Integration of a Novel Multimedia Classroom for Distance and Hybrid Learning

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Background

Attempts to mitigate the COVID-19 pandemic have required educators to make significant and rapid changes to teaching methodology. In early 2020, schools rapidly transitioned to remote education using commercial videoconferencing solutions, requiring herculean efforts from educators and achieving mixed levels of success. As students return to the classroom in late 2020 and early 2021, the challenge will be compounded by precautions for educator and student safety and the significant likelihood of significant numbers of students desiring to access synchronous education remotely in hybrid educational models.

We are sharing our experiences in development of a videoconferencing solution for classrooms, in hopes that the broader educational and business communities can benefit from what we have learned. Towards that end, we are publishing all of the software and hardware details, deployment instructions, and configurations involved in deploying a system like ours.

Design Considerations

Commercial videoconferencing systems are not well-adapted for use in active classrooms. They are generally focused on either sharing content from one side of a conference room table or webcasting a lecture hall. Generally, they are well-adapted to sharing previously prepared business presentation content rather than fostering collaborative discussions that span an entire classroom.

There is also considerable variation in instructional styles according to subject matter and individual instructor preference, not all of which are easily adapted to touch display boards and existing interactive presentation solutions.

Minimizing direct contact between instructors and students is essential for both student and staff safety. Therefore, more effective ways of sharing content and demonstrating techniques from the front of the classroom are required.

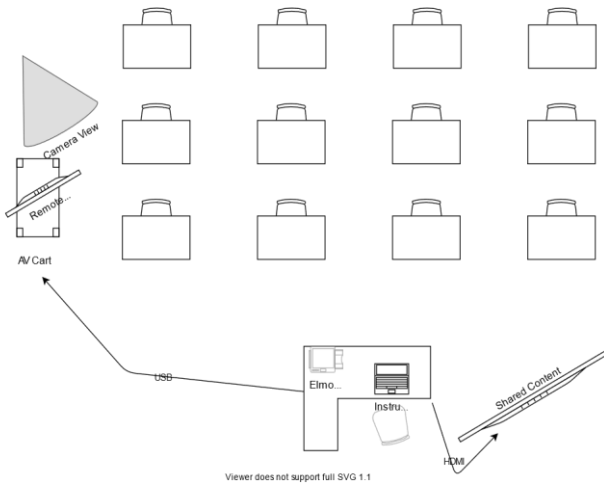

Figure 1: An example classroom arrangement. The instructor can easily share content from their laptop, documents on their desk, or can choose from views of the overall classroom. Local and remote students have a seamless experience. The instructor can see remote students when surveying the classroom and can establish eye contact when directly addressing the remote pupil.

We have designed a system supporting hybrid instructional uses, wherein an instructor shares content with and collaborates with a mixture of local and remote pupils. This system has an assortment of cameras and microphones that allow the remote students to fully participate in their familiar, dynamic classroom. It allows new modes of classroom interaction while minimizing the amount of change required for instructors to be immediately effective.

The audio configuration has been carefully optimized to ensure that the instructor's voice always has priority

over other classroom noise sources, ensuring student comprehension.

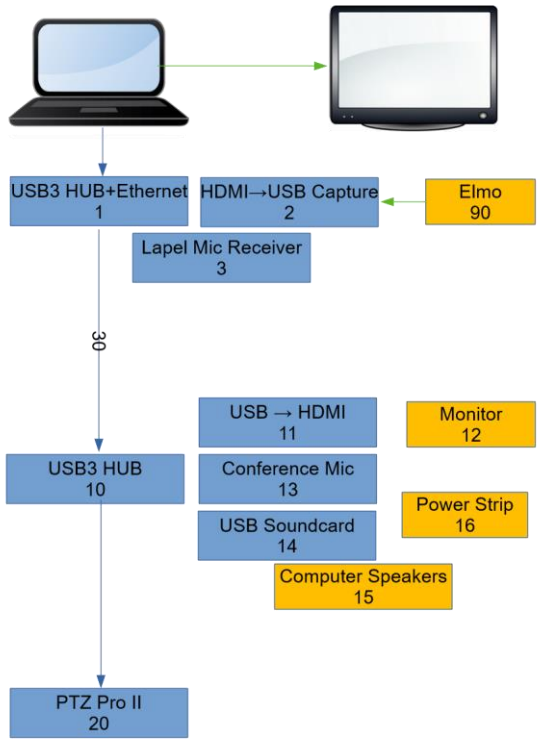

Figure 2: The hardware used is a straightforward integration of inexpensive COTS products. Precise specifications are included in the system Bill of Materials.

At top are the items on/near the instructor's desk; the middle items are on the AV cart, and the PTZ Pro II is mounted on the wall above the cart.

