Outline of possible synchronous Solutions and Experiences in order to supply large Groups of Students with Learning Content in Classroom and mixed Classroom/Distance Scenarios

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Abstract. Universities are regularly confronted with the challenge to increase student numbers in order e.g. to receive more base funding from the state. Depending on the actual amount of students increase, this includes normally a number of tough challenges for the university. One of the most demanding issues occurs, when the amount of students exceeds the maximum capacity of the biggest lecture room, hence making it impossible to easily give frontal lectures anymore. In this case literally two options exist: either the problem is solved organizationally or technically. In this paper, we will point out three technical solutions to solve the problem without the necessity to increase personnel costs, not having to extend existing room capacities or significantly change the curriculum planning. We will point out solutions capable of supporting classroom but also hybrid and pure distance scenarios. We will further outline the requirements on these scenarios, possible use cases, discuss the advantages and disadvantages of the scenarios, and share our experiences on the planning and implementation.

Keywords: Real world experiences, lecture streaming, hybrid teaching, asynchronous and synchronous teaching, virtual teaching.

1 Introduction

Universities are regularly confronted with the challenge to increase student numbers in order e.g. to receive more base funding from the state. At our university, this happens approximately every 5 years. Depending on the actual amount of students increase, this includes normally a number of tough challenges for the university. One of the most demanding issues occurs, when the amount of students exceeds the maximum capacity of the biggest lecture room(s), hence making it impossible to easily give classroom lectures anymore. In this case literally two options exist: either the problem is solved organizationally or technically. Organizationally you can divide the students in a number of sub groups, however, this means one and the same lesson has to be given several times to each of the groups resulting in an increase of personnel costs and room resources. Good technical solutions will avoid on the one hand both problems and on the other hand still guarantee a maximum quality of service for the students.

In this paper, we will point out three technical solutions to solve the above problem without the necessity to increase personnel costs, to extend existing room capacities or significantly change the curriculum planning. We will point out solutions capable of supporting classroom teaching but also hybrid and pure distance scenarios. With hybrid scenarios we mean lectures where one part of students still resides (voluntarily) in the classroom, the other part is geographically dispersed. We will further outline the requirements on these scenarios, possible use cases, discuss the advantages and disadvantages of the scenarios, and share our experiences on the planning and implementation.

2 Model for virtual learning scenarios

Recently – especially driven by the Corona pandemic - a great number of different terms was used by the community, including virtual teaching, blended learning, distance learning, eLearning, synchronous and asynchronous teaching and hybrid teaching. In a first step we clearly classified the different scenarios and terminology used and defined a model for virtual teaching scenarios embedded in university teaching in general. The by us elaborated model is depicted in **Fig. 1**.

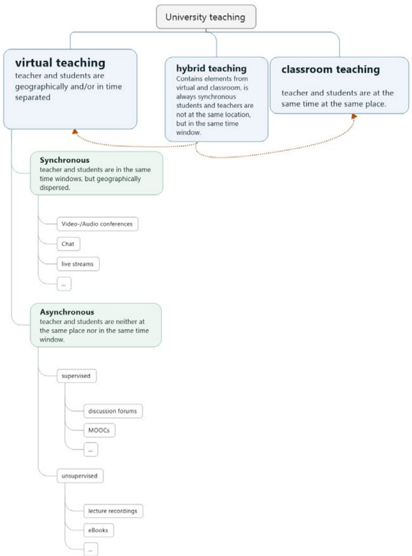

Fig. 1. Model for virtual teaching scenarios

Generally, we distinguish between virtual teaching, hybrid teaching and classroom teaching. Virtual teaching means teacher and students are geographically and/or in time separated. Here we further distinguish between asynchronous virtual teaching (and synchronous virtual teaching. Asynchronous virtual teaching means that, neither teachers nor students are at the same place nor in the same time window. Synchronous virtual teaching means that teacher and students are in the same time windows, but geographically dispersed. The asynchronous virtual teaching can be further classified by a supervised and unsupervised mode, meaning that students either study completely on their own or get active support during the study phase.

