A Large-Scale Mixed-Methods Analysis of Live Streaming Based Remote Education Experience in Chinese Colleges during the COVID-19 Pandemic

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The COVID-19 global pandemic and resulted lockdown policies have forced education in nearly every country to switch from a traditional colocated paradigm to a pure online "distance learning from home" paradigm. Lying in the center of this learning paradigm shift is the emergence and wide adoption of distance communication tools and live streaming platforms in education. Here, we present the first-ever study on live streaming based education (LS learning) experience during the COVID-19 pandemic through mixed methods. We focus our analysis on Chinese higher education, carried out semi-structured interviews on 30 students, and 7 instructors from diverse colleges and disciplines, meanwhile launched a large-scale survey covering 6291 students and 1160 instructors in one leading Chinese university. Our work not only reveals important design guidelines and insights to better support current remote learning experience during the pandemic, but also provides valuable implications towards constructing future collaborative education supporting systems and experience post pandemic.

CCS Concepts:
• Human-centered computing → Empirical studies in HCI; Empirical studies in collaborative and social computing; • Applied computing → Distance learning; E-learning.

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INTRODUCTION

The COVID-19 global pandemic and resulted lockdown/social distancing policies have forced education across the world to abruptly switch from a traditional co-located paradigm to a pure online distance learning paradigm. As billions of students leave their school and proceed with their studies from home, instructors turn to various technologies to support their instructions. Lying in the center of this learning paradigm shift is the wide adoption of live-streaming based learning (LS learning) mode, where teachers connect with students through distance communication tool (e.g. Zoom, live-streaming platforms), give lectures, hold sessions and interact with students via software interfaces in real-time. Meanwhile, students rely on these platforms to collaborate and group learn with peers.

As demonstrated in Figure 1, live streaming based education deviates from traditional learning experiences in many important ways: Traditional classroom [37] corresponds to a co-located synchronous interaction mode where all teacher-student and student-student interaction takes place live at the same location. Massive online open course (MOOC) [46] belongs to a distant asynchronous interaction, where recorded videos are distributed online and learners could access the content any time they want. In contrast, LS learning belongs to a distant synchronous mode, where interaction happens in real-time yet physically far apart. Even though similar experiences as LS learning has emerged before the pandemic, e.g. [2], they are limited in coverage and restricted to very specific learning purposes. In comparison, current LS learning is distinct in that it is 1) large-scale in coverage, 2) ubiquitous and widely used across disciplines, and 3) primarily aimed for long term formal learning process rather than informal experience (e.g. one-time painting class). We wonder how LS learning experiences differ from more traditional educational formats, yet no study to date has systematically characterized LS learning experiences.

Given the importance of LS learning under the ongoing COVID-19 pandemic, as well as its expected significant roles in the upcoming 'hybrid' educational era, it is important to study how better LS learning experiences can be supported. We present this paper to fill in this research gap. Specifically, we ask: How has such LS learning support student learning from home experience during the pandemic? What are the issues and challenges under the current setups and how may we address them through future design? Perhaps most interestingly, are there any human-computer interaction (HCI) lessons we can take away from this unprecedented natural COVID-19 ‘learning from home’ experiment that can guide us in designing future education tools after the pandemic?

To shed light on these research questions, we present a first ever study on LS learning experiences during the COVID-19 pandemic through mixed methods. We focus our analysis on Chinese higher education, carried out semi-structured interviews on 30 students, and 7 instructors from diverse disciplines, meanwhile launched a large-scale survey covering 6291 students and 1160 instructors in one leading Chinese university. We focus our analysis on 1) individual learning experience, and 2) interaction experience between instructor-student and student-student. Our findings suggest live-streaming based education do help students and teachers achieve their education goal to a great extent, yet there are several key challenges emerging under the current paradigm, including students’ difficulties in paying continuous attention, decreased learning efficacy, and lack of engagement/collaboration experiences. We further demonstrate how various interaction formats (including audio, video, text box, danmaku, quiz, vote) within LS learning platforms enable novel learning experiences under LS learning, which contributes to variations in instructor-student and student-student relationships. Based on our analysis, we further propose
and discuss several teaching/learning practices under LS learning for courses of different characteristics. Finally, we propose important design guidelines and insights to better support current remote learning experiences during the pandemic, and offer valuable implications towards constructing future collaborative education supporting systems and experiences post-pandemic.

Contributions of this paper can be summarized as follows:

- To the best of our knowledge, we present the first large-scale systematic analysis of LS learning experiences through mixed methods in Chinese colleges.
- We reveal challenges and possibilities with regard to LS learning, and provide concrete guidelines on how to enable better LS learning experience given the current technology.
- Our study points to several important design implications on future educational tools to support LS learning (e.g., balance of anonymity and real-name systems).

2 RELATED WORK AND BACKGROUND

We first position our work in the rich education, live streaming, and remote collaboration literature from the HCI community, and provide an overview of popular LS learning platforms used by Chinese colleges during the COVID-19 pandemic.

2.1 Education Formats

Past human-computer interaction (HCI) and computer-supported cooperative work (CSCW) researches have shown that the spatial distance [34] and temporal synchronization [16] would exert immense distinctions in efficiency and experiences in the education domain. With these two aspects as classification criteria, education can be divided into 4 categories: co-located and synchronous, distant and synchronous, co-located and asynchronous (rarely implemented), and distant and asynchronous (see Figure 1).

Traditional classes belong to the co-located and synchronous format. HCI and CSCW researchers attempted to develop tools for digitizing and supplementing face-to-face learning, helping provide peer feedback [37], support reflection, communication and planning [20], deliver quizzes [35], and reflect on teachers’ performances [1], etc. The majority of works on the distant and asynchronous education format concentrated on Massive Open Online Courses (MOOC). Some research efforts have been dedicated to investigating MOOC students’ [46] and instructors’ [47] motivations and perceptions towards MOOC usages. Other researches focused on understanding
and modeling specific MOOC features, including forum use [3], virtual team formation [42], geographic diversity in MOOC discussions [22], divided attention [44], and MOOCs’ support on employability [7]. Some other researchers focused on paid degree programs within distance education. For instance, Sun, Rosson and Carroll [38] investigated community among online learners in remote learning programs. Sun, Wang and Rosson [39] uncovered how distance learners connect with special focus on shared identity, focused work and future possibilities.

However, very limited attention has been paid to the distant and synchronous learning form. Works on telepresence, such as Newhart and Olson’s [33] has taken the preliminary steps into understanding remote learning engagement, but only from instructors’ perspectives. Chen, Freeman and Balakrishnan [2] revealed how different modalities shape language-learning live streaming. However, existing work on synchronous distant learning is constrained to voluntary/informal learning, the context and motivations of which is far different from formal education (e.g. college). Different from them, in this work we examine the live streaming based remote education experience – the form of distant and synchronous learning enabled and forced by COVID-19 at scale in Chinese colleges where studies are carried out under formal education settings.

2.2 Live Streaming in HCI and CSCW

As an increasingly popular medium, live streaming has attracted the attention of numerous researchers in the HCI community. One line of work focused on the general usage of live streaming and highlighted its similarities and differences compared to other mediums. For instance, Juhlin, Engström and Reponen [18] demonstrated what contents are shared on these platforms and how people manage these contents. Dougherty [8] evaluated live streaming from the civic engagement angle. Tang, Venolia, and Inkpen [41] characterized motivations behind live streaming, and Lu et al. [28] focused on China as a case study. Haimson and Tang [11] identified immersion, immediacy, interaction, and sociality as drivers of engaging live streaming experiences. Other studies focused on the use of live streaming in specific domains, for example, video games [12, 24], visual art [45], intangible cultural heritage [25], knowledge sharing [27] and outdoor activities [26]. Some recent studies have taken the first steps into leveraging live streaming for learning. Faas et al. [9] examined how live streaming enables programming mentoring. Chen, Freeman and Balakrishnan [2] investigated how diverse modalities can be used for live streaming to support language learning. Sun et al. [40] revealed how live streaming can be adopted for online lectures with audience flow prediction. Here, we focus on understanding student experience under recent emerging live streaming enabled formal education (LS learning) during the pandemic - an important yet not well-studied application instance of live streaming.

2.3 Remote Collaboration Tools and Experience

Remote collaboration has long been a central topic in CSCW literature. Much work has been done in this space to understand and support better remote collaboration tools and experience [21, 34]. Two important lines of studies that closely relate to our work are performance and peer to peer relationship research under remote collaborations. With regard to performance, Gumienny et al. found that idea generation and feedback collection can be facilitated if a remote collaboration system offers real-time synchronous editing as well as asynchronous inputs [10]. A series of research has been done to understand the role of spatial audio and video in supporting more engaging remote collaboration experiences [14, 31]. Junuzovic et al. [19] studied the layout guideline for designing more effective multi-party, gaze-aware desktop videoconferencing tools. In terms of member relationships under remote collaboration, research has been done to investigate remote team viability [43]. Macaranas et al. [30] studied how watching video programs together at a distance affects team cohesion. Building on top of the rich CSCW literature on remote collaboration, here we investigate how LS learning as an emerging instance of remote collaboration between student and teacher, impacts learning experience from both individual learning outcome and group collaboration effectiveness/inclusiveness perspectives.
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2.4 Live Streaming based Remote Learning Platforms in China

We then give an overview of popular live streaming based remote learning platforms in China. Several platforms are adopted for live streaming based learning in China during the pandemic. These platforms share the functions of enabling synchronized and live sharing of visual and audio contents. Here we introduce and summarize characteristics of different LS learning platforms used in China (Table 1).

