Tales of Hybrid Teaching in Software Engineering: Lessons Learned and Guidelines

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***Abstract*—*Contribution:* This paper contributes empirical insights on hybrid teaching of software engineering courses. Results include the systematic analysis of hybrid teaching attendance and interaction, perception of hybrid teaching, and grade distributions. Results are synthesised into eight evidence-based guidelines.**

***Background:* Hybrid teaching, *i.e.,* teaching simultaneously to in-person and online students, is gaining an increasing adoption. However, how to improve the experience of students with respect to hybrid teaching is still an open question.**

***Research questions:* RQ: How can the experience of students with respect to hybrid teaching be improved? RQ_1: Are there differences between in-person and online student attendance and interaction? RQ_2: What is the student perception of hybrid teaching? RQ_3: Is in-person and online supervision influencing grades of students?**

***Methodology:* A mixed-method empirical research process is used, by considering two Master courses in software engineering. The process leverages three data sources, namely quantitative and qualitative data collected during lectures, a student survey, and student grades. Summary statistics, coding processes, and a statistical analysis are used to answer the research questions.**

***Findings:* Students prefer to attend more frequently online, as it provides (among other factors) flexibility and convenience, while coming at the cost of lower focus and interaction quality. Following in-person is statistically a better choice to gain a median grade, while following online can lead with more probability to a higher or lower grade. Various guidelines are presented, ranging from hybrid classroom setup, to online student management, and course component design.**

***Index Terms*—Hybrid Teaching, Blended Teaching, Software Engineering, Education**

I. Introduction

WHEN the COVID-19 pandemic hit, numerous academic institutions had to rethink the way university courses were structured and provided. Pushed by the increasing level of digitization and digitalization, the modernization trend of transitioning from classic in-person classes to hybrid or blended settings was actually already happening [1]. In this context, it comes to no surprise that hybrid classes, *i.e.,* classes followed simultaneously by local (in-person) and remote (online) students, experienced an increasing adoption [2]. Albeit hybrid teaching opens up for numerous opportunities, restructuring a course from in-person-only to hybrid can entail disruptive changes, which can negatively affect the experiences of both educators and students. As highlighted by Raes *et al.* [1], to date empirical studies on the subject have only begun to emerge and more evidence-based research is needed to study different pedagogical scenarios and their impact on students. In order to fill this gap, and contribute towards a common knowledge on hybrid teaching of software engineering courses, its characteristics, perils, and opportunities, this research presents concrete insights into hybrid teaching, based on data collected from teaching two software engineering courses. The ultimate goal of this study is to understand the student perception of hybrid teaching, by answering the question: *How can the experience of students with respect to hybrid teaching be improved?* To answer such question, this study presents systematically structured and analyzed hybrid teaching "tales": empirical data, patterns, experiences, and evidence-based guidelines on hybrid teaching. These results are made available to help educators adopt good practices for hybrid teaching. The main contributions of this study can be summarized as follows:

- An in-depth empirical record and analysis of teaching hybrid courses, ranging from student presence to interaction, feedback, preferences, and grades;
- Eight evidence-based guidelines for hybrid teaching;
- A replication package containing the entirety of the raw, intermediate and final data / analysis traces of this study.[1]

II. Research Design and Execution

In this section, the design and execution of this research are reported, starting from a documentation of the research goal and questions (Section II-A), to a description of the context in which the research was conducted (Section II-B), and a report of the research process followed (Section II-C).

A. Research Goal and Questions

The aim of this research is to understand how hybrid teaching can be improved for software engineering students. By utilising the Goal-Question-Metric approach [3], this objective can be formulated as follows:

Analyze *student attendance, interaction, feedback, and grades*
For the purpose of *improving the experience of students*
With respect to *hybrid teaching*
From the viewpoint of *educators*
In the context of *software engineering courses.*

From the goal 4 research questions (RQs) guiding this study are derived, namely:

RQ *How can the experience of students with respect to hybrid teaching be improved?*

This main RQ of the study aims at determining, based on the experience of students and the data collected for this study, how hybrid teaching can be improved, in terms of concrete reusable guidelines. In order to answer the main RQ, two different facets of hybrid teaching are investigated, as further framed by the following sub-RQ.

[1]https://github.com/S2-group/tales-of-hybrid-teaching-rep-pkg. Accessed 10th November 2022

RQ$_1$ *Are there differences between in-person and online student attendance and interaction?*

RQ_1 aims at assessing if students are more prone to attend classes in person or online, and if attending online or in-person leads to a difference in the frequency of student interaction.

RQ$_2$ *What is the student perception of hybrid teaching?*

RQ_2 is designed to gain a deeper understanding of the student perception of hybrid learning in terms of, among others, their general preference of online or in-person teaching, the rationale behind their preference, and potential impediments they experience with respect to hybrid teaching.

RQ$_3$ *Is in-person and online supervision influencing grades of students?*

RQ_3 aims at investigating if supervising students in-person or online has an effect on the grades of students, and hence if one way of conducting supervision is less effective than another, in terms of the achieved learning objectives.

B. Research Context

The findings of this study are based on the data collected by considering two Masters of Sciences (MSc) Software Engineering courses. Both courses were provided in hybrid mode, *i.e.,* students were allowed to follow every course component (see Section II-B1) either in-person or online, with the exception of student presentations, which had to be given in-person. Similarly, students were given the possibility to be supervised by a Teaching Assistant (TA), again either in-person or online.

The courses were *Service Oriented Design* (SOD), which focused on software services principles and architecting[2], and *Digitalization and Sustainability* (D&S), which focused on the design and assessment of sustainable digitalization projects[3]. Both courses were conducted at the Vrije Universiteit Amsterdam during the months of September and October 2021. The selection of courses was guided by their similarity, in terms of teaching mechanisms, course components, teaching period, and duration. This allowed to consider two distinct yet comparable data sources for the study, to run the study in parallel by considering both courses, and to mitigate potential external validity threats characteristic of a single source of data.