With hybrid teaching we refer to a synchronous teaching mode, where part of the students are in the classroom, and another part resides at different locations. The classical classroom teaching involves all students at the same time at the same location.

In this paper we concentrate on virtual synchronous and hybrid scenarios. Concretely we will investigate the following three scenarios, all suitable to support teaching with large groups and flexible to student numbers:

1. Extending local room capacity by offering bidirectional transmission between local lecture rooms (hybrid classroom scenario / synchronous)
2. Provision of lecture streaming with backchannel to the students by expanding an open source lecture recording system (virtual hybrid scenario / synchronous)
3. Bidirectional lecture streaming by integration of an existing video conferencing system into classroom teaching (virtual hybrid scenario / synchronous)

3 Virtual synchronous and hybrid teaching scenarios for large student groups

Each of these scenarios significantly influences teaching practices since not all students remain within one room anymore. This affects mainly but not only the questions students might have and the feedback given by the teacher. For each scenario, we will point out what especially a teacher has to consider when being forced to teach in such a scenario.

In this chapter, we give an extensive overview on advantages and disadvantages for each of the scenarios listed in the previous chapter, helping decision makers and teachers at other universities to select the most appropriate implementation for their own universities. Furthermore this input will be a valuable basis in order to develop your own individual best fitting scenarios.

Last but not least, we will also outline technical issues having to be considered during planning and implementing such scenarios. How to select appropriate software and what requirements shall be considered.

3.1 Extending local room capacity by offering bidirectional transmission between local lecture rooms

This scenario is the most obvious, though that’s why many decision takers have it first in their. However, this scenario is also the most problematic one in terms of acceptance by students and teachers and very greedy in terms of room resources needed. Also technically it puts quite high demands on the local infrastructure.

Characteristics and technical implementation issues.

This scenario is characterized by using two (or more) classrooms - instead of originally one - which together provide enough capacity to hold the entire large group of students. In one room the teacher resides and holds his lecture as usual. In the other room the lecture is transmitted via video and audio. Ideally the transmission is bidirectional, meaning that students in the other room also have an option to ask questions.

Technically this requires at least a camera and an audio equipment (microphone, amplifier, speakers) in the classroom the teacher resides, cable transmission of video and audio to the other room(s), and ab audio backchannel from the room(s) only the students resides back to the room with the teacher. Even though audio equipment is a standard in large lecture rooms, video transmission to other rooms and audio backchannels are not. The later must be also clarified organizationally – hence it must be made clear how students in the other room(s) are expected to interact with the teacher. Shall they just shout in the micro, shall they press a button and the teacher gets a visual sign, shall the use a chat, just to point out different possibilities.

In case you want to implement this scenario at your university on a bigger scale, meaning that you want to have a high flexibility in connecting different rooms very fast with video transmission and audio channel, you shall consider to install a matrix based solution as we have installed it at our campus. A matrix – as depicted in **Fig. 2** – enables you to configure communication paths amongst different rooms in a very flexible way. The number of matrixes basically needed depends on the number of connections you want to have in parallel and how many rooms you want to interconnect. This solution requires a significant investment of money and needs – if you do not want to invest extra in a proper user interface - technical experts for configuring and changing the paths.

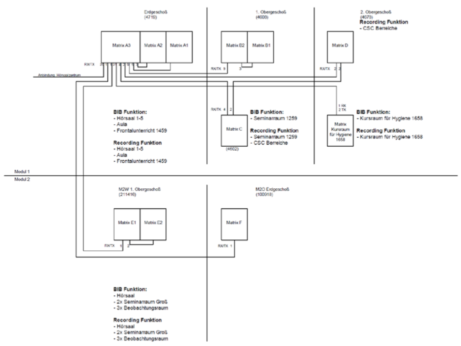

Fig. 2. Connection matrix for video and audio streams at the Medical University of Graz

Advantages.

