DIGIWIND

D2.3
DIGIWIND CLASSROOM EXEMPLAR

D2.3 – DIGIWIND CLASSROOM EXEMPLAR

Dissemination Level	PU-Public
Title of Deliverable	DEM
Work package number	WP2
Task number	T2.2 Methodologies and operating procedures for learning experiences
Due date	31/12/2024
Submission date	30/06/2025
Deliverable lead	DTU
Version	3.0
Authors	Karsten Kryger (DTU), Elena Stroo-Moredo (TUD), Pål Stabel Keim (NTNU), Marek Chodnicki (PG), Gerard Cahill (TUS)
Reviewers	Tuhfe Göçmen (DTU)
Abstract	A report detailing the construction and functions of the DigiWind Classroom Exemplars, state-of-the-art training facilities for virtual and hybrid teaching in DigiWind.
Keywords	State-of-the-art hybrid classrooms, virtual classrooms

DigiWind

Grant Agreement: 101122836
Project name: Digital Masters of Wind and Energy Systems
Call: DIGITAL-2022-SKILLS-03
Topic: DIGITAL-2022-SKILLS-03-SPECIALISED-EDU
Granting authority: European Health and Digital Executive Agency
Start Date of Project: January 2024
Duration: 48 months

Document Revision History			
Date	**Version**	**Author/Contributor/ Reviewer**	**Summary of Main Changes**
20/05/2025	1.0	Karsten Kryger (DTU)	Initial draft – report structure
04/06/2025	2.0	Elena Stroo-Moredo (TUD), Pål Stabel Keim (NTNU), Marek Chodnicki (PG), Gerard Cahill (TUS), Anne Søndergaard Forsbøl (DTU)	Edits and updates per partner facilities
30/06/2025	3.0	Tuhfe Göçmen (DTU)	Reviews and edits towards a submission-ready version

LEGAL NOTICE

This project has received funding from the European Health and Digital Executive Agency under the Grant Agreement No 101122836. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

The European Commission is not liable for any use that may be made of the information contained herein.

Executive summary

This report documents the design, implementation, and testing of state-of-the-art hybrid and virtual classroom facilities across five DigiWind higher education institutions: DTU, TUD, NTNU, TUS, and PG. These DigiWind Classroom Exemplars form a cornerstone of the DigiWind Virtual Campus and are designed to enable high-quality, scalable, and inclusive learning experiences for MSc students and lifelong learners.

Each partner has established classroom environments tailored to local needs, ranging from hybrid lecture rooms and breakout spaces to virtual studios and mobile recording labs. These set-ups are equipped with advanced AV systems and control technologies that support synchronous and asynchronous learning, multi-campus teaching, and cross-border collaboration.

All sites underwent technical evaluation and real-world testing, including structured trials of hybrid delivery, breakout sessions, and audio-visual setups. Results confirmed strong performance across most functions, while also identifying areas for improvement such as room acoustics, camera framing, and user training. Based on corrective actions already taken or planned, all institutions are now equipped to deliver DigiWindd WP3 and WP4 teaching activities, integrated with the DigiWind Virtual Campus.

Contents

Definitions, Acronyms and Abbreviations

Acronym/ Abbreviation	Title
DigiWind	Digital Skills in Wind Energy Systems (Project)
WP	Work Package
D2.3	Deliverable 2.3: DigiWind Classroom Exemplar
LLL	Lifelong Learning
HEI	Higher Education Institution
DTU	Danmarks Tekniske Universitet
TUD	Technische Universiteit Delft
NTNU	Norges Teknisk-Naturvitenskapelige Universitet
TUS	Technological University of the Shannon
PG	Politechnika Gdańska

Term	Definition
Hybrid Classroom	Classroom designed for simultaneous in-person and remote learning
Virtual Classroom/Studio	Digital production space for remote teaching
Breakout Room	Secondary room for small-group hybrid interaction

1. Introduction

1.1. Purpose of the Deliverable

This report documents the design and implementation of the DigiWind Classroom Exemplar—an important activity under Task 2.3 of WP2—to create advanced hybrid learning spaces aligned with the DigiWind project goals. The exemplar supports the delivery of Lifelong Learning (LLL), MSc, and self-paced programs through flexible, digitally enhanced teaching environments. The document outlines the specifications, pedagogical vision, and infrastructure setup at five key partner institutions: DTU, TUD, NTNU, TUS, and PG.

1.2. Relation to other DigiWind tasks.

WP 2 focuses on enabling digitally supported learning within the DigiWind ecosystem. Task 2.2 specifically aims to develop methodologies, operating procedures and learning spaces that facilitate high-quality, scalable, and inclusive education. The classroom exemplars form the physical and virtual backbone of the DigiWind Virtual Campus (Tasks 2.3 and 5.1) and are key to showcasing best practices in digital learning infrastructure.

1.3. Document Structure

The document begins by outlining the pedagogical rationale and objectives behind the classroom exemplar activity (Section 2). Section 3 presents detailed partner-specific designs and configurations. Section 4 covers the testing methodologies and outcomes, while Section 5 reflects on long-term sustainability and scalability. The annexes provide detailed technical documentation for each partner.

2. Background and Objectives

2.1 Rationale for Hybrid and Virtual Learning Spaces in DigiWind

Hybrid and virtual classrooms are critical enablers of modern education delivery. Within the DigiWind project, they serve a dual purpose: to provide geographically distributed learners with access to high-quality teaching, and to support DigiWind higher education institutions (HEIs) in delivering engaging and scalable learning experiences for MSc students, Master students and LLL learners.

Hybrid classrooms allow for real-time engagement between learners who are physically present and those who are participating remotely. Specifically, this approach enables DigiWind HEIs to deliver MSc courses on-site, following traditional teaching methods, while simultaneously allowing students from other DigiWind partner institutions to join the classes remotely – a new and innovative practice within the consortium. The hybrid classrooms facilitate inclusive live discussions, collaborative problem-solving, and teamwork that transcends physical and institutional boundaries. Available resources make it impractical to deliver a course first to on-site learners and then repeat it for online participants from partner institutions. Instead, teaching staff enjoy increased flexibility, since hybrid classrooms allow them to teach in-person and online audiences together at the same time. Learners are immersed in enriched environments where peer interaction occurs across various contexts and backgrounds. Moreover, for HEI institutions with several campuses, such as NTNU, DTU and TUS, the hybrid classrooms allow twinned classrooms with students on two campuses following the same class and hence flexibility in course implementation for both teachers and learners.

Online-only virtual classrooms offer an even broader reach. They are ideal for learners who cannot attend on-site activities due to work obligations, caregiving responsibilities, or geographic limitations. These classrooms support synchronous as well as asynchronous learning, allowing participants to engage with materials at their own pace. They also facilitate the creation of high-quality, reusable educational content, such as recorded lectures and interactive modules, thus amplifying teaching efforts across time and place. Additionally, virtual teaching models lower the carbon footprint of education and allow institutions to deliver content to large-scale audiences without compromising quality. The DTU online Master in Wind Energy is an example of combined synchronous and asynchronous teaching at master level. Lectures are recorded and asynchronous, while Q&A sessions are held weekly by the lecturers at two different times to allow learners from around the world and all time zones to have real-time engagement with the professors. This model will also be tested for DigiWind LLL courses as well.

By supporting both hybrid and virtual configurations, the DigiWind classroom infrastructure equips educators with adaptable tools that align with learner needs, program goals, and institutional strategies. Together, these models underpin a resilient and future-ready learning ecosystem.

2.2 Scope of the DigiWind Classroom Exemplar

The DigiWind Classroom Exemplar equips DigiWind HEI partners with hybrid classrooms, virtual classrooms, mobile studios, virtual reality labs, media labs and hybrid breakout rooms to support modern teaching scenarios. These environments are conFigured to accommodate both synchronous and asynchronous hybrid and online only learning, and real-time engagement across locations. Each partner has

tailored their space to local institutional strategies, technological capabilities, and learner needs.

2.3 Expected Impact on Learning Delivery

The DigiWind Classroom Exemplar will serve as real-world testbeds for the DigiWind learning journey. By enabling seamless integration of digital technologies in classroom delivery, the classrooms aim to enhance learner engagement, reduce geographical barriers, and improve the scalability of the educational offerings. Lessons learned will inform broader dissemination and uptake across the DigiWind consortium and beyond.

3. Design and Specifications of Hybrid and Virtual Learning Spaces

3.1 Common Design Principles Across the Consortium

Across the DigiWind consortium, hybrid and virtual learning environments are guided by a shared commitment to accessibility, flexibility, and digital excellence. The following principles shape the design and implementation of all hybrid and virtual classroom setups:

Pedagogy First: Technology serves pedagogy. Each space is designed to support interaction-rich teaching formats, lectures, workshops, group work, and asynchronous learning alike.

High-End AV and Wi-Fi Infrastructure: All hybrid and virtual spaces are equipped with professional-grade audio-visual systems that ensure seamless video, sound, and screen sharing for both in-room and remote participants. Clear sound and reduced noise are critical to the learning experience. Low latency, no delays and supporting numerous learners, including up to 50 on-site learners with laptops running, requires significant bandwidth and Wi-Fi infrastructure. “Intelligent” microphones installed across the room eliminate the need for passing microphones around between on-site students during Q&A.

Interoperability and Scalability: Classrooms are built to integrate with the DigiWind Virtual Campus and are future-proofed for modular upgrades.

Instructor and Learner Support: User-friendly control interfaces and integrated support systems help instructors deliver high-quality teaching with minimal technical difficulties.

Inclusivity and Accessibility: Layouts and technologies are selected to maximise inclusivity for learners across diverse geographies and learning needs.

Sustainability by Design: Facilities are selected and operated with energy efficiency and long-term maintenance in mind.

While implementation varies based on institutional context and facility constraints, these principles form the backbone of all configurations deployed across DTU, TUD, NTNU, TUS, and PG.

3.2 DTU Risø Learning Hub

The DTU Risø Learning Hub marks a significant milestone in the integration of education and research on the Risø Campus, located approximately 40 kilometres from DTU's main campus in Lyngby. Historically focused on research and testing in wind and energy systems, the new facilities now enable full-scale teaching and Lifelong Learning (LLL) activities directly on-site at the Risø Campus.

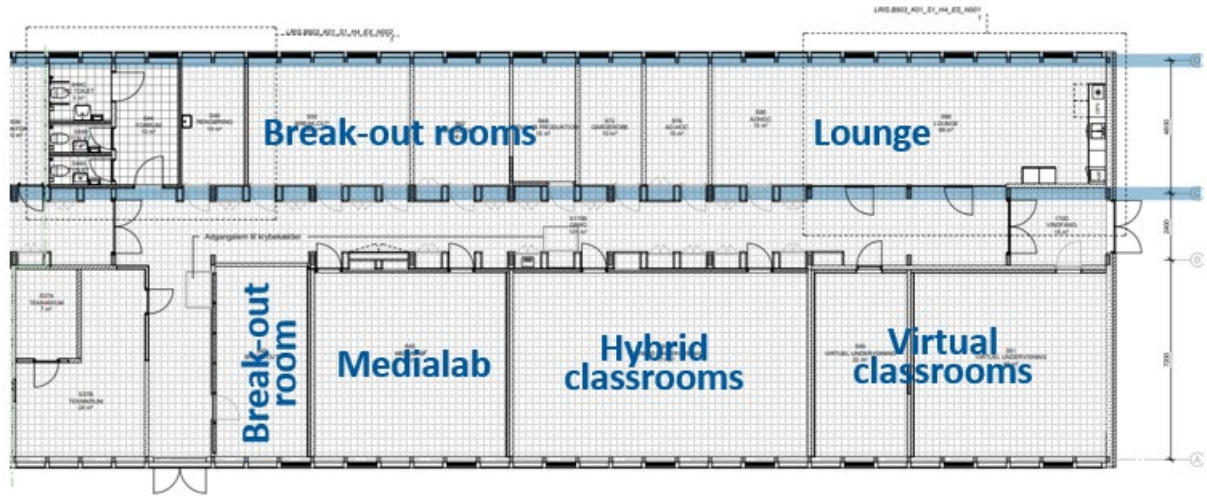

Figure 1. DTU Risø Learning Hub facility plan

Figure 2. DTU Risø Learning Hub entrance

The DTU Risø Learning Hub includes:

A Hybrid Classroom: Accommodating up to 30 on-site learners, this classroom is equipped with high-end AV systems and offers a fully interactive hybrid learning experience. Designed for flexible seating and multiple instructional modes, it supports live streaming, digital whiteboarding and annotation, a close-up desktop camera for showing e.g., blade materials before and after break-tests, etc. Ceiling-

mounted screens and camera ensures that the teacher has the same screen settings as learners and does not turn their back on learners. The camera tracks the teacher during movement. Ceiling-mounted microphones and loudspeakers enable high-end audio.