In total, 97 students followed the SOD course, while 52 the D&S one. The SOD course was supported by 7 TAs, of which 4 conducted their supervision in-person and 3 online. The D&S course instead involved 9 TAs, of which 6 worked in-person and 3 online.

As further discussed in Section V, the results of this study need to be interpreted both in light of the educational context considered and the COVID-19 pandemic, *i.e.,* the period when the data of this study was collected.

1) Course components and organization: Both courses included different components, namely (i) *recorded lectures*, *i.e.,* pre-recorded course lectures that students could access online, (ii) *guest lectures*, *i.e.,* live lectures conducted by a guest speaker online, (iii) *Q&A sessions*, *i.e.,* live sessions, carried out simultaneously in-person and online, where students could ask questions on the content of pre-recorded lectures, (iv) *Menti Quizzes*, *i.e.,* interactive live quizzes[4] where students could assess their current understanding of course content in a gamified fashion, (iv) *TA Sessions*, *i.e.,* live sessions, conducted either in-person or online, where students could ask feedback to their TA on course material and deliverables. All course material, such as pre-recorded lectures, reading material, lecture links, etc., was shared with students through the learning management system *Canvas*[5]. The platform was also used to manage student groups, assignment deliverables, and asynchronous interaction with students *via* discussion boards.

For both courses, the weekly schedule included a recorded lecture, a Q&A session (integrated with either a guest lecture or a Menti quiz), and a TA session. In addition, each week of the SOD course, a student presentation was held, while only one student presentation was carried out for the D&S course.

2) Learning objectives assessment: To assess the achievement of learning objectives, the students of both courses were evaluated on two group deliverables, with each group being composed of 2-3 students. In addition, for both courses, an individual responsibility grade was given to each student by considering the average grades of the sections the students were responsible for. Each deliverable grade contributed to 40% of the final grade, while the individual responsibility constituted the remaining 20%. Grades could range from 1.0 (very poor) to 10.0 (outstanding) in increments of 0.1. Grades were assigned by TAs, responsible for 1 or more student groups, who jointly discussed grades with other TAs and course instructors for correctness and harmonization purposes.

C. Research Process

In order to answer the research questions of this study, a mixed-method empirical research process was utilized. The research process relied on different data sources to answer each specific sub-RQ, and entailed the collection and analysis of both quantitative and qualitative data. An overview of RQs, data sources, and analysis methods is summarized in Figure 1, and further described below.

To answer RQ_1, during each live session (*i.e.,* Q&As, guest lectures, and student presentations), the number of students attending in-person and online, as well as the number of times each type of student interacted with the class (*e.g.,* to ask clarifications or pose comments), was recorded. The number of online students who had their web cameras turned on was also registered. In addition, qualitative research notes were taken by a researcher during each lecture to record salient attendance and interaction behaviour observations (*e.g.,* "*Online students sometimes want to intervene, but experience difficulties in taking the floor in time [. . .]*"). The qualitative research notes were refined iteratively, and analysed *via* open and subsequent axial coding. The quantitative attendance and interaction data was instead analyzed and interpreted by simple statistical

[2]https://studiegids.vu.nl/en/2021-2022/courses/X_405061. Accessed 23th December 2021

[3]https://studiegids.vu.nl/EN/courses/2021-2022/XM_0089. Accessed 23th December 2021

[4]https://www.mentimeter.com. Accessed 23th December 2021

[5]https://www.canvas.net/. Accessed 23th December 2021

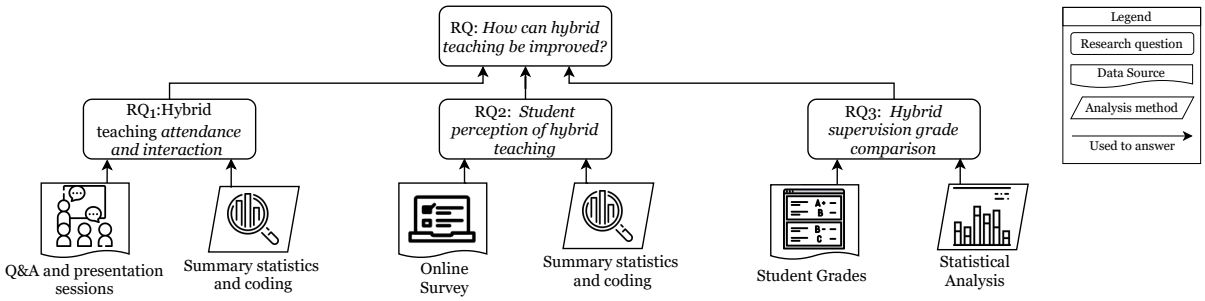


Fig. 1. Overview of research questions, data sources, and analysis methods.

TABLE I
STUDENT SURVEY QUESTIONS

ID	Question text [closed-answer options text]	Response Type	Compulsory
Q1	Which course did you follow? [SOD, D&S]	Multiple-choice	Yes
Q2	Did you follow the course more frequently in-person or online? [In-person, Online]	Single-choice	Yes
Q3	Based on your previous answer, why did you follow the course more frequently in-person / online? [*Convenience, Commuting, Not based in Amsterdam, Better Focus, Easier to Schedule, Interaction with class, Interaction with Students, Interaction with Instructors, Other (please specify)*]	Multiple-choice and open-ended	Yes
Q4	Which type of class did you prefer to follow in-person and online? [*Q&A Sessions, Student Presentations, Guest lectures, TA Sessions*]-[*In-person, Online*]	Multiple-choice	Yes
Q5	How satisfied were you with the following course components? [*Q&A sessions, Recorded Lectures, Guest Lectures, Menti quizzes, TA sessions, Canvas (content organisation, discussions,* etc.*)*]	5-point Likert Scale per option	Yes
Q6	Which difficulties did you experience related to following the classes in-person?	Open-ended	No
Q7	Which difficulties did you experience related to following the classes online?	Open-ended	No
Q8	In which format would you prefer future courses? [In-person only, Online only, Hybrid]	Single-choice	Yes
Q9	Do you have suggestions on how we could improve the virtualization of the course next year?	Open-ended	No
Q10	Any further comment or observation?	Open-ended	No

means, *i.e.,* data plotting and basic summary statistics (*e.g.,* calculating median values, percentage differences, *etc.*).