- Students do not need any technical equipment to participate
- Teachers can easily handle the technics (in case a proper user interface was programmed or the configuration is already done in advance during planning)

Disadvantages.

- Students in the room without teacher have a significant disadvantage in terms of noise level (usually the presence of the teacher regulates the noise level in the room!) and classroom "feeling" (it is much easier - for both teachers and students - in the classroom to raise your hand when you have a question than using fancy technology)
- Given this fact someone has to decide which students may stay with the teacher and which do have to reside in the other room? This needs extra organizational efforts.
- Students are forced to come to the campus without having any benefit in comparison to a standard video conferencing tool which would allow them to be location independent
- More than one room is needed for a single lecture which reduces room resources significantly
- Technical equipment is very expensive in comparison to the benefits achieved.

Experiences

We tried to implement this scenario about 5 years ago at our University, however, it was strongly rejected by students and teachers even before we could practically start it. Main reasons were the clear disadvantage of students not residing in the same room with the teacher and the necessary organizational issue to force them, and the lacking possibility to use the black-/whiteboard. At our new campus we have implemented the matrix solution as given in **Fig. 2**, however, it is not used for teaching purposes but just for isolated public and internal events such as info events and conferences. We cannot recommend this scenario being implemented permanently for teaching.

3.2 Bidirectional lecture streaming by integration of an existing video conferencing system into classroom teaching

This scenario offers a solid hybrid solution in terms of a good student experience and – depending on which video conferencing solution is taken - low investment costs on local infrastructure. Depending on the software chosen it may involve considerable licensing costs. But the solution is much more scalable in terms of remote student numbers then the two classroom scenario.

Characteristics and technical implementation issues.

The bidirectional lecture streaming format is characterized by the usage of a standard video conferencing solution using the presenter PC in the classroom and integration into the existing lecture room audio equipment. Speaking in technical terms a standard

USB camera on the control monitor of the classroom PC and the possibility to use the classroom micro also on the classroom PC is sufficient. Alternatively, in case there is no classroom PC, a laptop can be connected in combination with a headset. However, this requires usually two microphones, one for the room and one for the video conferencing software, which might be tedious for the teacher.

The first step is to select an appropriate video conferencing tool. In our case the best solution was to license the commercial software WebEx [5] from Cisco because this software was already used by many teachers who also work at the university hospital, which is driven by the federal State of Styria, hence they were already familiar with the system. Additionally, we could negotiate a good price. So we licensed this software for all affiliates and students of the University. Other reliable commercial video conferencing software includes Zoom [6], Microsoft Teams [7], Google Workspace [8], GoToMeeting [9], Ring Central Video [10], and U Meeting [11]. Commercial solutions have the clear advantage not having to care about the software maintenance and the streaming and storage infrastructure but involves license costs.

In case you want to go for an open source solutions (for example because of data protection issues), the software we know best and is currently used by many universities in Austria is Big Blue Button [12]. There are also other open source solutions such as Jitsi Meet [13], Jami [14], NextCloud Talk [15] and Element [16]. Since Big Blue Button is used by two universities we closely cooperate we know, that you have to invest a significant amount of money in streaming server and storage infrastructure in order to set up a proper environment for these tools. Parameters such as number of parallel users and minimal transmission quality are key parameters for taking a decision. Furthermore you have to consider personnel resources for software maintenance and support. Taking all this into consideration we came to the conclusion, that a commercial product is the cheaper solution.

Advantages.

- Students have the clear advantage of being location independent – they just need an Internet connection.
- No expensive local streaming and storage infrastructure nor software maintenance needed (in case you select a commercial solution)
- Access for students with acceptable technical equipment possible (smart phone, tablet, laptop)
- No expensive local matrix / cable infrastructure needed for interconnection of rooms
- Back channel for students is automatically available and integrated (audio, video and chat)
- Seamless integration into existing technical classroom audio equipment possible (avoiding e.g. two micros for video conference tool and classroom)

Disadvantages.