Table 1. Summary of the basic characteristics of LS learning platforms.

| Platform                  | Example              | Video | Audio | Textbox | Danmaku [26] | Quiz | Vote |
|---------------------------|----------------------|-------|-------|---------|---------------|------|------|
| E-Classroom               | Rain Classroom       | ✓(1)* | ✓(1)  | ×       | ✓             | ✓    | ✓    |
| Video Conference          | Zoom, Tencent Meeting| ✓(2)  | ✓(2)  | ×       | ×             | ×    | ×    |
| Traditional Livestream    | Bilibili, Kuaishou   | ✓(1)  | ✓(1)  | ✓       | ×             | ×    | ×    |

*The number in the bracket indicates the interaction directions available (one-way/mutual interactions).

E-classroom. A few platforms are specifically designed for education, also known as e-classrooms. These platforms support synchronized visual and audio interactions and thus enable LS learning. One widely-adopted instance is Rain Classroom, which has been utilized by a wide range of universities. In Rain Classroom, instructors can not only broadcast live video and audio, share their screens, but launch quizzes and votes to students in the e-classroom. However, students are not able to turn on their own cameras or microphones to share their own visual or audio information. Thus most of the time the interaction is one-way, i.e., from instructors to students. Nevertheless, students could interact with the instructors through textual danmaku [26], which the instructors could choose to have it turned on or off.

Video conference. Online video conferencing platforms have also been adopted by a great many instructors [15, 17, 23] to fulfill LS learning, among which Zoom and Tencent Meeting are two of the most frequently used software. On these platforms, should the instructors/administrators permit, anyone in the class is able to turn on his or her microphone or camera, sharing audio or video contents. Text boxes are integrated into video conferencing tools which enable textual interactions.

Traditional Livestream. Some instructors implement LS learning through live streaming platforms such as Bilibili and Kuaishou. In these platforms instructors usually take the role of streamers, allowing them to share

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(a) LS Learning Through E-classroom, (b) LS Learning Through Video Conference, where (c) Demonstration of the Quiz/Vote Function. Where danmakus are marked in red circles, the instructors’ video is marked in red rectangle and the instructors’ video in blue rectangles and screen sharing is on the left.
audios, images and screens in real-time. Students act as viewers of the live streams and interact with instructors through text boxes. Some platforms such as Bilibili also support danmaku, where textual comments in the text box are shown upon videos in a danmaku manner.

In later analysis, we refer to all of the aforementioned instances as LS learning platforms. We focus on deriving conclusions that generalize to all LS learning experiences, rather than those specific to a single platform.

3  METHOD

To gain a more profound understanding of user experience under LS learning, we adopt a mixed-methods methodology combining in-depth interviews and a large-scale survey.

3.1  Semi-structured Interview Study

We interviewed 7 instructors and 30 students who engaged in LS learning in Spring 2020 semester, where we tried to diversify the disciplines of the instructors and majors of students as much as possible to attain variation [5]. Table 2 and Table 3 demonstrate the detailed information of the students and instructors participated, respectively. Interviewees starting with S (S1-S30) represent students, and participants starting with T (T1-T7) are instructors. The interviews were completed either in person or through remote audio calls and took the form of a semi-structured manner. In the interviews, we penetrated into how courses were taken through LS learning during the COVID-19 crisis, how the teaching/learning experiences were and how they differed from traditional face to face learning and MOOC learning, how the learning outcomes were, how instructors and students collaborated, and how they felt their relationships. The interviews were all conducted in Mandarin, each of which lasted around 30-45 minutes and compensated with an honorarium of 50 CHN. After receiving the oral consent of the participants, we audio-taped the interviews and transcribed them leveraging transcription service and manual modifications, where we removed the identifiable information to guarantee better protection of interviewees’ privacy.

Table 2. Summary of the basic information of interviewed students.

| ID  | Gender | Major              | ID  | Gender | Major              | ID  | Gender | Major              |
|-----|--------|--------------------|-----|--------|--------------------|-----|--------|--------------------|
| S1  | F      | Human Resources    | S2  | F      | Calligraphy        | S3  | M      | Chemistry          |
| S4  | M      | Electronic Engineering | S5  | F      | Materials Science  | S6  | M      | Electronic Engineering |
| S7  | M      | Math               | S8  | M      | Humanity           | S9  | F      | Law                |
| S10 | F      | Medicine           | S11 | M      | Telecommunication  | S12 | M      | Telecommunication  |
| S13 | F      | Public Policy      | S14 | F      | Marine Technology  | S15 | M      | Information Science|
| S16 | F      | Geophysics         | S17 | F      | Electronic Engineering | S18 | F      | Law                |
| S19 | F      | Automation         | S20 | F      | Building Environment | S21 | M      | Information Science|
| S22 | M      | Computer Science   | S23 | M      | Oral Interpretation | S24 | F      | Economics          |
| S25 | F      | Telecommunication  | S26 | M      | Telecommunication  | S27 | F      | Telecommunication  |
| S28 | M      | Mechanical Engineering | S29 | F      | Art               | S30 | F      | Foreign Language   |

To analyze the interviews, we first open-coded [5] the transcriptions. Two Mandarin-speaking authors separately coded 5 interview transactions and appointed for a discussion on the codes until reaching consensus. Then, one of these authors coded the remaining transcriptions and periodically discussed with the other author to guarantee agreements on the codes. One other native Chinese author was responsible for the translation of the codes and corresponding quotes into English and the aforementioned two authors were responsible for validating and refining the translations. Upon finishing these procedures, the whole research team thoroughly discussed the contents that had been extracted. With sub-categorization and constant comparison, we developed and continually amended the emerging themes.
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3.2 Survey Study
To ensure the generalizability of our findings, we further launched a large-scale survey study in a leading Chinese university where several live streaming platforms and distance communication tools are officially provided for teachers to enable LS learning. The survey was distributed through a college-level administrative approach towards (1) instructors who have taught at least one course in both Fall 2019 semester and Spring 2020 semester, and (2) students who have taken coursework in both Fall 2019 semester and Spring 2020 semester. We compared the learning experience in Fall 2019 semester (all education in traditional co-located classrooms) vs. Spring 2020 semester (all education through LS learning). We focused on the differences between the two consequent semesters so as to measure the changes brought by LS learning. Questions include learning/teaching experience, quality, outcomes, practices, and effectiveness, with a special focus on education experiences and learning and teaching behaviors. A total of 1160 instructors and 6291 students participated in and validly responded to the survey.

The instruments utilized in the survey are adapted from previous research [32, 36]. A four-point rating scale was used with descriptions such as ['not at all', 'very little', 'quite a bit', 'very much'] or ['never', 'rarely', 'sometimes', 'often']. It is worth noting that due to the large-scale nature of the survey study, statistical significance testing is not appropriate as large scale data tend to signify most differences as significant. Therefore, we adopt an ‘effect size’ perspective instead, where a difference no less than 1/3 of a standard deviation in the mean score is considered as a meaningful effect [4].

4 FINDINGS
In this section, we report our findings on LS learning experiences. The major themes emerging from our mixed-methods study can be characterized into: 1) interaction formats experience on specific platform features, 2) overall individual learning experience, and 3) interactive learning experience between instructor-student, student-student, and community perception.

4.1 Interaction Formats in LS Learning
LS learning supports a wide range of interaction formats, ranging from audio, videos, text box messages, danmakus, quizzes to votes. All these features have been recognized as contributing to the overall functioning of live streaming-based remote education by our participants, where participants illustrated how these features shape live streaming-based remote education.

**Audio.** Audio was the most used modality by instructors. In a live streaming class, in most cases only the instructor leaves the microphone on throughout the class, and students only turn it on when they answered questions – otherwise the class would be too noisy (T2, T3, T4). There were also some classes that required every student to turn on their microphones, especially small classes, which allowed students to interrupt the class anytime if they had questions (T5), and classes that required a substantial amount of interactions between instructor and students. One example is during a Russian class, the instructor asked everyone to turn on his/her microphone since “the class needed synchronous practices of Russian between students or between students and me. **Table 3. Summary of the basic information of interviewed instructors.**

| ID | Gender | Discipline                        | ID | Gender | Discipline                        |
|----|--------|-----------------------------------|----|--------|-----------------------------------|
| T1 | F      | Foreign Languages and Literature  | T2 | F      | Education                        |
| T3 | M      | Data Science                      | T4 | M      | Telecommunication                 |
| T5 | F      | Physical Electronics Experiment   | T6 | M      | Nuclear Science and Technology   |
| T7 | M      | Foreign Languages and Literature  |
Chen and Cao et al. [the instructor]” (T1). T1 also emphasized that only small classes could allow students to turn on their microphones throughout the class: “if this was a big class, we cannot do it since there would be too much background noise that would interrupt the class”.