Figure 3. DTU Risø Learning Hub, Hybrid Classroom

Two Virtual Studios: Tailored for online-only teaching, these studios support live webinars, flipped-classroom production, and high-quality asynchronous recording. Each studio features advanced lighting, soundproofing, and camera systems.

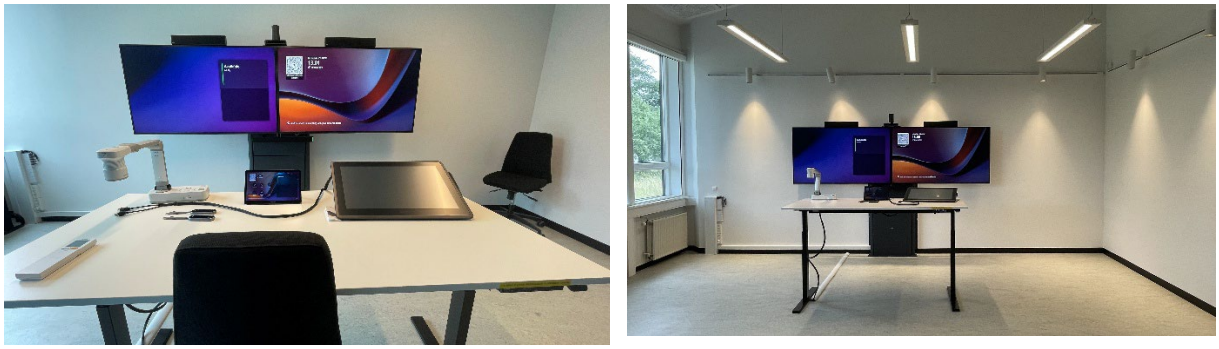

Figure 4. DTU Risø Learning Hub, virtual classrooms/studios for online synchronous teaching

Three Breakout Rooms: Each breakout room serves 8–12 learners and is fitted with professional-grade AV systems identical in quality to the main hybrid classroom. These spaces support small-group hybrid activities, coaching sessions, and collaborative project work. The break-out rooms facilitate integration of on-site and online learners in group work.

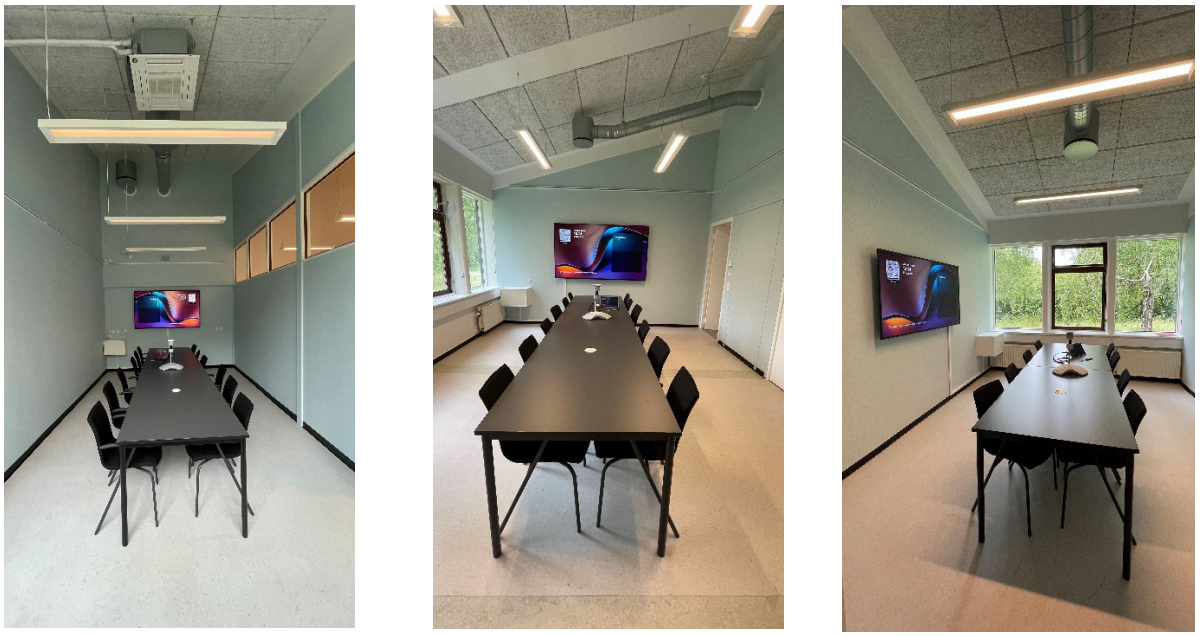

Figure 5. DTU Risø Learning Hub, Breakout Rooms

Lounge Area: Capable of hosting up to 40 learners, the lounge functions as a social and informal learning space. It includes integrated AV equipment, enabling informal talks, hybrid meetings, demonstrations, and streamed networking events. It may also function as a fourth breakout room.

Figure 6. DTU Risø Learning Hub, Lounge Area

Centralized Control System: All AV systems in the Risø Learning Hub operate through an integrated Yealink control solution. This system provides centralized management of audio-visual operations, ensuring ease of use for instructors and consistent quality for learners. The system also allows bring-your-own-device setup.

Remaining work: Sound tests in classrooms and break-out rooms show that there is excessive reverberation in the rooms that may impair speech intelligibility, listening comprehension and cause fatigue of students and teachers. To mitigate the reverberation, sound absorbers will be installed in all classrooms and break-out rooms. The work is in progress at the time this report is being completed.

The DTU Risø Learning Hub exemplifies how a research-centric campus can be expanded to host hybrid and digital education, supporting both MSc-level teaching and lifelong learning.

3.3 TUD Hybrid Learning Environment

At TUD a multifunctional hybrid classroom has been created in a generic educational building. On campus of TUD several dedicated educational buildings have been created (either new build or renovated) over the last decades. These buildings accommodate for the increasing number of students, as the 'old', traditional lecture rooms in the faculty buildings did not offer sufficient space.

Together with Facility Management and Campus Real Estate a lecture room in one of those buildings was assigned to turn into the hybrid classroom. The room is located in the educational building Pulse (building 33) located on the City Centre side of the campus. The mayority of the students and employees pass by this part on their way to their own faculties.

Figure 7. TUD Building 33, Pulse, hosting the hybrid classroom (Technology Room)

The black circle in Figure 8 marks building 33 where the hybrid classroom is located.

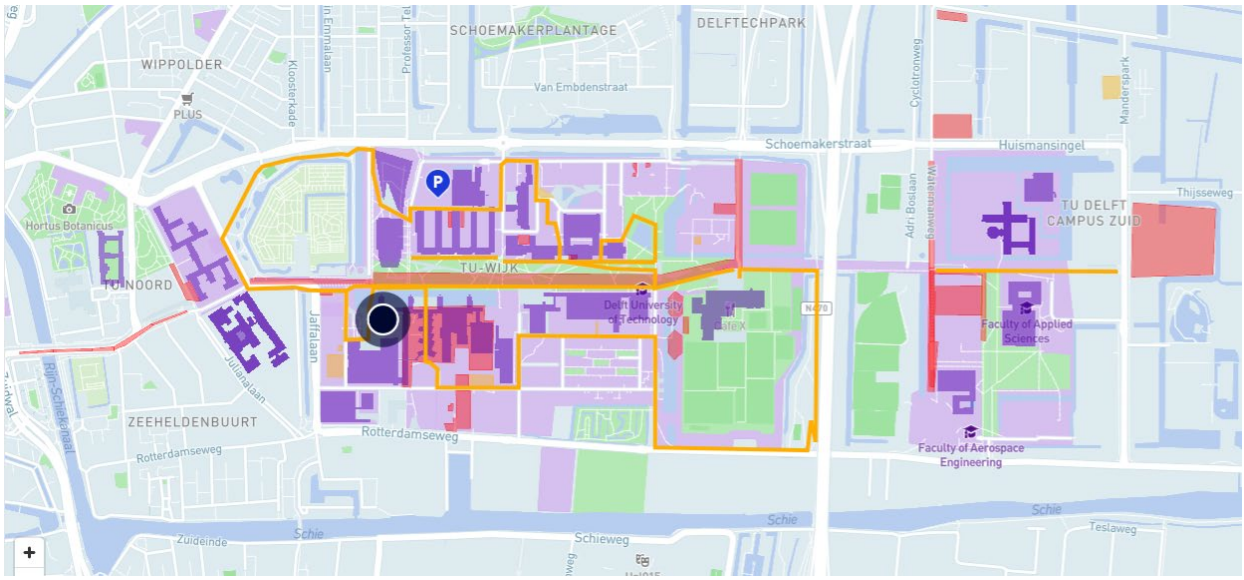

Figure 8. A map of the TUD campus

The room assigned is called the Technology Room and was already equipped with many of the equipment necessary to create the hybrid learning environment. The layout and equipment are shown in both Figure 9 and 10. A maximum of 50 on-site students fit in this classroom.

Due to the layout and equipment of the Technology Room it is suited for both lectures and group work all possible for in-person, hybrid, fully online mode.

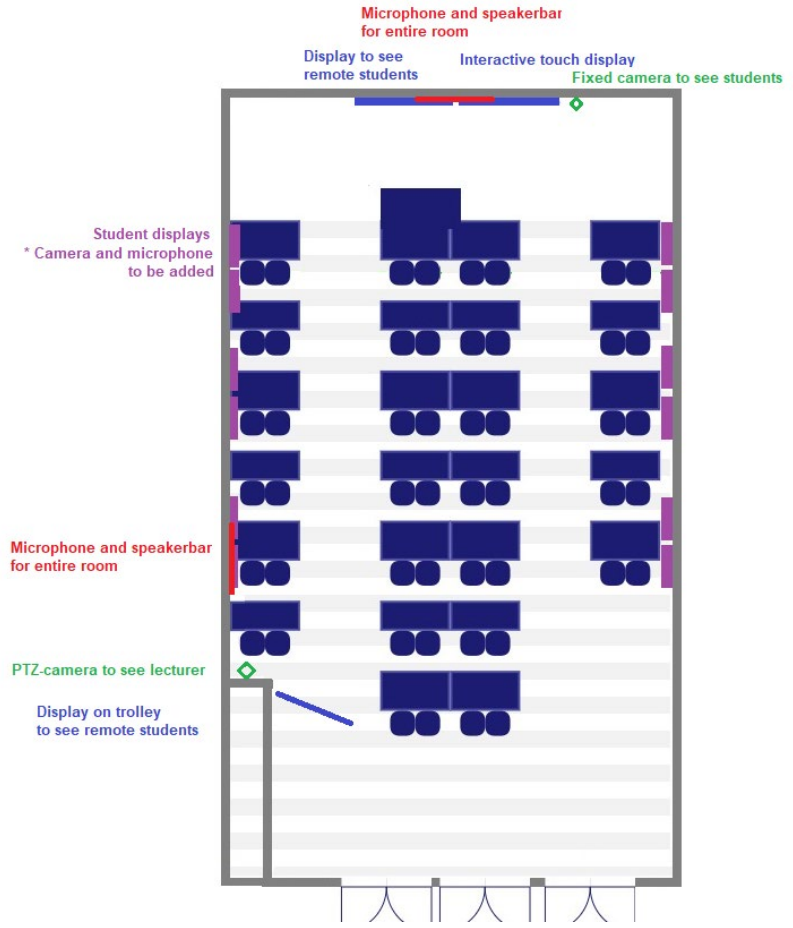

Figure 9. Floor plan Technology Room before upgrading

Cameras and sound:

The room has two cameras: one focussed on the teacher and one focussed on the students. The teachers can control the zoom and direction of the teacher from the console. Two microphones and speaker bars are located providing excellent reception and sound throughout the room.

Screens:

In total the lecturer has 3 screens he/she can use. Two fixed screens, one of which is an interactive touch display screens also suited to make annotations for the online learners. One smaller screen is available on trolley, that the teacher may use to display remote students. The teacher can position this screen to his/her own preference.