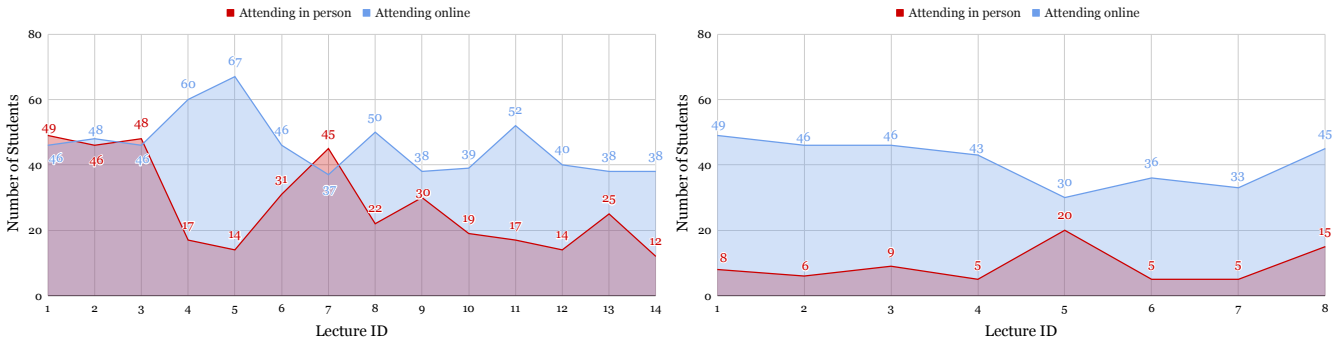
To answer RQ_2 an online survey, that students were invited to fill-in at the end of the SOD and D&S courses, was utilized. The survey was composed of 10 questions of open- and closed-ended nature (see Table I). The survey covered demographic questions (see Q1-Q2 Table I), questions regarding student preferences and the rationale behind it (Q3-Q5), questions on potential hybrid teaching impediments (Q6-Q7), and further advice and comments on hybrid teaching (Q8-Q10). The quantitative data gathered with the survey was analysed by following the same approach used to analyze the quantitative data of RQ_1. Similarly to RQ_1, for RQ_2 the qualitative results obtained from the open-ended survey questions were analyzed *via* an open and subsequent axial coding process.

To answer RQ_3, a quantitative analysis was conducted. The final grades of the students supervised in-person were compared with the grades of the students supervised online. The grades were compared *via* a statistical analysis, by utilizing the course (SOD and D&S) as blocking factor. For the comparison, the data was analyzed by visual means and summary statistics, followed by a two-sample Kolmogorov–Smirnov test [4]. The two-sample Kolmogorov–Smirnov test resulted to be best fitted to answer RQ_3, as it provided a nonparametric test allowing to assess if two underlying one-dimensional probability distributions (*i.e.,* in the context of this study, the grades of students supervised in-person/online) differ.

Finally, to select the research process the following rationale was adopted.

In order to comprehensively answer the main and sub-research questions, a mix of approaches borrowed from the related literature were used. Specifically, to answer RQ_1, which focused on student attendance and interaction, a mix of qualitative analysis, leveraging data such as in-person/online presence frequency, and qualitative analysis, based on research notes, was used. Relying on quantitative data allowed to gain impartial empirical insights to answer RQ_1, by relying on a research method widely adopted in the related literature [5], [6], [7], [8]. Nevertheless, quantitative data alone could not capture nuances, such as student interaction impediments, which were relevant to adequately interpret the results. Therefore, similar to other related studies [9], [10], the qualitative data was complemented with qualitative research notes to provide a more comprehensive interpretation of the results.

To answer RQ_2, which focused on student perception of hybrid teaching, a common method used to study student opinions, namely surveys [11], [12], [13], [10], was used. The survey was designed as a mix of multiple choice and open-ended questions, in order to gather a sufficient level of depth to answer RQ_2, while requiring a short amount of time to be filled in (to stimulate more responses and counter participant fatigue). In contrast to other research methods, such as interviews or focus groups, the survey allowed to gather the opinions of a high amount of students in a time-efficient manner. From a preliminary inspection of the survey responses across the courses, the answers did not result to drastically differ. Therefore, in order to allow a compact presentation and discussion of the survey results while avoiding to



(a) In-person and online attendance SOD

(b) In-person and online attendance D&S

Fig. 2. Overview of the students attending lectures in-person and online.

loose relevant insights, the unified results of the survey across the two courses are presented. All data is made available for further scrutiny in the replication package (see Section I).

To answer RQ_3, which focused on student grades, a quantitative approach based on the collection and statistical analysis of grades was conducted. This method, common to studies focusing on the assessment of learning objectives [14], [15], [8], [16], allowed to answer RQ_3, which is purely characterized by a quantitative nature, in a statistically significant manner.

III. Results

A. Results RQ_1: Hybrid Teaching Attendance and Interaction

In this section, the findings regarding hybrid teaching attendance and student interaction are reported. Regarding student attendance, Figure 2 depicts the number the SOD students (Figure 2a) and D&S students (Figure 2b) attending in-person and online each lecture. The online attendance was overall higher than the in-person one, with a median difference of 26 additional students attending online the SOD course, and 34 students the D&S one. The only exceptions were the SOD Lectures 1, 3, and 7, where more students attended class in-person, with a maximum difference of 8 additional students attending in-person Lecture 7. As no notable difference distinguishes lectures 1, 3, and 7 from the rest, their high in-person attendance might be due to their positioning towards the start of the course and the deadline of the first group deliverable.

As emerging from the research notes, in-person students tended to be mostly punctual, while online students tended to join throughout the first 30 minutes of the lectures.