Most instructors would set up separate question and answer (Q&A) sessions to answer students’ questions after class, and in this case students would be allowed to turn on their microphones throughout the session. “Audio makes communication more convenient and accurate”, according to S25, “thus I’m more willing to ask my questions by speaking up instead of typing up”.

There were also some complaints about using audio. S5 raised the concern that the interaction between the instructor and students through microphones might interrupt the pace of the class. For example, during one of his fast-paced classes, “occasionally there would be some students asking trivial questions that would drag the pace of the whole class behind” (S5). S5 also mentioned that he felt “the quality of communicating online through microphones is worse than the quality of face-to-face office hour session at offices due to the absence of boards and pens: it would make much more sense if the instructor could draw some graphs to explain how things work instead of pure talking” (S5). Furthermore, S27 reported a technical instability that once her microphone was automatically turned on in one of her classes and made her feel “very awkward” since she was singing.

Video. Apart from audio, video was the second frequently used modality by instructors. There were mainly two kinds of video displays combined in a live streaming class: 1) turning on video and displaying one’s face through the front camera and, 2) sharing one’s screen. For the majority of classes, only the instructor turned on the camera to let students see his/her face throughout the sessions. In most live streaming sessions, the instructor also would share his/her screen to let students see lecture slides or anything that was related to the class. While sharing one’s screen with students, most instructors insisted on showing their faces to students. As commented by T2, "No matter how advanced technology is, we think humanity plays an irreplaceable role in education ... it is very important to let students see us, so that they would feel like in a real classroom” (T2).

In most LS classes, students would not turn on video all the time. If everyone turned on his/her camera throughout the session, sometimes the internet and the platform would become very unstable, thus negatively affecting the quality of classes. Due to the technical issue, T1, T3, T4, and T5 chose to turn off students’ cameras. However, many teachers emphasized the importance of seeing students’ faces in the interviews. For example, T1 would ask students to turn on their cameras for several minutes sometimes during the class to have a better sense of “students’ states”, and T2 felt it necessary to see every student’s face to “promote emotional interactions”.

From students’ perspectives, the majority of students agreed that turning on their cameras “made them feel more motivated and concentrated” during the class (S21, S23, S27 & S29). S9 and S29 also mentioned that they liked to see everyone’s face since “it just feels like a normal class: we are sitting in a classroom and listening to the teacher” (S9).

There were also some students, e.g., S23 & S25, who disliked showing their faces to everyone: “it’s so awkward turning up the camera and I really don’t like others seeing me wearing pajamas in my bedroom” (S23). Another concern was raised by S2, who complained about the inconvenience of using the video modality when she was practicing calligraphy in class: "previously, since the instructor was in the classroom, the instructor could provide feedback to each student immediately if he/she found something wrong; now we have to show our calligraphy by the front camera after we finished, thus we could not receive the feedback in time” (S2).

In addition, many students reported that a benefit of the video modality during a live streaming class is that students could “see the instructor’s face and blackboard clearer and listen to the instructor’s voice clearer”, while pre-pandemic only the first several rows of students in a classroom could see and hear the instructor clearly (S1 & S12).

Text box. Text box was used frequently throughout the live stream sessions by students. Students used the text box for various purposes: greetings (S12, S20), asking questions (S5, S20, S23), discussing problems (S6, S25, S27), providing feedback to instructors (S10, S21), etc. "Because the comments were not anonymous, we were cautious
when sending comments”, said S25. The majority of the students made similar observations to S25’s. Many of them also reported that “discussing problems in the text box made us closer” (S12), pointing out that thinking about other peers’ questions was inspirational and helpful for their own learning.

On the other hand, teachers did not use the text box as frequently as students did. For example, both T1 and T4 admitted that they seldom checked the text box since they “forgot to check it while teaching” (T4). Other interviewees said they mainly used the text box to post some simple quizzes (T2), get feedback from students (T2), and answer students’ questions (T3, T5). In addition, the text box was not presented at the screen unless the user clicked it. During a live streaming class, the instructor checked the text box at a specific time – normally at the end of the class, since “checking text box too frequently would interrupt the pace of the class” (S10). Thus, according to S6, “instructors seldom answer questions immediately, creating some gaps between students’ discussion and the instructor”.

Danmaku. Besides the text box, danmaku was another frequently used modality throughout the live stream classes by students. Danmaku refers to a form of user comments that are displayed over videos [29]. In the scenario of live streaming, danmakus are real-time user comments that are displayed over the live video during the live stream [26]. During a live streaming class, students could send danmaku at any time, which would be displayed synchronously at the top of the screen and visible to everyone in the class, including the instructor. Danmaku appeared at the top right of the screen, moved from right to left, and eventually disappeared from the screen. Unlike the text box, danmaku was anonymous, which made the comment “less formal and much more casual” (S12), and thus “encouraging more students, especially those who were too shy to speak up in front of people and to participate in the class” and “building a stronger tie between the instructor and students” (S8). The majority of students made similar comments to S8’s, including S4, S6, S8, S12, S16, S18, S20, S27, etc.

Some students, e.g., S6, S12, and S27, expressed their concerns towards danmaku that sometimes sending danmaku can be contagious, and a large amount of irrelevant and useless danmakus might “interrupt the class and distract people’s attention” (S6). This issue could be avoided if users clicked the disable danmaku button. For example, S29 chose to disable danmaku during one of her classes when “the instructor said something very funny, and everyone started to send 'haha' or amusing emojis” to avoid distraction. In addition, another concern of danmaku is that danmaku cannot be kept or saved, but sometimes “the content of danmaku can be essential to learning and worthy of being saved” (S18). Similar perspectives are also expressed by S6 and S8.

Unlike students who were enthusiastic about danmaku, teachers rarely used it. As T2 commented, “danmaku is more of a communication way between students than between us and students”, and T1, T2 and T3 all reflected that they did not often check danmaku or not enable it at all. Moreover, although T4 always paid attention to danmaku during the class since there were some “valuable questions”, he mentioned a drawback of danmaku that “sometimes students sent long and complicated danmakus, but those danmakus just slipped away too quickly so that I could not grasp”.

Quiz. Quiz (Figure 2(c)) was occasionally assigned to students during LS classes. Instructors mainly used the quiz to test “whether students paid attention to classes” and to “get some feedback from students” so that they could adjust their teaching schedules accordingly (T2). T4 also mentioned that the quiz could remind students to focus on the class if they got distracted. Correspondingly, from students’ point of view, e.g. S6 & S16, solving quizzes was indeed “helpful in staying concentrated in class” (S6). Moreover, some interviewees, including S18 & S20, also agreed with the instructors that “quizzes were an efficient way to reflect our [the students'] understanding of the materials so that the instructor could adjust the pace and materials based on the results of the quizzes” (S20).

A quiz mostly consisted of simple multiple-choice questions. Some instructors mentioned in the interview that they would like to try some short-answer questions, but by doing this there would be some technical issues, including the inaccuracy of “character recognition”, according to T2. T4 also reflected that most quizzes could not “reflect students’ understanding comprehensively” due to their limited length and form.
Technical instability was reported by students while taking a quiz. Since in most cases there would be a grade of the quiz which might affect one’s grade point average (GPA), technical issues might affect students’ grades a lot. According to S7 & S8, some of their classmates encountered technical issues using quizzes: “there was one time my friend could not submit the quiz due to the technical issue of the software and got a zero in the end” (S7). Furthermore, many students reported that taking classes remotely made them hardly focus on the class or stay vital, which consequently affected their performances on quizzes: S5 mentioned that sometimes he “made many mistakes on simple questions when I [he] felt distracted and asleep”.

Vote. During a live streaming session, the instructor sometimes used votes (Figure 2(c)) to better understand students. Unlike taking a quiz, votes would not generate a score or affect students’ grades. For instance, S25 mentioned that his teacher initiated a vote on choosing “submitting an electronic version of homework or taking pictures and then uploading them” (S25), and S29 reported that in one of her art history class, the instructor initiated a vote on students’ preferences on art pieces. Based on the vote, the instructor would focus on the most favored ones during the class, which “makes the materials of the class more fascinating and humanized” (S29). Moreover, some interviewees, e.g. S6 & S8, reflected that votes “encouraged more participation in the class, inspired more discussions, and thus made us [students] feel more concentrated and energetic”.

