2023 | EN

Hands-on-Remote

Guidebook

2023

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All materials and contact details can be found on the project websites as well as in the Erasmus+ project profile:

https://sites.google.com/campus.ul.pt/hands-on-remote-language/home **link**

https://erasmus-plus.ec.europa.eu/projects/search/details/2020-1-DE02-KA226-VET-008295 **link**

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Print: February 2023

Co-funded by the Erasmus+ Programme of the European Union

ISBN EN: 978-989-8753-82-3

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1. The “Hands-on-Remote” project

1.1. Introduction

The Covid-19 pandemic has clearly shown the lack of digital structures in our school systems, both on a technical level and on a content-related-didactic level. Accordingly, there is a need to build capacities for online and hybrid learning, for high-quality content and, generally to further develop the skills of students and teachers for remote learning and teaching. New, innovative teaching formats that can be used in various scenarios – virtual, hybrid, or on-site – are therefore essential.

The main objective of the “Hands-on-Remote” project is to improve the digital skills of teachers and students and to provide teachers in vocational education[1] with free resources so that they can react flexibly, with innovative approaches and high-quality concepts in various corona-related scenarios.

Practical work is part of general school practice in vocational schools and essential for learning technical, IT, and scientific methods. However, during Covid-19 measures, a lot of this became simply impossible. This is exactly where our project comes in: We want to enable vocational training teachers to carry out classic hands-on student experiments with virtual support in flexible locations – at home, in several locations at the same time, or with appropriate distance in a classroom – depending on the hygienic and security requirements.

A second challenge of the pandemic situation is the isolation of people, thus a lack of a ‘school community’. By linking experiments as well as students, a shared experimental situation is created that awakens motivation and interest and promotes cohesion – both locally and in Europe.

1 In the development we focused on vocational educations, since there is an increased need in practical work – however, the modules and especially the teaching methods are universal can be used in any secondary school.

1.2. This Guidebook

The COVID-19-crisis is perceived as a 'turning point' regarding the use of technology in education and training and, connected to this, the need for high-quality digital content being readily available and affordable for learners and educators has been underlined. At the same time, there is interest in capacitating teachers for developing their own teaching contents – based on the hands-on remote scheme. This guidebook aims to assist teachers in doing so by laying out the general principles and theoretical background of this scheme.

Transforming the teaching of hands-on experiments into the digital realm allows not only to improve the education situation for (vocational) students under any pandemic conditions but also allows a closer link between work at home and work at school. In addition, the approach seems likewise usefully in situations beyond the pandemic: The type of digital collaboration proposed can support international teams in their cooperation – and possibly save some air travel and CO^2 emissions, especially in view of the climate crisis. The hands-on remote approach can also enable distance learning during local weather events - also an important consideration at this time, due to class cancellations and learning delays caused by Corona. Educators from other fields (e.g., out-of-school learning places as museums, science centers, or student laboratories) may as well be interested to create their own resources and develop new ideas based on the foundations laid in this project.

This guidebook is made available in two versions – digital and printed – with the purpose of enhancing the visibility of the project and inspiring new users to apply the teaching modules and the project's core idea of hands-on remote teaching in group settings. The dissemination of this guidebook in different events – teachers' professional development initiatives, school information events and conferences – will ensure a long-term and flexible use of the material and ideas developed in the "Hands-on-Remote" project.

This guidebook includes several sections:

1. A short and practice-oriented theoretical background on remote teaching, including a special focus on remote hands-on activities and the group building measures that are a core part of each module;
2. A collection of hands-on remote learning examples from other projects;
3. Several practice-oriented How-To's on developing exemplary remote hands-on experiments;
4. A section on considerations that lead to the current form of the teaching modules ("Why did we develop the modules as they are?");
5. A detailed description of the modules from a developmental perspective.

