Guidelines

Virtual Hands-on Laboratory Training

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On behalf of the Federal Government of Germany, the Physikalisch-Technische Bundesanstalt promotes the improvement of the framework conditions for economic, social and environmentally friendly action and thus supports the development of quality infrastructure.

Executive Summary

Virtual hands-on laboratory training is practical training on how to handle laboratory equipment or perform certain processes, which is conducted remotely (with the trainer and the trainees being in different locations). The main challenge posed by conducting such training virtually is centred around how to demonstrate the practical aspects without on-site presence. However, virtual training also offers the advantage of forcing trainees to be more active, as they cannot rely on the trainer doing things for them. Another advantage is the opportunity to do synchronous and asynchronous work, as the training is divided into shorter sessions over a period of time.

The preparatory phase is critical for the success of the training. During this phase, one or more meetings should be organized between the trainer and the laboratory staff. The purpose of the meetings is to assess the knowledge and skills of the trainees and to collect technical information on the laboratory and the equipment. This is the basis for agreeing on the general and specific objectives of the training as well as the logistical and technical details such as time and frequency of training sessions, choice of streaming platform and necessary tools.

Taking into account the information from the preparatory meetings, the trainer designs the training concept by planning out in detail all individual steps and tasks (e.g. in the form of a so-called agenda script or process plan) and shares all preparatory materials with the trainees. These could include the trainer's own materials, which are tailor-made for the training (e.g. presentation slides, checklists, diagrams, pre-recorded videos, LabView files) in addition to already available online tutorials, videos, publications, etc.. Lastly, if necessary, the trainer should also review the equipment manuals and settings. The trainees should prepare by reviewing the materials provided by the trainer, gathering all necessary equipment and laboratory materials and preparing the laboratory for the training, e.g. by setting up cameras and installing applications. A technical check before the training is essential to troubleshoot any technical difficulties.

During the training, emphasis should be put on interactivity. The trainer should lead the participants to foresee challenges, come up with questions and arrive at answers themselves rather than directly providing information. He or she should demonstrate not only the correct way of working but also highlight common mistakes. Enough time should be allowed for so that all trainees can practise handling the equipment, ask questions and receive feedback and guidance. The trainer needs to assess the understanding of the trainees continuously, by asking them questions or making them repeat steps in order to avoid misunderstandings.

An advantageous setup for virtual training is one whereby both the trainer and the trainees have access to a laboratory and similar equipment. Group size should be kept relatively small in order to give a chance to all trainees to practise and perform tasks with the equipment. The proximity of the trainer in the laboratory of the trainees can be simulated through a range of hardware and software solutions. Fast-speed and stable Internet and high-quality cameras are important prerequisites. The use of at least two cameras in the laboratory is recommended: one focused on the equipment or instrument and the other one on the participants or the general laboratory environment. Ideally, the trainer should also have two monitors. Videoconferencing platform with screen-sharing function, remote control of laboratory equipment, automatization of the measuring and virtual laboratories are some of the technical tools that additionally facilitate the virtual conduct of the hands-on laboratory training.

The live hands-on sessions should be complemented by asynchronous work, meaning individual offline learning of trainees. Between training sessions, the expert can assign practical individual or group tasks and other homework assignments.

After the training, the instructor should schedule a meeting to recap accomplishments, provide (individual) feedback to participants, discuss any follow-up steps and collect feedback on the training.