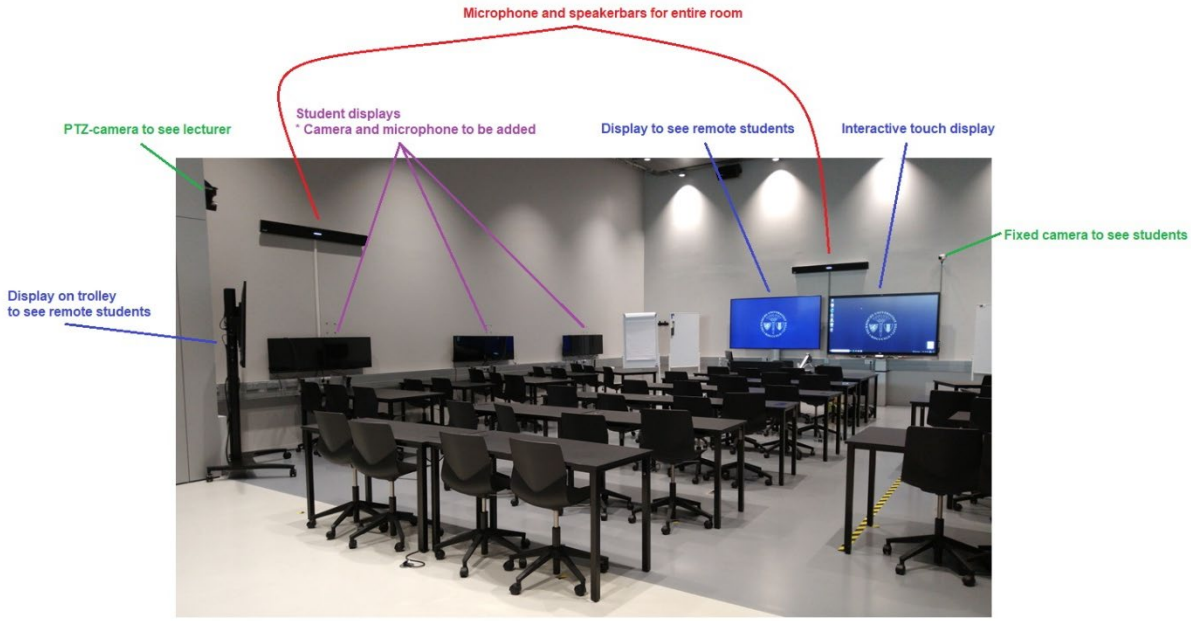

Figure 10. Technology Room before upgrading

Console:

The teacher can control the entire from the console (see Figure 11. He/she can use the computer in the console and plug in their laptop. The console works intuitive and the mayority of all lectures rooms across campus have a similar console making it easy to use. The consoles can be used by simple logging in using their standard TUD credentials. If desired the teachers can use the screens of the console and their laptop during their sessions. Thus, the teacher can have a total number of five screens available for the online/hybrid sessions.

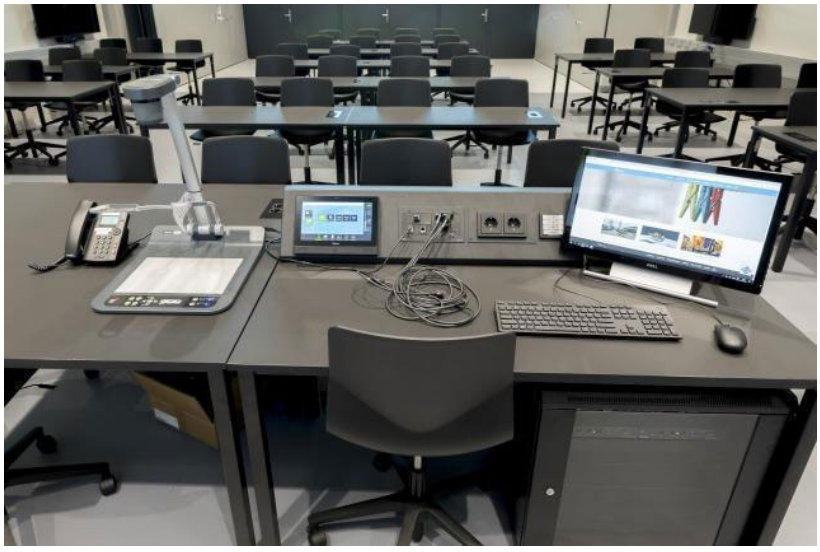

Figure 11. Console Technology Room

Furniture:

The tables have a proper depth, making it perfect for group work. The chairs have wheels so the students can easily turn around to form a group. Some tables can be moved as well, while others are fixed and those are equipped with power sockets.

Break-out sessions:

The tables at the side were already equipped with double screens. This was the basis for the break-out 'rooms'. Only cameras, microphones and docking stations needed to be added, indicated by the purple texts in Figure 9 and 10 For the break-out sessions, as well as the 'normal' hybrid or online sessions, Teams can be used. The teacher can control the break-out rooms via his/her laptop or via the console. If all groups are mixed with on-site and remote students, the teacher can check group work and answer questions by simple walking around the hybrid classroom. The on-site students can use the larger two screens work sharing content and discussions.

Equipment installed:

As mentioned the equipment installed were six cameras with integrated microphones/speaker bar and six docking stations (see Figure 12. The docking stations were installed to make facility the use of the two screens alongside each group table. The students can use the screens via a simple plug and play principle.

The equipment was first tested with a single remote user and multiple users in the room. The view was good, as well as the sound. The microphones did not pick up any conversations or even music from neighbouring tables. The remote user was also well audible via the speaker bar.

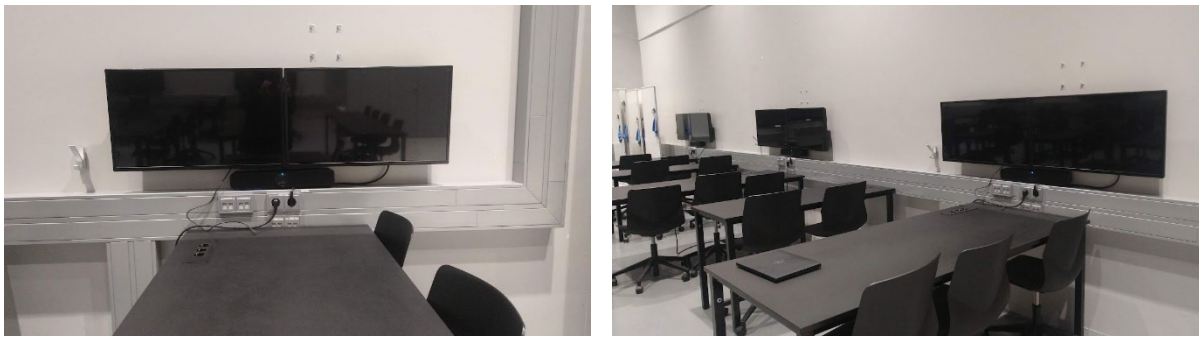

Figure 12. The break session screens incl. cameras and microphone/speaker bar

Work to be done:

There are aspects left that needs to be done and that is testing the acoustics within the room when multiple break-out rooms tables are used. Tests will be done to assess if the on-site students within the room experiences issues related to sound/noise from adjacent break-out groups in the same room. If so, TUD will look into acoustics measures to dampen the surrounding noise. Till then, it is also possible to use a headset in the break-out rooms. During the main test on May 19th 2025, the on-site testers used their head-sets and that also worked perfectly.

Another aspect that remains is writing instruction manuals focused on the digital didactics of the rooms. As described above, the equipment and layout of the room

facilitate many different teaching set-ups for hybrid teaching. How a teacher will use the equipment, may depend on their own personal preference. However, to inform the teachers of all the possibilities a manual will be written explaining the different set-ups. Any pros and cons to each set-up will be described so a teacher can make a well-founded choice for a particular set-up.

TUD already has several technical manuals in place. However, these do not touch upon the digital didactics. And we want the hybrid classroom to be used to its' full potential.

3.4 NTNU Classroom Setup and Breakout Rooms Integration

The NTNU Electric Energy Department constructed a hybrid classroom in 2023, which will be reserved for DigiWind activities. In addition, a mobile virtual studio has been purchased and assembled with funding from DigiWind.

Figure 13. NTNU Electro building entrance

The Hybrid Classroom:

The hybrid classroom accommodates 24 on-site learners and is equipped with high-end AV systems, supporting live streaming and extra option for high-definition recording. The furniture is designed for flexible seating and multiple instructional modes. The hybrid classroom is in the NTNU Electro building on the Gløshaugen campus in Trondheim, 13.

Screens: A large wall-mounted screen is positioned behind the teacher (Figure 14), and a large annotation tablet in front of the teacher (Figure 15) serves as both an annotation device and a mirror for the wall-mounted screen. This enables the teacher to maintain eye contact with learners throughout presentations.

Cameras: The ceiling-mounted camera tracks the teacher's movement; the camera only moves to the next preset frame when the teacher steps out of the frame,

avoiding any distracting continuous movement of the camera. The tracking camera will follow the teacher to the whiteboard, providing an alternative annotation option to the digital annotation tablet. An audience camera helps display the audience during discussions; the camera operates by alternating between showing the whole audience and automatically focusing on any speaking members of the audience. See camera positions in 11.

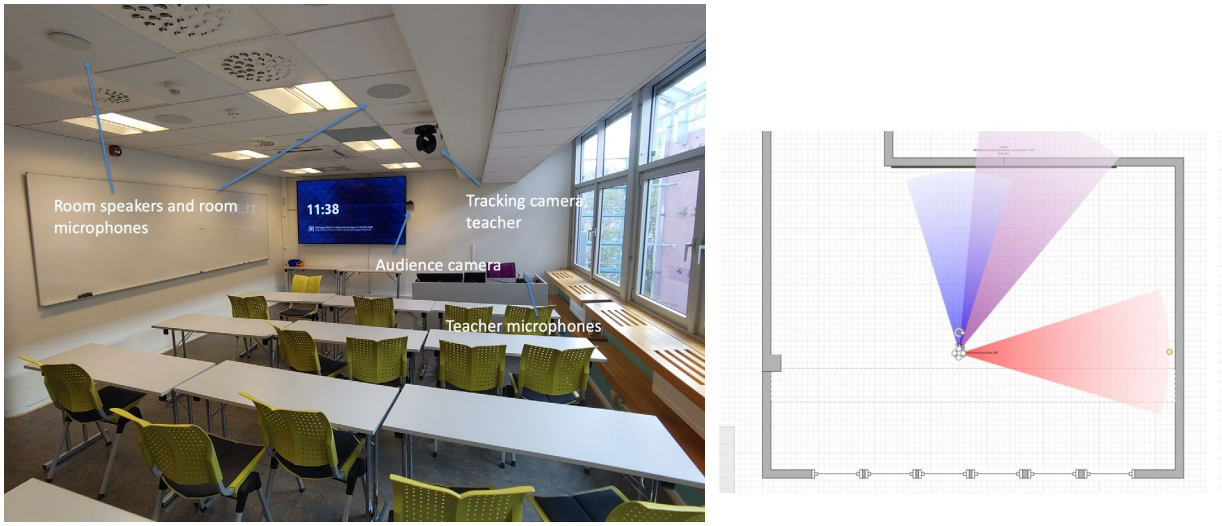

Figure 14. NTNU Electro hybrid classroom, learner perspective and teacher camera zones

Microphones: Ceiling-mounted microphones and loudspeakers enable high-end audio for the audience. Two dedicated teacher microphones reduce noise from the room and deliver superior sound quality for the teacher's voice. See microphone positions in Figure 14.

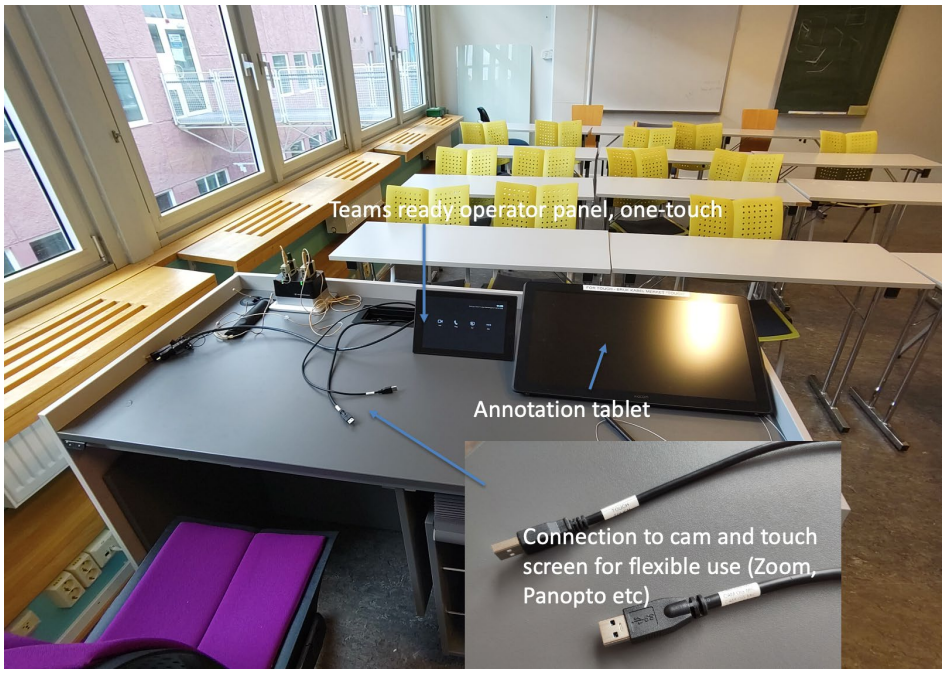

Figure 15. NTNU Electro hybrid classroom, teacher perspective

Operator panel: A Teams-ready operation panel is placed on the presentation desk (Figure 15), enabling fast, one-click connection to hybrid presentation sessions. USB

connections to cameras and a sound system are provided for the use of alternative software, such as Zoom or high-definition recording software.

