On the Quality of Experience of Content Sharing in Online Education and Online Meetings

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***Abstract*—The turn of the decade introduced a new era of global pandemics to the world through the appearance of COVID-19, which is still an active crisis at the time of this paper. As a countermeasure, the phenomena of home office and online education became not only widely available, but also mandatory in many countries. However, the performance, reliability and general usability of such real-time activities may be severely affected by unfavorable network conditions. In both contexts, content sharing is now a common practice, and the success of the related use cases may fundamentally depend on it. In this paper, we present our surveys and subjective studies on the Quality of Experience of content sharing in online education and online meetings. A total of 6 surveys and 5 experiments are detailed, addressing topics of student experience, user interface settings, sharing options of lecturers and employees of the private sector, the perceivable effects of network impairments and the related long-term adaptation, the rubber band effect of slide sharing, the overall perceived quality and the separate quality aspects of media loading times, and the preference between visual quality, average frame rate and frame rate uniformity. The findings of the subjective studies do not characterize the use cases of the investigated topics on a general, widely-applicable level, as only a single online platform is involved throughout the experiments. However, their experimental configurations are reinforced by comprehensive surveys and many results indicate statistically significant differences between the selected test conditions.**

***Index Terms*—Quality of Experience, Quality of Service, online meeting, online education, video quality, video resolution, loading time.**

I. INTRODUCTION

DUE to the ongoing global pandemic SARS-CoV-2 – also known as COVID-19 – the employees of more and more companies and institutions perform their daily occupation-related activities from the safety of their homes. Similarly, as the virus appeared in every corner of the world – threatening the lives of millions – education suddenly shifted towards its online variations, as an attempt to battle this crisis. In numerous countries, online education is still the only reasonable option in 2021, since even at the time of writing this paper, although vaccines are already available, yet the disease remains to be dealt with – particularly due to the continuously evolving variants. Additionally, new threats are on the rise, such as the 2022 human monkeypox outbreak, and other pandemics may emerge as well.

Remote education via modern technology is far from being a completely novel phenomenon. In fact, media (i.e., radio and educational films) was already utilized for educational purposes more than a hundred years ago [1]–[3]. In the age of the Internet, we have a vast array of techniques to choose from. There are multiple types of self-learn, self-study software, pre-recorded lectures are available online – either publicly or solely to the students of the institution – and classes, lectures are interactively held via online communication platforms. However, the latter is a real-time educational service, and therefore, its perceived quality highly depends on network conditions. Of course, quality in this context refers to media quality, yet unfavorable network conditions may indeed affect the educational quality of such online classes. Unfortunately, there are so many factors that can degrade network conditions during real-time online education. It only makes matters worse when resource-demanding dynamic multimedia – and not just static slides – is being shared, such as the introduction of the usage of certain technical tools via a camera. Network impairments during the different types of content sharing may have a severe effect on online education. Yet, throughout longer portions of online lectures with shared multimedia, students may adapt to smaller extents of such impairments.

In the context of home office, a notable percentage of online activities happen in real time. Probably the most commonly known form of such real-time activities is the online meeting. In online meetings, content sharing is relatively frequent. In most cases, the shared content is a sequence of slides, but other contents may be shared as well, such as a video or the window of a specific application, or even the entire screen. However, when such action is started, the content is not necessarily available instantaneously to the other participants of the meeting. The amount of this delay may depend on a variety of factors, like the type of the content and the associated bandwidth requirements. The initial delay of content sharing may not only affect user experience, but in a professional context, it may also cause further undesirable effects – for example, missing important information related to the subject at hand. Moreover, when a video is shared, playback may be subject to the rubber band effect (i.e., playback is not uniform in terms of frame speed), especially right after it becomes available to the observers.

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Therefore, the Quality of Experience (QoE) of online education and online meeting platforms in general has become more relevant than ever. In this paper, we address the contexts of online education and online meetings through a series of surveys and subjective studies. The work we carried out over the past two years covers various topics that are relevant to the phenomena mentioned above. We particularly focused on the degradation of video content sharing QoE via network impairments, the rubber band effect, initial loading delay and frame rate variation. The surveys not only provide useful insights into the investigated topics, but also supported the experimental configurations of the subjective studies.

Regarding the online meeting platform of choice, one could repeat a certain experiment over the most commonly used platforms to carry out an exhaustive performance comparison. Instead, we used a single platform for all the tests, and the surveys were designed for that specific platform as well. Hence, the primary focus of the work was on the investigated research questions of the QoE-related phenomena and not on the capabilities of various meeting platforms. For our surveys and tests, we selected Microsoft Teams, since it is the default meeting platform of the institutions of all the authors of this paper.

As for the methodology of the subjective tests, the experiments were always implemented as a Teams meeting between the test participant and the conductor of the test. Having multiple test participants simultaneously is typical in online education and meetings; however, in order to avoid any issue or irregularity that may originate from such circumstance and thus distort the obtained results, in the scope of this paper, multi-participant scenarios are not addressed. Additionally, our approach of having only a single test participant in a call enabled test stimulus randomization; each test participant was provided a unique sequence to assess.

The students, lecturers and employees of the private sector who completed our surveys and participated in our tests reside in many different countries, including (but not limited to) Austria, China, France, Germany, Hungary, Italy, Jordan, Poland and the United Kingdom. Information on demographics (age and gender) is provided in the *Results* subsection of each subjective study. A total number of 303 individuals completed our surveys and 88 individuals participated in our studies. As there were 4 subjective studies, the results of each study were based on the ratings of either 20 or 24 test participants. While this may be perceived as a limitation of the work, statistically significant rating differences were achieved for multiple experiments nonetheless. Although the same statement is not applicable to other tests, the collected data initiates novel research questions for future scientific efforts in the field of QoE.

The remainder of this paper is structured as follows: Section II reviews the scientific literature related to both primary topics. Sections III and IV present our surveys and subjective studies on online education and on online meetings, respectively. Section V concludes the paper and highlights the potential continuations of the addressed topics.