Introduction
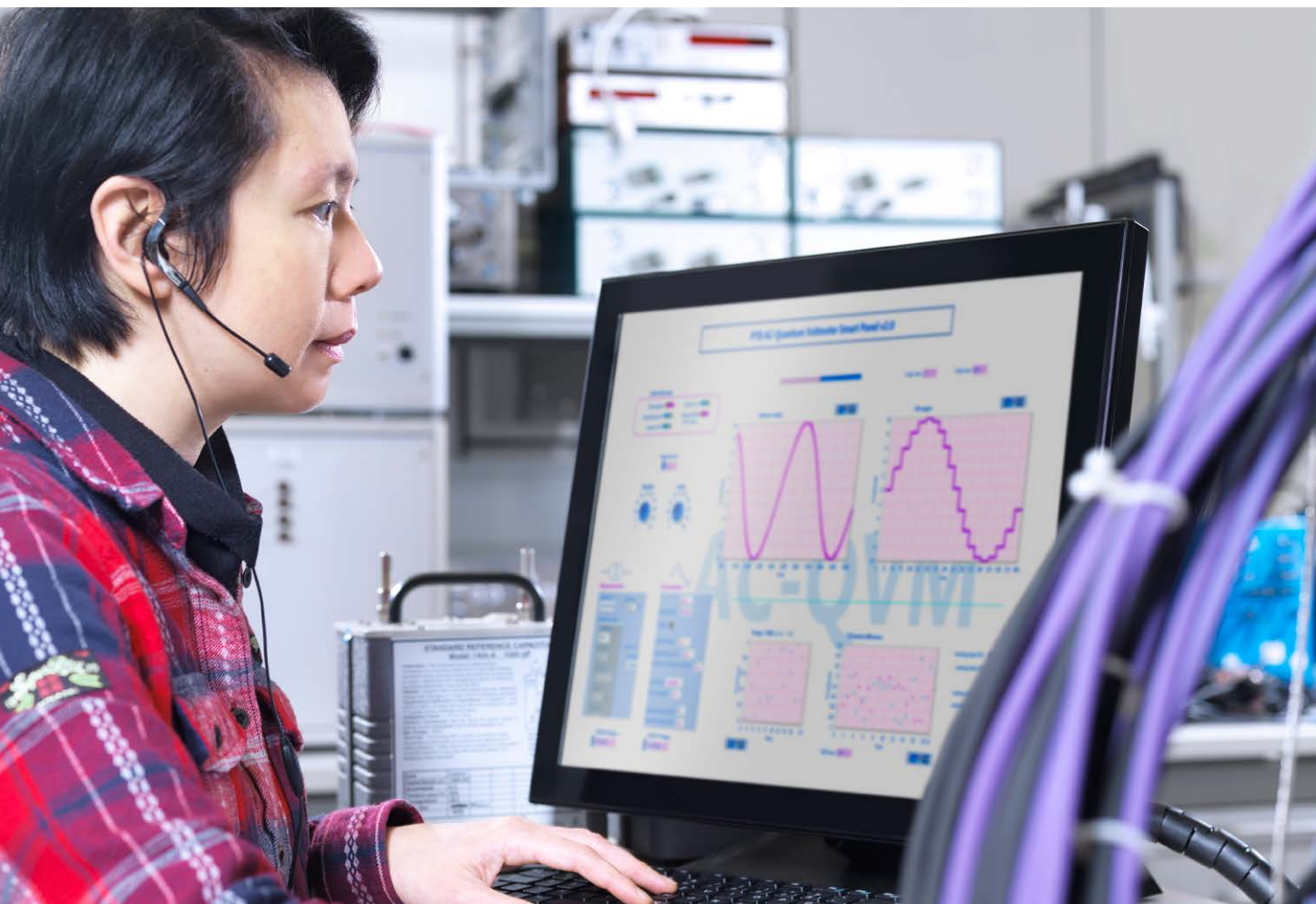
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Laboratory staff from calibration and metrology laboratories need to be trained on a number of practical skills such as how to handle (new) laboratory equipment and materials, how to perform certain technical procedures and processes, record and analyse measurement results, as well as some basic principles of laboratory techniques and best practice in laboratories. One of the most effective types of training is hands-on one, which applies the principle of learning by doing. Such training in a laboratory setting can be quite complex. It also has a strong practical focus in that it works best when there is an in-person demonstration by a trainer and an opportunity for all trainees to physically handle the equipment.

Challenges and Advantages

On-site presence for training is not always possible (especially in the context of a pandemic). As a result, training designs and methods have to be adapted to be conducted remotely. The central challenge with the virtual mode of practical laboratory training is that the demonstration of the equipment or the process/technical procedure cannot be done in person. Small but important details could be missed. Differences in the model or settings of the laboratory equipment available to the trainer and the trainees can also lead to complications. Unlike theoretical training, which can be easily adapted to a virtual environment, the practical laboratory training requires hands-on engagement and direct observation of the work with the equipment.