- Additional set up expenditures for teachers getting the video conference started and the presentation shared in comparison to a normal classroom lecture

- Additional organizational expenditures in terms of defining meetings in the video conferencing tool and enrolling students (sending out invitations)
- Licensing costs (when a commercial solution is chosen) or local infrastructure and maintenance costs (when an open source solution is chosen to be driven locally)
- Only learning content presented by the PC running the video conferencing tool may be shared to the remote students (when teacher writes e.g. on a black board or white board, remote students won't see it)
- Teacher has to be trained on the video conferencing tools and must elaborate e-moderation skills such as watching the chat for questions from the remote students (depending on the rules he has defined at the beginning)

3.3 Provision of lecture streaming with backchannel to the students by expanding an open source lecture recording system

This scenario is the most promising in terms of student acceptance (quality of streamed content, ease of use) and flexibility (in terms of location and student numbers). It requires either an already existing lecture recording system or the set up of such a system. A lecture recording system is nowadays anyway standard at many universities, in case at your university such a system is not existing so far – this scenario would be another good reason to install one. If you decide to implement a lecture recording system from the scratch, we strongly recommend that you already include also the streaming feature, since in the meantime it became a standard on many universities and gives you a lot of flexibility for teachers and teaching formats.

Characteristics and technical implementation issues.

Our existing lecture recording system [1], is based on the open source software OpenCast [4] and Epiphan Pearl I recording hardware [17]. It is a highly customized system with a, for our university individually tailored technical workflow [2], [3]. Our lecture recording system is capable of recording two synchronized Full HD streams, the teacher video (including blackboard if required) and the PC output. It features a capture management interface programmed by ourselves utilizing the Epiphan application programming interfaces, a quality assurance oriented manual editing of recordings and the publishing on a video portal and within our learning management system Moodle using the by IMS standardized LTI [18] interface. The system is fixed installed in 5 huge lecture rooms and includes a fixed installed camera filming the presenter and the blackboard / whiteboard and an integration into our touch screen based audio visual control interfaces in the lecture rooms. Teachers can easily start / stop the recording by pressing a view keys on a touch screen.

So far our lecture recording system was only able to record lessons, not to stream them in a live setting. Since both, the already existing Epiphan recording hardware and the OpenCast Software also support live streaming, we decided to extend our system by this feature. Hence offering now recording and live stream in parallel, or in case the teacher only wants to use one feature, also only recording or only streaming. This scenario serves perfectly for hybrid settings, where a part of the students remains in the lecture room, the other part will follow the lecture remotely with their digital devices location independently.

Technically the upgrade from a recording system to a recording and streaming system is quite challenging. We started with this project in March 2021 and are currently in the implementation phase. But we can give you already a good impression how the technical workflow will look like, and which important decisions have to be taken. Based on our experiences from the past with lecture recording and from many talks and experience exchanges with two local universities having already set up lecture streaming we designed a technical workflow indicating the main necessary elements, the data flow and the requirements. This technical workflow is depicted in **Fig. 3**.

The main components for the streaming workflow are the transcoding server, the data delivery server and the video portal. In the diagram you can further find the recording hardware delivering the streams directly from the lecture room and the control interface in the lecture room, which is used by the teachers to activate the recording, the streaming or both. Additionally they will be able to chose whether their live stream is public available or can be only viewed by students and affiliates of our university.

The first important component in connection with streaming is the transcoding server. This server is responsible to produce different resolutions in different bitrates (a higher resolution/bitrate refers to a better video quality). The first important requirements and decisions which has to be taken in this connection: in which resolutions and quality do you plan to deliver to the students and from how many rooms in parallel? Different resolutions and qualities are necessary in order to provide students with for their devices optimally fitting quality and bandwidth. The latter is in most cases also a matter of money, since many students have not a flat rate for data but pay on the actually consumed amount. The number of parallel rooms goes hand in hand with the transcoding capabilities of your transcoding server, hence GPU cards can only handle a certain number of streams in parallel.

