid strategies, students studied in one of the following four learning environments: i.e.

- On-campus students, delivered in Parallel mode
- On-campus students, delivered in Mixed mode
- Remote-learning students, delivered in Parallel mode
- Remote-learning students, delivered in Mixed mode

(B) Data Collection

Data collection started in Week 13 (final week) of Semester 1, with the survey setup using Microsoft Forms. The specific questions of interest that were asked in the survey are provided in the Appendix. The exercise was entirely voluntary and anonymous as personally identifying information were not required. An announcement was sent through the digital learning system, Canvas, to the students enrolled in these 12 Units to request their participation in the survey. This initial request was reinforced by tutors via in-class announcements. The survey ran for two weeks before it closed. It returned a total of 272 responses (n = 272), i.e. 21% of the underlying population size. The overview of the survey and its response is summarised in Table 1. Among the entire population, 22% of on-campus students responded to the survey, while 20% of the remote students did. On another dimension, 19% of mixed-mode students responded, and 26% of parallel-mode students did. In addition to the ranking-style questions, the returned responses also included 110 specific student comments that were used for the qualitative analysis.

Table 1: Overview of the collected survey data

# (and %) of the student responding to the survey	Mixed Mode	Parallel Mode	Total
On-campus students	122 (21%)	47 (23%)	169 (22%)
Remote-learning students	59 (16%)	44 (30%)	103 (20%)
Total	181 (19%)	91(26%)	n = 272 (21%)

(C) Descriptive Statistics

First, the authors studied the entire dataset of samples by computing means, medians and standard deviations for three indicators: learning activities (Q3), tutors' teaching (Q4), and the effectiveness of the mixed group (Q5). All three indicators were rated out of 5, indicating the level of satisfaction (refer to the Appendix for more detail). These results are summarised in

Table 2. Overall, the ratings for both learning activities and tutor's teaching are greater than 4 out of 5, indicating some level of satisfaction at the macro level. In contrast, the ratings of mixed group effectiveness are only 3.16 (note that only mixed-mode student samples were used to calculate this number). This means students did not perceive any significant benefit of collaborating virtually, indicating that remote-learning and on-campus students were not related very well in this type of group arrangement. As for Q6-whether to keep the hybrid lab in the future, surveyed students had a split view with 116 of Yes, 68 of Maybe and 88 of No, indicating no clear advantage of the hybrid lab perceived by students to traditional on-campus labs.

Table 2: Basic statistics from samples (indicators rated out of 5)

	Mean	**Median**	**SD**
Learning Activities	4.06	4.00	1.01
Tutors' Support	4.24	5.00	1.02
Mixed Group Effectiveness	3.16	3	1.41

The authors then computed the correlations among key indicators, as shown in Table 3. Learning activities, tutor teaching and mixed group effectiveness are highly correlated. E.g. of those students who rated 5 for lab learning activities, 92% also rated 5 for tutors' teaching. It is clear that students' perceptions of both were correlated. Therefore, to simplify the analysis that follows, the authors will focus on the ratings of Lab Learning Activities as the leading indicator in the rest of the paper.

Table 3: Correlation between indicators

	Learning Activities	**Tutors' Teaching**	**Mixed Group**
Learning Activities	1.00	0.67	0.55
Tutors' Teaching		1.00	0.45
Mixed Group			1.00

The authors further investigated the samples between on-campus and remote-learning students and data between mixed-mode and parallel-mode students. In addition, the entire samples can be divided into four subgroups: i.e. on-campus mixed-mode, on-campus parallel-mode, remote mixed-mode, and remote parallel-mode, and four broad categories: i.e. between on-campus and remote-learning, between parallel and mixed modes. The results were computed and illustrated in Table 4. The data shows that the sample means of Learning Activities Ratings between on-campus (4.08) and remote-learning students (4.02) are close. However, parallel mode (4.51) scores 15% higher than mixed-mode (3.83). In particular, the subgroup of remote mixed-mode (3.63) scored significantly lower than the rest of the subgroups. This observation has prompted the authors to plan improvement strategies for this subgroup in the future.

Table 4: Sample Mean of Learning Activities Ratings across groups, categories and overall

	Mixed mode	**Parallel mode**	**Category (on-campus or remote-learning)**
On-campus students	3.93	4.47	4.08
Remote-learning students	3.63	4.55	4.02
Category (mixed or parallel)	3.83	4.51	**Overall:** 4.06

(D) Hypothesis Test – Satisfaction and Experience Gap

Given the unknown mean and variance of the entire population, Hypothesis tests with t-statistic are used to evaluate the significance of the results (Gravetter & Wallnau, 2007). The sample

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data from the underlying population would answer the two key research questions outlined in the Introduction section.