This system offers unique telepresence capabilities while achieving a cost that is low in comparison to existing commercial offerings, though there is a moderate amount of integration effort required for each classroom. Most of the system resides on an AV cart that can be assembled and tested at a central location and can be replaced if a classroom experiences hardware failure. Additionally, we have acquired a small number of conventional videoconferencing systems that can be used to quickly bring a classroom experiencing technical problems back online.

Ease of use is critically important in a classroom, including the minimization of setup and transition times. We have consolidated the cabling so that only three connections need be made to the instructor's laptop: power, HDMI, and a USB cable, and we have developed automation software that simplifies starting the videoconference before each class.

We have also prioritized the selection of components that will continue to be useful in the school environment after a return to normal instruction. Classroom recording capabilities are useful to many instructors for presentation reviews or for operating "flipped" classrooms, and the monitors and document cameras are expected to find many uses in the years to come.

Key Hardware Components

USB Hubs

There are USB hubs to minimize cabling requirements; one is at the instructor workstation and the other is in the cart that contains the equipment in the back of the classroom. They are USB3 for bandwidth.

Classroom TV

A large television (already existing in many classrooms) is used to share content with the students physically in the classroom. It shows whatever content is being sent over the Zoom stream. It is connected to HDMI on the teacher laptop.

Figure 3: This is the view from a student desk in our example classroom (please excuse the temporary setup and cabling!), illustrating the gallery monitor (right) and presentation view (left) during initial testing.

PTZ Camera (Logitech PTZ-Pro2)

This is a high-resolution, motorized USB camera with a 10x zoom lens. It is controlled by an infrared remote control and can be pointed anywhere in the classroom. There are 3 position presets that teachers can produce

for normal use cases. This is the primary camera used in the system. It is on the wall approximately 5 feet high.

Placement of the pan-tilt-zoom camera and gallery view varies from classroom to classroom based on layout and instructor preference; in some cases, it is placed on the side of the class near where a student desk would be. In other cases, it is placed in the back of the class.

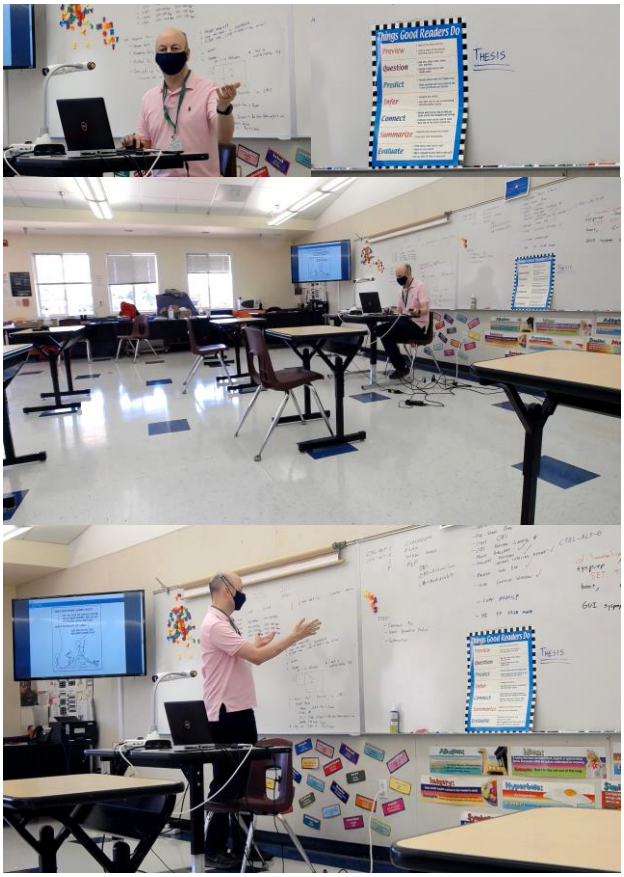

Figure 4: Examples of classroom views that can be selected from the Pan-Tilt-Zoom camera. The actual camera will be a few feet higher.

It is powered by the power strip in the AV cart and connected to the USB hub in the cart.

Gallery View Monitor

A 32” monitor is used to show the Zoom gallery view. It is important that it be placed under the PTZ camera with a direct eye-line from the instructor’s primary position. When the instructor looks at the gallery view to respond to a remote student, the student and instructor perceive eye contact; this is essential for interactive conversation.

The monitor is angled to allow students in the classroom to turn and see remote students while minimizing potential for disruption and distractions from interactions with remote students during instruction.

A USB-to-HDMI adapter is used on the AV cart is used to reduce cabling requirements and to simplify daily setup.