The above challenges are quite formidable but for the most part can be overcome with the help of appropriate hardware (multiple cameras, audio speakers, etc.) as well as software (video streaming platform, remote access applications, virtual laboratories, etc.) to compensate for the fact that the trainer and the trainees are not physically together in the same space. Equally important are a thorough preparation prior to the training and the integration of pedagogical principles of remote learning in the training methods.

Despite the substantial challenges, virtual hands-on laboratory training has also advantages. It put trainees in charge of their own training, which makes them more responsible and active. They are motivated to prepare in advance because they cannot rely on the trainer doing things for them in the laboratory and have to perform all the steps by themselves. Another advantage is that since the expert does not need to travel to the laboratory, the training can be split into several shorter sessions over a given period of time, making the training speed more suited to the trainees' ability to assimilate information. Breaking down the training content into shorter sessions improves retention and provides opportunities for asynchronous work. For example, trainees can be assigned tasks to complete offline.

Challenges	Advantages
Explanation takes longer than demonstration; within the same timeframe less can be achieved virtually than on site	Without the trainer next to them to demonstrate, trainees are put in charge and have to problem-solve themselves
Higher risk of misunderstanding instructions	Virtual training can be split into several shorter sessions over a period of time, which allows time to process the new material and improves retention
Technical glitches are likely to occur	Possibility of taking advantage of asynchronous work between sessions and supplement the training with additional available resources

Scenarios Influencing the Interaction

Virtual hands-on laboratory training is highly interactive. It requires continuous exchange between the trainer, the trainees and the equipment. The trainer provides detailed instructions and assesses the understanding of the trainees through feedback, whereas the trainees apply the instructions, receive guidance and ask questions and clarifications. The **training group size** should be kept small to ensure that all participants have the opportunity to practise the procedures that are being taught and work with the equipment. The actual number of participants can vary depending on the available space in the laboratory, the type of training and the prior knowledge of the trainees. In some cases one-on-one training might be the most effective, while in other cases up to 12 participants may be appropriate. The determining factor is to make sure that all participants have a chance to interact with the equipment and with the trainer.

In a virtual mode, there are **several scenarios** for the remote training setup.

The ideal scenario is when both the trainer and the trainees are in their respective laboratories and both laboratories are equipped with similar equipment. In such a case, the trainer can stream his/her demonstration to the trainees and the trainees can repeat it in their laboratory while the trainer observes. However, this scenario is also the least likely to be possible in practice.

Sometimes the trainer is a freelance expert who used to conduct on-site training before the pandemic and might not currently have access to a laboratory for remote training. In this hybrid training scenario, only the trainees have access to the laboratory and are all there together. While the trainer cannot demonstrate procedures as he or she does not have access to a laboratory, he or she can still provide explanations, direct the trainees and give feedback on their activities. In case of shift work whereby not all laboratory staff can be together, or where participants join in from various locations (e.g. in the context of multilateral cooperation), there might be a mixed model. In these cases, some participants gather in a laboratory and others including the trainer are connected via videoconferencing.

It is possible that in some cases the trainer can run the training from a laboratory, but the trainees cannot be together in a laboratory and are all watching from separate (home) locations.

Finally, the least advantageous interaction scenario is when neither the trainer nor the trainees are in a laboratory for the training. In that case, practical exercises are almost impossible.