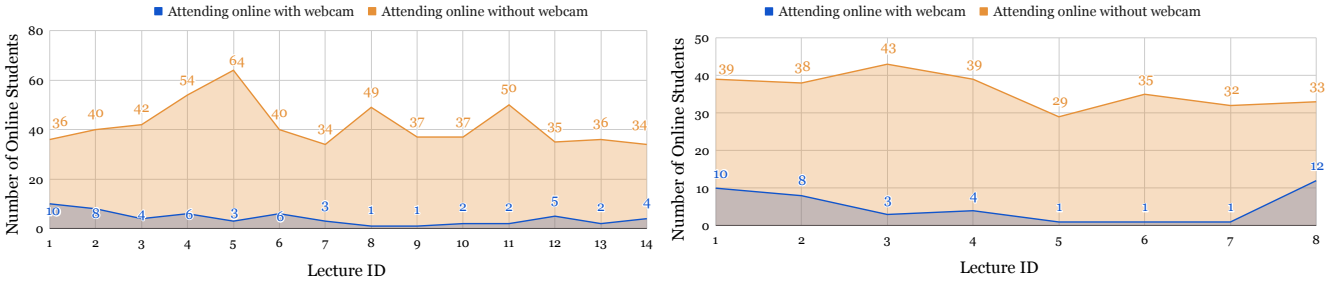
Regarding the use of web cameras, an overview of the number of online students connected to each lecture with and without cameras is reported in Figure 3. As depicted in the figure, only a small fraction of online students made use of cameras, with a high of 10 students out of 46 online students using cameras during the first lecture of SOD (see Figure 3a), and 12 out of 45 online students in the last lecture of D&S (see Figure 3b). By considering median values, 3.5 out of 46 online SOD students and 3.5 out of 44 online D&S students participated to the lectures with their cameras turned on.

From the qualitative research notes, students resulted to repeatedly switch on and off cameras throughout the lectures, mostly due to unknown factors, or to interact with other people present in their room, or to distance themselves from their desk. The total number of students utilizing web cameras resulted to steadily decrease throughout lectures, with only few to none left on towards the end of lectures.

At the intersection of web camera use and online attendance behaviour, research notes reported that online students did not always connect from their houses, but also from other places, *e.g.,* parks, university buildings (including the ones where the lectures were being held), or even public transport. In addition, in some cases students resulted to meet outside the classroom in order to jointly follow the lectures online.

Regarding student interactions, their total number, mapped to student types and courses, are reported in Figure 4. The figure shows differences of interaction patterns among the two courses. For the SOD course, the majority of interactions were carried out by in-person students (138 out of 195 total interactions), while for D&S the number of in-person and online interactions are comparable (52 in-person and 58 online interactions). By focusing exclusively on online interactions, it emerges that more than half of the time students preferred to interact with the class with their camera turned on (68 out of 115 total online interactions).

Research notes shed further light on hybrid student interaction. In general, online students were observed to experience more interaction impediments. Notably, giving the word to online students took more time than in-person students, potentially as in-person students requesting to intervene were more swiftly noticed by lecturers. In some cases, this led to giving the floor to online students when their question had been already answered, or was no longer relevant. Similarly, spontaneous interaction requests from lecturers to the class, such as asking an explanation or a show of hands, resulted to be more effective with in-person students. As a further impediment for online students, questions raised by in-person students were at times hard to be heard online and, if the question was not repeated by the lecturer, the answer could lose value for online students. Hybrid teaching appeared to affect to a certain extent also in-person students. Specifically, in-person students were observed to experience challenges regarding focusing on questions or comments posed online,



(a) Web camera use by online SOD students

(b) Web camera use by online D&S students

Fig. 3. Overview of online students connected with and without web camera.

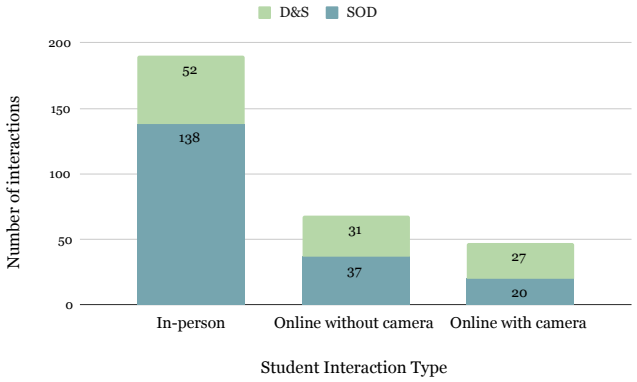


Fig. 4. Distribution of student interaction type (in person, online without camera, online with camera) of the SOD and D&S courses.

potentially because they had to switch their focus from a primarily in-person setting to a hybrid one. Lectures which were designed as hybrid-first, *e.g.,* guest lectures given by online speakers, eased the transition between in-person and online interaction, as continuous attention had to be given both to the online and in-person students (by the guest speaker and course lecturer respectively). Menti quizzes resulted to be quite effective in stimulating students, with an average of 73.53% students attending the SOD course who participated to the quizzes, and an average of 74.67% for the D&S course.

B. Results RQ_2: Student Perception of Hybrid Teaching

In this section the findings regarding the student perception of hybrid teaching, based on the answers to the survey designed for this study, are documented.

In total 55 students participated to the survey, 34 of whom followed the SOD course, and 21 the D&S one (see Q1 Table I). Regarding lecture attendance (see Q2 Table I), the majority of respondents followed the lectures more frequently online (34/55), while a minor part in-person (21/55), reflecting the attendance results collected for RQ_1 (see Section III-A).

Regarding the motivation behind attending lectures more frequently in-person or online (see Q3 Table I), an overview of the answers is depicted in Figure 5. Online students mostly motivated their choice due to general convenience (27/34), scheduling ease (26/34), commuting avoidance (17/34), and distance from campus (8/34).

In-person students instead followed lectures more frequently from the classroom to interact with other students, instructors, and the class (19/21, 16/21 and 12/21 respondents respectively). The fourth most recurrent motivation of in-person students was to focus better (12/21), which interestingly was also a motivation to follow lectures online for 6 students.

Other motivations provided by online students were (i) the general preference of following lectures online, and (ii) avoiding to be one of the few students attending in-person. The enjoyment of going to university facilities after COVID-19 restrictive measures were lifted was an additional motivation provided by a student attending more frequently in-person.