4.2 Individual Learning Experience Under LS Learning

Besides specific interaction features, students and instructors also illustrated how students’ overall learning experiences were shaped by live streaming-based remote education under the COVID-19 pandemic. Here we focus on three major aspects of individual learning experience: study time, focus and engagement, and learning outcomes.

Study Time. Some students, including S5, S9, S10, S16, S21 & S25, reported that they spent approximately the same amount of time on studies compared to the pre-pandemic traditional learning. As reported by S21, “we just followed the same schedule before the pandemic outbreak, so there were not many differences: same classes, same workload, same people” (S21). However, many other students in our interview study reported that they were studying longer time under LS learning. Many of these interviewees attributed this to decreased study efficiency (e.g., S2, S3, S6, S14, S20). As reported by student participants, their study efficiency was lowered due to the decrease in concentration (S2, S3, S6, S18, etc.). We would talk about the reasons for students’ decreasing concentration during LS learning in more detail in Section 4.2.2.

Some interviewees also reflected that they had spent more time on searching for extra-resources (S29), reviewing class recordings (S2, S6), and doing homework, since peer collaborations and discussions, which benefit a lot for course understanding and homework completion, were hard to organize online (S11 & S29). This increase in study time per course was further corroborated by our survey: 37% of students reported an increase in time on average for each course; in comparison, 22% of students reported a decrease.

Besides self-study time, it is also noted that non-study issues took up much time that should have been dedicated to studies during live streaming sessions. Several students, including S3, S18, S20, S23 & S27, reported that they had spent less time on actual studying in lectures because of technical difficulties. According to S23 & S27, there was lots of in-class time wasted on adjusting equipment and questions such as students asking whether the instructor could hear them. This cut into the amount of actual learning time during the lecture.

Focus and Engagement. Almost all interview participants reported low study efficiency at home. They found it difficult to focus on live streaming videos, and this reduced their studying productivity. As commented by S10, “I kept telling myself that I should be productive and focus on the instructor, but I always got distracted by some trivial stuff while staring at the screen and when I realized I was not paying attention to the class, I was already far behind ... so I just gave up on this class and did my own stuff”. Many participants, including S1, S3, S4, S7, S14,
S18, and S25, expressed experiences similar to those of S10’s. Our survey also supported this conclusion: 43% of students reported a decrease in concentration, but only 27% of students reported an increase.

Perhaps the primary contrast to students’ experiences before and after the pandemic may have been the change in the environment: from campus, a community-based public area consisting of various facilities such as libraries, dormitories, and classrooms, to home, an individual private area with limited resources. The absence of peers physically around and the lack of a community-based learning environment were mentioned as two leading factors in the decreased focus, engagement, and productivity. “At my own home, I was just not in the mood to study”, said S29, “and I really missed libraries since looking at peers studying in libraries would motivate me to study”. S7 also conveyed the same feelings, “in libraries there are a lot of students studying, but now there is only my studying, which makes me feel very lonely”. Moreover, according to S25, “since there were no people around me, I did not feel any pressure to study”, and thus she felt she could “do whatever I [she] want[s] and allow[s] myself [herself] to get distracted”. The survey also reflected similar results that the mean score of whether remote learning created a good intellectual environment decreased from 3.14 in Fall 2019 to 3.07 in Spring 2020. A drop of 0.07 supported the finding that a less satisfactory learning environment during remote learning. However, this drop did not reach 1/3 of the standard deviation and we concluded that not a meaningful educational effect was spotted through our survey.

Multitasking [6] was a leading consequence of the changes in the study environment. Without the instructor’s supervision, many students reported that they spent most of their time playing on their phones. Conversely, in a traditional classroom, students admitted that they would not have used their phones as frequently since “obviously the instructor could see me [them]” (S2). In addition, S9 described another common multitasking situation: “I used to listen to peers carefully when they would ask or answer questions; however, now I always browse websites while other students are talking”, and situations such as eating (S11) or even sleeping (S15) while taking LS courses are also mentioned.

Apart from multitasking, interruption was another consequence of the changes in the study environment. Many participants said that there was always trivial stuff happening at home which would interrupt the ongoing lecture. For example, “sometimes there were people knocking at the door so I need to open the door” (S27) or “my mom suddenly asked me to help her move the table” (S21). Consequently, those domestic interruptions strongly distracted students’ attention from the class.

In addition, fatigue was also a common problem with learning from home. The majority of the participants, including S5, S6, and S8, reflected that after staring at the screen for a long time, they felt dizzy, exhausted, and heavy-eyed. As S5 described,

“On Tuesday, I have classes from 8 am to 12:15 pm, then have lunch, and then take classes from 1:30 pm to 3:05 pm. During this process, I just feel so dizzy staring at the screen in my room. (I) could not concentrate. However, when I looked at the blackboard in a real classroom, I do not feel this tired ... I am supposed to do homework in the evening, but I just don’t feel like studying or doing any work. And days just pass like this. Very inefficient and wasted. I also don’t get the chance to talk to people (in real person), to go out for a walk, or to do sports, which should ameliorate fatigue.” (S5)

**Learning outcomes.** In terms of learning outcomes, from the perspective of grading, most students reported that their grades had been affected little by switching to live streaming class, including S2, S4, S5, S6, S7, S11 and S12. As S21 explained: “The instructor teaches the same materials as before, and the only difference is that now we take virtual classes”. The result of the survey was also parallel to S21’s comment. According to the survey, students gave relatively similar scores on whether instructors had a clear and helpful course structure (AVE(Fall 2019)=3.21 vs. AVE(Spring 2020)=3.17) and whether the course developed critical thinking during remote learning (AVE(Fall 2019)=3.21 vs. AVE(Spring 2020)=3.20) on average.
Several students, e.g. S8, S14 & S16, shared that their grades had been higher than before because they felt “the instructors were less harsh on grades and gave relatively higher GPA” (S16). When we interviewed teachers about the grading policies, some instructors, including, T2, T3, and T5, did acknowledge that they had given open-book exams and were more generous in grading due to online learning. Another reason for students getting higher grades was due to a more effective virtual teaching environment. According to S1 and S8, they got higher grades because of remote education due to the change in environment, as was explained in detail in Section 4.2.2. “I just did not have a feeling of studying”, S3 commented, “since there was no peer pressure to motivate me to study”.

Since grading alone was not a comprehensive measure of students’ performances, we chose to investigate knowledge mastery through theory and practice and social skills to get a better sense of students’ overall performances.

From the theoretical perspective of knowledge mastery, there seems to be little difference between traditional learning and LS learning. The survey suggested similar scores on how well students had mastered field-specific knowledge and skills: a drop from 3.31 (Fall 2019) to 3.27 (Spring 2020) was spotted, creating a small difference that did not reach 1/3 of the standard deviation and thus not showing a meaningful effect. Similar perspectives were also expressed in the interviews. The majority of interviewed students reported that they did not think they had mastered more or less material than they had in traditional learning, including S1, S8, S18, S23, and S27, since “the materials that were required to understand did not change” (S27).

Besides theories, practice was also essential to mastery of course materials. Many students complained about their laboratory courses or courses that involved real-world practices. As the survey suggested, the average score of whether remote learning promotes research experiences dropped from 2.31 in Fall 2019 to 2.15 in Spring 2020. With a drop of 0.16 that exceeds 1/3 of the standard deviation, a meaningful education effect was observed. This is corroborated by the interview study as well. For example, S4, S5, S6, S16, and S27 all studied engineering-related majors. Each mentioned they had struggled while conducting experiments remotely. S5, a materials science major, complained that since it was impossible to conduct experiments remotely, “the teacher sent us [students] a photograph of the apparatus and asked us [students] to draw pictures based on the photograph”. However, “the photo was too vague to reflect the 3D structure in detail”, and he could only “use imagination to draw”. S20, a computational law student, also pointed out that in one of her classes, students were supposed to provide legal aid to people, but this real-world practice of law was canceled and changed to online case reviews. “The whole class just became pointless”, S20 commented. Some students reported good online practice. For example, S29, an art major, reflected: “Live streaming sessions actually brought new forms and inspired students. For example, in one of my modern art history classes, there was a presentation session. Normally in a traditional class, we would just make a PPT for the presentation. However, in a live streaming presentation session, many students were inspired to use more innovative forms, such as animation and mindmap”.

Other than academic aptitude, socializing was also important to college students to maintain mental health [32]. Many students, including S21 and P27, expressed that they were afraid of the gradual loss of in-person communication ability, if remote classes were instituted as a long-term policy. As reported by S21, “although we could chat through audio or some chatting software, that kind of daily casual interaction kind of disappears” (S21), S29 agreed with S21 and added that he felt due to the loss of daily casual interaction with peers, “it was kind of ‘cheaper’ to communicate online, and I felt I was getting lazy and gradually losing the ability to make real in-person conversations with people”. The results of the interviews were parallel with those of the survey. From the perspective of students, the mean score of social skills dropped from 3.19 for Fall 2019 semester to 3.03 for Spring 2020 semester, which makes a decrease of 0.16 that surpasses 1/3 of the standard deviation and thus suggests a meaningful educational effect.
4.3 Collaborative Learning Experience Under LS Learning

We present results on three kinds of collaborative learning experiences under LS learning: 1) the instructor-student interaction experience, 2) the student-student interaction experience, and 3) sense of community.