It is important to adapt the training depending on the specifics of the particular scenario. The guidelines below presuppose that the trainees have access to a laboratory.
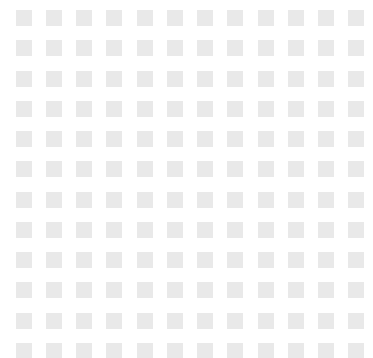
Phase 1 – Before the Training

As in all virtual formats but even more so for practical hands-on laboratory training, investing in the **preparation of the virtual training** is key to its success. It is recommended that the trainer set up at least two **preliminary meetings** with the laboratory staff. The information exchanged during these meetings is crucial for the appropriate design of the training and the choice of platforms and tools.
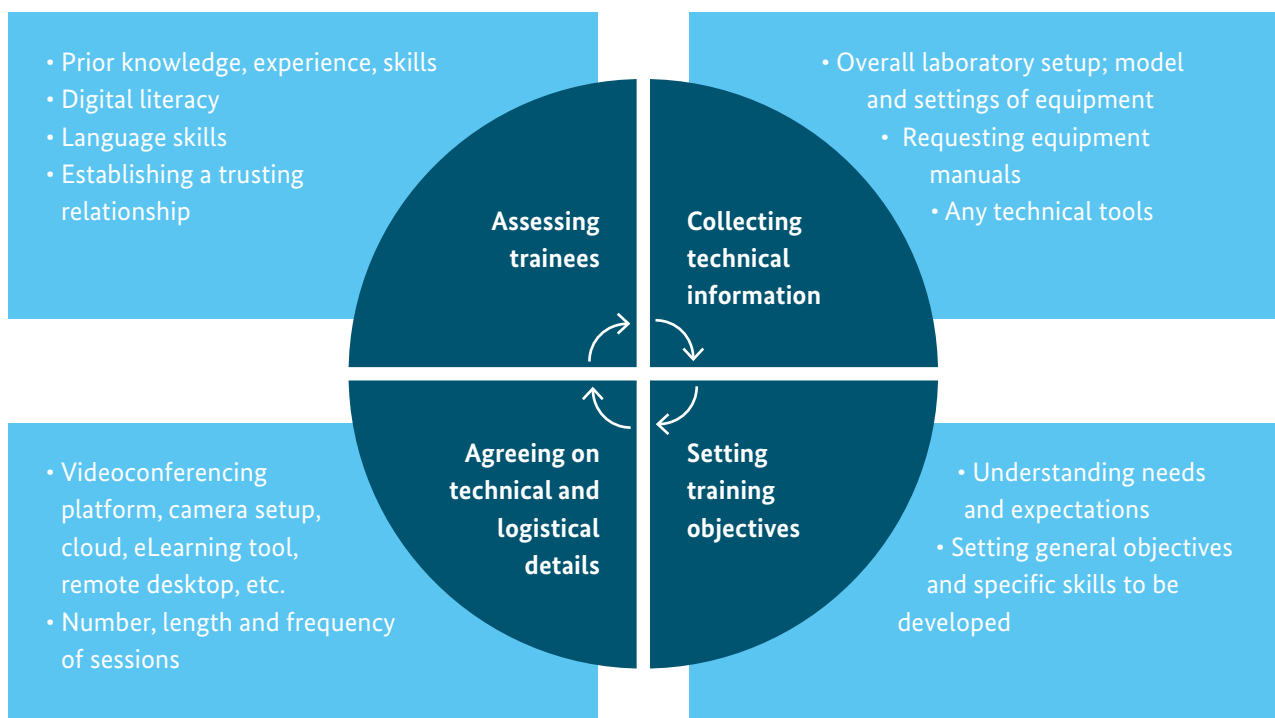
One of the purposes of the preparatory meetings is to **evaluate the trainees** in terms of their prior knowledge and experience, technical skills, digital literacy and language abilities as well as to get a sense for the variation across the group. Have trainees worked with similar equipment before? Are most trainees roughly at the same level or some participants are more advanced than others? What kind of technical tools are they familiar with? Will real-time interpretation be needed? Such information can be collected either through interviews or

through a written questionnaire to be filled out by the trainees. It is essential to accurately assess the trainees, as this assessment informs the training design and determines how ambitiously the training objectives can be set.