II. RELATED WORK

Studies related to online education have boosted their relevance significantly during the past years due to the ongoing global pandemic. Many works particularly address online education separately from the perspectives of students and teachers [4]–[6], compare the most frequently used online platforms [7]–[10], and investigate the phenomenon of e-learning [11]–[13]. The work of Husniyah *et al.* [4] concludes that numerous teachers avoid real-time online engagements in order to elude the effects of unfavorable network conditions, and that alternative solutions are often preferred (e.g., pre-recorded lectures). On the other hand, the publications of Mukhtar *et al.* [14] and Dhawan [15] call attention to educational issues caused by the lack of immediate feedback – applicable to both real-time and asynchronous education. Yet the results of Barbour *et al.* [11] indicate that students are likely to prefer evading real-time communication (i.e., via microphone and/or camera) and communicate via chat instead. The research of Coman *et al.* [5] states that the most significant challenge regarding online education is the threat of potential technical issues – which may impose particular learning problems in the context of early childhood education [16] – and urges institutions to develop training sessions for teachers. Scarlat *et al.* [17] also emphasize this redirection of efforts. The recent papers of Chen *et al.* [18], [19] highlight that students focus more on the quality of real-time interaction since the outbreak of the pandemic, and that personal factors do not directly influence satisfaction. However, personal factors do correlate with motivations connected to learning under the circumstances of the current era, as signified by the work of Nurhopipah *et al.* [20]. While the "sense of presence" in cutting-edge research is primarily applied to novel glasses-free 3D technologies [21], [22], the paper of Chessa *et al.* [23] addresses this topic in the contexts of conventional online education and virtual-reality-assisted training, the findings of which correlate with the theoretical framework of Shea *et al.* [24]. On a more general level, Bao [25] concludes the essential need for the five principles of appropriate relevance, effective delivery, sufficient support, high-quality participation and contingency plan preparation in large-scale online education; and Prasetyo *et al.* [26] characterize the relevant constructs of system quality, information quality, perceived usefulness, perceived ease of use, user interface, behavioral intentions and actual use. Finally, as education in many parts of the world is now slowly reverting back from virtual to presential formats, post-lockdown studies are continuously emerging, such as the work of Kassahun [27].

The performance of video conferencing platforms [28]–[35] – regardless of their usage – is relevant to the investigated contexts. Multimedia QoE, in general, is fundamentally based on image quality, resolution and frame rate [36]–[38], but it is also affected by a plateau of other aspects, phenomena and effects, such as the memory effect [39], the contrast effect [40] and the labeling effect [41]. The effect of the initial delay on the QoE of real-time video streaming [42]–[44] can be looked at as one of the major motivators for modern adaptive streaming solutions. However, it is not only the system that is adaptive, but the users as well, since works on the topic of QoE over time [45]–[47] indicate that personal tolerance may evolve against quality degradation – if the extent of degradation is not severe enough to render the specific use case useless, of course. Thus far, according to the best knowledge of the authors, the adaptation to quality degradation caused by network impairments has not been studied in the contexts of online meeting platforms yet, especially in the context of real-time educational multimedia. The same is applicable to the rubber band effect of slide sharing, the initial loading times of multimedia contents, and the frame rate values and fluctuations of such videos.

III. Surveys and Subjective Studies on Online Education

A. Survey on Student Experience

The survey focused on the subjective perception of online education via Teams. The questions utilized a 7-point symmetric rating scale [48] to assess satisfaction regarding the investigated aspects (*very unsatisfied*, *unsatisfied*, *slightly unsatisfied*, *neutral*, *slightly satisfied*, *satisfied* and *very satisfied*).

1) Questions: The questions of the survey were related to performance, addressing both delay-sensitive (i.e., real-time) and delay-tolerant (i.e., downloading), short-term (e.g., taking part in an oral exam) and long-term (e.g., participating in a lecture) tasks. The students who completed our survey had to assess the following: (Q1) reliability of downloading study-related materials, (Q2) speed of downloading study-related materials, (Q3) reliability of uploading study-related materials, (Q4) speed of uploading study-related materials, (Q5) taking part in oral exams, (Q6) being updated by lecturers regarding tasks and deadlines (i.e., information sharing outside the lectures), (Q7) sharing content during real-time activities (e.g., a student presentation during lecture), (Q8) taking part in lectures and (Q9) the comparison of online education to contact classes (e.g., the rating *very satisfied* indicates that online classes are much better from the perspective of the student). We also asked students about the weekly number of disconnections they suffer during online lectures.

2) Results: The survey was completed by 46 university students (25 B.Sc., 19 M.Sc. and 2 Ph.D. students). 80.4% of the students connects to the real-time lectures via laptops, and 93.5% uses wireless Internet connection. The results are shown in Table I, using the numerical equivalent of the scale (e.g., 3 corresponds to *very satisfied*). The questions related to downloading and uploading (Q1–Q4) received favorable ratings, and similar observations are applicable to information sharing outside lectures (Q6). The short-term activity of taking part in oral exams (Q5) obtained comparably lower ratings, and content sharing (Q7) and lectures (Q8) received the lowest ratings, particularly the latter. This may be connected to the fact that the students who completed this survey suffer from disconnections during lectures nearly 2 times per week on average. As for the preference (Q9), 58.7% of the students prefer online education – despite the potential issues – and only 13.04% chose regular contact classes. Generally, the results are indeed favorable, but the pitfalls of real-time activities – particularly lectures, which are the heart and soul of online education – are notable.

TABLE I
RESULTS (IN %) OF THE SURVEY ON STUDENT EXPERIENCE.