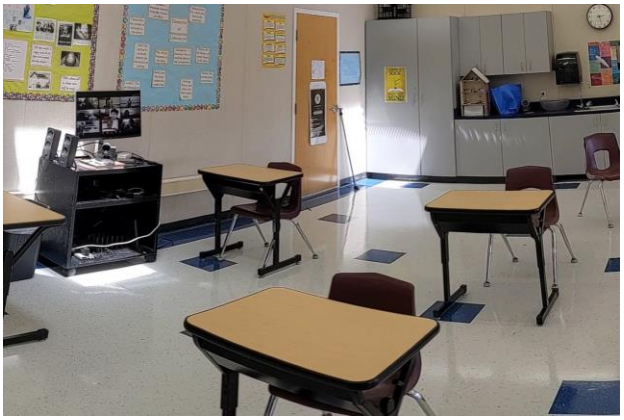

Figure 5: A view of our demonstration classroom from the instructor's desk, with the gallery monitor at left.

To minimize resource usage on the instructor laptop, the gallery view monitor is driven at a low resolution (800x600). With limited resolution, performance of the gallery view remains sufficient for the intended purpose of engaging with remote students.

Document Camera (ELMO TT-12)

This camera is very versatile. Because it can be positioned to face anywhere in the room, and has significant zoom, it can be used for a variety of uses:

- The primary design use case for this camera is to point down at materials that the instructor is sharing from the front of class, such as manipulatives, content from textbooks, or instructor demonstrations.
- The PTZ camera can provide a reasonable view of the whiteboard, but the portion of whiteboard that is nearest the instructor’s desk can often be seen most clearly through the document camera.

- Alternatively, instead of using the whiteboard, the instructor can write work directly in a notebook and share the contents with remote students over Zoom and students in the classroom using the television.
- Finally, when a student is presenting from their desk, the camera can be pivoted to point at them. The PTZ-Pro2 camera is behind many students, so the document camera often offers a better view.

The school has TT-12 of different vintages; some do not support acting as a standard USB camera. Therefore, a HDMI capture USB3 device is used. This also offers a higher framerate than the newer document cameras provide over USB2.

Figure 6: Document camera views, from left to right: textbook on instructor's table, a student's desk, and the whiteboard.

The TT-12 is also able to switch to an external HDMI source, which allows the instructor to attach additional video sources to the system, such as a video player or auxiliary computer.

Instructor Microphone

An inexpensive wireless microphone with a cardioid pattern is used to capture audio from the instructor's area at the front of the classroom while rejecting audio from other sources. It can be used in a desktop, headset, or lavalier mode depending upon instructor preference. To prevent interference, microphone radio frequencies were chosen such that nearby classrooms occupy different channels.

Boundary Omnidirectional Microphone

A boundary ("conference room") microphone is used to capture audio from the back of the classroom. It is placed on the AV cart and attached to the USB hub.

If a directional microphone is used for this purpose, it should be pointed away from the speakers and towards the back of the classroom, and rigidly attached to the cart (e.g. with adhesives) to maintain a consistent orientation.

Computer Speakers

Ordinary computer speakers are placed on the AV cart facing away from the boundary microphone. We chose speakers that do not have advanced functions like auto-power-off. They are attached to a USB sound card plugged into the cart's USB hub.

Software Components

Zoom

Zoom is used to connect the remote students. Zoom screen sharing and source switching are not used; instead Open Broadcaster Software is used to composite a view for remote students. Similarly, Zoom's microphone level is set to the maximum value, and OBS is used for audio mixing. Zoom's echo cancellation and noise reduction technologies are still used, however.

Open Broadcaster Software (OBS)

Open Broadcaster Software is a program that is frequently used in producing webcasts and Twitch streams. It is capable of switching and compositing video sources, while mixing and filtering audio sources.

In our system, it is used to combine the different sources of classroom audio (shared multimedia content, the instructor microphone, and the ambient classroom microphone). It is also used to switch between different "scenes" that present different types of content to remote students (classroom, document camera, screen sharing, or combinations of these).

OBS has a "projector" view where the content sent over the stream can be shown on a monitor. This is used to show the presently streamed content (screen share, document camera, or whole-classroom view) on the main classroom television. It also has global hotkeys; an instructor can switch between different scenes with simple keystrokes.

The profile and scenes directories from our reference OBS computer are imaged onto every teacher laptop, reducing the amount of effort required for configuration.