Another goal of the preparatory meeting is to collect **technical information**. Firstly, the trainer needs to get a view of the laboratory environment and equipment and ask questions about the hardware (exact model, settings, etc.), software, reference materials, consumables needed during training sessions as well as request equipment manuals and other documentation. Secondly, the trainer needs to ensure that all the necessary tools and accessories (e.g. cables, adaptors, chemicals, glassware, pipettes, etc.) are available.

Thirdly, it is important to understand the **training needs** of the staff and align the **objectives of the training** with them. In other words, it is important to be pragmatic

Objectives of preparatory meetings

- Prior knowledge, experience, skills
- Digital literacy
- Language skills
- Establishing a trusting relationship

Assessing trainees

Collecting technical information

- Overall laboratory setup; model and settings of equipment
- Requesting equipment manuals
- Any technical tools

- Videoconferencing platform, camera setup, cloud, eLearning tool, remote desktop, etc.
- Number, length and frequency of sessions

Agreeing on technical and logistical details

Setting training objectives

- Understanding needs and expectations
- Setting general objectives and specific skills to be developed

about what can be achieved through remote training given the laboratory setup, the available equipment and the trainees' existing knowledge and skills. In planning the training sessions it is important to keep in mind that less can be accomplished remotely than on site within the same timeframe. This is because it takes longer to explain something than to show how it is done. In addition, technical glitches are likely to occur. The specific objectives and intended outcome of the training, including what concrete skills the trainees are expected to acquire, need to be agreed upon as well.

Finally, the preparatory meeting should be used to discuss and agree on the **logistical details** of the remote training: choice of streaming platform, eLearning tool, number of cameras, who will operate them and how, frequency and scheduling (time and length) of the sessions.

The preparatory meetings also have the added benefit that the trainer and the trainees get to know each other and feel more comfortable during the training. It is important to invest in the social component of the interaction and to establish a trusting and error-tolerant working atmosphere from the beginning.

To make most use of the training time, it is recommended that both the trainer and the participants prepare as much as possible in advance. The trainer should carefully plan out all the steps for the training sessions and break them down into sub-tasks. Drafting a detailed script for each training session, outlining all steps and sub-tasks together with required equipment, extensions and materials might help to structure it in a realistic way, including efficient use of online tools. He or she should **upload corresponding training materials** (own slides, own pre-recorded videos, available online tutorials, external guidelines, checklists, diagrams, bibliography, etc.) to a cloud or the eLearning platform agreed during the preparatory meeting and share them with participants before the training. It is useful to provide, for example, lists and diagrams with all the needed connections for trainees to review in advance. In addition to designing the training sessions, the trainer also needs to prepare by reviewing the equipment manuals and checking instrument settings. Pre-recorded videos by the trainer or trainees might also be very helpful as a preparation for the other party.

> **A script for each training session**
> - Define session objectives
> - List all individual steps and sub-tasks
> - List required equipment and materials/consumables for each step
> - Develop guiding questions and exercises for the trainees for each step
> - Set some time aside for questions, repetition and breaks

The participants also need to prepare in advance on their own by reviewing the resources provided by the trainer, gathering all required materials and prepare the lab and equipment for the training.

Shortly before the start of the training, it is recommended that a **technical check** is conducted. It could be a good idea to assign a person from the laboratory whose sole responsibility is to set up the cameras, operate them during the training sessions and manage and troubleshoot other connectivity tools so that everyone else can focus on the training itself. The designated person can conduct the technical check prior to the training. This includes performing camera and sound checks, making sure the lighting is appropriate and testing remote work tools and applications. Participants who are not familiar with the tools to be used, for example the video conferencing tool or the virtual laboratory tool, might benefit from a prior tutorial or test to avoid technical complications later.

Phase 2 – During the Training

A training session might be split in the following sequence: introduction to the subject and the session, demonstration (including both correct and incorrect examples), assignment of clear practice tasks with clear objectives (preferably for each participant), observation of how this is resolved/guidance if questions come up, evaluation of performance and discussion/lessons learned.