The first null hypothesis is that, on average, students from the entire population, as well as each underlying sub-category, are satisfied with the hybrid lab model (i.e. the mean of the rating for the lab learning activity is above the benchmark value of 4.10). This benchmark score of 4.10 was derived by averaging Unit of Study Survey results across four semesters before 2020. In that sense, the satisfaction is being determined relative to pre-pandemic levels. Mathematically, the first null hypothesis can be expressed as below:

$$H_o: \mu_{lab\_act} \geq 4.10$$

The alternative hypothesis would state that, on average, students are not satisfied with the lab learning activities in the hybrid model. The significant level of these tests is set as 0.05 for one tail. Degree of freedom equals the respective number of samples (from Table 1) minus 1. The authors perform this hypothesis test for the entire population and each category, respectively. The calculated t-statistics and t-cutoff are presented in Table 5. When t-statistic is less than the t-cutoff, this implies that the null hypothesis is to be rejected. Otherwise, the hypothesis is to be accepted. According to Table 5, on average, the entire population is satisfied with the hybrid lab model, statistically. As for the categories, on-campus students, remote-learning students, and parallel mode students are also satisfied with the labs. However, mixed-mode students have t-statistic in the rejection region, indicating dissatisfaction with their learning mode.

Table 5: Hypothesis testing using t-statistics of the entire population, on-campus, remote-learning, mixed and parallel students (the level of significance α at 0.05 for one tail)

	df	**t-stats**	**t-cutoff**
Entire population	271	-0.69	-1.65
On-campus students	168	-0.30	-1.65
Remote-learning students	102	-0.78	-1.66
Mixed-mode students	180	-3.56	-1.65
Parallel-mode students	90	4.68	-1.66

The second null hypothesis is that, on average, students from on-campus and remote learning perceive the same lab learning experience under the hybrid model. (i.e. the difference in means of lab learning activity between on-campus and remote-learning students is zero), Mathematically, it can be expressed as below:

$$H_o: \mu_{campus-}\mu_{remote} = 0$$

The alternative hypothesis would state that, on average, there is a perceived satisfaction gap between on-campus and remote-learning students. T-test: two-sample assuming unequal variances are performed, and the significance level of these tests is set as 0.05 for two tails. Again, the authors calculate the t-statistics and t-cutoff for the overall population, mixed-mode and parallel-mode students, respectively, as presented in Table 6. When the absolute value is less than the t-cutoff, the t-statistic is in the acceptance region, and the null hypothesis is accepted. Otherwise, the hypothesis is to be rejected. According to Table 6, on average, students between on-campus and remote learning statistically had the same satisfaction level under the hybrid model in Semester 1 2021, across the entire population, mixed-mode and parallel-mode students, respectively.

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Table 6: Hypothesis testing - difference in the mean using t-statistics (the level of significance α at 0.05 for two tails)

	df	t-stats	t-cutoff
Entire population	201	0.44	1.97
Mixed-mode students	106	1.79	1.98
Parallel-mode students	89	-0.44	1.99

Findings

Two key goals of developing a hybrid lab program are (1) to expand course enrolment options to accommodate remote-learning students while continuing to deliver quality lab education that students are satisfied with and (2) to provide the same learning experience between on-campus and remote-learning students. Overall, the hybrid lab program as implemented has been successful so far. Statistically, the entire population of students, both remote and on-campus students, had no less satisfaction rating than the traditional lab program delivered before the pandemic. In addition, on-campus and remote learning students had close satisfaction level under the hybrid model. However, when assessing subgroups, the authors observed that students in the parallel-mode rated lab learning activities 15% higher than those enrolled in the mixed-mode.

Qualitative detail of the survey can get lost in analysis of the statistics alone, and so it is equally valuable to consider students' comments to get a picture of how the students experienced the program. Comments from parallel-mode students (both online and on-campus) were, in general, positive and it was encouraging to see that they supported the findings from the quantitative data. In contrast, we observed that the most negative comments were from mixed-mode students – from both on-campus and remote-learning cohorts - with some criticisms such as:

> "*Don't combine online students with campus students. Communication is hard, especially with different time zones and language barriers*."
>
> "*Combining remote and on-campus students is a bad idea. Maybe just give remote students a slightly different Lab 6 project that can be done online*?"
>
> "*Mixing online and in-person learning makes interactions and tasks difficult - I would mostly prefer to keep the modes separate.*"

Those comments were effectively reflected in the poor survey ratings for learning activities (Q3), tutors' teaching (Q4), and the effectiveness of the mixed group (Q5). Finally, the authors observed comments from remote-learning students that they would prefer to enrol in the on-campus cohort if a choice could be given. This is interesting as, despite both on-campus and remote-learning students having close satisfaction level under the hybrid model, there is a perception amongst some remote-learning students that on-campus learning is preferable.