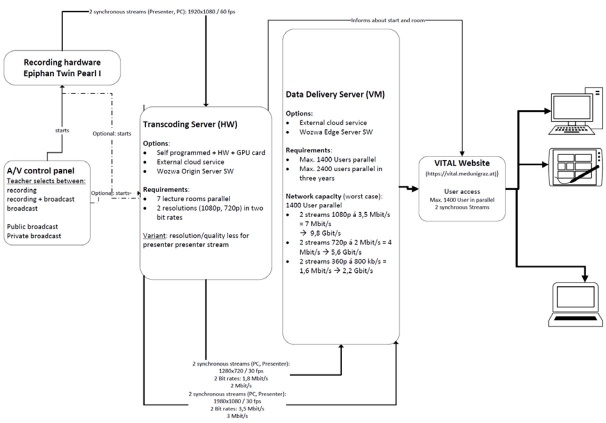

Fig. 3. Technical workflow and requirements for lecture streaming

Our decision is to go for 1080p (1920x1080) 3 Mbit/s und 3.5 Mbit/s and 720p (1280x720) 1.8 Mib/s und 2.5 Mib/s, which seems to be future proof and state of the art. It also guarantees that even small text or images such a radiologic or anatomic images can be viewed in a reasonable quality. For the transcoding server it is further very important that all transcoding can be done in real time, otherwise the delay between streaming and live event would become bigger and bigger which is not acceptable. Furthermore it must be decided whether you implement and host the transcoding server on your own or use an existing cloud service. In case you host it on your own you must invest in transcoding hardware, graphic cards respectively, capable of transcoding all the necessary streams in real time. In connection with transcoding also the maximum delay between the live event and the streaming is a key parameter, especially when you offer a back channel e.g. via chat. This is obvious, because in case you have a high delay (let's say minutes or more) students will ask questions to content which was presented a long time before and maybe confuse the teacher. We defined here a maximum delay of 10 seconds, which still is acceptable. With our configuration we expect to achieve 2 – 3 seconds.
As mentioned above, it is also important, that you must define how many rooms you want to serve in parallel, since this directly affects the transcoding hardware. In our case we want to serve 7 rooms. For our specific case we will need for each room 8 streams (2 resolutions * 2 qualities * 2 streams). A reasonable priced graphics card (such as nvidia tesla T4 – approx. 2.500 €) can transcode up to 8 streams in the resolutions and qualities given above. Hence we will need 7 graphic cards to serve 7 rooms in parallel. When you consider a cloud service, we can recommend Amazon AWS media [20], which offers transcoding for reasonable prices.

The resolutions cannot be decided in an isolated way, but are strongly interconnected to the second important unit in the technical workflow, the data delivery server. This server is responsible to deliver the streams to all connected users in their required resolution and quality. The key parameter here is available bandwidth, and this goes hand in hand with the offered resolution and quality and the number of parallel users. Hence here you must define on the maximum number of parallel users being capable accessing your streams. Based on this number you can calculate the maximum bandwidth being used. And this can be the basis for your decision whether you have to rent external servers / bandwidth or you can still use the usually cheaper university network infrastructure and bandwidth. In case you have to outsource the data delivery, again Amazon offers a quite reasonable service with its CloudFront [20] service. In case you want to rent a server within Europe, we can recommend Hetzner [21], which offers servers with 10 Gib/s bandwidth for prices as low as approx. 700 € / month. This was also our choice.

In our case we calculate for a first phase with maximum 1400 user in parallel, in three years with 2400. For 1400 user in parallel you will need a maximum bandwidth of 9.8 Gbit/s, assuming that all students access with the highest resolution and the highest available bitrate. Speaking of data volume that would be 3.5 Mbit/s max. bitrate, 2 Streams → 7 Mib/s max. bitrate. With 1400 user: 9.8 Gib/s = 1.2 GiB/s → 4.3 TiB/h.

The third important part in the workflow is the video portal where students can finally access the streaming content. Here we plan to extend our already existing open source video portal VITAL [19] by a new tab where you get a list of all rooms presented which are capable of streaming. Furthermore it will be indicated, in which rooms there is currently a live event transmitted and the name of the lecture. Students know from their curriculum in which room their current lessons take place and can start the appropriate stream by selecting the room in the video portal.