A common difficulty with remote practical training is that instructions and directions can be misunderstood. To ensure that the trainees have understood correctly, the trainer should present explanations and tasks visually, for example by using a virtual drawing pad, a whiteboard or a chat feature. He or she should regularly pause and allow for questions from the trainees. It is useful to have one of the cameras focused on the trainees so that the trainer can observe their reactions and facial expressions and whether they are following the instructions correctly. Having two monitors is good practice for virtual trainers. The trainer should also ask the trainees to repeat the steps to confirm that there is no confusion. In designing the training, it is a good idea to set aside enough time to give opportunity to all participants to try out and get comfortable with the equipment. It is also a good idea for the trainer to demonstrate not only the correct way of doing something but also to demonstrate common mistakes and how to avoid them.

To acquire and retain knowledge, demonstration and practice are crucial, but it could be complemented by theory exercises to ascertain whether the practical knowledge has been assimilated. To keep participants focused and engaged, the training sessions should be as **interactive** as possible. Before providing answers, the trainer should give participants the possibility to foresee challenges, come up with solutions and raise questions. The trainer can continuously ask simple questions like "Where do you think this cable goes?" or "What do you think will happen if we do X?". Presentation slides can be helpful, but might also distract from listening and observing. To bring variety to the **methods**, the training sessions could also incorporate polls, whiteboard work, presentations by participants and videos. Time should be given to the trainees to perform exercises. The exercises

Encouraging active participation
- Create a pleasant atmosphere by starting with a short warm-up round
- Promote balanced participation by encouraging more reserved trainees to speak up
- Use questions and assign small tasks to stimulate participation
- Allow room for mistakes

should be corrected in a group so that questions are debated by all. If the group is a large one, breakout groups might be helpful to engage participants, but in this case several trainers might be needed so that there is a trainer for each breakout group. As hands-on training typically requires a lot of effort and concentration from both sides, breaks to rest and take time to digest the content should not be omitted.

It is important to remember that demonstrating the correct procedure is only a small part of the training. The bigger learning potential lies in trainees attempting the procedures on their own, making mistakes, getting feedback and asking questions. Apart from demonstration, coaching is an important part of hands-on training. Coaching usually happens during the practice step and again during the instructor's follow-up, after the formal training ends. It is a continuous back-and-forth between the trainer and the participants.

Phase 3 – Between Training Sessions

In contrast to on-site training, virtual training does not need to happen in one long session. Instead, it can be split into several shorter sessions. For a series of practical hands-on training sessions, it is advisable to schedule short sessions over a predefined period of time. For example, a series of hands-on training sessions could consist of three sessions per week each lasting from one to three hours over a period of one month.

Dividing a training unit into multiple sessions has several advantages. First, conducting shorter sessions is more suited to the shorter attention span of participants during virtual events, or events that require a lot of concentration. This allows participants to process the training, reflect on it and ask questions in the following session. Also, if any issues occur such as technical problems or lack of important accessories (e.g. cables, adaptors, consumables), the issues can be resolved by the next session. Second, participants can benefit from asynchronous

Synchronous and asynchronous working
To maximize the use of limited training time, it is important to take advantage of asynchronous working, meaning completing tasks before or between training sessions.

learning, meaning that they can work offline at their own pace in between sessions. Between training sessions, it is also a good idea to assign practical independent tasks for the trainees to complete such as performing their own measurements while keeping notes of any difficulties and questions that might arise in the process of completing the independent tasks. The trainer can set aside time to answer any questions during the following session or in a post-training meeting.

Phase 4 – After the Training

It could be a good idea to record the training sessions for the laboratory staff's future reference. However, permission to do so needs to be obtained from all of the participants in advance. It is important to keep in mind that recording the training sessions might make some trainees feel less comfortable and less willing to participate and ask questions. Recorded training sessions might be watched back by the participants afterwards and shared with other colleagues. If a training session is recorded, time for editing should be allowed for, to cut out the unnecessary parts and keep the video as short as possible.