Finally, the survey data was compared across years (junior, intermediate, senior) and Unit-by-Unit at a micro level. The authors observed that senior-year students studying Units with labs consisting of system-level experiments reported a much better experience. It is believed that this outcome is due to being able to mediate system-level processes almost wholly using digital technologies, thus making those Units more successfully adapted to the hybrid mode. In contrast, many first-year Units have fundamental labs consisting of hands-on component-level experiments which are more difficult to adapt.

Discussion

In response to challenges presented by the pandemic, many educators have been driven to innovate alternative ways to deliver lab education which they have traditionally conducted on-campus. Overall, the hybrid lab program resulted in a satisfactory learning experience for students. This means that implementing electrical engineering in hybrid mode is both practical and applicable. While trying to ensure that the learning experience of both on-campus and

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remote-learning students were similar, and that teaching outcomes were maintained, the authors observed that success in adaptation to the hybrid teaching model differed between the mixed and parallel modes of the hybrid program. This study provides a window of opportunity to further study the program systematically at a macro level. It is now understood that the student cohort in the remote learning hybrid mode reported poor experience among other modes. This finding can guide educators where to direct more attention when fine-tuning its program, as both qualitatively and quantitative data point to the challenge faced by this cohort of students.

To motivate students in the laboratory, the educators need to have a lab program which meets students' psychological needs as well as their technical needs. To successfully implement the hybrid mode, the authors believe that the challenge is not purely technical, as digital technologies have removed the boundary between on-campus and remote learning. Niemiec and Ryan (2009) outlined some evidence from their studies that meeting students' three psychological needs (autonomy, competence and relatedness) would facilitate the learning experience and academic performance. The Nobel Prize-winning Physicist R. Feynman once said, "imagine how much harder physics would be if electrons had feelings". This study now shifts the authors' focus from purely technical aspects to psychological readiness. The authors now realise that all three psychological factors described by Niemiec and Ryan (2009) might not be well addressed, particularly for remote-learning students in the mixed mode. For example, before the study, the authors did not sufficiently consider the fundamental shifts in interactions between students, teachers and apparatus in the new environment. Among those negative comments, the criticisms tended to be directed towards the collaboration issues instead of technical content.

In the parallel mode, on-campus students would take the traditional physical labs, while online students would do corresponding simulation labs instead. Both cohorts have rated the learning activities highly, as evidenced in the lab survey (average 4.47 for on-campus students and 4.55 for remote-learning students). On-campus students effectively worked in a pre-pandemic environment, while remote-learning students would most likely feel more confident working with simulation models (which are not restrained by on-campus hardware, network latency or group member dynamics) than remote-lab activities. However, some specific learning outcomes can only be achieved through hardware-facing labs (either physically or by remotely interacting with the hardware) and there continues to be a challenge to design lab activities which effectively meet the related learning outcomes.

This study had incorporated one semester of data. Different UoS will be offered in Semester 2, 2021 and the authors intend to continue the study to include these Units, so that a full year of the course program can be investigated.

Conclusions

The pandemic has already had a transformational impact on engineering education. Commencing in Semester 2, 2020, the authors' School has offered a hybrid teaching model which simultaneously delivers laboratory content to both on-campus and remote-learning cohorts. While the hybrid model can successfully deliver engineering laboratory education, the degree of success and student experience varies between the different cohorts and UoS. This preliminary study found that overall, the hybrid lab program resulted in a satisfactory learning experience for students. However, this paper serves as the starting point for the community to discuss the new norm for engineering laboratory education. Hybrid education may not be transient. Instead, it is an excellent opportunity for reform and innovations.

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Appendix – Survey Questions

2021 S1 Teaching Laboratories Survey

1. Which Unit of Study are you enrolled in?
2. Are you enrolled as an on-campus student or remote-learning student?
3. How would you rate Lab Learning Activities? (5-star is the highest rating, and 1-star is the lowest rating)
4. How would you rate Lab Tutors? (5-star is the highest rating, and 1-star is the lowest rating)
5. Many UoS combined on-campus and remote students into groups. How would you rate the effectiveness of working with your group members under this arrangement? (5-star is the highest rating, and 1-star is the lowest rating)
6. In Semester 1 2021, we are running most labs in hybrid mode: on-campus labs and remote learning labs. After Covid-19 is resolved, do you still want us to keep both options in the future? Yes, No or Maybe.
7. Any other comments/suggestions?

Note that for the rating scale (Q3,Q4,Q5)

- 5-star means Strongly Agree/Satisfy
- 4-star means Agree/Satisfy
- 3-star means Neutral
- 2-star means Disagree/Dissatisfy
- 1-star means Strongly Disagree/Dissatisfy

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