**Instructor-student Interaction: Most Experience a Closer Relationship.** According to the survey, the average interaction score between teachers and students, from the students’ perspectives, increased from 3.19 in Fall 2019 to 3.22 in Spring 2020, where the increase does not reach 1/3 of the standard deviation and thus does not demonstrate a meaningful education effect. However, in our interview study, many students did report that they had developed a closer relationship with their instructors. S7, S8, S16, S18, S20, S25, S27, and S29 each mentioned that live streaming-based classes, especially the text box and the danmaku, had made them feel “more relaxed, less awkward, and more motivated to respond to teachers” (S29). “I really like the text box”, S7 said, “since we can comment or ask questions whenever we want without interrupting the class”. Similarly, S25 commented about the danmaku modality that “we don’t need to raise our hands and wait to be called anymore ... we can always send a danmaku whenever we want to say something”. Many students, including S8, S27, and S29, also reflected that the anonymity of danmaku encouraged more students to participate in class, and thus “shortened the distance between teachers and us [students]” (S20). Furthermore, S29 not only reported more frequent conversations with the instructor in class, but also after class:

> “Due to live-streaming classes, I found some of my teachers were actually very friendly and interesting, and I had not felt this way before. Sometimes we would send funny danmaku during the class, and the way our instructor responded was as if he was our friend. After class, I would directly send messages to the instructor if I had questions” (S29).

There also were a few students who reported an equal or a more distant relationship between themselves and their teachers. S9 and S21 felt that their relationships with teachers had become neither closer nor more distant since “we [students] were having classes just as before and we [students] never felt close to teachers ever” (S21). For some students, their perceptions of instructor-student relationships may have changed over time. For example, S10 emphasized that in the beginning of the live-streaming remote education, he had not been used to having conversations with teachers through online chatting, so he “felt distant with the teachers in the beginning” (S10); but soon he acclimated to the new learning mode and no longer felt the same way anymore. Moreover, S8 mentioned that although he felt “psychologically closer to the instructor”, he also felt “physically distant from the instructor”.

Contrary to the closer student-instructor relationship reported by most students, some teachers felt that interaction with students was less efficient and that they had a more distant relationship with them because they could not see their faces during a live-streaming session. As we explained in Section 4.1.2, in most cases students would turn off their videos due to network instability. Many instructors mentioned that the inability to see students’ faces during a live streaming class would impede “some of the emotional attachment” and “instantaneous feedback” between teachers and students (T4). As T4 reflected:

> “As a teacher, I can see whether students understand the materials through their eyes and their stares. If many students look really confused, I can immediately receive this feedback from their faces and explain the material again. In addition, recognizing students’ faces is significant to me since it makes me feel close to students emotionally”.

However, this was relatively hard to maintain when courses are turned online.

Furthermore, according to most instructors, this loss of instantaneous instructor-student feedback decreased teaching efficiency. For example, T1 described:

> “I could not see students, and I did not know what they were doing. They might have been playing computer games or chatting with friends while I was teaching. They could have been doing whatever
they wanted... This is definitely a disadvantage of remote learning: significantly decreased teaching efficiency. A traditional class feels like a group discussion: both students and I [the instructor] contribute to the class; a remote class feels like me talking to myself. I don’t know how well students understood the materials or what the teaching pace should be”.

Instructors tried various means to cope with this loss of real-time feedback: calling on students to answer questions (T1), using the chat box to answer students’ questions (T7), asking students to turn on their cameras occasionally (T1), and staying after classes or providing additional office hours sessions to talk to students (T6). In addition, some instructors did mention that some modalities of live-streamed learning had indeed increased teaching efficiency. For example, T2 mentioned that giving quizzes during the class increased teaching efficiency since he could receive students’ grades immediately for a sense of their performance. These means did allow teachers to build closer relationships with students, on average. According to the survey, the average score of interaction between teachers and students from the perspectives of teachers increased from 3.47 in Fall 2019 semester to 3.52 in Spring 2020 semester. However, the increase did not prove to hold a meaningful education effect since it did not reach 1/3 of the standard deviation.

Student-student Interaction: Most Experience More Distant Relationship. In terms of interactions between students, our survey result suggested a decrease in student-student interaction, since its average score (from the view of students) decreased from 2.88 for Fall 2019 to 2.74 for Spring 2020, where a drop of 0.14 exceeds 1/3 of the standard deviation and indicates a meaningful education effect. Although student-student experience involved various scenarios, participants in our interviews discussed this subject mainly through two lenses: studying and leisure interaction. In terms of students’ interactions during their study time, what was frequently mentioned is student-student interactions during peer collaborations. For the latter part, special attention was paid to social interaction between students during their leisure time, which refers to activity that is unrelated to academics.

Many students reported less frequent interaction with other students and decreased work efficiency during online group work according to the survey: the mean score of students to report working effectively with each other decreased from 3.18 in Fall 2019 to 2.95 in Spring 2020, creating a meaningful education effect where the 0.23 drop exceeded 1/3 of the standard deviation. This is in line with what was reported in our interview study. S7 and S14 reflected that rather than actually collaborating, they simply split the work by assigning work to each group member, and during the process of group collaboration, there was no other communication. What’s more, it was reported that some students may lack the motivation to attend online meetings and cooperate (S10 & S14). For example, according to S10, there were always "some members who never showed up to the meeting and did not reply to any messages in the group chat". Although sometimes this is also the case for the offline settings, with a layer of screen mediated, cases like this are more likely to happen (S10 & S14). Moreover, in a traditional meeting, students often booked a room so that all members could work together, where "each group member would know other members’ progress and give feedback immediately if something is going wrong” (S10) and “a sense of collaboration was sensed” (S15). However, when collaborations were turned online and peers were segregated physically, “not a sense that we are working together” (S15) was felt. Students felt rather isolated and collaborations turned to the mere “assigning tasks to each individual and checking the progress of each other one by one” (S10). In addition, since setting up a remote meeting for every group member was hard due to students’ different schedules, the chat box was frequently used to discuss ideas. In this way, group members would communicate asynchronously. S10 and S20 both reported that sometimes it was "hard to use text to convey the exact information” and kind of "a waste of time while waiting for others’ responses” (S20).

On the other hand, some students reported an increase in student-student interaction, as well as increased study efficiency. As discussed in Sections 4.1.3 and 4.1.4, the chat box and danmaku stimulated a significant increase in communication between students, and some students reported "a deeper understanding of the materials” and
higher study efficiency since “teachers did not have time to answer every question immediately” (S12) while other students can provide the expected answers in real-time. Furthermore, contrary to students who complained about the asynchronous communication of the chat box, S7 argued that this asynchronism indeed “motivate[d] me to think more and think deeper before typing”, thus “creating a more accurate, useful, and efficient conversation”.

In terms of students’ interactions during leisure time, the majority of the students felt more distant in their relationships with peers due to the absence of in-person interactions. As S3 reflected on his feelings about taking a new class with no acquaintances:

“I just don’t know how to start a conversation online. In a normal class, when I walk in the classroom and take a look at everyone, I will develop some senses of the peers: who they are, what are their majors, etc. But now, everyone is just a ‘name’ appearing on the screen. Before the remote learning, it was natural to get to know people and initiate some conversation: I would say ‘hi’ to people who were sitting near me or have natural conversation about the class. Later we would add each other on social media and maybe study together. This process went smoothly. However, remote classes make this process very weird and awkward” (S3).

Many participants agreed with S3, including S2, S8, S9, S10, etc., that they had made fewer friends during live-streaming classes than in traditional learning. Furthermore, as discussed in Section 4.2.3, some participants reported declining in-person social skills, which could be a serious problem in the long run.

**Weaker Sense of Community.** Given that most students reported weaker relationships with their peers, as stated in Section 4.3.2, it is no surprise that the majority of students reported a lower perceived class-based sense of community. As mentioned before, the lack of visual impressions and face-to-face interactions both contributed to weaker social ties between students. S7, S9, and S10 all made similar comments: students “did not know what other peers or the instructor looked like” (S7) and nor did they “talk a lot after class” (S9). As S10 concluded, “although we had classes together, classmates seemed to be very far away, and I did not feel like I knew them, not to mention being close to them”. A few participants felt the opposite way. For instance, S16 reported a stronger class-based sense of community. According to S16, in a traditional class, “people just come to listen to the lecture and go”, but in a live-streaming class, “everyone’s name is displayed on the screen”, which kind of “reinforce(s) a feeling of connection between us”.