The preference of students to follow specific course components in-person and online (see Q4 Table I) is reported in Figure 6. Students highly preferred to follow Q&A sessions online, while a comparable number preferred to follow guest lectures in-person and online. Students preferred the in-person setting only slightly more than the online one for the student presentations, while noticeably more for the TA session.

Regarding the student satisfaction of the hybrid course components (see Q5 Table I, and Section II-B1), the results are documented in Figure 7. Overall, recorded lectures received the most mixed level of satisfaction, with the highest number of unsatisfied respondents (12/55) and among the lowest satisfied respondents (21/55). Guest lectures resulted to be better received, by displaying the overall highest number of satisfied respondents (34/55). Q&A sessions reported a high number of satisfied respondents (25/55), while also a high number of neutral responses (16/55). Similarly, Menti quizzes also reported a high number of neutral responses (16/55), but reported also among the highest satisfied (27/55) and very satisfied (13/55) values. TA sessions also resulted to be well received, by showcasing highest number of very satisfied respondents (29/55), and only a negligible number of unsatisfied (1/55) and very unsatisfied ones (2/55). Finally, Canvas was valued by most respondents, with only a minor number of neutral (7/55), unsatisfied (1/55), and very unsatisfied values (1/55).

Impediments related to following the hybrid courses in-person (see Q5 Table I) were described by 15/55 survey participants. The overall most recurrent impediment (6/15) resulted to be the commuting effort required to be present on university campus. Other single yet interesting impediments described the unease of being one of the few students present

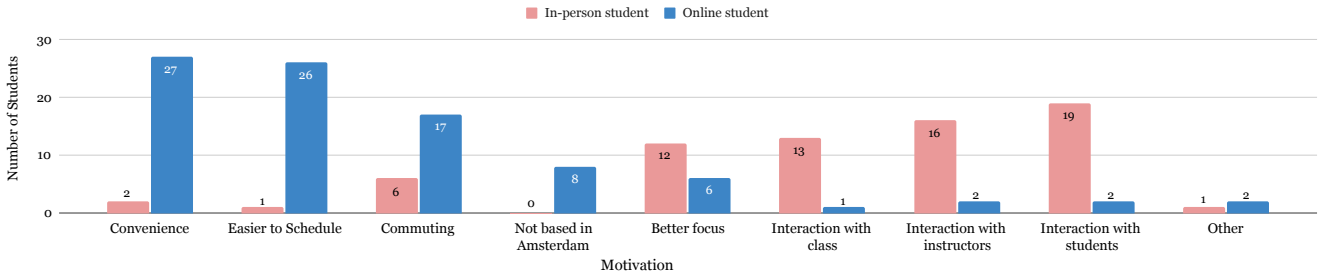


Fig. 5. Motivation behind following in-person and online of student survey respondents (Q3 Table I).

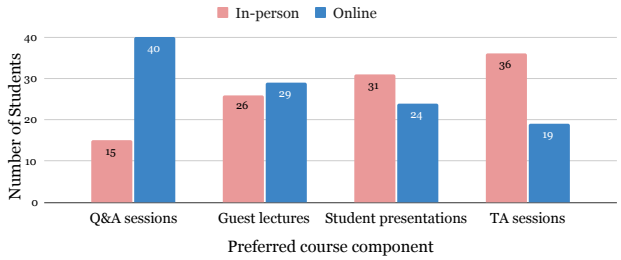


Fig. 6. Course component attendance preference of student survey respondents (Q4 Table I).

TABLE II
GRADE DISTRIBUTION SUMMARY STATISTICS

	SOD		D&S	
	In-person	**Online**	**In-person**	**Online**
Min	5.82	5.5	4.2	4.68
Max	9.34	8.76	8.92	8.9
Mean	7.64	7.95	7.44	7.38
Median	7.77	7.94	7.65	7.49
σ	0.82	0.64	1.17	1.19
CV	0.10	0.08	0.15	0.16

σ: standard deviation; CV: coefficient of variation.

in the classroom, the need of utilizing a laptop in class to participate to the Menti quizzes, and lower audio due to the technical set-up in class. Remaining answers regarded general observations on the course structure (3/15).

Impediments related to following the hybrid courses online (see Q6 Table I) were described by 19/55 survey participants. Interaction was the most recurrent impediment (7/19), with respondents describing difficulties in interacting with the class (*e.g.,* to pose questions or comments) or with other students. Impediments related to the technical setting in the classroom were the second most recurrent issue (6/19), mostly describing issues in understanding questions/comments posed by in-class students. Difficulties to focus were reported by 6/19 participants, while only few respondents experienced technical issues (2/19), *e.g.,* connection stability problems.

Regarding the preference of future course structure (in-person, online, or hybrid, see Q8 Table I), the vast majority of respondents favored hybrid teaching (41/55). Other respondents preferred "in-person only" (11/55), while a minor portion regarded "online only" as best future format (3/55).

Further suggestions on hybrid teaching, provided by 24/55 respondents (Q9 Table I), regarded general considerations on the course structure (7/24), or feedback on the pre-recorded lectures (7/24). In general, students mostly expressed their preference for live lectures instead of pre-recorded ones, preferably followed up immediately by a Q&A session. Other suggestions provided by respondents regarded the technical in-class setup (*e.g.,* equipping in-class students with microphones), providing more attention to online students, and giving incentives to attend in-person.

Further comments and observations, provided by 12/55 respondents (Q10 Table I) mostly resulted to be out of scope (6/12), and regarded course material rather than hybrid teaching. Other suggestions iterated the dissatisfaction of prerecorded lectures, further articulating the inability such lectures provide to immediately interact with instructors to ask clarifications on the content of the lectures.

C. Results RQ_3: Hybrid Supervision Grade Comparison

In this section, the findings regarding grade differences of students supervised in-person and online are reported. An overview of the grade distributions is documented in Figure 8, while related summary statistics are presented in Table II.