	-3	-2	-1	0	+1	+2	+3
Q1	0	4.35	2.17	19.57	21.74	32.61	19.57
Q2	0	2.17	2.17	19.57	15.22	41.3	19.57
Q3	0	0	2.17	32.61	13.04	41.3	10.87
Q4	0	0	2.17	26.09	21.74	43.78	15.22
Q5	0	2.17	8.7	30.43	10.87	36.96	10.87
Q6	2.17	0	6.52	26.09	15.22	34.78	15.22
Q7	0	2.17	4.35	34.78	30.43	19.57	8.7
Q8	0	4.35	13.04	30.43	26.09	13.04	13.04
Q9	4.35	4.35	4.35	28.26	23.91	19.57	15.22

B. Survey on User Interface Settings

The survey enquired about the user interface settings of Teams during lectures, particularly whether students have the list of participants or the chat open.

1) Question: The survey included a single multiple-choice question, asking about the preferred state of the right side of the application screen during lectures where the lecturer shares educational content. The students had to choose either *list of participants*, *chat* or *none*. In this context, the answer should reflect the state that is personally preferred, without special events. A special event can be that at one point of the lecture, the lecturer posts the link of a website or the title of a paper on the chat, which can prompt students to temporarily open the chat if it is not open by default.

2) Results: The survey was completed by 33 university students (16 B.Sc., 14 M.Sc. and 3 Ph.D. students). The dominant preference was the list of participants (18), followed by chat (14), and only a single student stated that none of these is preferred. We considered extending the survey with more test participants, however, the obtained results already provided sufficient evidence to support the experimental setup of the subjective studies, particularly the one on the effects of network impairments.

C. Survey on General Content Sharing Options

The survey addressed the personal preference of lecturers regarding the different possible options for general content sharing via Teams.

1) Question: The survey included a single multiple-choice question, asking about the preferred method of content (any educational content) sharing via Teams. The possible answers were the following: Desktop sharing (fullscreen); Window sharing; Presentation sharing directly via Teams; MS Whiteboard; Freehand; Webcam; Audio only.

2) Results: The survey was completed by 74 university lecturers from institutions where Teams is the default platform for online education. The dominant preference was window sharing (38), followed by fullscreen desktop sharing (26). Sharing directly via Teams (1), MS Whiteboard (2), webcam (7) and audio-only (1) methods were also preferred by some, while no preference was registered for Freehand. However, this survey covers all intents of content sharing in online education.

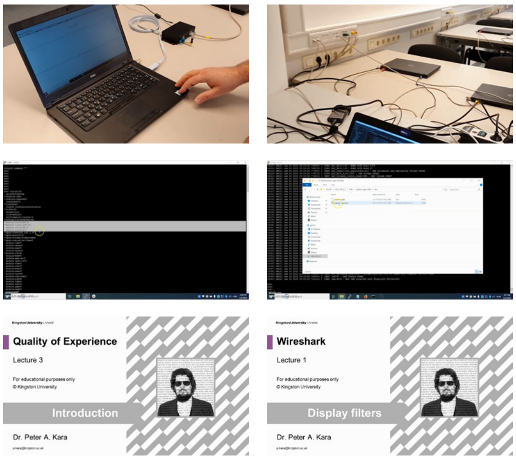

Fig. 1. Source video sequences of the study on the effects of network impairments.

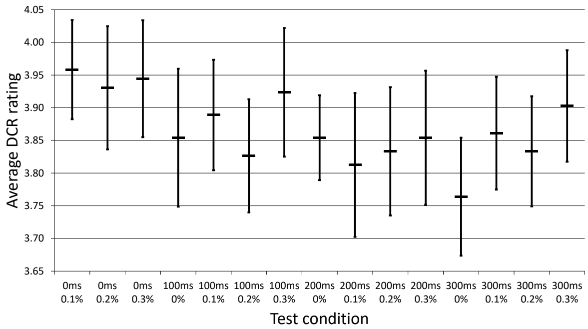

Fig. 2. Average of the DCR scores obtained for the study on the effects of network impairments.

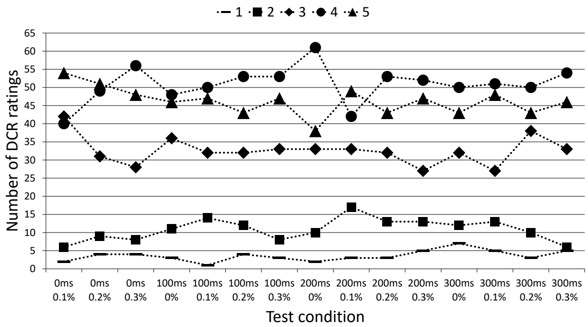

Fig. 3. Rating distribution of the study on the effects of network impairments.

Therefore, in order to have results more focused on video sharing – which is the topic of the subjective studies – we repeated the survey with the appropriate alterations.

D. Survey on Video Content Sharing Options

The survey addressed the personal preference of lecturers regarding different options for video content sharing via Teams.

1) Question: The survey included a single binary question, asking about the preferred method of video sharing (i.e., sharing the playback of a video file) via Teams. The possible answers were the following: Desktop sharing (fullscreen); Window sharing.

2) Results: The survey was completed by 48 university lecturers from institutions where Teams is the default platform for online education. The dominant preference was window sharing (33), followed by fullscreen desktop sharing (15). Therefore, in the subjective studies, we utilized the option of window sharing.

E. Subjective Study on the Effects of Network Impairments

The task of the test participants was to assess the quality of content sharing, comparing the perceived audiovisual quality of artificially degraded test cases (with added delay and packet loss values) to reference videos (i.e., where the transmission was not degraded additionally).

1) Experimental Setup: Based on the answers collected by the survey on content sharing options, the content was shared via application window (i.e., a video player running in fullscreen mode). This was also very convenient for using the same computer for setting the parameters of network conditions, without the test participants noticing it (which could have been an issue during single-screen fullscreen sharing).