To better understand the overall experiences of students, we turn to the result of our large-scale survey study. Comparing the experience of participation in class activities in Spring 2020 semester (AVE(Spring 2020)=3.60) with Fall 2019 semester (AVE(Fall 2019)=3.76), a decrease by 0.14 was spotted, which was around 1/3 of the standard deviation and thus could be considered as a meaningful educational effect. Therefore, we concluded that a weaker sense of community was experienced on average on the class level.

At the level of school-based sense of community, weaker school-based feelings of connection were reported by the majority of the students we interviewed. The absence of an environment – campus – was the most primary reason. The interviews showed that physical presence on campus was essential to students’ feelings of connection to the university. For example, according to S6, “when I was on campus, every day I would go to the dining hall, the teaching building, the dorm, and the library. However, now the only space I can move between is from one room to another room at home” (S6). Since the physical presence of campus strengthens students’ shared identity as part of a school-based community, its absence weakens this feeling of connection (S6), and S12 and S23 both expressed similar feelings.

Another important factor that contributed to the weaker school-based feelings of connection was the lack of campus activities. There was some evidence that connections with school-based communities “may arise as a feeling of organization commitment, which relates to people’s affinity to a group as a whole” [39]. According to the interviews, most extracurricular activities were canceled due to the closed campus. Even if some activities could happen online, according to S27, “many club members felt less motivated to organize online activities since
they were normally not that attractive.” Without those activities, many participants, such as S6, S7, S21, and S27, reported a weaker or even zero sense of connection to the school. The survey also reflected that the lack of campus activities had a significant educational effect, since participation decreased from 2.92 in Fall 2019 to 2.54 in Spring 2020, resulting in a decrease of 0.38 which was much higher than 1/3 of the standard deviation.

There were also a few students who reported no difference in school-based feelings of connection between taking traditional classes and having remote education. This happened especially when students had acknowledged that members allowed to participate in the LS classes had been limited to students from the same university. As S25 suggested, “although we did not know what they [other students] looked like during live-streaming classes, we did know that they were from [university name]. Thus, I don’t think that live-streaming classes lowered my sense of connection to [university name].”

5 DISCUSSIONS

5.1 Instructors versus Students

Our study demonstrates both student and instructor perspectives, which enables the direct comparison of instructors’ and students’ views. Here we aim at uncovering the similarities and differences between the experiences and perceptions of instructors versus students.

In general, it can be derived from the interview study that teachers could understand students’ dilemmas during online learning, and they would try their best to improve the existing issues of remote learning to further create a more ideal learning experience for students. Attention and performance were two leading examples. To prevent students’ attention from being distracted, instructors tried to maintain students’ attention by interacting more with students through various means: calling out students to answer questions, giving online quizzes or voting, etc. To provide better LS learning experiences, instructors learned to use the modalities introduced in Section 4.1 especially for senior professors who were not familiar with the emerging platforms. From Section 4.2.3, we also noticed that the majority of instructors tried their best to accommodate to students’ needs during remote learning. For example, many teachers uploaded more supplementary resources to students and made virtual experiments possible or mailed the materials required for experiments to students to ensure that students get a good understanding of practices as the traditional learning provided.

However, discrepancies between instructors and students are shown, too. From the survey, we observed an obvious mismatch regarding the experience and quality of remote education reported by teachers and students. First of all, although teachers had some sense of the difficulties that students might encounter learning at home, they were too optimistic about the extent of influence brought by the change of the environment. For example, students reported a decrease from 3.22 in Fall 2019 to 3.00 in Spring 2020 on average regarding the entire online education experience, where the drop of 0.22 surpasses 1/3 of the standard deviation and thus creates a meaningful educational effect. However, teachers only reported a little drop from 3.41 to 3.40 from Fall 2019 to Spring 2020, the effect of which is far from being regarded as meaningful. The leading examples of teachers being overly optimistic about the impacts brought by remote learning on students included the importance of an effective learning environment, the experience of conducting researches or practices remotely, the interactions between students, and participation in school and class activities, etc.

Another major gap between instructors and students related to instructor-student interaction in LS learning. According to the interview, almost all instructors expressed their concerns about not seeing students’ faces during live streaming sessions. As Section 4.3.1 concluded, many instructors reported a less effective interaction and a more distant relationship with students because of the loss of non-verbal expressions. However, from the perspective of students, non-verbal expressions were not mentioned at all. As reported by students, not showing faces to instructors did not influence their relationships with instructors, and turning on their front cameras would only help them concentrate on class better.
5.2 Blur of Study and Life

The experiences of learning from home through LS learning has caused the blur of the boundary between studies and lives. Specifically, most students’ actions of learning are taken at home, sometimes even on the bed, and their only connection towards the school settings is the screen through which LS learning takes place. Therefore, they find it relatively hard to tell whether they are in a state of ease at home or they are in a tight mode at studies. In most cases, a blurring and blending of the two is reported. What’s more, under such a situation, it is also rather easy to switch between the status of studies and daily routines. In the absence of instructors’ timely monitoring, some students have a higher tendency of multitasking while taking courses – having breakfast, playing with their cell phones, etc. This has led the learning process to be more casual, which lowered their learning efficiency. Their learning processes are also more likely to be interrupted by daily necessities at home, where their parents may have them do housework, greet guests to their houses, etc. This may turn learning to be somehow intermittent and lead students to miss some parts of the courses, which is detrimental to the efficiency and effectiveness of studies.

5.3 Decoupling Learning from Home and Learning Enabled by Live Streaming

Taken at home and enabled by live streaming, the LS learning experience under the COVID-19 pandemic share the features of learning from home plus learning enabled by live streaming. Here we set out to decouple how these two features shape LS learning experience during the COVID-19 pandemic, respectively.

Learning from home saved time for commuting. However, the total time for studies may not be reduced and sometimes may even increase. This is in part because learning from home also determines the context for learning, where the context of home poses challenges to efficient learning. Firstly, when the circumstance of classrooms at school is replaced by comfortable home settings, as reported by LS learning participants, students become more relaxed and their study status is turned to be more casual. This can in turn lead students to be more likely to be distracted and reduce the efficiency of learning. Secondly, it is also the context of home that reduces the distance between one’s desk for learning and bed and kitchen, which provides prerequisites for students’ multitasking such as sleeping or eating while course taking. When students are in lack of self-discipline, the effectiveness of education would be impaired. Thirdly, the aforementioned interruptions are also somewhat home-specific, where forces to greet guests and disturbances by other family members are seldom the case for other scenarios.

Live streaming enables features that facilitate more efficient and more engaging learning. Firstly, the support of multiple modalities enriches the channels for interactions, which enables students to more willingly participate in the course and promotes better instructor-student communications and interactions. As reported by our interview participants, this can in turn bring the relationships and perceived distances between instructors and students closer regardless of the physical segregation, which contributes to better study experiences. Secondly, LS learning is praised for its synchronous nature by LS learning practitioners. This not only makes it possible for timely Q&A, but also creates an atmosphere that the class is specially for the students (especially when compared with MOOCs), which, as articulated by LS learning students, increases their enthusiasm for participation and engagement.

6 IMPLEMENTATIONS, IMPLICATIONS AND FUTURE TAKEAWAYS

In this section, we present the practical implications of our research, including guidelines for lectures under LS learning, design implications to better support LS learning, and future takeaways from LS learning in co-located/hybrid education experiences.
6.1 LS Learning Implementations for Different Courses

As revealed in Section 4, the adaptability of traditional face-to-face education to LS learning may vary across courses and disciplines. Here we aim to identify the feasible implementations of different courses for live streaming based remote education from the angle of course characteristics. Specifically, we here discuss the implementations of large-scale lecture courses, small-scale lecture courses, interaction courses, practice courses, and labs.

**Large-scale lecture courses.** Numerous courses, especially general foundation courses and engineering courses, take the form of large-scale lectures, where the top priority is the mere transfer of knowledge. In these courses, not much difference between face-to-face learning and LS learning is perceived in terms of outcomes (T4). Sometimes when the scale of the lecture classes is sufficiently large, the learning experiences may be even better without disturbance and with better sights of course contents (S1, S8 & S13). In this scenario, only the sharing of the instructor/lecturers’ audio, video, and screen would be sufficient to enable quality studies. Students’ basic interactions such as Q&A and greetings with the instructors can be satisfactorily accomplished by text box messages and danmakus, and learning status and effectiveness can be timely checked through quizzes. However, if group presentations are integrated, the sharing of students’ audio, video, and screen would be necessary.

**Small-scale lecture courses.** Similar to large-scale lecture courses, the combination of textual messages, instructors’ audio, video, and screen sharing would support the basic delivery of course contents of small-scale lecture classes, where text box messages and danmakus support in-time interactions. One way for small-scale classes to motivate engagement is to enable direct verbal Q&A where instructors are convenient to ask anyone and to directly check how someone learns. However, if this function is to be supported, LS learning platforms should allow two-way mutual audio interactions, where students should be allowed to turn on their microphones to voice their opinions and answers.