2. A practice-oriented theoretical background on remote teaching with a special focus on remote hands-on activities

Practical work (hands-on activities performed by students) and experimentation (hands-on activities where students can introduce changes in some variables and observe the effect of those changes in some phenomenon) are important components of general school practice in vocational schools and essential for learning science, technology and engineer concepts and processes (Lytvyn et al., 2020). However, during Covid-19 restrictions, these educational practices were impossible to perform in presence at schools. This situation provided a good context and pretext for the exploration of good educational alternatives to these presential activities.

Several institutions tried to bypass the limitations imposed by Covid-19, adopting different strategies: a) developing kits with the necessary materials for the implementation of practical activities at home and sending them by mail to students; b) resorting to remote experiments made available at remote labs; c) resorting to simulators of phenomena made available at digital labs. All these options can also be particularly useful to overcome the disadvantages of traditional hands-on labs such as limited availability, expensive maintenance and safety problems (Destino et al., 2021; Gomes and Bogosyan, 2009; Ma and Nickerson, 2006; Schmidt et al., 2021; Tiernan, 2010).

In this guidebook we will refer to three different types of experiments according to the way resources are accessed (remote or local) and the physical nature of the lab (simulated or real). Our modules resort to experiments that are: a) **local and real** (to be implemented by the students at their home through the use of resources sent by mail or available at their place); b) **remote and real** (real experiments based in a physical lab – remote experiments – to be accessed and controlled synchronously by students, on a time of their own choice, through

Internet connection); and c) **remote and virtual** (virtual experiments, mainly simulations – based in a virtual lab, – to be accessed and controlled by students, on a time of their own choice, through Internet connection).

Several projects of kitchen chemistry (materials bought by the students or sent home as a package by the teacher) have been created in response to the disruptions caused by the SARS-CoV-2 pandemic. The low cost of these kits offers an opportunity to address unmet needs for lab experiences in this kind of circumstance (Destino et al., 2021). Schmidt et al. (2021), for example, developed a set of remote learning modules that use household adhesives as a context for teaching organic and polymer chemistry remotely. These modules provide hands-on learning experiences, about polymer chemistry, outside of the traditional laboratory. The modules: a) address the key-concepts of polymer synthesis, intermolecular interactions, thermomechanical properties, structure-function relationships, and molecular design; and b) promote research skills such as searching for primary literature sources, producing test samples, explaining unexpected experimental results, and revising experimental procedures.

In another project, students felt empowered by building and tracing circuits at home, with affordable materials, as compared to using expensive high-fidelity devices at the university. The use of their own self-made loudspeaker to validate circuit functionality was particularly rewarding for students (Alamatsaz and Ihlefeld, 2021).

However, nowadays, remote experiments seem to be gaining ground relatively to other available means to perform experiments. Remote experiments have two basic characteristics: 1) the user and the experimental setup are located at different places (e.g., the user is at home and the setup is in a lab); and 2) they use a real experimental setup possible to be activated and controlled through Internet (Gomes and Bogosyan, 2009). This kind of setup (available 24/7) allows remote experiments to be conducted as homework (from any other place), without risk of damaging the equipment or necessity to have multiple instruments, and with the possibility of repeating as many times as desired without health risks. The control of the experiment (of its variables and logic) through Internet permits the student to resolve possible problems, activating inputs and observing the consequent outputs. This way, the remote laboratory reduces the costs significantly, making lab experiments available at any time and place, accommodating larger groups of students and personalizing student's learning pathways (Callaghan et al., 2021; Gomes and Bogosyan, 2009; Tatli and Ayas, 2020; Tiernan, 2010).

In spite of all the benefits of virtual laboratories, there are some limitations. One is that in most of the cases, only one user can perform an experiment at a time. However, sometimes, a scheduling system is available, allowing the allocation of time for each user. Other limitations are: a) the lack of opportunity to experience realistic troubleshooting based on unexpected results (an important skill for scientific research); and b) the oversimplification of health and safety in the lab environment (Lewis, 2014; Tatli and Ayas, 2020).