For the pair comparison, a 5-point Degradation Category Rating (DCR) scale [49] was used, which registers both perceptibly and annoyance. The scores were recorded on the meeting chat. It was deemed a life-like scenario to have the chat open while viewing the shared content, since according to the survey on user interface settings, the majority of students have either the participant list or the chat open during lectures.

The test sequences were separated by 5-second grey separation screens. After a stimulus pair, the test participant had to register the score during the separation screen. The network conditions were also changed during this period, according to the values defined by the test conditions.

The degradation of Quality of Service (QoS) parameters – the impacts of which are relevant to all forms of transmission contexts [50] – were simulated via Clumsy[1]. For both delay and packet loss, 4 values were chosen: 0 ms, 100 ms, 200 ms and 300 ms; 0%, 0.1%, 0.2% and 0.3%, respectively. There was a total of 16 test cases, as every single combination was included. Evidently, the condition with 0 ms delay and 0% packet loss was the reference. As in all our studies, the test condition order was uniquely randomized for each and every test participant, and the test conditions were applied to every single source sequence.

The 6 source video sequences were provided by the academic co-authors (i.e., university lecturers) of the paper. They are all 30-second long, 30-fps, 720p (1280×720 pixels) videos. As for the contained educational material itself, they were selected with the aim of content diversity. Sequence `A` and `B` were recorded by a hand-held device (i.e., smart phone), `C` and `D` were captured by a desktop recording software – the entire desktop was recorded – and `E` and `F` were rendered. In all of these videos, the lecturer continuously talks throughout

[1]http://jagt.github.io/clumsy/index.html

the entire duration. In sequence A, the lecturer introduces a specific device connected to a laptop, while holding the camera in a given position and angle (with minimal hand tremor) with one hand, and making hand gestures (i.e., pointing at certain devices) with the other. In sequence B, the camera is moved around in a laboratory, and it automatically refocuses when necessary. In sequence C, a piece of program code in a command terminal is explained, and some lines are highlighted by the lecturer. In sequence D, the lecturer navigates between different folder windows on the computer, and a program is launched. In sequence E, a fullscreen slideshow is presented, containing a single change between the slides. In sequence F, the same slide is shown throughout the entire video. A demonstrative screenshot of each source video sequence is shown on Figure 1.

2) Results: A total of 24 test participants completed the subjective tests (16m, 8f, avg. age 23). All of them were active university students (11 B.Sc., 11 M.Sc. and 2 Ph.D. students). 23 used wireless Internet connection and only 1 used a wired connection. Regarding devices, 19 students used laptops, 3 of them connected via a desktop computer, 1 participated through a tablet and 1 through a smart phone.

Figures 2 and 3 show the average and the distribution of the obtained scores, respectively. In the latter, the same rating options are connected over the series of test conditions to increase the quality of data communication. This approach is applicable to all the other cases of data series visualization in this paper as well. For every test condition, 144 ratings were collected, as a single test condition was rated by 24 test participants over 6 source contents. From the 144 ratings, even in the case of 0 ms delay and 0.1% packet loss, only 54 did not report perceivable differences, and the same was 46 for 100 ms delay and 0% packet loss. Regarding toleration, 32.6% reported annoyance to a given extent, but the rest indicated the total lack of irritation caused by quality degradation. In general, the results obtained for the test conditions do not differ significantly; the only statistically significant difference was between 0 ms delay with 0.1% and 0.3% packet loss values and between 300 ms delay and 0% packet loss. As for the source contents, the difference in scene dynamics is well-reflected in the results, as the two videos with slides (E and F) achieved the highest average ratings, 3.99 and 4, respectively. These are followed by the desktop recordings (C and D), at 3.89 and 3.85, respectively, and then by the camera captures (A and B), at 3.71 and 3.73, respectively.

The network parameter values in this experiment were added artificially to the already existing conditions as extra load, and almost every single test participant used wireless connection to take part in the study. Hence, variation over time regarding the real network conditions was possible, which can significantly affect the actual performance. However, this was an intentional decision within the experimental setup, in order to investigate realistic conditions. As for the added packet loss, it was not implemented in a strictly uniform manner (i.e., every n^{th} packet is dropped), thus its effect on content sharing was not deterministic, unlike the straightforward additional delay. The values were selected based on conclusions of the scientific literature [47], [51]–[55] and preliminary testing regarding

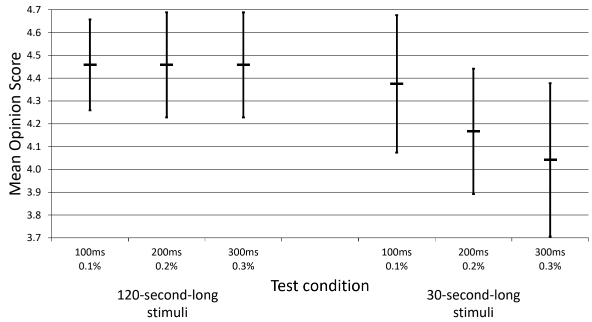

Fig. 4. MOS of the study on the adaptation to network impairments.

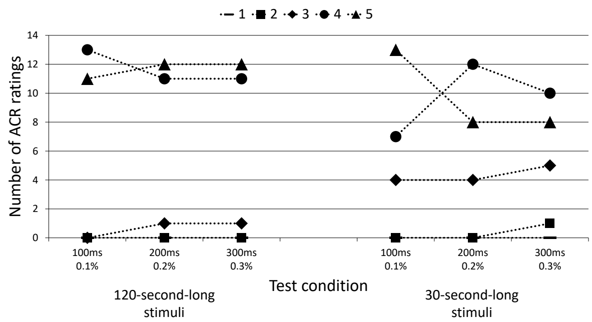

Fig. 5. Rating distribution of the study on the adaptation to network impairments.

just-noticeable differences (JNDs). Furthermore, no error correction was simulated. Finally, the experiment combined the assessment of the perceived video and audio quality. Based on the consistency of the ratings achieved by the different content types, we can assume that visual quality played a more significant role in the evaluation of the overall quality.