**Interaction courses.** Some courses call for recurrent instructor-student and student-student interactions, for example, oral interpretation classes and case study and group discussion classes. If the instructor needs to frequently check students’ speakings, mutual verbal interactions between instructors and students are indispensable. If frequent group discussions are a must, it is anticipated that LS learning platforms should pay special attention to improving their backing on grouping. Therefore, diversified forms of interactions including exchanges of audio and video information between multiple people are in demand. What’s more, to guarantee better experiences and effectiveness of peer discussions, one possible solution would be to support the sharing of everyone’s images and turn on everyone’s camera (at least in the group) so as to avoid awkwardness and unfamiliarity.

**Practice courses.** Practice courses such as dancing, painting, and physical education classes call for frequent visual monitoring and timely guidance and corrections. Therefore, support on both the instructors’ and students’ videos is crucial, and sometimes they highly require clarity and smoothness in terms of the video quality. Delay may be detrimental because if the timeliness for information to be passed through the instructor-student-instructor cycle is not guaranteed, the instructions given by the instructors may run behind what the students are actually operating, which would reduce the virtue of the instructions. Therefore, timely feedbacks and strong synchronization are vital.

**Labs.** Labs are relatively the hardest to implement through LS learning. However, some solutions may also be provided for this form of courses to be conducted remotely through a live streaming format. When the materials are convenient for mailing, sending the objects directly to students and letting students remotely follow the instructors at home would be preferable. When the equipment is large and expensive but can be directly connected to computers, changing the experiments to a computer-mediated version would be an option. Through remote control on the computers that instruments are connected to, the experiments can be accomplished remotely, which also allows the successful progression of labs.
6.2 Design Implications

Our work provides novel design implications for the HCI and CSCW community. We demonstrate users’ usages and perceptions on different interaction features in LS learning, which can be indicative of the design of future platforms to support live streaming based education of the kind. Specifically, to improve the user experiences in LS learning and to improve the applicability of LS learning platforms, we delineate the typical features of promising LS learning platforms.

**Diverse interaction formats.** It is recommended that LS learning platforms should support diverse forms of interactions, including but not limited to audio, video, text box messages, danmakus, quizzes, and votes. As mentioned before, it would be plausible to enable two-way audio, video, and screen sharing so as to address the demands of different courses. Text box messages and danmakus provide two ways of textual engagements where the former is more formal while the latter is perceived to be more relaxing and casual. Quizzes grant prompt feedbacks of students’ learning, while votes simplify thought collection and encourage engagement.

**Balance of anonymity and real-name system.** While the real-name system of text box messages is appreciated, the anonymity of danmaku is also welcomed. Therefore, for interface designers, it is worth carefully considering whether real-name systems are integrated and to what extent and for which functions real-name systems/anonymity may be used. For example, a combination of real-name systems and anonymity may be a feasible choice. With different systems integrated into different modalities, one can find a channel suits better for him/her and for his/her words.

**Activation and deactivation.** To avoid disturbance, we advocate that instructors should have the right to decide if features such as danmuku and students’ sharing of their voices and visuals would be activated through the courses, and students should be allowed to show or hide the messages and danmakus. From the instructor’s perspective, it is up to him/her to decide how the course progresses and if an interaction format is allowed; from the student side, it would be better if he/she is allowed to adopt a learning circumstance that suits him/her best.

**Focus mode.** A focus mode is appreciated by LS learners. Specifically, as mentioned by participants, if someone else keeps his microphones during lectures, the fluency of the instructors’ speeches received by students would deteriorate, where the students’ voices would be very bothering. Supporting a focus mode would solve the problem to a certain degree. It would be intriguing if users can decide their priorities for accepting whose audio and video information. If one is allowed to prioritize the acceptance of the instructors’ voices and visuals, other students’ unintended vocal disturbance would not hinder his/her studies.

**Hierarchical role system.** LS learning instructors and students also appreciate the support of hierarchical role systems, which echos the case of previous work such as Hamilton et al.’s [13]. Instructors should maintain control of the whole course, while mediators (maybe teaching assistants and group leaders) can be assigned some of the instructors’ rights so as to better regulate the course. What’s more, with some of the rights only attributed to certain roles such as group leaders, less bandwidth would be needed for allocation and the robustness for disturbance is enhanced.

**Peer work and collaboration.** Support for peer work and group collaboration is warmly welcomed. Instructors and students speak highly of the “group discussion” function, where both random grouping and assigned grouping have their own merits. What’s more, instructors such as T1 call for the simultaneous monitor of different groups so as to better control the progression of the whole class.

**Recordings and playbacks.** Course recordings and playbacks have been highly praised by most interviewed students. This is perceived to contribute to a better understanding of the course contents and benefit the review of lessons. For example, students are likely to be distracted due to factors like interruptions. If recordings and playbacks are allowed, students can replay the parts they miss or fail to understand, which would be beneficial for better comprehension. However, concerns on course recordings are raised by instructors. Not only are they afraid of copyright infringement and vicious dissemination of certain contents (T1), but they also express concern.
that too much reliance on playbacks would lead to laziness: not keeping up with the class and only watching all the playbacks before exams, which would cause a significant drop in the effectiveness of learning (T7).

6.3 Future Takeaways

Discussions are also made on what can be derived from the experiences of live streaming based remote education during the specific period of the COVID-19 pandemic. Here we pay special attention to what future takeaways can be extracted for post-pandemic education.

Firstly, experiences from LS learning shed light on the promising future of hybrid learning, where the advantages of online and offline learning may be integrated. Specifically, there is the possibility that certain interaction features of LS learning may be kept for utilization in post-pandemic periods. For example, allowance of chatbox and danmaku may enhance instructor-student interactions and benefit the sharing of different perspectives which may contribute to a more active class atmosphere. The usage of quizzes and votes would enable instructors to have the first-hand knowledge of students’ current knowledge mastery, which helps instructors to accordingly adjust their teaching in time. With different interaction modalities integrated, the learning experience of traditional classes would be improved.

Secondly, LS learning demonstrates the possibilities of effective distant education. Although platforms such as MOOCs have been available for distance learning for years, the outcomes of the learning on those platforms can be far from satisfactory (S15), where “courses are seldom treated seriously” (S21). However, LS learning provides a means with real-time interactions with the teacher, where students feel that “a live person is teaching for you” (S14) rather than a feeling that “I feel I am not taking a course at all” (S11). Therefore, for future design targeting at improving the effectiveness of distance learning, the usage of LS learning and the integration of these different modalities should be taken into consideration.

Thirdly, some defects still lie within LS learning which future HCI and CSCW researchers may take into consideration. For example, students feel it easy to be distracted because of a lack of formal study context. One possible direction for addressing the problem may be to set up a “real” virtual classroom space for interactions, possibly through technologies such as virtual reality (VR). We call on future efforts to compensate for the defects reported by our participants while maintaining and even improving the advantages of LS learning.

7 LIMITATIONS, GENERALIZABILITY, AND FUTURE WORK

Our research inevitably suffers from limitations. First of all, our data were collected in mainland China, so likely not all conclusions will apply to different cultures. For instance, aside from Zoom, other LS learning platforms (e.g. Tencent Meeting, Rain Classroom) are not widely used outside mainland China. Some modes of interaction, e.g. danmaku, are more East Asian specific. Therefore, one could expect different experiences on other platforms. Beyond that, culturally the instructor-student relationship in East Asian is more distant than Western culture, so the implications of relationship may not naturally extend. Nevertheless, our study is based on large-scale interview and survey studies where we carefully sample participants from diverse backgrounds, which we argue ensures the generalizability of findings in China. In the future, we plan to extend our research to different cultures and disciplines, and carefully tease out the cultural effect on user experiences.

8 CONCLUSION

In this paper, we present the first-ever study on live streaming based education (LS education) experiences during the COVID-19 pandemic through mixed methods. With a focus on Chinese higher education, we carried out semi-structured interviews on 30 students and 7 instructors from diverse disciplines, meanwhile launched a large-scale survey covering 6291 students and 1160 instructors in one leading Chinese university, and analyzed user experiences on LS education. Our findings suggest LS learning do help student and teachers achieve their
education goal to a great extent under remote setting, yet there are several key challenges emerging under the current paradigm, including students’ difficulties in paying continuous attention, decreased learning efficacy, and lack of engagement and collaboration. We further demonstrate how various interaction formats enable several novel learning experiences under LS learning, which contribute to variations in instructor-student and student-student relationships in both positive and negative ways. Based on our findings, we propose important design guidelines and insights to better support current remote learning experiences during the pandemic, and systematically discuss design implications to construct future collaborative education supporting systems and experiences post-pandemic.