Breakout Room:

A breakout room (Figure 16) is available on the floor above the Electro hybrid classroom and is equipped with professional-grade AV systems identical in quality to those in the main hybrid classroom. These spaces support small-group hybrid activities for 8-10 people, coaching sessions, and collaborative project work. The breakout rooms facilitate the integration of on-site and online learners in group work. See an example of a digital link between the hybrid classroom and the breakout room in 6.

Figure 16. Breakout room from two perspectives.

Remaining work to be done: The NTNU Electro hybrid classroom and breakout room have successfully passed all technical tests and are fully operational, see examples of use in Figure 17 and Figure 18.

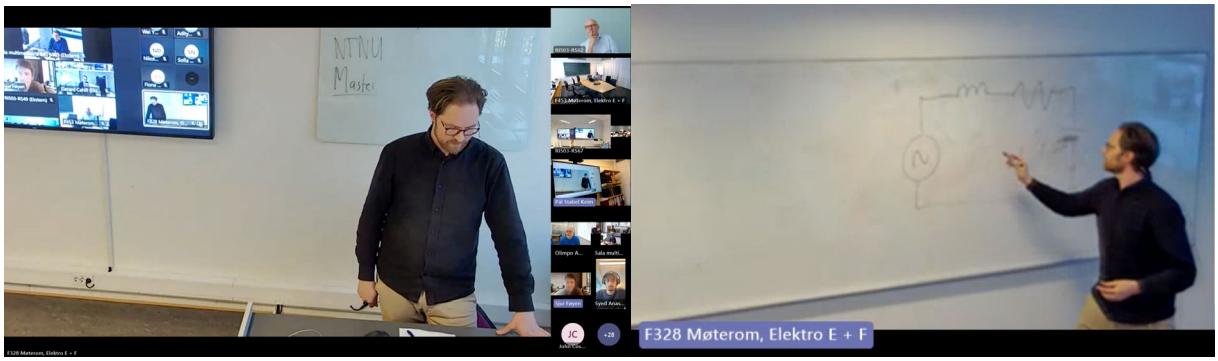

Figure 17 – Example use of tracking camera and whiteboard in the NTNU Electro hybrid classroom.

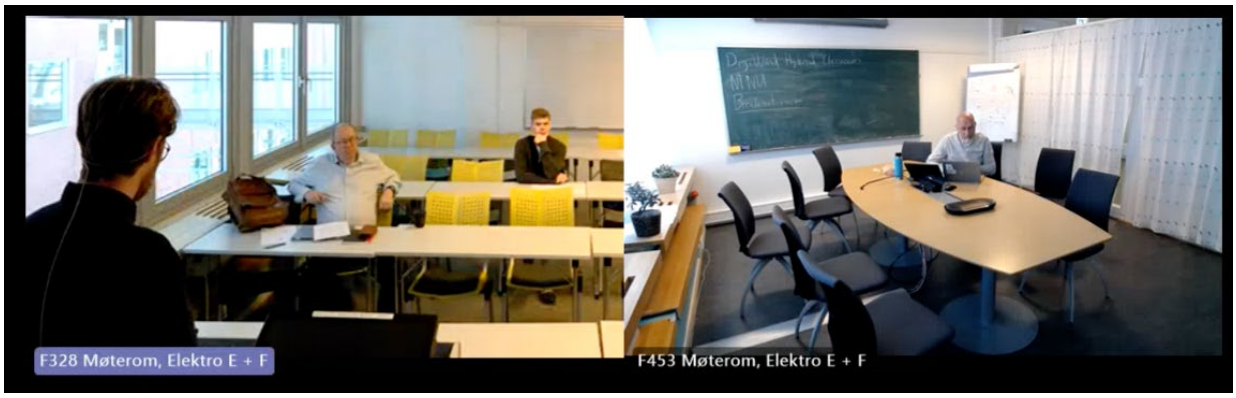

Figure 18 – Example digital connection between the NTNU Electro hybrid classroom and the breakout room.

Mobile virtual studio: In workshops with DigiWind course developers a common concern was how to perform hybrid sessions in the laboratories. As a response to this need, a mobile virtual studio was developed. The mobile studio may be used in laboratories, offices or other sites for streaming and recording in high-end video quality. The mobile studio comprises a stand with two screens, two cameras, microphones, lighting, a green screen, and a computer. An example of on-site assembly of the mobile virtual studio is shown in Figure 20 and Figure 21. All the equipment can be mounted on a single, movable stand for transportation, as shown in Figure 19.

Figure 19. Mobile virtual studio in transport mode.

Figure 20. On-site use of mobile virtual studio, front view.

Figure 21. On-site use of mobile virtual studio, side view.

A demonstration of the mobile studio's functionality can be seen in the following videos: Overview of the mobile virtual studio, remote camera angle control with a gimbal, remote camera angle and zoom control. Further example of produces output is given in Figure 22 and Figure 23.

Figure 22 – Two camera angles with green screen, front and side position.

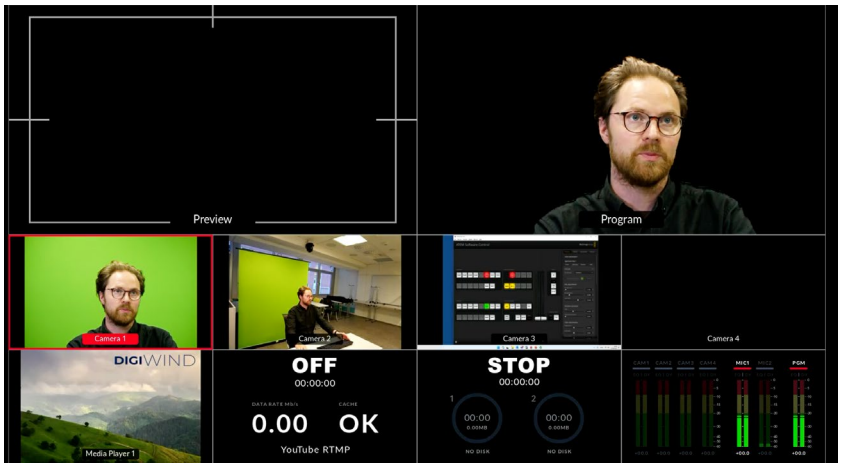

Figure 23 – Lower screen view on the stand showing the different inputs the teacher may choose from.

Remaining work: Demonstration tests with the mobile virtual studio was successful, except for excessive noise pickup from the ventilation system. A system for noise suppression will be investigated and added to the setup. Further use case tests with course developers will be performed, any necessary changes to functionality will be made in cooperation with the users.

3.5 TUS Virtual Studio and Teaching Scenarios

The TUS Coonagh Campus Hybrid Classroom is designed to support in-person, hybrid, and fully online learning. Located in Coonagh, Limerick (2km from the TUS, Moylish campus), it sits within the newest of the state-of-the-art campus, a 5,819 square metre engineering building. This modern engineering facility is designed to accommodate an additional 800 students.

Figure 24. Coonagh Campus

Figure 25. Coonagh Campus Ground Floor, Hybrid Classroom highlighted

Soundproofed learner pods are also located near the hybrid classroom.

Figure 26. Learner Meeting Pods

Figure 27. Hybrid Classroom

The Hybrid Classroom: allows flexible room arrangements for between 20 and 30 on-site learners with large screens surrounding the seating area ensuring clear views of material.

A separate area is available for VR / XR demonstrations, either as part of in person classes or conducting virtual demonstrations on relevant equipment / schematic models for hybrid / online presentation.

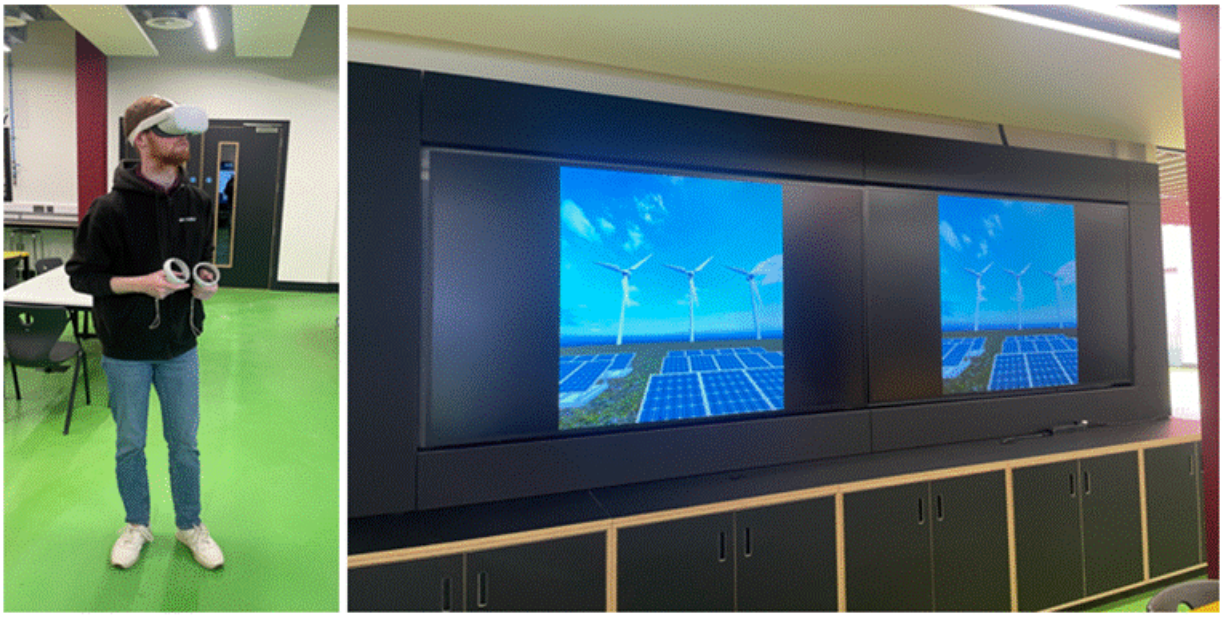

Figure 28. VR Demo area / Output

The camera in use provides remote viewers with a wide-angle view of the room and participants, which automatically focusses on one, two or three speakers during interactions.

From the main teacher's podium, there is access to all screens and additional sources can be added on the fly, with switching between sources using either software or the physical buttons on the console.

Figure 29. Physical Controls


Figure 30. Room Layout


Figure 31. Teacher Console

Camera and sound options are still being evaluated, based on the feedback and lessons learned from the first inter-institute demonstration / test. Plans are in place to acquire additional equipment tailored to seamless shared teaching / learning experiences. This process is still in progress.

Thus far, the TUS Hybrid Classroom utilised for DigiWind is a significant addition to the Technological University of the Shannon at Coonagh and enables wider availability of current and future teaching and learning.

3.6 PG Local Hybrid Lab Specification

The hybrid teaching room has been placed in room 303 in building 40 on the Gdansk University of Technology campus. The building belongs to the Faculty of Mechanical Engineering and Ship Technology.

Figure 32. Location of hybrid classroom on campus

Construction and implementation of the room took a year and were divided into stages. Finally, the hall was commissioned in December 2024.

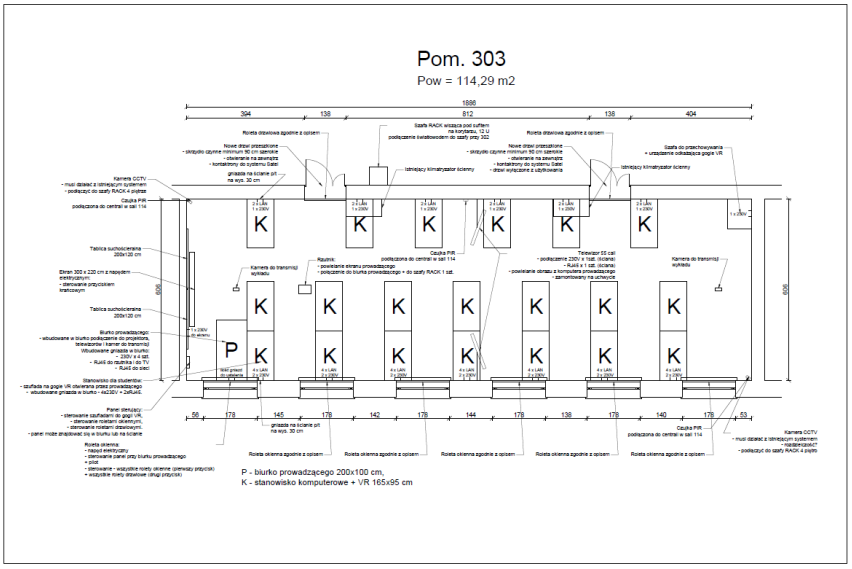

Figure 33. Floorplan of the hybrid classroom

4. Testing and Evaluation of Hybrid Classrooms

4.1 Test Schedules and Operational Milestones

To ensure the effective deployment and functionality of the DigiWind Classroom Exemplars, all five HEI partners executed a common test run, in which each partner institution developed and implemented a localized testing schedule. These schedules cover key operational milestones such as equipment installation, system integration, functional trials, and user simulations involving both instructors and

learners. The schedules were designed to reflect the diversity of infrastructure and teaching formats across the consortium.