F. Subjective Study on the Adaptation to Network Impairments

Similarly to the previously introduced subjective study, the task of the test participants was to assess the quality of content sharing. However, in this study, we addressed the effect of content length and variation as well. Through such, the students' adaptation to suboptimal network conditions was investigated.

1) Experimental Setup: In the tests, the number of test conditions was limited to 3: 100 ms delay with 0.1% packet loss; 200 ms delay with 0.2% packet loss; 300 ms delay with 0.3% packet loss. These 3 test conditions were assessed in 2 test scenarios. In one, only a single 120-second-long video was played. In the other one, 4 30-second-long sequences were shown, separated by 5-second-long separation screens. The overall quality of the stimuli was to be evaluated via a single 5-point Absolute Category Rating (ACR) score [49]. This means that the 4 videos in the second scenario were not to be rated separately, but as a whole; perceived quality was to be averaged. The rationale behind the choice of ACR was that from the perspective of the test participants, DCR ratings are less straightforward to average out.

The study used the same source video sequences as the previous study on the effects of network impairments. However, longer cuts were taken from the same contents in order to satisfy the requirements of the first scenario (i.e., to have 120-second-long videos). Additionally, sequences `E` and `F` were not included in the study due to their low variations in visual information. Therefore, we used 4 source contents in total, and thus, the stimuli of the second scenario were always composed of the same 4 videos, in randomized order.

2) Results: A total of 24 test participants completed the subjective tests (14m, 10f, avg. age 23.3). All of them were active university students (12 B.Sc., 9 M.Sc. and 3 Ph.D. students). 23 used wireless Internet connection and only 1 used a wired connection. Regarding devices, 9 students used laptops, 4 of them connected via a desktop computer, 3 participated through a tablet and 8 through a smart phone.

Figures 4 and 5 show the Mean Opinion Score (MOS) and the distribution of the obtained scores, respectively. For the 120-second-long stimuli, the MOS is consistent across all test conditions, signifying adaptation. In fact, all of these values based on the ratings of the 24 test participants are 4.46. Furthermore, there is no deviation at all between the rating distribution of the two test conditions with higher levels of degradation. On the other hand, the results on the 30-second-stimuli indicate the impact of the artificially added delay and packet loss. Although there is no statistically significant difference between the obtained ratings, there is a shift of 0.33 between means, and 0.42 when compared to the results of the 120-second-long stimuli. Furthermore, the rating distribution of the subjective study on the effects of network impairments signifies the perceivable differences for the shorter stimuli, which, in the case of the current study, does not directly translate to ACR ratings. This is due to the fundamental dissimilarities between the scales themselves: the DCR scale serves a dual purpose, while the ACR scale of the same size has uniformly distributed options. Therefore, while differences are, in fact, perceivable, they hardly reach a quality threshold for shorter stimuli, and for longer stimuli, the selected test conditions did not cause any difference whatsoever, accentuating adaptation.

IV. SURVEYS AND SUBJECTIVE STUDIES ON ONLINE MEETINGS

A. Survey on Content Sharing in the Private Sector

The survey addressed the personal preference of employees within the private sector regarding the different possible options for content sharing via Teams.

1) Question: Similarly to the survey on content sharing options in the context of online education, this survey included a single multiple-choice question, asking about the preferred method of content sharing via Teams. However, this question was more focused on presentations (i.e., slide sharing), and thus, accordingly, the possible answers were the following: Desktop sharing (fullscreen); Window sharing; Presentation sharing directly via Teams.

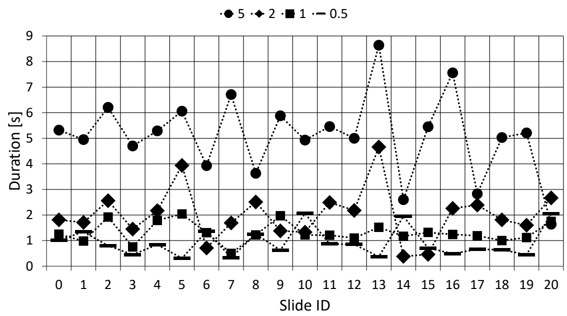

Fig. 6. Results of the study on the rubber band effect of slide sharing. The 4 data series represent the different transition times in seconds.

2) Results: The survey was completed by 61 employees from companies where Teams is the default meeting platform. The dominant preference was window sharing (42), followed by fullscreen desktop sharing (19), while no preference was registered for sharing directly via Teams. These results provided additional support to the experimental configurations; the studies on online meeting utilized application window sharing as well.

B. Preliminary Study on the Rubber Band Effect of Slide Sharing on Online Platforms

Prior to the subjective study on the perceived quality of media (i.e., video) loading times, we carried out an experiment using slides to address the rubber band effect.

1) Experimental Setup: We created 21 slides in total. Every slide had a high-resolution image (equivalent of a 720p video frame) as background – greatly varying with regard to spatial complexity – and a large number in the middle of the slide, going from 0 to 20. The experiment was to share the slides between two clients (i.e., computers) in an online meeting – using Teams as in all of the tests – in order to measure the potential rubber band effect. For this, timed slideshows were used with 5-second, 2-second, 1-second and 500-millisecond transition times.

At first glance, the selected transition times may seem unrealistic in practice. Indeed, changing rapidly between slides during a university lecture or a presentation in the private sector is definitely not the most common practice. However, it does make sense and may serve various purposes. For example, it can be used as a tool to make a point, having only one large image per slide; it is not vital to carefully examine the images themselves. This may be appropriate to emphasize that there are so many examples or use cases to a specific topic; the presenter or lecturer only speaks one word or technical term per slide (1 or 2 seconds per slide is easily realistic in such case). Another example is a “manual” animation, in which the slides behave as frames (even 0.5 seconds per slide may be realistic, depending on the content). Such approach is more than adequate to exhibit the progress related to the content, and the presenter may easily revert the direction of progress (i.e., moving back and forth between slides).