A post-training workshop can be a good way to end the training. The meeting can be used to summarize the results achieved and clarify remaining questions. Another objective of the meeting is to provide timely feedback to the trainees. Ideally, feedback should be personalized

and should include specific recommendations for areas that require more work from the participant and next steps for improvement. To this end, the trainer could provide links to additional online training activities and resources. These can include web-based training courses, resources made available by peer institutions, international or regional organizations and self-assessment resources. When taking an e-learning approach, the online training material needs to be periodically revised. Finally, the post-training meeting can include discussion of any follow-up steps (e.g. coaching options) and ask trainees to provide feedback on the training by filling out an evaluation form.

Software Applications

There are a number of tools and applications that can be used to support remote training.

Streaming platforms: A number of platforms are available which allow real-time video streaming so that the expert can view the training laboratory and guide the trainees, or the trainees can observe the demonstration by the trainer, depending on the specific training configuration. Some common platforms include: Cisco WebEx, Zoom, DFN, Microsoft Teams and Skype.

Screen sharing: An important feature of most video conferencing platforms is the screen-sharing function, so that trainers or trainees can use it as a whiteboard to show routine examples or calculations, for example, when recording or analysing measurements.

Remote control of laboratory equipment: It could be useful for the trainer to be able to have remote access to the lab equipment. In this way he or she can directly interact with the equipment rather than instruct trainees where to click. TeamViewer and Microsoft Remote Desktop are commonly used applications for remote control. Other examples include AnyDesk and TightVNC.

Automatization of measurement processes and setups: One of the tools that can be used is LabView. It can be developed and initiated remotely. However, the time taken to program LabView files should not be underestimated as it can require patience and specific skills. There are a number of other tools serving the same purpose which function slightly differently (e.g. Fluke and other devices can be used with MetCal).

Virtual laboratories and Virtual Instrument Systems In Reality (VISIR): There are some platforms that virtually simulate laboratories such as V-lab (*https://www.vlab.co.in*) and Labster (*https://www.labster.com*). The advantage of virtual laboratories is that the trainees do not need to worry about accidentally damaging the equipment. The disadvantage is that the hands-on aspect is missing, which means that trainees cannot get a sense of the weight of instruments or other accessories and how to handle them. VISIR is a remote laboratory for designing, wiring and measuring electronic circuits. The user can access the laboratory remotely from any location. This platform is most suitable for training on highly sophisticated analytical techniques to make processes easier to comprehend, or in situations where experiments may have an impact on the operator's health or wellbeing.

Videos: In some cases, if the trainer has access to a laboratory, he or she can pre-record a video. The advantage is that the demonstration can be filmed in a controlled setting rather than in real time. The first step is to decide on the scope of the video and prepare a script which outlines the different steps and settings. Using two or more cameras might be helpful to record from different angles, so that the trainees can see all important details. The two sets of footage can be combined in the editing phase. It is recommended that the trainer first record the video and then later add the instructions and explanations as a voiceover. It is necessary to edit the video, to make it as short as possible and of good quality. In some cases, it can also be useful for trainees to prepare a video on the way in which they perform a procedure for the trainer to review before the training.
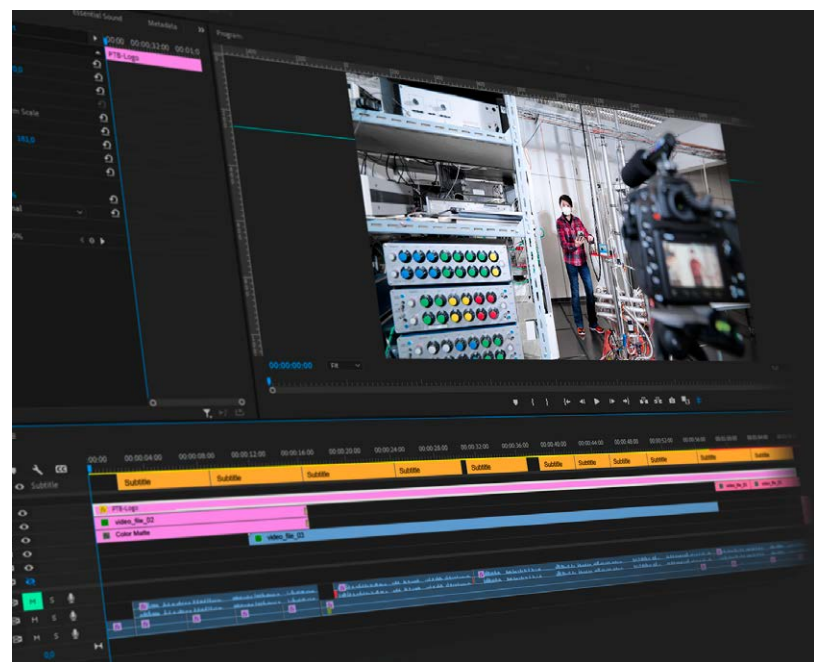
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Pre-recording a video
- Prepare a script prior to the recording, outlining the sequence of steps to be demonstrated and necessary instruments and materials
- Add a voiceover with instructions/ explanations during the editing phase
- Edit the video to keep it as short as possible