Another less expensive opportunity offered by the evolution of technology (and currently being intensively developed) are virtual labs (Heradio et al., 2016; Villalba et al., 2008), involving web based applications (simulators) in order to help students to understand complex processes (Chittaro and Buttussi, 2015; García-Zubia et al., 2009; Manuel et al., 2019). They also have the benefit of enabling students to work collaboratively at the same time (De la Torre et al., 2015), what is not allowed by remote labs. However, they don't provide real visualization of information from the laboratory like the remote labs (Borrero and Marquez, 2012; Rodriguez-Gil et al., 2014).

Besides the important benefits of reduced costs, enhanced availability and accessibility, improved autonomy and flexibility during learning process, large-scale observability, and increased safety, some studies show that virtual labs can replace the position of the practice labs (Brinson, 2015) and attract students to STEM related fields of study and careers (Kolloffel and de Jong, 2013). However, the impossibility of real research, affects the full development of practical skills (e.g., the use of measuring instruments and how they are connected and the measurement of physical quantities) (Jaakkola et al., 2011; Zacharia, 2007), requiring a balanced combination with practical laboratories (Brinson, 2015; Zacharia et al., 2008).

Remote and virtual labs are used in different countries for vocational education (e.g., Poland, Portugal, Indonesia and Brazil), allowing to promote a more independent and flexible learning, according to the needs of students, and a more practical and efficient learning in contexts strongly affected by the lack of resources (Grądzki, 2021).

3. Hands-on remote learning examples from other projects

No.	Title/*Institution*	Topics	Form (*LR, RR, RV**)	Languages
1.	Experimentieren@home/ *Deutsches Museum*	Science and Technology, especially physics	Hands-on experiments to do at home, with supporting video materials (*LR*)	German
2.	Museum-on-Demand/ *Deutsches Museum*	Physics, Elementary Science	Museum visit via video conference in combination with exhibition-related experiments that students can perform at home or at school (*LR*)	German
3.	PhIT with the Arduino/ *Technical University of Munich*	Physics, Informatics, Technology	Livestream Workshop with the opportunity to program and experiment right away	German
4.	Remote Robotics – Mission on the Moon/*Technical University of Munich*	Robotics, Informatics	Livestream Workshop between School and "Moon" (university lab) (*RR*)	German
5.	Laboratorio Remoto de Fisica/*Federal University of Itajubá/Institute of Education, Lisbon University*	Physics	Remote lab with a choice of several physics experiments (RR)	English, wide range of European languages, Asian and African languages
6.	e-lab romote laboratories/ *Instituto Superior Técnico (IST), Lisbon University*	Physics	Remote lab with a choice of several physics experiments including data analysis tools (RR)	English
7.	Robolab/*University of Alicante*	Robotics, Automatics	Simulation, Remote lab' (*RR, RV*)	English, Spanish

8.	#kopernikwdomu, eSzkola Nauka z CNK/*Centrum Nauki Kopernik*	Physics, Chemistry, Biology	Video materials with hands-on-experiments to do at home (*LR*)	Polish
9.	Science for You/*Ministry of Science and Higher Education*, Poland/*Centrum Nauki Kopernik*	Physics	Simple and fast experiments to do at home or at school, mobile exhibitions (*LR*)	Polish
10.	LabXChange/*Harvard University with support from Amgen Foundation*	Among others: Biological Sciences, Health Science, Physics, Chemistry, Science & Society, Scientific Process, Global Health, Data Science, Mathematics	Interactives, Simulations (*RV*)	Among others: Arabic, Chinese, Dutch, English, French, German, Italian, Polish, Portuguese, Spanish, Turkish, Ukrainian
11.	Virtual Biology Lab/*Virtual Biology Lab*	Biology (Ecology, Evolution, Cell Biology)	Interactive stochastic Simulations, (HTML, HTML 5), the data generated are realistic (*RV*)	English
12.	Learn.Genetics Genetic Science Learning Center/*University of Utah*	Genetics	Interactive lab practices, videos (*RV*)	English
13.	Virtual Labs/*South Dakota State University, North Dakota State University, New Mexico State University*	Food Safety	Interactive Simulations (HTML 5), videos (*RV*)	English
14.	Phet-Interactive Simulations/*University of Colorado Boulder*	Physics, Chemistry, Math, Earth Science, Biology	Interactive Simulations (*RV*)	English, a wide range of European languages, several African and Asian languages
15.	Praxilabs/*Praxilabs*	Biology, Chemistry, Physics	3D interactive Virtual Labs (*RV*)	Arabic, English