As a first step, both computers were validated in terms of performance. Both passed the validation, as during the local playbacks, the slides were transitioned with the correct time slots (with negligible deviations).

2) Results: Figure 6 shows the results. The test was repeated and similar data was obtained. Beside the apparent rubber band effect, the total time needed to reach the end of the slideshow was sometimes longer as well: instead of 105, 42, 21 and 10.5 seconds, it needed 107.03, 42.16, 27.57 and 19.43 seconds, respectively. Technically, the more frequent the transition was, the longer the total duration became. Furthermore, certain patterns are detectable among the transition duration trends, which are due to the differences in spatial information between adjacent slide backgrounds. Moreover, less-frequent, higher-duration transitions resulted higher jitter, as exhibited by Figure 6. Yet, it needs to be noted that positive alterations (i.e., more time is needed for the transition) are subsequently balanced out by negative alterations better, which issued the lower deviation regarding the total time. Moreover, while the absolute value of the jitter measured for higher-duration transitions may be greater (e.g., more than 8.5 seconds for a five-second transition), the percentage-wise fluctuation for lower-duration transitions is notably higher (e.g., more than 2 seconds for a half-second transition). A more in-depth analysis of the phenomenon is required to adequately address the open questions related to the topic.

C. Subjective Study on the Overall Perceived Quality of Media Loading Times

The task of the test participants was to report the amount of initial content delay (i.e., how much they missed from the beginning of the video) and to rate the overall quality.

1) Experimental Setup: Following the concept of the previously introduced study, in every single video, a large number in the middle of the frame counted the seconds passed since the video was started. The videos were 21 seconds long, as the counter went from 0 to 20. The task of the test participant was to report the number first visible when the video image became available and to evaluate the overall quality. Again, during the test, the participant had to report 2 numbers: (i) the first perceivable number when the video content appeared on the screen and (ii) the subjective score of the overall quality, rated via a 5-point ACR scale. Hence, 2 numbers were reported per test stimulus. The data was reported verbally, via Teams. The first number was provided by the test participant when the content became visible, and the second one was registered at the end of the stimulus. It needs to be noted that reporting the scores verbally was quite viable as the stimuli contained no audio. Furthermore, the test participant was instructed to take everything into account, including the behavior of counter (i.e., uniformity of counter progression) when assessing the overall quality.

The test conditions of the experiment were the combinations of different video resolutions and content structures. As there were 5 content structures displayed at 3 resolutions, the total number of test conditions was 15. The 3 resolutions were 480p, 720p and 1080p. We considered using 2160p as well, but according to a small one-question survey on 2160p in online education (a binary question whether the individual uses 2160p resolution for content sharing via Teams or not), less than 5% of the respondents use such high resolution. Therefore, we considered it to be unrealistic in the scope of the experiment. Some may argue that 480p might also be deemed irrelevant in this day of age, yet certain older but relevant professional materials may not be available in higher resolution.

TABLE II
FIRST VISIBLE NUMBER IN THE TESTS WITH OVERALL QUALITY

	480p	720p	1080p	a	b	c	d	e
0	11	7	3	7	4	3	2	5
1	85	92	95	52	56	55	56	53
2	3	1	2	1	0	2	1	2
6	1	0	0	0	0	0	1	0

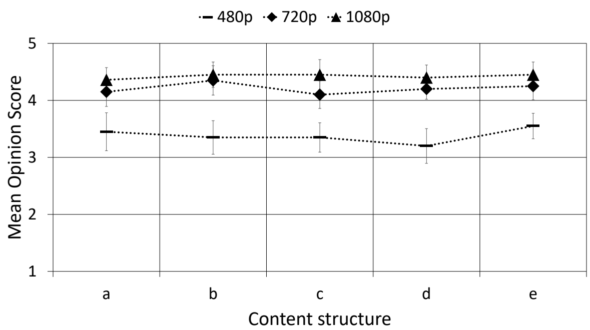

Fig. 7. MOS for overall quality.

The 5 content structures (i.e., the alternations of the background behind the counter) of the experiment were the following: (a) static black screen, (b) a single video sequence without cuts, (c) sequences change every 3 seconds, (d) sequences change every 2 seconds and (e) sequences change every second. The adjacent sequences were selected in a manner to have as much difference as possible, with regards to Spatial Information (SI) and Temporal Information (TI), scene dynamics, camera motions, content types (i.e., camera-captured or rendered), etc.

The source video contents were selected from the Xiph.org Test Media[2] collection. The sequences typically alternated between rendered (e.g., Big Buck Bunny) and camera-captured (e.g., Netflix's El Fuente) scenes, but the aforementioned parameters were taken into consideration as well.

2) Results: The experiment involved 20 test participants (9m, 11f, avg. age 21.6). 15 used wireless connection to access the Internet and 5 connected via Ethernet cable. 14 used the Teams desktop application, 3 used the mobile application and 3 used a web browser. Table II shows the results for the initial loading times (i.e., how many times test participants perceived a given counter number first). At first glance, the results for each category seem pretty much the same, with 1 being dominant. However, Pearson's chi-squared test indicates statistically significant differences: for resolution categories, in the case of 480p and 1080p ($p < 0.01$); for structure categories, in the cases of a and b ($p = 0.04$), a and c ($p = 0.03$), a and d ($p < 0.01$), b and c ($p = 0.03$), b

[2]https://media.xiph.org/

and d ($p = 0.03$), b and e ($p = 0.03$), d and e ($p = 0.03$). A clear conclusion that can be drawn here is that higher resolutions result in higher initial media loading times – which is, of course, expected – and thus, greater differences in resolution result in greater differences between such values. While the adjacent resolutions do not differ on a statistically significant level, the lowest and the highest do. Furthermore, the variations in the spatial and temporal complexities of the transmitted multimedia content may also have a significant impact on the loading times.