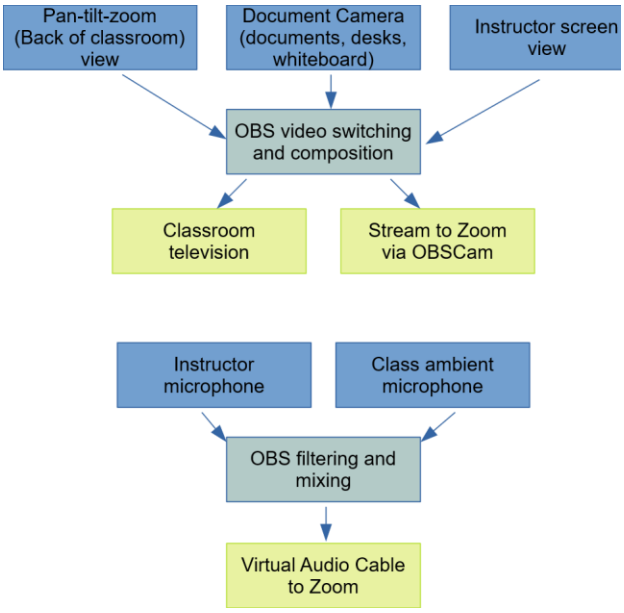

Figure 7: Conceptual diagram of the video and audio paths from classroom sources to remote students and the classroom monitor.

Open Broadcaster Software is used for composition, source switching, and audio mixing, while Zoom's audio processing provides echo suppression and additional noise suppression.

One particularly powerful piece of OBS functionality that we use extensively is the audio compressor with "sidechain ducking." This allows the level of an audio source to be automatically reduced when another audio channel is active. We use this to reduce the levels of classroom audio when a video is being shared (preventing reverb) and to give the instructor's microphone priority.

To simplify deployment of OBS, we manually copy the configuration files to the instructor's laptop.

OBS-VirtualCam

By default, OBS streams to external platforms over the Internet directly. To integrate with Zoom, we use the OBS-VirtualCam plugin. This takes the OBS output video and presents it to Zoom as a virtual camera.

VB-AudioCable

Similarly, a third-party driver "VB-AudioCable" is used to take mixed, filtered audio from OBS and present it to Zoom as a virtual microphone. This is the only software component with an associated cost: single user licenses cost 5 Euros, or approximately 6 dollars (though there are volume discounts).

Conference Launch Assistant

Conference Launch Assistant is a small program we wrote ourselves. It has a few functions:

- Performs diagnostics, ensuring that all cameras and microphones are plugged in, and warning the user if anything is missing.
- Launches and configures OBS.
- Sends keystrokes to Zoom to pop out the "Chat" and "Participants" panels
- Moves the "Chat" and "Participant" panels to the instructor's screen
- Positions the Zoom gallery as a full-screen view on the auxiliary monitor
- Remains running, listening for a Ctrl-Alt-G hotkey. The Ctrl-Alt-G hotkey moves the Zoom gallery to the "next monitor" (e.g. to show the gallery to all the students in the room).

Supplement: Software Configuration

Configuration files as used in our environment can be found at [XXX: TBD]. Below is a description of how the settings were developed in our test classroom.

Zoom Audio Settings

Microphone: Virtual Audio Cable Output, microphone level set to 100% (all the way up).

Speaker: USB Sound Card attached to speaker on cart.

OBS Audio Settings

Overall

Monitoring for all sources set to Virtual Audio Cable Input and enabled, to ensure mixed audio gets to Zoom.

Source: Desktop audio

No filters; this source is set to capture audio sent to TV in classroom.

Windows audio output is set to TV in classroom.

Source: Main microphone path (instructor)

Gain, 25dB: Our wireless microphone has low audio level, so some gain is needed.

Compressor, sidechain ducking from "Desktop Audio", 30:1, threshold -50dB: If there is "desktop audio" from a presentation, this quiets the other microphones to avoid echoes.

Expander, 1.5:1, threshold -40dB: This lowers the volume of small sounds when there's no active speech.

Limiter: A limiter prevents audio clipping, threshold -3dB.

Source: Ambient microphone path (students)

Gain, 12dB: This is a moderate level adjustment.

Noise suppression, level -45: Lessens ambient noise from ventilation, paper rustling, etc.

Compressor, sidechain ducking from "Desktop Audio", 30:1, threshold -50dB: If there is "desktop audio" from a presentation, this quiets the other microphones to avoid echoes.

Compressor, sidechain ducking from main microphone path, 32:1, threshold -36dB, attack 10ms, release 320ms: This yields in preference to instructor / main microphone

Expander, 1.5:1, threshold -40dB: This lowers the volume of small sounds when there's no active speech.

Limiter: A limiter prevents audio clipping.

All other audio sources

All other audio sources (document camera, etc) turned all the way down.

OBS Scenes

Classroom View

Single video source: Logitech PTZ Pro 2. Hotkey: Ctrl-Alt-C

Elmo (Document Camera) View

Single video source: HDMI USB capture attached to Elmo document camera. Hotkey: Ctrl-Alt-E

Laptop Camera View

Single video source: Laptop built-in webcam. Hotkey: Ctrl-Alt-L

Picture-in-Picture View

HDMI USB Capture source fullscreen, with classroom view in corner. Used to avoid excessive switching between the first two scenes.

Screen Sharing View

Single video source: Display capture. Hotkey: Ctrl-Alt-S