*LR: Local and real experiments, RR: Remote and real experiments, RV: Remote and virtual experiments (s. categorization in chapter 2)

Deutsches Museum

1. **Science and physics with household materials**

The Deutsches Museum developed a collection of activities and experiments on several topics (e.g., "How to distinguish raw from boiled eggs?", "How does the egg get into the bottle", "Building boats", "DIY-Robots" and "Cloud chamber"), that students can do at home (https://www.deutsches-museum.de/museumsinsel/programm/programm-a-z/experimentierenhome **link**).

This Experiment@home program is supported by online videos available at https://www.youtube.com/playlist?list=PLqvZktQdyL4uGgib_OhBQsprWAJCBd75G **link**

2. **Virtual museum tours combined with science experiments in the classroom**

Also created by the Deutsches Museum, the digital & analog Program allows students to try something out with their own hands despite the physical distance to the museum (https://www.deutsches-museum.de/museum/ueber-uns/bildung/museum-on-demand **link**).

This program brings the museum virtually into the classroom (or students' home) and provides the appropriate experiments and materials (sending material packages by mail beforehand).

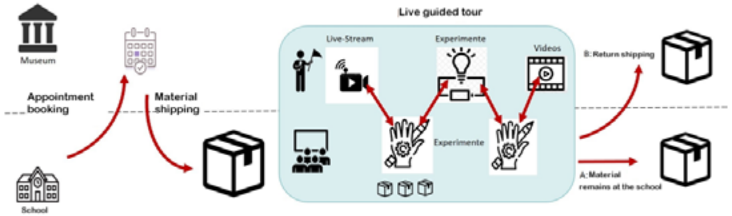


Figure 1 The Museum-on-Demand Program “analog-digital” (Deutsches Museum)

Through video conferencing software and the help of experienced guides, students can wander through the exhibitions and try things out using the resources from the material packages, allowing them to deepen the understanding of what they were able to see.

The “Digital & Analogue” programmes offered cover energy, engines, statics and bridge building for Sekondary School students, and water, hydraulic engineering and bridge building for primary school students.

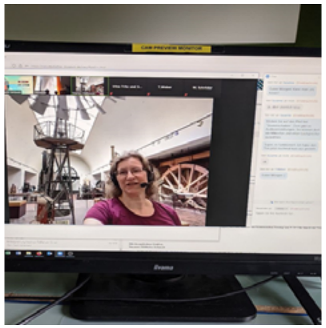


Figure 2 Interaction with an expert guide (Deutsches Museum)

For example, this program allows Secondary Schools to have contact with energy and motors. After a virtual tour to the Power Machinery exhibition, focused on ways of using different forms of energy, students are invited to conduct experiments on energy conversion using simple electric motors from a material package mailed by the Deutsches Museum (https://www.deutsches-museum.de/museumsinsel/programm/angebot/digital-analog-energie-und-motoren link).

Another proposal allows Elementary School students to gain experience with the properties of materials and develop their own ideas on how these properties can be used technically. After a virtual tour to a water and bridge building exhibition, students carry out simple experiments themselves (e.g., designing and building their own bridges and discovering what is important in bridge construction)(https://www.deutsches-museum.de/museumsinsel/programm/angebot/digital-analog-bruecken-bauen link).