Data Protection and Security: It is important to keep in mind and comply with the data protection and privacy regulations in the location of the trainer and trainees. The software applications mentioned above serve only as examples. Before use, users should check whether they comply with the General Data Protection Regulation and other applicable legislation as well as meet IT security requirements.

In addition to shooting a video in a real-world environment, the trainer can prepare a video animation. There are a number of software applications for animations such as Pencil, Synfig, CreaToon, Ajax Animator and Blender. In a second step a video editing application such as Video-Pad or AIVS Video Editor can be used. Also, in the case of animated videos, it is a good idea to add sound or record the voiceover separately during the editing stage. One example is the animation video *Understanding the Biosafety Levels* produced using Pencil, Blender and VideoPad (credit: Karen Darbinyan).

Audiovisual Equipment

For remote hands-on training a fast, stable Internet connection is critical, as the streaming images need to be sharp and the audio clear. A wireless Internet connection in the laboratory is in general more stable than a mobile phone network, especially when people are moving around.

A proper sound system (external speakers or headsets) is preferable to relying on a laptop's built-in audio equipment. It is recommended for participants to watch on a large monitor or via a projector rather than using their smartphones.

For the trainer, having two monitors is recommended: one for presentation of slides and one to observe the video stream from the laboratory. As in other formats, an interactive participatory approach is the key to the success of an online training, so the trainer must be able to observe the participants.

Having at least two cameras is recommended for trainees in a laboratory. One can be pointed at the equipment or instruments and the other at the laboratory environment/ trainee group. The quality of the cameras and proper lighting can make a big difference. To make it possible to see both camera streams, the cameras can be logged into the video conference via two different computers/ accounts. Alternatively, two different videoconferencing platforms can be used for the two cameras and the trainer can switch between them.

Budget

Conclusion

On the one hand, no travel and accommodation expenses for the trainer are incurred in virtual training. On the other hand, the trainers need to put more hours' work into the preparation of the training. This includes time to conduct preparatory meetings, draw up checklists and other materials and upload them, pre-record videos or animations (if necessary), conduct technical checks prior to the training, etc. Depending on the software used, licence fees might apply. It is a good idea to invest in high-quality cameras. If purchasing one solely for the training is not cost effective, options for renting equipment could be explored. Similarly, additional charges might apply for high-speed Internet access. Lastly, in some cases an interpreter might be needed and will need to be budgeted for accordingly.

While some hold the view that nothing can be an adequate substitute for hands-on laboratory training on site, first experiences with conducting such virtual training show that this method is worth exploring further. In the spirit of *building back better*, it is conceivable that more sophisticated tools may soon become available, which would make virtual hands-on laboratory training more intuitive and less technically challenging. In the future there will be an ever-increasing number of online resources such as video tutorials and simulations. Such developments will create more opportunities for blended learning and the use of digital alternatives, which will ultimately increase the accessibility and quality of training. However, it is also clear that there is still a long way to go, and the scientific community can benefit enormously from sharing solutions and practical approaches to common challenges in virtual hands-on laboratory training. We are happy to have taken a step in that direction with the publication of these Guidelines. If you have any feedback on them, please contact us at *9.3-corona-response@ptb.de*.

Notes

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