From the visual inspection of the Figure 8, the grades of students supervised in-person and online appear to be bounded to similar empirical ranges, and present comparable median values. The similarity in ranges and median values is confirmed by the summary statistics presented in Table II, where similar minimum, maximum, mean, and median values can be observed for both SOD and D&S courses. In addition both courses showcase similar variability of grades (CV).

Nevertheless, from the visual inspection of Figure 8, a potential difference in distribution shape of in-person and online grades appears to be present. Online student grades seem to be more equally distributed across the empirical ranges, while in-person grades seem more concentrated towards the median grade values. To a small extent, such difference emerges also from the standard deviation values (σ) reported in Table II.

To systematically evaluate potential differences in distribution shapes, as preliminary step, both SOD and D&S distributions are tested for normality. From the inspection of Q-Q (quantile-quantile) plots, and the results of Shapiro-Wilk normality tests (W = 0.916, p-value = 1.133e-05 for SOD grades, and W = 0.865, p-value = 2.874e-05 for D&S), grade

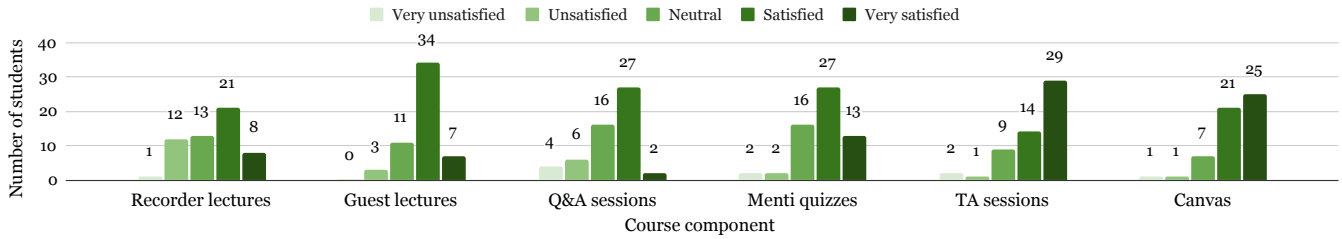
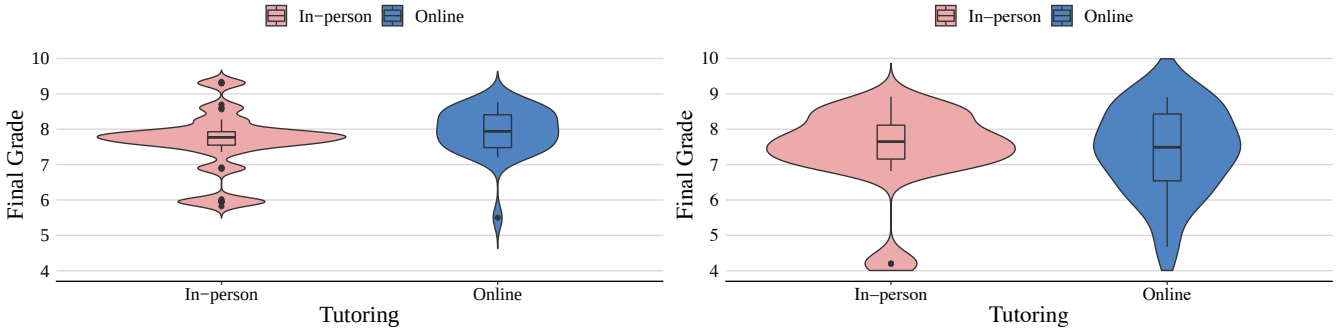


Fig. 7. Satisfaction with with hybrid course components of student survey respondents (Q5 Table I).



(a) Distribution of SOD grades

(b) Distribution of D&S grades

Fig. 8. Final grade distributions of students supervised in-person and online

distributions result not to be normally distributed for both courses. Therefore, the two-sample Kolmogorov–Smirnov (K-S) nonparametric test is used to evaluate potential differences. From the K-S test results (D=0.295, p-value=0.0447 for SOD, D=0.22917, p-value=0.6058 for D&S), grades of students supervised in-person and online result to be sampled from populations with different distributions for SOD, and same distributions for D&S. In other words, no statistically significant difference is observed for in-person/online D&S grades, while a difference is present for the in-person/online SOD grades.

IV. Discussion

In this section, a discussion of the results is documented as revisited RQs (Section IV-A) and guidelines (Section IV-B).

Regarding the applicability of the results, it would be expected that variations of the fine-grained RQ_1-RQ_3 results (Section IV-A) could be observed if different settings are considered, as further discussed in Section V-3 and Section VII. Regarding the guidelines instead (Section IV-B), given their general nature, they are very likely to apply to most hybrid teaching contexts.

A. Research Questions Revisited

Findings RQ_1 (Attendance and Interaction): From the results reported in Section III-A, a trade-off emerges between being able to focus/interact better in class, or follow lectures in a less formal and comfortable setting online. Most students prefer online, as it enables to be "present" and focus at will, while not being observed by other peers and lecturers. The possibility to be present online only when desired emerges also from webcam use, which steadily decreases (potentially with the focus of students) throughout the lectures, with webcams being used primarily to ask questions when desired. The frequency of in-person/online interaction depends on the specific course, and hence it cannot be concluded that in-person or online students interact more frequently than the others. However, it might be difficult if not impossible to bring the quality of online interaction on par with in-person interaction. As implication to RQ_1, the tradeoff between the pros and cons of following a course online or in-person is a highly personal choice, that ultimately should be made by the students themselves, and not forced upon them by educators.

Findings RQ_2 (Student Perception of Hybrid Teaching): The trade-off between in-person focus/interaction or online comfort, already discussed for RQ_1, is further remarked by the RQ_2 results (see Section III-B). Online attendance enables flexibility and avoids commuting, while in-person attendance provides better interaction and focus. Course components characterised by a higher need for swift interaction, *e.g.,* TA sessions and students presentations, are preferable to be provided in-person. The choice of providing a certain course component in-person or online can highly influence student course satisfaction. Even if following courses online comes with challenges, *e.g.,* worse interaction quality, and audio/focus issues, students highly prefer hybrid teaching. The choice might be rather obvious, as hybrid teaching provides students with the possibility of choosing the setting they prefer, while coming at the small cost of experiencing some potentially new and unfamiliar impediments. The answer to RQ_2 implies that hybrid teaching, while coming with unique pros and cons, allows for a flexibility which is highly appreciated

by students. Therefore, educational systems should strive to provide hybrid teaching, by mitigating as much as possible its potential drawbacks (as discussed in this and the next section).