An overview of the test phases and their completion status is included in Appendix D of this deliverable, which provides a detailed breakdown of activities by institution, along with timelines and responsible personnel. The documentation serves both as a record of quality assurance and a reference for future scaling and replication.

4.2 Technical Evaluation Procedures and Checklists

To complement the test schedules, each DigiWind partner conducted a detailed technical evaluation of their hybrid classroom setups using a standardised checklist. The purpose of the checklist was to ensure functional readiness, technical robustness, and pedagogical usability across diverse platforms and configurations. All key hardware and software components were reviewed, including AV systems, connectivity, user interfaces, and support for hybrid teaching formats.

The evaluation process focused on three core aspects: connectivity and displays, audio-visual fidelity, and interactivity between on-site and online participants. Connectivity was assessed by testing the ease and reliability of connecting multiple user devices and platforms. Gallery views, content sharing from various sources, and display consistency were all rated on a scale from 1 (poor) to 5 (excellent).

Audio functionality was evaluated in terms of clarity and balance between teacher microphones, in-room learner microphones, and online participant input. Special attention was given to how well the systems handled simultaneous audio from multiple locations, as well as mute/unmute responsiveness. Visual elements such as camera tracking (including automated tracking of the teacher and learners), whiteboards, annotation tools, and screen sharing setups were also tested.

Instructors simulated hybrid teaching sessions to assess breakout group functionality, system responsiveness, and troubleshooting workflows. These hands-on trials revealed key insights into the practical delivery of hybrid teaching and the ease with which support staff could resolve issues during live use.

The full checklist, along with partner-specific ratings and implementation notes, is included in Appendix D. These results inform ongoing refinement and provide a common reference framework for other institutions seeking to adopt similar classroom models.

4.3 Summary of Test Results and Follow-up Actions

The results from the technical evaluation tests conducted at each DigiWind HEI site reveal both the strengths and challenges associated with deploying hybrid classroom infrastructure. While performance was generally strong across key

functional areas, the evaluations also identified several areas where follow-up action is required to optimise usability and consistency.

At DTU Risø Learning Hub, connectivity and audio-visual systems performed well under real-world testing, particularly in scenarios involving content sharing, teacher tracking, and document camera usage. However, several limitations were identified in break-out room functionality and control system configuration. For example, online learners occasionally experienced interruptions due to weak internet connections on their side, highlighting the importance of recording lectures for asynchronous access. Access control settings within the Microsoft Teams environment also required adjustment to prevent learners from inadvertently altering room settings. Additional user guidance and IT policy configurations were recommended.

Microphone levels and camera tracking responsiveness varied between spaces. While sound quality for on-site learners and teacher microphones was mostly clear, personal headset configurations occasionally led to suboptimal audio capture. Likewise, camera tracking of on-site learners proved inconsistent and overly reactive in certain scenarios, prompting a recommendation for revised tracking presets and further calibration by AV specialists. DTU has addressed the issues observed during the tests and initiated acoustic improvement of all classrooms through sound absorbers. The first classes have been taught successfully in the hybrid classroom. Teacher feedback from use of the facilities will be incorporated in guidelines for the use of the DTU Learning Hub.

At TUD, the technical setup demonstrated high reliability in connectivity, audio, and content sharing. Teachers experienced consistent sound quality even while moving through the classroom, and in-room microphones clearly captured questions from students at the back of the room. However, feedback from both instructors and students indicated that the effectiveness of visual layouts, including gallery views and content presentation, often depended on the teacher's familiarity with digital tools and preferences in managing Microsoft Teams settings. Based on these insights, TUD plans to provide practical training and best-practice materials for teaching staff to better utilise the available tools.

At NTNU, hybrid classroom testing confirmed stable performance across audio, connectivity, and core teaching functions. Teacher and learner microphones worked clearly, and online participants reported good sound quality. However, the teacher's video feed appeared too small in gallery mode, making it harder to identify the session leader. Camera tracking of the teacher was consistent but slightly slow; learners were tracked accurately when speaking.

Content sharing, breakout rooms, and mute/unmute controls functioned well. The camera followed the instructor when using the whiteboard. Although no advanced tracking systems were used, individual laptops provided stable visuals. No technical issues required IT support during the tests.

NTNU recommends spotlighting presenters and training users on gallery control in Teams. Minor adjustments to camera zoom and session layout could improve clarity and teaching presence.

At TUS, testing confirmed that the hybrid classroom setup performs reliably in core areas such as connectivity, sound quality, and basic teaching interactions. Participants connected easily, and on-site and online audio were both rated highly. A dedicated condenser microphone helped ensure that learner contributions from the classroom were clearly captured. However, some technical limitations were observed during breakout room transitions, where a small number of students were unexpectedly disconnected and experienced difficulty rejoining. This suggests a need for more robust co-hosting practices and clearer joining instructions. In terms of visuals, the "Owl" camera system generally performed well, though tracking sometimes lagged during instructor movement. Adding a second camera and refining positioning within the room are being considered to enhance coverage and responsiveness. Background noise from air conditioning was noted by participants and will be addressed through improved microphone setup and potential noise cancellation. Despite a brief interruption due to a system restart, the TUS team demonstrated troubleshooting capabilities and is planning targeted improvements in session preparation and user support.

At PG, the hybrid learning space delivered near-flawless performance across all tested dimensions. The classroom setup provided excellent connectivity and sound quality, with microphones and speakers supporting clear communication between on-site and remote participants. The multi-camera system enabled dynamic visual presentation, including the ability to frame separate instructors and learner groups simultaneously. PG's testing confirmed smooth transitions between breakout rooms, reliable content sharing, and effective annotation using both tablets and touchscreens. Visual tracking of on-site learners and the use of document and whiteboards also performed well. The only notable challenge was ensuring that remote presenters spoke clearly and at an appropriate pace—this was managed through simple verbal guidance rather than technical adjustments. With troubleshooting systems functioning efficiently and no significant issues reported, PG's setup is considered fully operational, requiring only minor enhancements to teaching support materials and orientation for new users.

The full set of evaluation checklists, and recommended actions for all partners are detailed in D. These results serve as a basis for iterative refinement, staff training, and long-term infrastructure planning across the DigiWind consortium.

All partners emphasised the importance of breakout room functionality and user control. While TUD reported success in managing breakout assignments and in-room interactions, there remains a need to optimise seamless break-out sessions in both in-room break-outs and break-out sessions in separate rooms. Across the board, BYOD (Bring Your Own Device) functionality in breakout rooms remains a point for further testing and potential technical support interventions. Based on the tests performed, and planned follow up mitigation action on systems controls with retesting and development of user instructions & guidelines, coupled with teaching

of teachers in the use of the systems, it can be concluded that all partners will be ready to deploy high quality hybrid learning facilities for the educational and lifelong learning activities planned in WP3 and WP4, and integration of the teaching facilities with the virtual campus in WP5.

Appendices

Appendix A: DTU Risø Learning Hub – Layout & Equipment

Hybrid classroom

The room is set up as a hybrid teaching space, allowing for hybrid instruction via Teams (see Figures below). Four cameras are installed: i) one in front of the teacher (with tracking capability), ii) one on the left side of the teacher console enabling recording of larger items, iii) one for recording the students, and finally iv) a desktop camera on the teacher console. All four camera feeds can be displayed simultaneously in a picture-in-picture mix if desired.

Two 98” screens are mounted at the end wall behind the teacher, and two 65” screens are mounted in the ceiling for the instructor to see online students and content. All screens have extra high brightness and a Haze/anti-glare effect of 47%, ensuring that the image is sharp and clear.

The room is optimised for two teachers, as DTU foresees two teachers being the standard mode for lifelong learning. Two headset microphones for the teachers and two ceiling microphones and 4 speakers are installed. The microphones are controlled via the control panel on the teacher console and can be turned on/off as needed, depending on whether students should also be heard. All microphone audio will be sent to Teams and not broadcasted in the room.

There is a 22” tablet and a 55” touch screen, allowing the teachers to connect their PC via a USB-C cable and HDMI cable and share a presentation, which can also be annotated or drawn on during hybrid teaching. If the teachers only need to present from their PC into the hybrid meeting, this can be done wirelessly using a USB-C dongle.

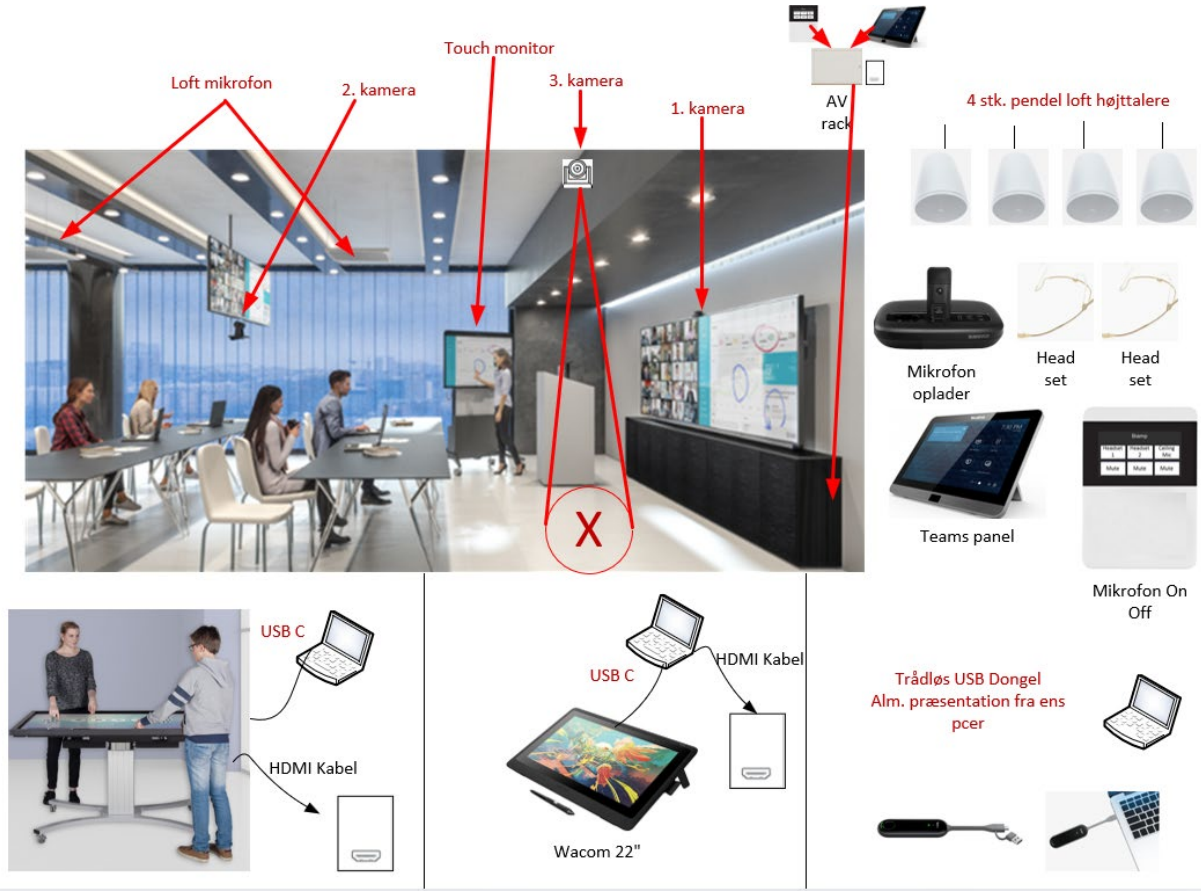

Figure 34. Layout of the hybrid classroom showing ceiling microphones, microphone headsets, loudspeakers, control panel, tablet and I3-digital whiteboard, monitors for students (one for content, one for showing remote learners), ceiling mounted monitors for teacher (showing same views as the monitors for students, so teacher can remain facing students)

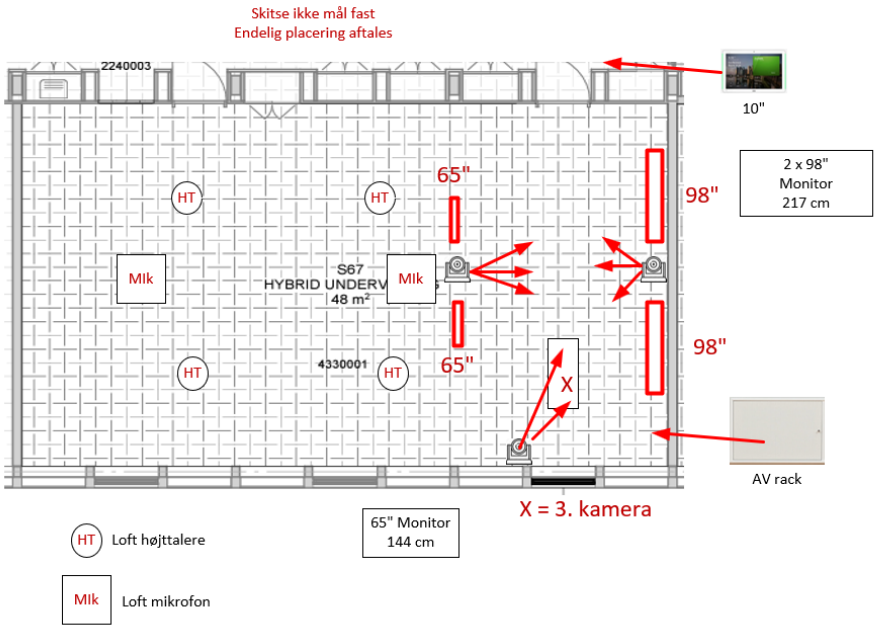

Figure 35. Placement of monitors, cameras, microphones and loudspeakers in the hybrid classroom.