Figure 7 shows the MOS values of the tests. Resolutions 720p and 1080p performed similarly across every content structure; although there was a clear preference towards 1080p, the differences were not statistically significant. Regarding the 480p stimuli, the ratings were significantly worse. In order to investigate the cause of the obtained results, the experiment was repeated with the same number of test participants, but with individual quality aspects.

D. Subjective Study on the Separate Quality Aspects of Media Loading Times

The aim of this study was to address the separate quality aspects of the previous experiment.

1) Experimental Setup: In this study, the overall quality was separated into 3 aspects: (i) the visual quality of the video, (ii) the frame rate and (iii) the uniformity, the behavior of the counter. These were all rated via the same ACR scale. Evidently, in the these tests, 4 numbers were reported per test stimulus.

2) Results: The experiment involved 20 test participants (12m, 8f, avg. age 21). 15 used wireless connection to access the Internet, 5 connected via Ethernet cable. 11 used the Teams desktop application, 5 used the mobile application and 4 used a web browser. Table III shows the results for the initial loading times. Although the categories follow a similar pattern, there are, in fact, statistically significant differences: similarly to the results of the previous experiment, for resolution categories, in the case of 480p and 1080p ($p < 0.01$); for structure categories, in the cases of a and b ($p = 0.01$), a and c ($p < 0.01$), a and d ($p < 0.01$), b and c ($p < 0.01$), b and d ($p < 0.01$), b and e ($p < 0.01$), d and e ($p < 0.01$). This is extended by a and e ($p < 0.01$), c and d ($p < 0.01$), c and e ($p < 0.01$). Technically speaking, this means that the results of every single structure category is significantly different from the results of every other structure category. The conclusions that can be drawn from these results – particularly regarding resolution – are analogous to the findings presented earlier.

Figure 8 shows the MOS values of the tests. Compared to the ratings obtained on overall quality, visual quality was assessed in a similar manner, but there were statistically significant differences between 720p and 1080p as well.

In the case of perceived frame rate, content structures a and b were not distinguished with respect to resolution; the plain-black and the single-scene stimuli caused either no degradations in frame rate or applied to every resolution at a similar extent. However, for the other videos with content switches (i.e., cuts), higher resolutions were penalized more, especially in the case of structures d and e.

TABLE III
FIRST VISIBLE NUMBER IN THE TESTS WITH QUALITY ASPECTS

	480p	720p	1080p	a	b	c	d	e
0	16	13	9	9	6	13	9	1
1	73	74	76	46	45	42	40	50
2	9	11	10	4	8	2	9	7
3	0	2	4	0	0	2	2	2
5	0	0	1	1	0	0	0	0
6	1	0	0	0	0	1	0	0
10	1	0	0	0	1	0	0	0

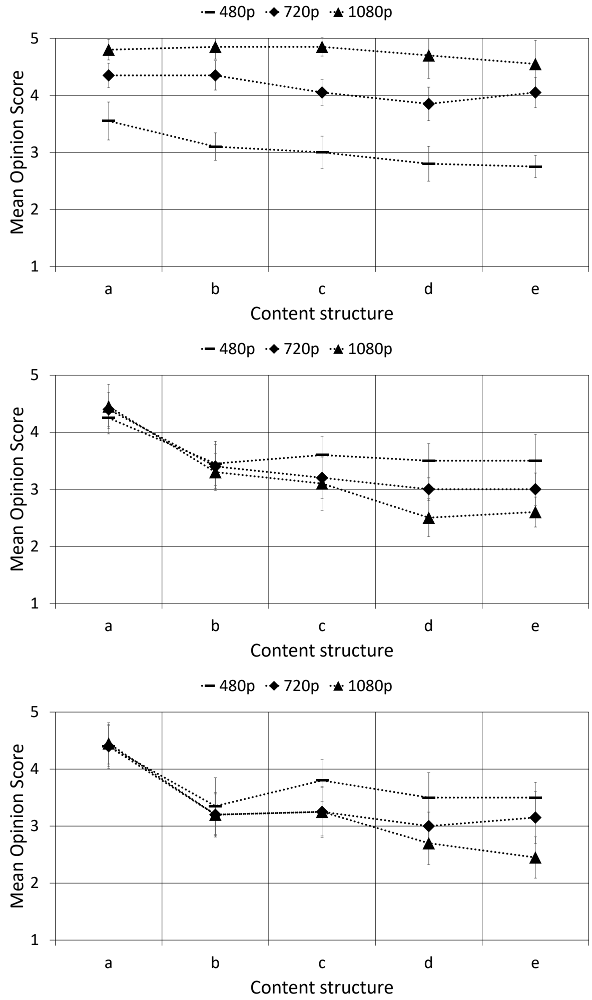

Fig. 8. MOS for visual quality (top), frame rate (middle) and counter assessment (bottom).

The subjective assessment of the counter was analogous to the evaluation of the frame rate, clearly indicating the connection between the two. It is important to note that it is technically possible to have video content sharing on an online meeting platform where the frame rate fluctuates but the behavior of the counter remains mostly uniform. In our experiment, the uniformity of the counter was affected similarly to the frame rate.

The topic of this study is additionally investigated by the following survey. While these results already signify that

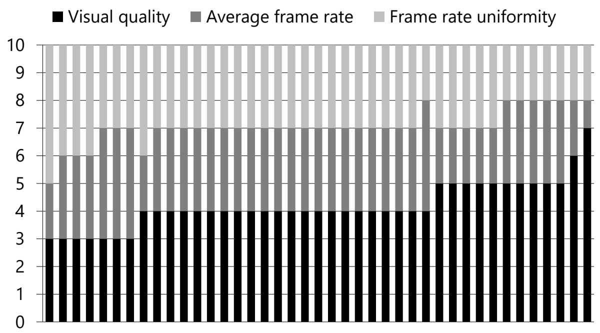

Fig. 9. Preference point distribution between visual quality, average frame rate and frame rate uniformity.

visual quality contributes the most to the overall perceived quality of content sharing in online meetings, these aspects were directly assessed on the level of personal preference.