Technische Universität München

3. **Physics and informatics with the Arduino with shipped material kits**

The Technical University of Munich (TUM) proposes a remote learning measurement experiment in the cross section of physics, informatics and technology ("PhIT with the Arduino"), helping students in their first steps with the Arduino at home. In order to support them tinkering with their own kit of materials, the university offers a livestream workshop that provides the opportunity to program and experiment right away. In this workshop, students learn how to use a smartphone as a measurement monitor and to control the measurements remotely (https://vimeo.com/511635767 **link**).

4. **Programming remote robots with school classes**

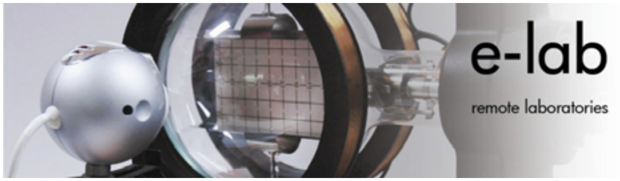
The project "Remote Robotics – Mission on the Moon" allows students to control a robot "on the moon" by programming it remotely (https://www.edu.sot.tum.de/tumlab/kursangebot/technik/robotik/robotik-mondmission/ **link**). Students can sit at their home's or their school's computer lab and control real robots that are located at the university lab (the "moon"). In one window, the students have the programming interface, in the other window they can observe through video conference how the robot moves. They can complete an experiment in the same way as if they were in the real laboratory. The only prerequisite for this program is a very good Internet connection between the two locations.

Laboratório Remoto de Física

5. **Remote physics laboratory**

https://labremoto.unifei.edu.br/src/welcome.php **link**

This remote Physics laboratory offers real experiments that users can operate remotely, even with a cell phone. The experiments cover topics such as Standing Waves, Physical Optics, Hydrostatic, Thermometry, Thomson Ring or Light curve. The laboratory provides additional materials for the experiments, e.g. files with Arduino codes.



6. Remote lab with physics experiments

http://www.elab.tecnico.ulisboa.pt/ link

e-lab is a remotely controlled laboratory hosted at the University of Lisbon. This laboratory provides remote control of real physics experiments over the Internet. Its main purposes are:

- to provide e-learning of science (24 hours per day and 7 days a week), by providing real scientific experiments (remotely controlled) and the tools needed for the subsequent data analysis,
- to provide to teachers and professors an auxiliary tool based on information and communication technologies for science,
- to motivate students to learn science by showing them real situations that prove the theory,
- to access data previously collected on in-person experiments,
- to perform not so safe experiments (e.g. radioactivity), to provide expensive experiments which cannot be acquired by a school or institution. Because of this, e-lab is a free, accessible, remotely controlled laboratory and can be accessed by everyone which has a computer with internet.

Some examples of experiments: Thermal Conductivity of Metals; Dielectric effect in a Cylindric Capacitor; Damped Pendulum Oscillations; Boyle-Mariotte Law; Dice Statistics; Free Fall; Elastic Collisions.

7. Virtual robotics lab and remote control of robot arm

The University of Alicante (Spain) developed a virtual lab (RobUALab – https://www.sciencedirect.com/science/article/pii/S1474667015315822 link) for training and learning in Automatics and Robotics. This system allows users to simulate and test positioning commands (through the Internet) for a robot in a virtual environment with augmented reality support. This system provides a complete robot and world simulation, a very realistic 3D graphical environment, robot dynamics, programming, remote power, lightning and robot control, and augmented reality.

CENTRUM NAUKI KOPERNIK

8. Science experiments with household materials via TV and YouTube

The Centrum Nauki Kopernik proposes video materials with simple hands-on experiments that students can do at home. They are available at a TV channel and a YouTube channel.