Figure 36. A 55" touchscreen/digital whiteboard on a hight adjustable trolley for teacher – many functions, e.g. for annotation of learning content

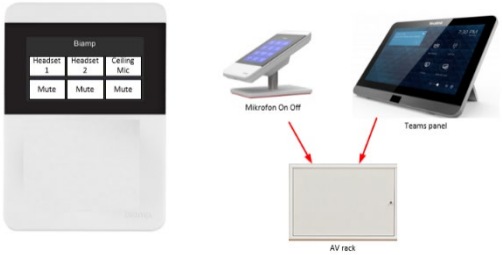

Figure 37. Touch panels for microphone control and for Teams and camera controls

Figure 38. 10" booking screens mount outside the door of each room in the DTU Risø Learning Hub.

Breakout rooms for hybrid teaching

Breakout rooms are set up with a Teams solution using a 360° camera, as shown below, with an appropriately sized monitor for each room and a wireless dongle like in the other rooms, ensuring consistent operation. The camera/microphone/speakers cover approximately 6 meters in diameter.

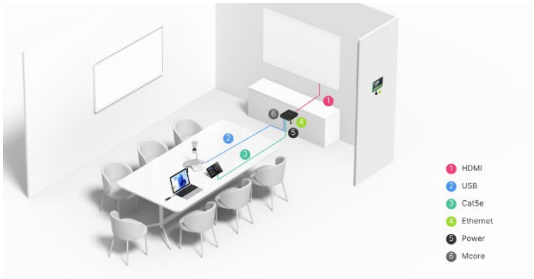

Figure 39. Layout of the hybrid break-out rooms

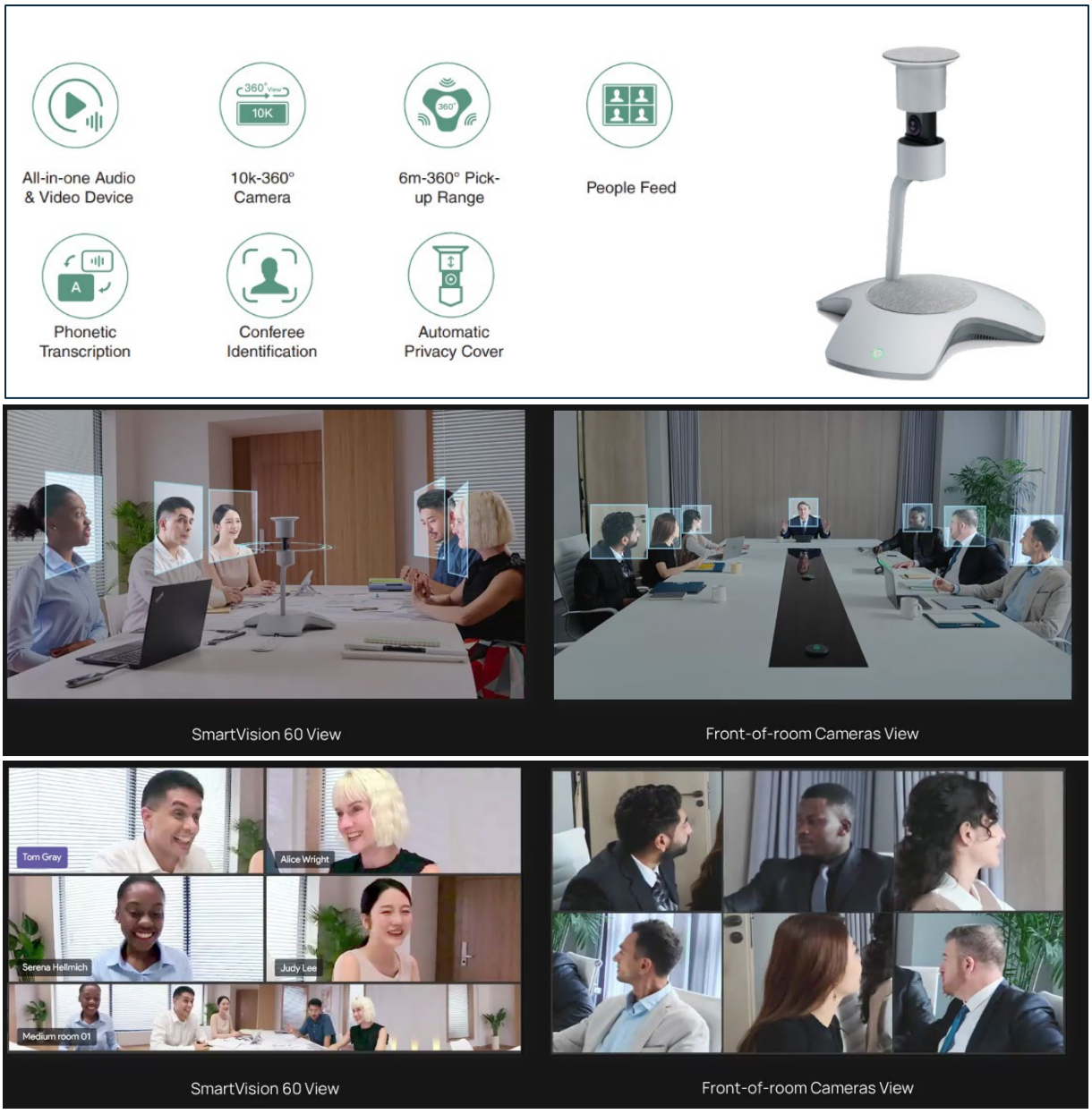

Figure 40. The all-in-one audio & video device and the view at remote end.

Virtual Classrooms

In the virtual classrooms, dual 65” screen solutions with Teams are installed on a motorized height-adjustable wall stand, along with 1 camera and microphone also on the height-adjustable system, and an additional camera for showing products, etc., as marked with an "X" below, along with 2 light spots.

Additionally, a 22” touch screen is available on the desk, allowing the instructors to connect their PC via a USB-C cable and share a presentation, which can be annotated or drawn on.

The room will function similarly to the larger hybrid room, but without the extra screens for students, ceiling microphones, and touch panels, as these are not necessary in this space.

If the instructors only need to present from their PC into the online meeting, this can be done wirelessly using the included USB-C dongle.

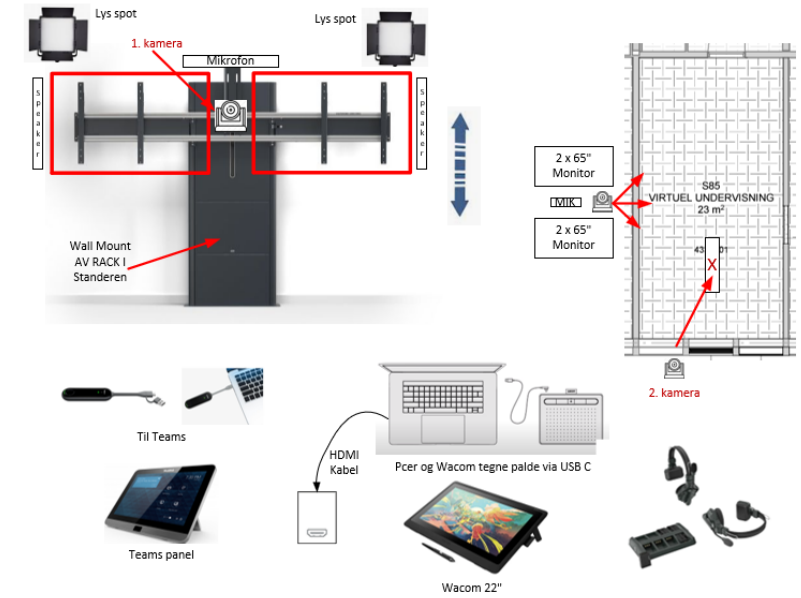

Figure 41. The technical set up and floorplan of the virtual classrooms

This wall-mounted Shure microphone adequately covers the room, so the instructors do not need headset microphones in this space. It can also be mounted on the ceiling, but in a room of this size with a short distance to the instructor, the best placement is directly in front of those speaking into the microphone.

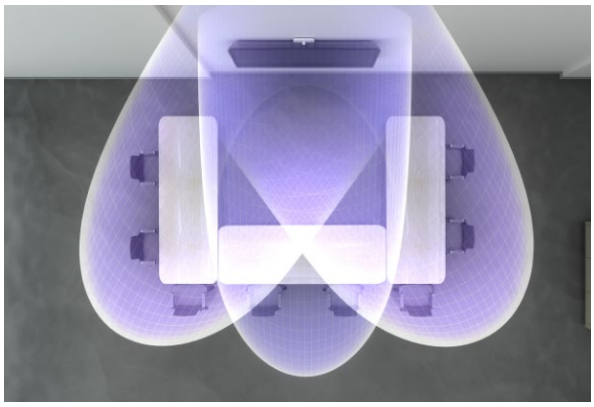

Figure 42. Coverage of the wall mounted microphone

Lounge / Workshop room

The lounge is equipped with a 98” monitor for this long room, along with 2 cameras: one that shows participants/attendees and another that can, for example, show the presenter by the screen. If a couple of regular whiteboards are installed, the second camera can also display those along with a view of the room from the first camera, if desired. There are many possibilities, and switching the display/layout is easily done via the Teams touch panel. Additionally, 2 microphones and 4 ceiling-mounted speakers are installed in this room.

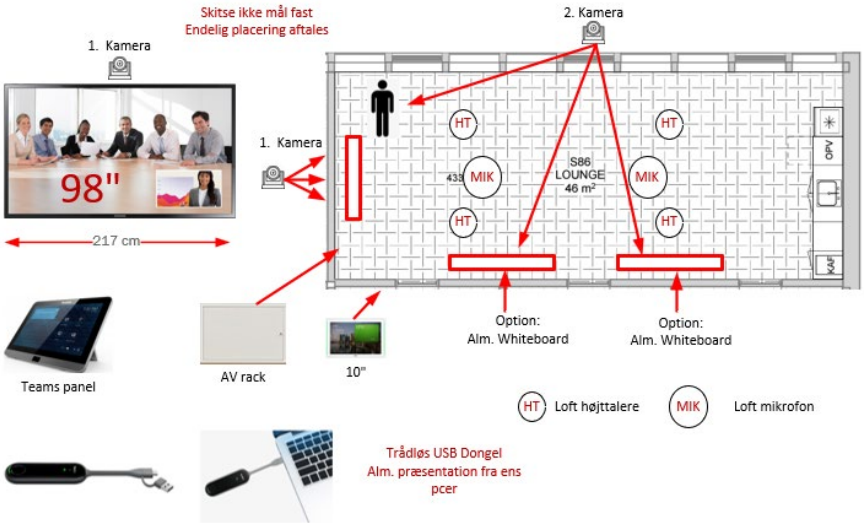

Figure 43. Planned layout of the lounge room. During refurbishment works, the lounge room was extended another 3 window sections, equivalent to 3,6 meters.

Appendix B: TUD – Layout & Equipment

The layout of the hybrid classroom is shown in Figure 44.