Findings RQ_3 (Hybrid Supervision Grade Comparison): The results of RQ_3 (see Section III-C) draw a clear picture: while the grades of students supervised in-person and online are comparable (even if some differences are course-dependent), online supervision might not be for everyone. In fact, while in-person/online grades are comparable in terms of range and other summary statistics (*e.g.,* minimum, maximum, and mean grades), in-person grades are more concentrated towards median grades, while the online ones are more spread out through the whole empirical range measured. Hence, in conclusion, in-person supervision is a statistically better choice to gain a median grade, while being supervised online can lead both to achieve a higher grade, as well as a lower one.

As implication of RQ_3, students supervised online should be made aware that their grade might deviate from the median grade more than the one of students supervised in-person. Online/in-person supervision implies a risk (to get a grade both higher and lower than the median one), that students need to consider when choosing their supervision mode. This implication is further processed in Guideline 6, which is presented in the next section.

Findings Main RQ (Improving hybrid teaching student experience): Building upon the results of RQ_1-RQ_3, the answer to the main RQ can be formulated in terms of guidelines, as presented in the following section (Section IV-B).

B. Guidelines

In this section, a list of guidelines are documented, providing further insights into the results, and knowledge that might be re-applied, refined, or even confuted by future educators and researchers. The guidelines were derived by considering the results obtained from the different sources of data of the study, *i.e.,* the quantitative data of RQ_1, the RQ_1 research notes, the student responses collected for RQ_2, and the grades analyzed for RQ_3. For example, Guideline 1 was derived from the RQ_1 research notes regarding the class setup (RQ_1), and the survey responses provided by the students (RQ_2), *e.g., "improve the audio quality of other people in the room"*. A complete mapping of the link between the guidelines and the data sources they were derived from, as well as the complete coded data, is provided in the replication package of this study.

Guideline 1: ***Ensure a proper hybrid classroom setup*****.** Before starting a hybrid course, a proper classroom setup should be established. Paramount success factors are: (i) microphones are made available for both lecturers and in-person students, (ii) students/lecturers talking online are clearly audible in the classroom, (iii) slides are shared live both in the classroom (*via* a projector) and online. In addition, for further improve student engagement, live cameras of the classroom/instructor desk can be made available, and online students can be displayed in the classroom.

Guideline 2: ***Establish an online etiquette*****.** At the start of a hybrid course, students must be presented with a clear and comprehensive online etiquette. Advices range from recommending the use of web cameras, to suggest to connect from a quiet and private place, mute microphones upon joining lectures, attend lectures on time, and set up an interaction protocol (*e.g.,* raise of hand, web chat, *etc.*). Students should also be reminded to maintain a professional and methodical attitude towards following the lectures online.

Guideline 3: ***Check frequently on online students, let their voice be heard.*** Interacting with the class might be challenging for online students. Instructors should pay significant attention to ensure that online students are not neglected, are given the floor in time, perceive their interventions as valuable, and are overall empowered to interact with the class. If necessary, a TA can be assigned to oversee online students and resolve potential online interaction impediments.

Guideline 4: ***Engage online students.*** Online students might experience issues in focusing during lectures, leading to passive students, *i.e.,* students who never intervene and refrain from utilizing web cameras. To mitigate this issue, gamified and/or interactive course components, such as online quizzes or virtual collaboration boards (*e.g.,* Miro[6]), can be a valuable tool. If necessary, imbalances of in-person/online interaction frequency can be mitigated by giving online students higher priority, *e.g.,* by providing them more time to intervene, hence countering the swiftness characteristic of in-person interaction.

Guideline 5: ***Warn online students about potential focus issues.*** Following lectures online comes with unique focus challenges, and requires self-discipline, maturity, and organization. At the start of hybrid courses, students should be warned about focus issues, which may affect their achievement of learning objectives, and their general course experience.

Guideline 6: ***Make students aware that in-person/online supervision might affect their performance differently.*** While being supervised online could be beneficial for some students, it could also be disadvantageous for others. Students should be made aware that online supervision might not be the best fit for everyone, and that they should independently assess which setting works best for them.

Guideline 7: ***Empower students with their attendance choice.*** In hybrid teaching, it is crucial to provide equal opportunities to online and in-person students. The attendance choice and the rationale behind it is personal, and should not be imposed. Measures have to be taken to balance in-person and online student opportunities, ranging from ensuring all students are provided equal attention, quality of supervision, access to course material, and that students are not being hindered in any other way by their attendance preference.

Guideline 8: ***Carefully design course components by considering the hybrid setting.*** While designing a hybrid course, it is paramount to carefully evaluate beforehand which course components should be provided live/pre-recorded, and in-person-/online-first (*e.g.,* in the context of this study, student presentations and guest lectures respectively, see Section II-B1). The evaluation should include an analysis of the rationale behind the hybrid course structure (*e.g.,* "*Is synchronous interaction important for course component X?*"), and an investigation of potential implications and trade-offs.

[6]https://miro.com. Accessed 10 January 2022

V. Threats to Validity

Despite the effort invested, the results of this study could be affected by validity threats. By following the classification of Runeson *et al.* [17], four aspects are considered.

1) Construct validity: if the operational measures are appropriate to answer the RQs. To answer RQ_1, intuitive metrics (*e.g.,* number of students and number of web cameras) were used, by further supporting findings with the captured research notes. This should nullify potential threats to RQ_1. For RQ_2, potential mono-operation and mono-method bias threats [17] were mitigated by adopting a mix of open-ended and closed-ended survey questions, with a total of 10 different questions used to answer RQ_2. RQ_3 should not suffer from construct threats, as the single available metric embodying learning objective achievement, namely student grades, was used.