Advantages.

- Students have the maximum available video quality and are completely location independent
- Can be easily operated by teachers (integrated in audio visual control interface of lecture room)
- No additional administration efforts in terms of invitation of students to video conferences or reserving additional rooms
- Since only open source software is used no license costs have to be paid
- Infrastructure failures can be handled internally (if locally implemented)
- This solution can also be used to stream in rooms of the university without having an expensive matrix based solution installed

Disadvantages.

- Back channel has to be implemented separately (The OpenCast server / paella player does not offer back channels) – but this can be compensated by installing a chat service
- Continuous costs for transcoding and/or data delivery (when components of the workflow have to be outsourced)

Experiences.

In March 2021 we performed a study of possible solutions and finally the University decided to go for the extension of the existing lecture recording system by a streaming service. What we can already say is, that the key parameters for seizing and designing the main components of the workflow (transcoding and data delivery server) are: maximum parallel users, maximum parallel rooms which stream and the offered resolutions and qualities. This has to be defined first, before you take any technical planning step.

The data delivery server is critical in terms of used bandwidth. It is easy to calculate the maximum bandwidth, however, it is nearly impossible to estimate the realistically used bandwidth. From our partner universities we know, that the maximum bandwidth was by far never reached. On the other hand, when you use a cloud service, this becomes expensive as well. First calculations using Amazon CloudFront results in about 150 $/h, on the assumption the maximum number of users access (1400) and all with the highest available quality. We have finally decided to go for an external server provider – Hetzner [21] – which offers us a server (EPYC™ 7502P 32-Core CPU, 128 GB DDR4 ECC RAM, 2x 960 GB NVMe SSD) with 10 GiB/s dedicated bandwidth and 20 TB data volume / month for 2.200 €/year. Each TB more is 1 €. This will be evaluated in terms of bandwidth and data volume used for one year and then we will decide, whether we will continue to rent the external server or if the local infrastructure of the university is sufficient.

4 CONCLUSIONS/RECOMMENDATIONS/SUMMARY

All of the described solutions are highly customized and therefore no out-of-the-box installations where you simply can buy an existing product and install it. They all require on the one hand special teacher skills and on the other hand on site technical personnel to plan and implement it. Within the paper we give our experiences in order to make this process as simple as possible and in order to avoid potential mistakes.

Hybrid scenarios are the most complicated scenarios in terms of technical set-up and requirements on teaching skills. Even though the students not residing in the local classroom will always have a disadvantage, the goal of the outpointed scenarios was to make their learning experience as good as it would have been when being present in the classroom.

None of the three scenarios is simply perfect for all purposes. Based on the requirements we gave teachers and engineers of other universities the chance, to select easily the scenarios being most appropriate for them.

The scenario extending local room capacity by offering bidirectional transmission between local lecture rooms suffers from our experience heavily from teacher and student acceptance. We know this from a former project where we encountered heavy resistance from the university teachers. Furthermore, it clearly discriminates the students who have to sit in the room without the teacher and at the university. In case a university wants to introduce this scenario in teaching, we highly recommend to perform a survey amongst the stake holders (teachers and students) before hand.

The for us most appropriate scenario is the extension of our already existing open source lecture recording system by means of a streaming feature including a text based backchannel. This is because it does not require quite expensive local cable and matrix infrastructure, it is scalable by means of number of remotely participating students, can be easily streamed to each room of the university if really needed, the software is open source and hence no license fees have to be paid, and it seamlessly integrates with our existing platform. Key parameters for setting up such a streaming scenario are: number of resolutions and bandwidth qualities to be offered for students, the number or parallel rooms to be served, the maximum of parallel students watching the streaming and the maximum delay you will accept between the stream and the live lecture. Important decisions to be taken include whether you set up transcoding and data delivery locally or you will use cloud services or hosting providers.

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