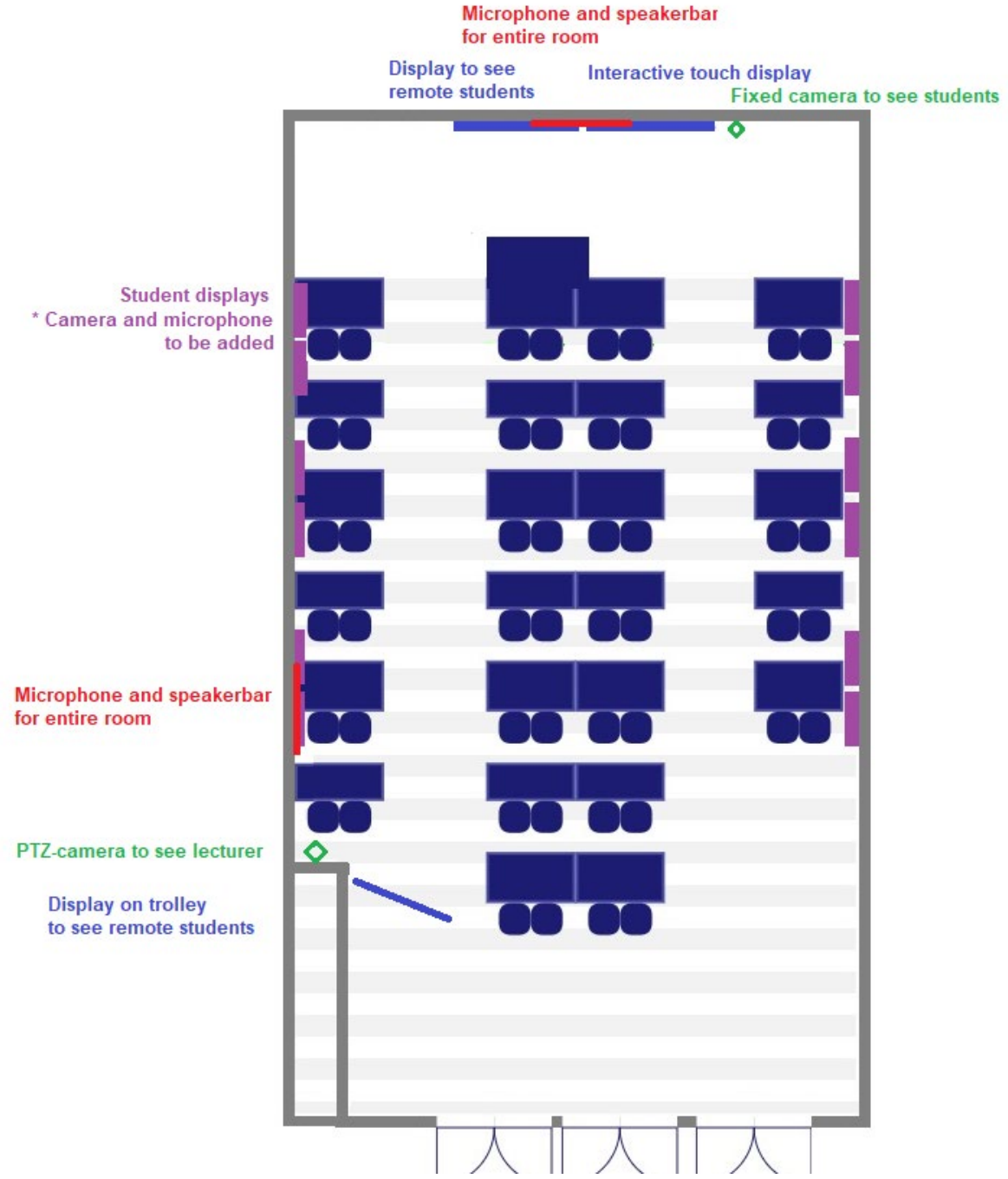

Figure 44. Floorplan hybrid classroom TUD

An overview of where the equipment is located is given in Figure 45.

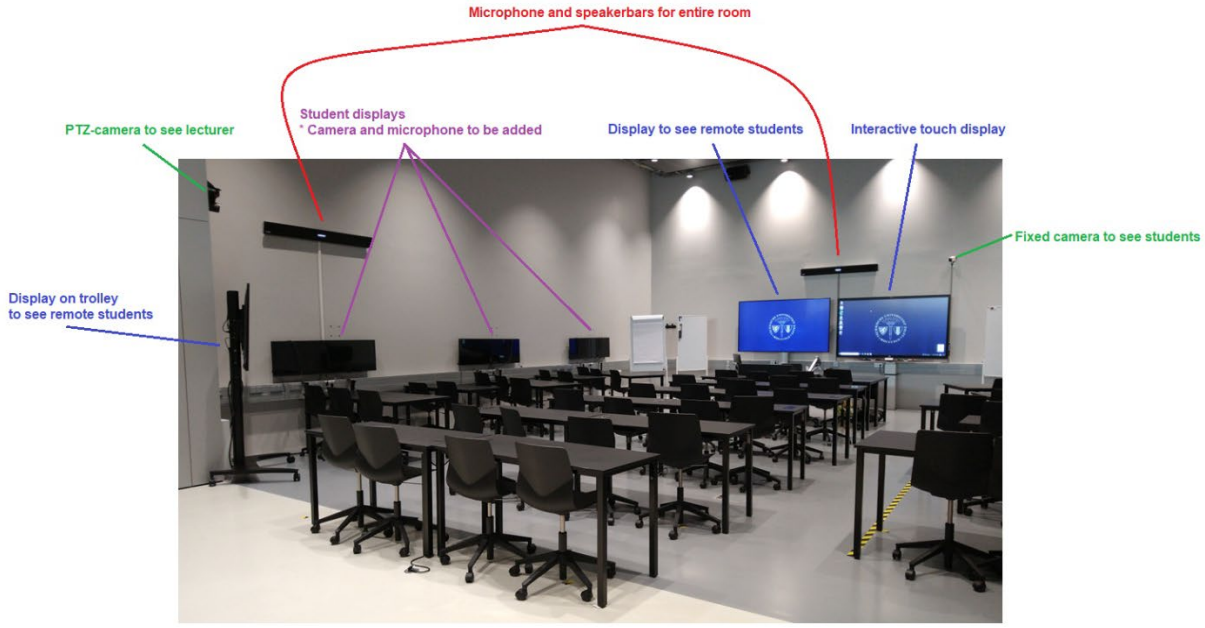

Figure 55 Overview location equipment hybrid classroom TUD

For the realisation of the hybrid classroom only 6 cameras, with integrated microphones and speaker bars; and 6 docking stations needed to be installed. Additionally, extra power sockets have been mounted on the 6 break-out room tables. This equipment facilitates the break-out room sessions for group work. All other hybrid teaching facilities were already present in the room.

The equipment installed is as follows:

- 6 Logitech MeetUp 2
- 6 DisplayPort cables
- 6 Power sockets
- 6 Dockings stations (Dell UD22 or Dell D6000)

The double screens already present at each break-out table are LG screens (type LG32SM5KB).

Appendix C: NTNU – Layout, Equipment, Guidelines

NTNU Hybrid Classroom

Figure 66 – Location NTNU Electro hybrid classroom, building F, room F328

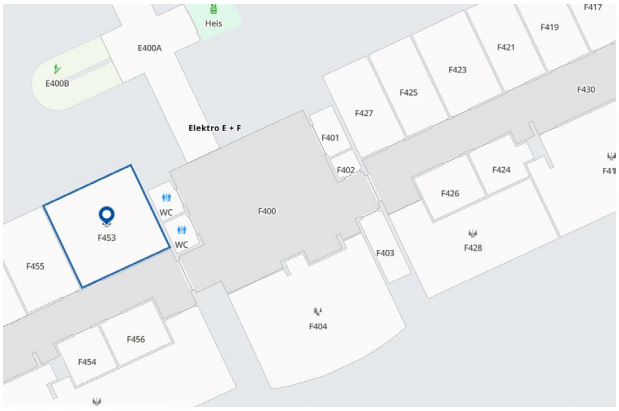

Figure 77 – Location NTNU Electro breakout room, room F453

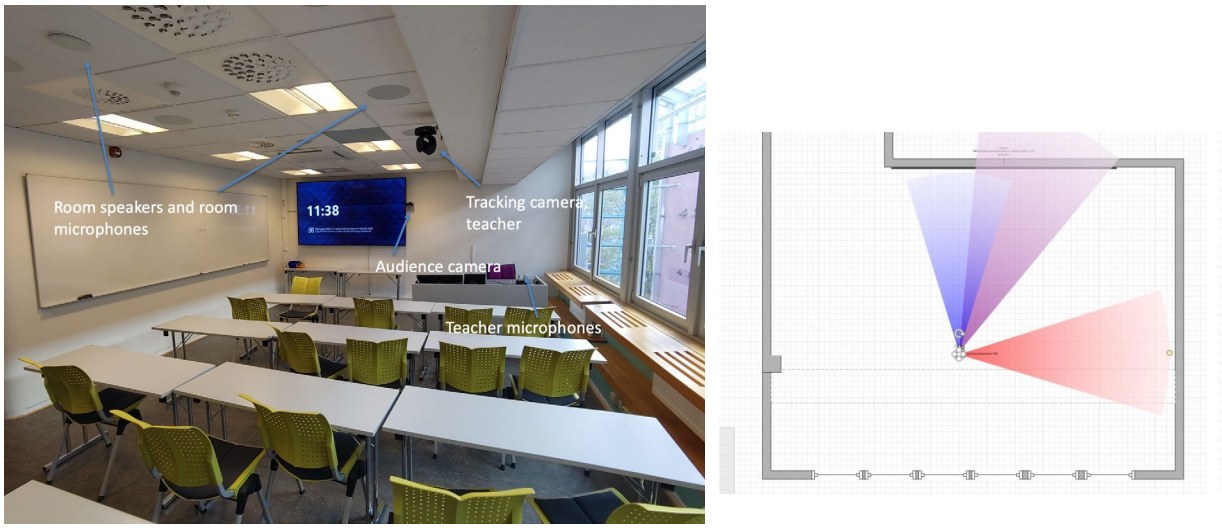

Figure 88 – NTNU Electro hybrid classroom, learner perspective and teacher camera zones

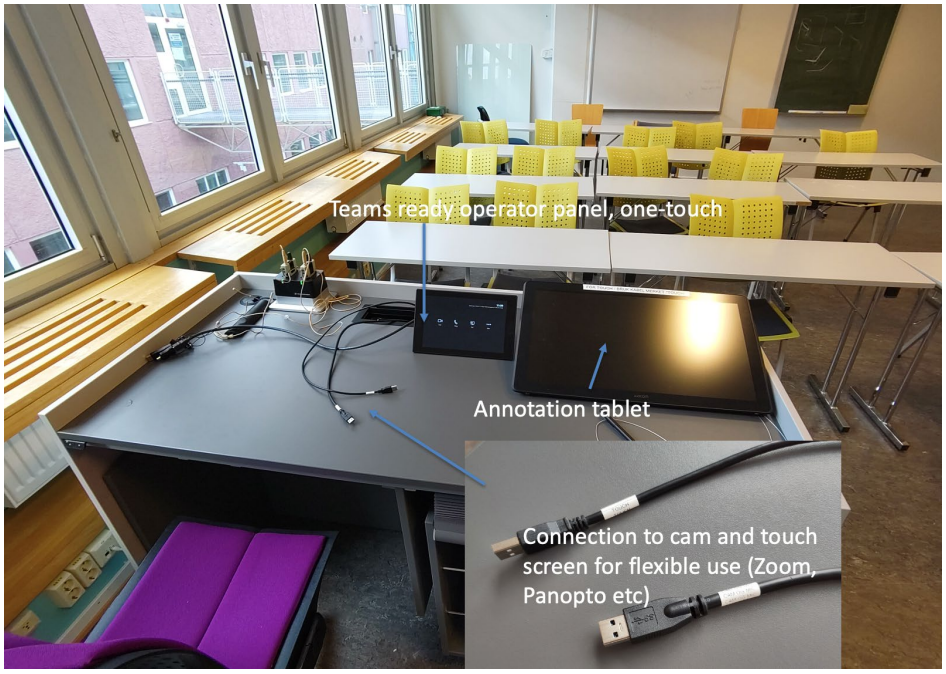

Figure 499 – NTNU Electro hybrid classroom, teacher perspective

Rom F-328

Rommet blir oppgradert med utstyr for fleksibel møblering og mulighet for hybrid undervisning og møter.