E. Survey on Visual Quality, Average Frame Rate and Frame Rate Uniformity

The survey addressed the personal priorities and preferences between visual quality, average frame rate and frame rate uniformity.

1) Questions: The first task within the survey was to distribute 10 points among visual quality, average frame rate and frame rate uniformity. Higher points reflected higher personal preferences. Any combination was permitted (including giving 10 points to one aspect and 0 to the others), and only integers were to be used. The two other questions directly addressed the investigated preferences with 3 options each. One asked about visual quality and frame rate (*better visual quality but lower average frame rate and frame rate uniformity*; *worse visual quality but higher average frame rate and frame rate uniformity*; *equal preference*) and the other one asked about average frame rate and frame rate uniformity (*higher average frame rate but lower frame rate uniformity*; *lower average frame rate but higher frame rate uniformity*; *equal preference*).

2) Results: The survey was completed by 41 individuals. The average preference points for visual quality, frame rate and frame rate uniformity was 4.2, 2.85 and 2.95, respectively. The distribution of the points for each individual who answered the survey is shown on Figure 9. These results are analogous to the findings shown on Figure 8; visual quality contributes the most to the overall quality, while average frame rate and frame rate uniformity are equally lower priority. The most common distribution is 4/3/3, which applies to the preference of 20 out of the 41 individuals.

Regarding the two other questions, the results are the following: 21 voted for better visual quality, 6 preferred frame rate and the preference was equal for 14 individuals; 9 voted for higher average frame rate, 19 preferred higher frame rate uniformity and the preference was equal for 13 individuals.

While the results of first question are somewhat analogous to the preference point distribution, the second question seems to contradict the distribution at first glance. In the distribution, points on average frame rate and frame rate uniformity were balanced, yet the results of the second question clearly favor frame rate uniformity over average frame rate. However, the point distribution task covered visual quality as well, and it was not necessarily a simple task to correctly indicate the relations between all 3 aspect at the same time, taking into consideration the assigned priority proportions. On the other hand, the questions did not take the magnitude, the weight of preference into consideration, enabling smaller differences with regard to personal priorities to be indicated.

Additionally, note that in the subjective study on the investigated aspects, the test participants provided ratings based on what they experienced in the scope of the experiment, while in the survey, responses were solely based on existing prior experience. Of course, in the subjective study, the test participants were fundamentally influenced by prior experience as well. The effect of such influence is also worth studying in the future.

V. CONCLUSION

In this paper, we presented our surveys and studies on the QoE of content sharing in online education and on online meeting platforms. The results of the individual surveys and studies support each other in terms of experimental configuration and aid the deeper understanding of the investigated phenomena. Furthermore, the obtained ratings for the different subjective studies on the same topic of interest draw similar conclusion.

The quality ratings in the context of online education indicate an excellent level of adaptation to impairments. However, as the degradation was set to be around the extent of JND, such adaptation may not be applicable to more severe impairments. Nonetheless, the topic of QoE over time is greatly relevant to online education – due to the potentially longer contents of educational multimedia – and further research may benefit the modeling of adaptation.

We conclude that the personal preference related to the visual quality and frame rate on content sharing via online meetings is the opposite of the trends of modern real-time Video-on-Demand (VoD) services. In the recent years, the majority of VoD platforms started utilizing Dynamic Adaptive Streaming over HTTP (DASH) – also known as MPEG-DASH – which may sacrifice visual quality by using lower-quality segments to ensure playback fluency. Our results gathered by both the subjective study and the survey indicate that DASH-like trade-offs (i.e., compromise regarding visual quality) are not necessarily beneficial to content sharing via online meeting platforms.

The results presented in the paper also highlight that there are statistically significant differences between resolutions (480p and 1080p) with regard to initial delay, and this is also applicable to the different content structures. Practically, as expected, contents with lower resolution initiate playback faster while being shared via an online meeting platform. Regarding the video content itself, higher TI values (i.e., greater differences between adjacent video frames) – particularly in the beginning of the video – may result higher initial delays. The obtained ratings also indicate notable differences with regard to frame rate uniformity on the basis of content structure, some of which are statistically significant.

While the paper did introduce a generous amount of research effort, there is still quite a lot of additional work to be done. First of all, the content characteristics of educational multimedia fundamentally affect the perception of quality impairments – as also indicated by the obtained consistent results. Our studies were limited to 3 archetypes, but there are many more to investigate, such as writing and drawing on a board. The work on adaptation should include wider varieties of content duration, and repeated impairment patters [47] should be addressed as well. Future research efforts should directly consider the SI and TI values of the investigated contents when studying the impacts of the rubber band effect (i.e., the stimuli should be created along a fine-grained SI/TI matrix). Additionally, the phenomenon of frame freezing in the contexts of both online education and online meetings is a relevant, yet underinvestigated issue, the addressing of which could benefit the understanding of both single-event scenarios and QoE over time. Finally, related studies should separately address the various technical options for connecting to the Internet while participating in such experiments, and data clustering based on the capabilities of the user endpoints is also advised, as online meeting platforms may optimize differently for different devices.

A particular limitation of this work is the number of test participants. Although a total of 391 individuals were recruited for the research efforts, this total was spread among 4 subjective studies and 6 surveys. Each of the experiments in the context of online education involved 24 test participants, and this number was 20 for online meetings. The ITU and the VQEG recommend a minimum of 15 [48] and 24 [56] test participants, respectively. Accordingly, many published QoE experiments are of this scale. However, having more test participants may greatly contribute to the statistical strength of the results (e.g., the same rating deviation would result a smaller confidence interval). As Brunnström and Barkowsky conclude [57], going below 24 test participants relies on low rating deviation. In the future, extensive studies of the investigated topics should aim to recruit more test participants.

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