REFERENCES

[1] Pengcheng An, Saskia Bakker, Sara Ordanovski, Ruurd Taconis, Chris LE Paffen, and Berry Eggen. 2019. Unobtrusively enhancing reflection-in-action of teachers through spatially distributed ambient information. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. 1–14.
[2] Di Chen, Dustin Freeman, and Ravin Balakrishnan. 2019. Integrating Multimedia Tools to Enrich Interactions in Live Streaming for Language Learning. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. 1–14.
[3] Derrick Coetzee, Armando Fox, Marti A Hatef, and Bjorn Hartmann. 2014. Should your MOOC forum use a reputation system?. In Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing. 1176–1187.
[4] Jacob Cohen. 2013. Statistical power analysis for the behavioral sciences. Academic press.
[5] Juliet Corbin and Anselm Strauss. 2014. Basics of qualitative research: Techniques and procedures for developing grounded theory. Sage publications.
[6] Mary Czerwinski, Eric Horvitz, and Susan Wilhite. 2004. A diary study of task switching and interruptions. In Proceedings of the SIGCHI conference on Human factors in computing systems. 175–182.
[7] Tawanna R Dillahunty, Sandy Ng, Michelle Fiesta, and Zengguang Wang. 2016. Do massive open online course platforms support employability?. In Proceedings of the 19th ACM conference on computer-supported cooperative work & social computing. 233–244.
[8] Audubon Dougherty. 2011. Live-streaming mobile video: production as civic engagement. In Proceedings of the 13th international conference on human computer interaction with mobile devices and services. 425–434.
[9] Travis Faas, Lynn Dombrowski, Alyson Young, and Andrew D Miller. 2018. Watch me code: Programming mentorship communities on twitch.  tv. Proceedings of the ACM on Human-Computer Interaction 2, CSCW (2018), 1–18.
[10] Baja Gumieny, Lutz Gericke, Matthias Wenzel, and Christoph Meinel. 2013. Supporting creative collaboration in globally distributed companies. In Proceedings of the 2013 conference on Computer supported cooperative work. 995–1007.
[11] Oliver L Haimson and John C Tang. 2017. What makes live events engaging on Facebook Live, Periscope, and Snapchat. In Proceedings of the 2017 CHI conference on human factors in computing systems. 48–60.
[12] William A Hamilton, Oliver Garretson, and Andruid Kerne. 2014. Streaming on twitch: fostering participatory communities of play within live mixed media. In Proceedings of the SIGCHI conference on human factors in computing systems. 1315–1324.
[13] William A Hamilton, Nic Lupfer, Nicolas Botello, Tyler Tesch, Alex Stacy, Jeremy Merril, Blake Williford, Frank R Bentley, and Andruid Kerne. 2018. Collaborative live media curation: Shared context for participation in online learning. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. 1–14.
[14] Jörg Hauber, Holger Regenbrecht, Mark Billinghamurst, and Andy Cockburn. 2006. Spatiality in videoteleconferencing: trade-offs between efficiency and social presence. In Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work. 413–422.
[15] Susan B Hopper. 2014. Bringing the world to the classroom through videoteleconferencing and project-based learning. TechTrends 58, 3 (2014), 78–89.
[16] Stefan Hrastinski. 2008. Asynchronous and synchronous e-learning. Educause quarterly 31, 4 (2008), 51–55.
[17] Jukka Hussa. 1996. Distance education in the school environment: Integrating remote classrooms by video conferencing. Journal of Open, Flexible, and Distance Learning 2, 1 (1996), 34–44.
[18] Oskar Juhlin, Arvid Engström, and Erika Reponen. 2010. Mobile broadcasting: the whats and hows of live video as a social medium. In Proceedings of the 12th international conference on Human computer interaction with mobile devices and services. 35–44.
[19] Sasa Junuzovic, Kori Inkpen, Rajesh Hegde, and Zhengyou Zhang. 2011. Towards ideal window layouts for multi-party, gaze-aware desktop videoteleconferencing. (2011).
[20] Ahmed Kharrufa, Sally Rix, Timur Osadchyi, Anne Preston, and Patrick Olivier. 2017. Group Spinner: recognizing and visualizing learning in the classroom for reflection, communication, and planning. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. 5556–5567.
[21] Benjamin Koehne, Patrick C Shih, and Judith S Olson. 2012. Remote and alone: coping with being the remote member on the team. In Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work. 1257–1266.
Zhicong Lu, Michelle Annett, Mingming Fan, and Daniel Wigdor. 2019. "I feel it is my responsibility to stream" Streaming and Engaging with Intangible Cultural Heritage through Livestreaming. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. 1–14.

Zhicong Lu, Michelle Annett, and Daniel Wigdor. 2019. Vicariously experiencing it all without going outside: A study of outdoor livestreaming in China. Proceedings of the ACM on Human-Computer Interaction 3, CSCW (2019), 1–28.

Zhicong Lu, Seongkook Heo, and Daniel J Wigdor. 2018. Streamwiki: Enabling viewers of knowledge sharing live streams to collaboratively generate archival documentation for effective in-stream and post hoc learning. Proceedings of the ACM on Human-Computer Interaction 2, CSCW (2018), 1–26.

Zhicong Ma, and Nan Cao. 2017. Video-based evanescent, anonymous, asynchronous social interaction: Motivation and adaption to medium. In Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing, 770–782.

Anna Macaranas, Gina Venolia, Kori Inken, and John Tang. 2013. Sharing Experiences over Video: watching video programs together at a distance. In IFIP Conference on Human-Computer Interaction. Springer, 73–90.

Sanjeev Mehrotra, Wei-ge Chen, Zhengyou Zhang, and Philip A Chou. 2011. Realistic audio in immersive video conferencing. In 2011 IEEE International Conference on Multimedia and Expo. IEEE, 1–4.

Robert W Moeller and Martin Seehuus. 2019. Loneliness as a mediator for college students’ social skills and experiences of depression and anxiety. Journal of adolescence 73 (2019), 1–13.

Veronica Ahumada Newhart and Judith S Olson. 2017. My student is a robot: How schools manage telepresence experiences for students. In Proceedings of the 2017 CHI conference on human factors in computing systems. 342–347.

Gary M Olson and Judith S Olson. 2000. Distance matters. Human–computer interaction 15, 2-3 (2000), 139–178.

Anthony Poon, Sarah Giroux, Parfait Eloundou-Enyegue, François Guimbretière, and Nicola Dell. 2019. Engaging high school students in cameroon with exam practice quizzes via sms and whatsapp. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. 1–13.

Ronald E Riggio, Kristin P Watring, and Barbara Throckmorton. 1993. Social skills, social support, and psychosocial adjustment. Personality and Individual Differences 15, 3 (1993), 275–280.

Amy Shannon, Alex Sciuto, Danielle Hu, Steven P Dow, and Jessica Hammer. 2017. Better Organization or a Source of Distraction? Introducing Digital Peer Feedback to a Paper-Based Classroom. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. 5545–5555.

Na Sun, Mary Beth Rosson, and John M Carroll. 2018. Where is community among online learners? Identity, efficacy and personal ties. In Proceedings of the 2018 chi conference on human factors in computing systems. 1–13.

Na Sun, Xiying Wang, and Mary Beth Rosson. 2019. How Do Distance Learners Connect?. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. 1–12.

Wei Sun, Yunzhi Li, Feng Tian, Xiangmin Fan, and Hongan Wang. 2019. How Presenters Perceive and React to Audience Flow Prediction In-situ: An Explorative Study of Live Online Lectures. Proceedings of the ACM on Human-Computer Interaction 3, CSCW (2019), 1–19.

John C Tang, Gina Venolia, and Kori M Inken. 2016. Meerkat and periscope: I stream, you stream, apps stream for live streams. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. 4770–4780.

Miaomiao Wen, Keith Maki, Steven Dow, James D Herbsleb, and Carolyn Rose. 2017. Supporting virtual team formation through community-wide deliberation. Proceedings of the ACM on Human-Computer Interaction 1, CSCW (2017), 1–19.

Mark E Whiting, Allie Blaising, Chloe Barreau, Laura Fiuza, Nik Marda, Melissa Valentine, and Michael S Bernstein. 2019. Did It Have To End This Way? Understanding the Consistency of Team Fracture. Proceedings of the ACM on Human-Computer Interaction 3, CSCW (2019), 1–23.

Xiang Xiao and Jingtao Wang. 2017. Understanding and detecting divided attention in mobile mooc learning. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. 2411–2415.

Saelyne Yang, Changyoon Lee, Hijing Valentina Shin, and Juho Kim. 2020. Snapstream: Snapshot-based Interaction in Live Streaming for Visual Art. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. 1–12.

Saijing Zheng, Mary Beth Rosson, Patrick C Shih, and John M Carroll. 2015. Understanding student motivation, behaviors and perceptions in MOOCs. In Proceedings of the 18th ACM conference on computer supported cooperative work & social computing. 1882–1895.
[47] Saijing Zheng, Pamela Wisniewski, Mary Beth Rosson, and John M Carroll. 2016. Ask the instructors: Motivations and challenges of teaching massive open online courses. In Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing, 206–221.