2) Internal Validity: if confounding factors influenced the results. TAs and students taking part to both SOD and D&S could have influenced internal validity. The potential impact of this threat is deemed small, as only a minority of TAs overlapped, TAs were distributed among online and in-person supervision (1 in-person, 2 online), and sessions to align TA feedback/grades were held. Only 3 out of 146 students attended both courses. The COVID-19 pandemic could have influenced student attendance preference, and results have to be interpreted within such context. However, attendance preference for future editions of courses (Q8 Table I) reflected the overall attendance findings of RQ_1.

3) External Validity: generalizability of the results. The findings of this study are embedded within the specific field of study (software engineering), and the educational context considered (*i.e.,* university, educators, student population, course topics, assignment structure, *etc.*). Therefore, the results have to be considered as framed within a middle-ranged theory. As discussed in Section VII, little assumptions can be made regarding the extent to which the results of this study can be transferred to other courses (especially if other domains or assessment methods are considered). From this threat emerges a call for action: the need of more evidence-based data on hybrid teaching already highlighted by Raes *et al.* [1]. As mitigation strategy, results were derived by considering two distinct courses, involving TAs with heterogeneous backgrounds, and a high percentage of international students (approximately 38%).

As additional threat, the results of this study were gathered during the COVID-19 pandemic. Therefore, the results need to be interpreted in light of the distinctive period of time considered. While this could have influenced the state of mind of the students, psychological implications of the pandemic are not part of the study. As such, it is complex to understand the possible psychological implication the pandemic had on students. Albeit this threat could not be mitigated, it did not appear to have majorly influenced the results, as student could independently choose to follow in-person or online, and the pandemic was never mentioned as a motivation behind attendance choices (see Section III-B). Given the raising trend of hybrid even before the pandemic [1], it would be interesting to see in future work if the same results can be observed.

4) Reliability: reproducibility and verifiability of the results by other researchers. To ensure independent reproducibility and verifiability of the results, all data and related formation is made available for scrutiny online.

VI. Related Work

With the popularization of information and communication technologies, hybrid teaching became a viable option for providing university courses [18]. The topic gained increasing popularity over time, and became a widely adopted solution during the COVID-19 pandemic [19]. In the context of software engineering, educators provided several insights of teaching hybrid courses. Through a survey, Motogna *et al.* [20] studied how transitioning from in-person to online/hybrid teaching affects student assessment. Differently from such study, this research does not focus on course adaptation, by concentrating on providing encompassing insights into hybrid teaching, where student assessment is only one of the facets considered. Włodarski *et al.* [13] investigated how hybrid teaching affects software projects delivered by students. Rather than focusing on software artefacts, this investigation aims at analyzing general hybrid teaching properties, with the goal of supporting educators with objective insights and guidelines. By surveying students, Shu *et al.* [21] demonstrated how hybrid teaching can be successfully used to increase learning opportunities and number of students. Rather than focusing exclusively on student impressions, this study adopts also lecture observations and student grades to gain a comprehensive overview of evidence-based hybrid class characteristics. Matthies *et al.* [9] documented experiences, challenges, and opportunities of teaching a project-based software engineering course online. Albeit noticing some common patterns, *e.g.,* seldom web camera use and poorer interaction quality, this study differs for the work of Matthies *et al.* for two main factors. First, this study focuses on hybrid, rather than online-only teaching. Second, this research concentrates on studying general aspects of hybrid teaching, rather than focusing on remote student project collaboration. Hjelsvold *et al.* [22], rather than focusing on hybrid students as this study does, considered the viewpoint of online-only computer science educators, by observing a strong motivation to collaborate and exchange experience between educators. Hodges *et al.* [23] warns about the differences between "emergency remote teaching" and online teaching. In the context of this study, "emergency *hybrid* teaching" might have influenced the results, as further discussed in Section V. However, the impact of such factor should have been mitigated by the fact that the SOD and D&S courses were provided in hybrid mode already a year before the COVID-19 outbreak.

From an independent scrutiny of the literature and a recent literature review on hybrid teaching conducted by Raes *et al.* [1], the findings of this study on hybrid lecture attendance [5], interaction [24], and grades [25] are corroborated by the existing literature. The review of Raes *et al.* [1] also identifies the guidelines present in the literature to optimize hybrid teaching. By comparing the guidelines present in the literature with the ones documented in this study, most guidelines results to be complementary, and treat different topics. For example, Cain *et al.* [26] suggest the role of "technology operators" to support educators and students with online course

components. In a different work, Grant *et al.* [27] highlight instead the importance of communicating expectations and the *modus operandi* of hybrid courses beforehand. The only guidelines presented in this study that are supported in the literature by other ones regard the attention that needs to be allocated to online students [28] (see Guideline 3), the use of quizzes to engage online students [29] (see Guideline 4), and the care with course components need to be designed in a hybrid setting [30] (see Guideline 8).

VII. Conclusions and Future Work

By presenting both raw data and refined results, this study provides evidence-based insights on teaching software engineering hybrid courses. The results support both (i) knowledgeable hybrid educators, who can compare their experience with the one reported in this study, and (ii) new hybrid educators, who can learn what running a hybrid course entails, and what is important to be aware of beforehand.

Based on the results gathered, driven by various reasons, students encourage the adoption of hybrid teaching. However, delivering a course as hybrid is a decision that should not be taken lightly. As documented in this study, while providing unique opportunities, hybrid teaching also comes with unique challenges. Loss of focus, poorer interaction, and higher grade variability are only some of the discovered risks. As reported by Raes *et al.* [1], a rich body of empirically-based knowledge needs to be built on the topic of hybrid teaching. This study, with its data, findings, and guidelines, strives to be a further step in that direction.

As future work, the threats to external validity of this study call for more evidence-based findings, collected by considering courses with other characteristics w.r.t. the ones considered (*e.g.,* non-project-based courses). In addition, it would be interesting to consider also courses outside the computer science domain, to assess if the results are replicable should a potentially less "technology savvy" audience be considered.

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