- Klient
  - Microsoft Teams møteromsklient med mulighet for Zoom, webex etc.
- Bilde
  - Philips 98" 4K Proffskjerm
  - Whiteboard 4m
  - Wacom interaktiv skjerm på kateter
- Teamsutstyr
  - 2 stk. Kamera
    - Kamera mot foreleser med pan/tilt/zoom og speakertracking
    - Kamera for møter monteres ved skjerm
  - 3 stk. Takmikrofoner skjult i himling som dekker hele rommet
  - 4 stk. Høyttalere skjult i himling
  - 2 stk. Hodebøylemikrofon til foreleser
- Kateter motorisert hev/senk NTNU Standard
  - 160cm med rack
  - Er utplassert i de fleste auditorium. Se EL4 etc.
- Tjenester
  - Demontering og opprydding eksisterende utstyr
  - Montasje tilbudt utstyr
  - Programmering lyd
  - Idriftettelse

Pris pr.stk		Beskrivelse	F-328
		MS TEAMS KLIENT	
kr	17 614	HP Presence Teams Klient med Touchskjerm og BYOD støtte for Zoom, Google etc.	1
		SKJERM/BILDE	
kr	73 864	Philips 98BDL4550D D-Line - 98"	1
kr	2 027	Unicol PZX9 veggfeste	1
kr	4 000	Whiteboard 4 meter	1
kr	13 636	Wacom DTK-2451 - Interaktiv skjerm	1
kr	4 293	Wacom bordstativ	1
		VIDEOKONFERANSE/KAMERA/LYD	
kr	64 323	Biamp X400 DSP med 2 takmikrofoner og 4 takhøyttalere	1
kr	18 014	Biamp AVB Beamtracking Takmikrofon Flat Hvit	1
kr	4 545	Biamp EX-UBT Teams interface USB	1
kr	9 380	Sennheiser DW3 - Sender og mottaker til mikrofon	2
kr	4 347	Sennheiser CHG 2 EU lader til mikrofon	1
kr	2 170	Sennheiser HS 2 Beige hodebøyemikrofon	2
kr	16 067	Kamera foreleser Aver 550 4K med pan/tilt/zoom og speakertracking	1
kr	15 901	Kamera møterom - Huddly L1	1
		KATETER STANDARD NTNU	
kr	43 750	Kateter 160cm hev og senk NTNU Standard 1 stk. Rack	1
kr	2 918	Cable Cubby 1202 black	1
kr	1 143	AC 102 EU Europe Outlets	1
		DIVERSE	
kr	1 013	Lindy USB 3.0 aktiv kabel 8m	1
kr	3 571	Diverse kabler, kanaler, festemateriell estimat - faktureres etter medgått	1,2
		TJENESTER	
kr	875	Kabling, demontering, montasje og idriftsettelse estimat - faktureres etter medgått tid	34
kr	1 025	Programmering lyd estimat - faktureres etter medgått tid	3
kr	1 000	Løsningskonfigurasjon	1
kr	1 025	Prosjektering/Tegning/dokumentasjon	7
		Total (alle priser er eks.mva)	**kr 355 825**
		mva	kr 88 956
		Totalsum pr.rom inkl mva	**kr 444 781**

Figure 50. Equipment list for NTNU hybrid classrooms.

NTNU Mobile Recording and Streaming Studio

Figure 51 – Front view of mobile virtual studio and gimbal mounted camera stand.

Figure 52 – Tripod with gimbal mounted camera for remote operation and green screen for background control.

Figure 53. List of equipment for the mobile studio

Appendix D: Testing Documentation (All Partners)

D1: Test Schedules

"Use case 1: a standard hybrid classroom with remote participants and with part of test allocated to start and end break out sessions. All partners will host a simulated hybrid teaching session and break out. Time must allow for all partners hosting as test run.

Use case 2: a split classroom/twinned classroom where one hybrid classroom is Master Classroom, while all other classrooms are remote classrooms. This is a special use case and time will not allow that all partners act as hosts. Those partners that want to act as host classroom with others classrooms twinned up as remote classrooms should contact Karsten at kkry@dtu.dk so we can plan and assess how many tests time allows."

During the tests conducted on 19th of May 2025, the priority was on use case 1, whereas use case 2 was designed for twinning of classrooms, that may only be relevant for HEIs with several campuses.

Terminology:

Master Classroom: The classroom with the lead teacher

Remote classroom: Any other hybrid classroom connected to the master classroom in twinned classroom arrangements

Digital Facilitator: Student assistant facilitating engagement of online learners and performing technical backstopping and troubleshooting of AV set.

TA: Teaching Assistant

Participants and classrooms

5 partner universities

5 hybrid classrooms

At least one break-out room (or break-out section of hybrid classroom) at each partner

Personnel (per location)

Teacher in Master classroom / Teachers in Remote classrooms

4-5 simulated learners in each location (to also make a bit of noise during e.g. break-up sessions)

1-2 AV technical staff at each location for fast problem-solving if technical problems occur

1 Observer/recorder at each location

Preparation before test day (14-16. May)

The list of participants in was completed in an Excel sheet hosted at the project repository with email and telephone numbers for easy problem solving if Teams connections would be lost during test. DTU started the list in Teams and the link was shared 14th May, 2025.

In the list, the email of the classroom and break out rooms were also included as they might appear as 'participants' in the test. The demonstration per HEI was then organised as follows:

TUD/GT/NTNU/TUS invited teams meetings with all partners and relevant room identifies for the specific test/timeslot allocated in below schedule (a session per HEI). This will ensure that we do not need to invite new teams meetings during the test. Note that the calendar will thus include several teams meetings during the 2 hour slot in the calendar, but separated according to the below schedule.

All partners consolidate the specific test procedure that you want to run given the time slots allocated. (see draft DTU-test description in DTU slot below)

Technical evaluation checklist (to be drafted by DTU and shared 14th May evening.

II Pre-Test Setup, 19th May (20-30 minutes before Start Time)

Duration: 20–30 minutes prior to test

Each university site ensures:

One person at each destination leads the test at that location

Briefing of team on test procedure and roles of the local team

All video/audio equipment powered and connected

Hybrid platform (Teams/Teamsroom) launched and tested

Classroom layout checked for visibility and acoustics

Documents or files to be used during test of sharing of teaching content in place

Ensure that all have the technical evaluation checklist at hand in print or digital

III. Test Schedule (Total Duration: ~2 Hours)

Use Case 1: Standard Hybrid Classroom with Online Learners

Each university will host a 15-minute session where their hybrid classroom acts as the Master Classroom and all other participants join as online learners. Order of rotation: DTU → TUD → GT → NTNU → TUS

Make sure each partner will record their own session

13:00–13:10 | Initial System Check – all rooms connected to call

Join joint session from all locations

Confirm:

Audio/video from each site

Annotation tools

Online learner access and view

Quick orientation and protocol reminder

Assign observers/recorders to take structured notes

13:10–13:25 DTU Session (15 minutes)

1.a: Teacher presents content to online learners, (approx. 6-8 minutes).

Yealink MTR system

Camara tracking of teacher

Camera switching during lecture

Camera tracking of student - zoom/focus on learner asking a question

Audio of teacher/on-site learner and remote learner

Mute/unmute functions

Content sharing on relevant devices: (lap-top (video/still); tablet (annotation); large screen (annotation/whiteboard function)

1.b: Teacher initiates breakout sessions (3 minutes):

Breakout groups are either auto-generated or pre-selected.

Learners test camera, mic, and shared screen usage.

1.c: Teacher ends breakout and conducts 1-minute wrap-up/evaluation. [surely one minute is insufficient, hence use the technical evaluation form to ensure that we capture every comment from all involved]

1.d: End teams call and all join the next teams call from TUD

[Buffer of 3 minutes to change to TUD Teams meeting]

13:28–13:43 TUD Session (15 minutes) [to be consolidated by TUD team]

1.a: Teacher presents content to online learners, (approx. 6-8 minutes).

Visibility of remote learners for teacher and on-site learners (which screen can best be used), added value for on-site learners, raising hands for questions, etc.

Audio of teacher/on-site learner and remote learner

Mute/unmute functions

Content sharing on relevant devices: making notes on interactive digi-board

Switch between teacher and student camera

1.b: Teacher initiates breakout sessions (3 minutes). At TUD the on-site learners will remain in the hybrid classroom and have a meeting table, 2 screens and one mic to connect with the remote learners

Breakout groups will pre-selected to ensure that remote learners are linked to onsite learners.

Learners (in break-out room and remote) test camera, mic, and shared screen usage.

Audio/noise from other break-out rooms/tables. Do onsite learners experience hinder, do remote learners experience hinder?

Create schedule which table is which break-out room?

1.c: Teacher ends breakout and conducts 1-minute wrap-up/evaluation.

1.d: End teams call and all join the next teams call from GT

[Buffer of 3 minutes to change to GT Teams meeting]

13:46–14:01 GT Session (15 minutes) [to be consolidated by GT team]

1.a: Teacher presents content to online learners, using different content sharing devices (lap-top (video/still); tablet (annotation); whiteboard/blackboard; (approx. 6-8 minutes).

1.b: Teacher initiates breakout sessions (3 minutes):

Breakout groups are either auto-generated or pre-selected.

Learners test camera, mic, and shared screen usage.

1.c: Teacher ends breakout and conducts 1-minute wrap-up/evaluation.

1.d: End teams call and all join the next teams call from NTNU

[Buffer of 3 minutes to change to NTNU Teams meeting]

14:04–14:19 NTNU Session (15 minutes) [to be consolidated by NTNU team]

1. +0 min – Start session

Intro

Verification all learners connected: in situ breakout rooms and individuals (cam and mic)

Record session start

+1 min - Connect teacher laptop, share presentation

2. +5 min - Use tablet annotation function

3. + 7 min - Check camera tracking and whiteboard:

Tracking one teacher to whiteboard, check writing visibility for learners

4. + 9 min - Check audience cam:

Questions from on-site learners

5. +11 min - Check breakout rooms: digital an in-situ breakout rooms active

Learners test camera, mic, and shared screen usage.

6. +14 min - Back to master room, check mobile recording studio and end session

Teacher calls out mobile recording studio, then end breakout and conducts 1-minute wrap-up/evaluation.

7. +15 min - End teams call and all join the next teams call from TUS

[Buffer of 3 minutes to change to TUS Teams meeting]

14:22-14:37 TUS Session (15 minutes)

1.a: Teacher presents content to online learners, using different content sharing devices (lap-top (video/still); presentation (with annotation); shared output from student VR interaction. (approx. 6-8 minutes).

1.b: Teacher initiates breakout sessions (3 minutes):

Breakout groups are pre-selected.

Learners test camera, mic, and shared screen usage.

1.c: Teacher ends breakout and conducts 1-minute wrap-up/evaluation.

1.d: End teams call and all join the next teams call

[14:37-14:45 Buffer to make up for lost time and change to DTU Teams meeting]

Use Case 2: Twinned/Split Hybrid Classrooms

DTU hybrid classroom will act as Master Classrooms. Other hybrid classrooms act as Remote Classrooms. Another partner xx can opt for acting master class (if time does not allow, this will be cut or done in follow-up test if possible)

14:45- 14:55 DTU as Master Classroom

2.a: Teacher in Master Classroom delivers short interactive session to remote hybrid classrooms. Audio and video tests

2.b: Pre-selected breakout groups are initiated across the split classrooms (3 minutes).

Test voice and camera clarity during interaction.

Use content screens collaboratively.

2.c: Return to Master Classroom with 1-minute wrap-up and evaluation.

[Buffer of 3 minutes to change to XX Teams meeting]

14:58- 15:08 XX as Master Classroom (6 minutes)

2.a: Teacher in Master Classroom delivers short interactive session to remote hybrid classrooms.

2.b: Pre-selected breakout groups are initiated across the split classrooms (3 minutes).

Test voice and camera clarity during interaction.

Use content screens collaboratively.

2.c: Return to Master Classroom with 1-minute wrap-up and evaluation.

14:55-15:05 Buffer to make up for lost time: If not needed we proceed directly to next step

15:10-15:30 Evaluation (to the extent that time permits)

Overall impressions,

Key issue to follow up on

Need for re-test of any elements?

(Detailed evaluation on meeting 27.May based on collation of points noted on Technical evaluation checklists.

D2: Technical Evaluation Checklists

Partner	Tick relevant partner/use case
DTU, Use case 1	
TUD	
GT	
NTNU	
TUS	
DTU Use case 2	
Xx Partner, Use case 2	

Item	Grade 1-5 (5 best)	Notes
Connectivity and displays		
Connecting participants		
Gallery views of all participants		
Teams vs Zoom vs Linux vs xxx		
Audio		
Teacher mic/sound		
On-site Learner mic/sound		
Online learner mic/sound		
Break out sessions: online/onsite learner communication		
Mute/unmute functions		
Visuals		
Camera tracking, teacher		

Camera tracking, two teachers		
Camera tracking, on site learners		
Content sharing		
Teacher lap-top		
Tablet with annotation function		
Touchscreen with annotation function		
White board		
Blackboard (pre-set camera?)		
Document camera		
Break-out sessions		
Pre-set groups functionality		
Gallery/Display of participants on-site/online		
Camera tracking of on-site learners		
Miscellaneous		
Trouble-shooting effectiveness		
Trouble-shooting reaction time		
Additional Notes & Comments		