TV channel:

https://vod.tvp.pl/video/eszkola-nauka-z-cnk,doswiadczenie-fizyczne-cnk-soczewka,47432293 **link**

https://vod.tvp.pl/video/eszkola-nauka-z-cnk,doswiadczenie-fizyczne-cnk-paradoks-lejka,47432212 **link**

https://vod.tvp.pl/video/eszkola-nauka-z-cnk,doswiadczenie-fizyczne-cnk-oporne-powietrze,47432292 **link**

YouTube channel:

https://www.youtube.com/hashtag/kopernikwdomu **link**

9. Physics with household materials and mobile exhibitions for schools

The Centrum Nauki Kopernik also offers the program “Science for You” with simple and fast experiments in physics, that students can performe on their own at home or in school (https://www.kopernik.org.pl/en/learning/science-for-you **link**).

Several buses transport mobile exhibitions to schools in more distant regions.

10. **Student-centered online learning with simulations and interactives on different topics**

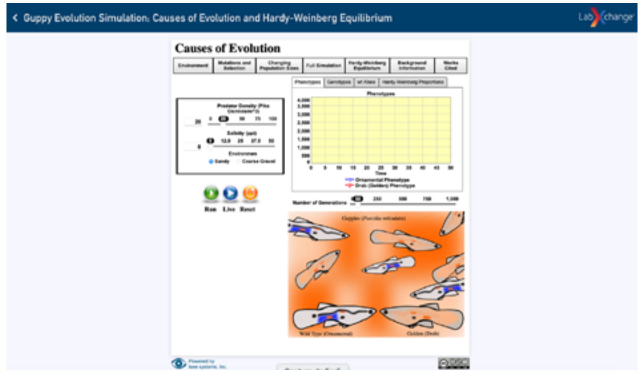
https://www.labxchange.org **link**

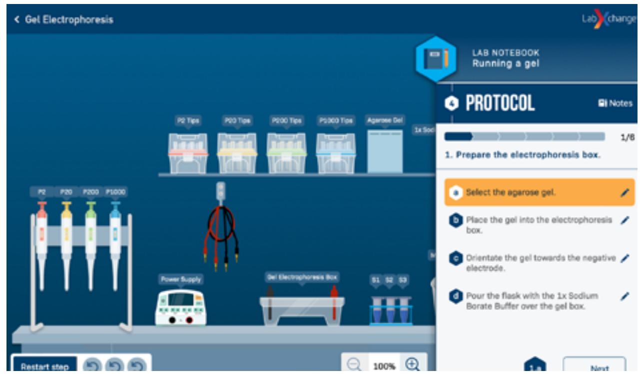
LabXchange is an initiative of Global Education Coalition form UNESCO aimed at supporting the millions of students worldwide that lack access to high-quality science education and experiences. It was launched to ensure that students everywhere have equal opportunity to be successful in science.

LabXchange is a project from Harvard University funded by the Amgen Foundation that makes the best of digital science education available to the world for free through a flexible and interactive online platform. It includes many virtual lab simulations and interactive animations that can be articulated according to different learning contexts and necessities. Several social features (private classes, discussion forums, and mentorship) are available in order to connect learners with educators and researchers worldwide.

Some free professional development webinars show educators how to use LabXchange to support differentiated, student-centered online learning, develop student lab skills and scientific literacy, and help students explore STEM careers.

As an example, it includes simulations (about several subjects) aimed at: a) testing the pH of different things like coffee, spit and soap; b) exploring causes of evolution and Hardy-Weinberg Equilibrium through a Guppy Evolution Simulation; c) exploring a fragment of a DNA strand; d) introducing gel electrophoresis, a technique used to separate biological molecules; e) transforming bacterial cells with a recombinant plasmid using the heat shock method; f) moving the sun, earth, moon and space station to see how it affects their gravitational forces and orbital paths; g) understanding the relation between temperature and pressure; h) visualizing the gravitational force that two objects exert on each other and to adjust properties of the objects in order to see how changing the properties affects the gravitational attraction.





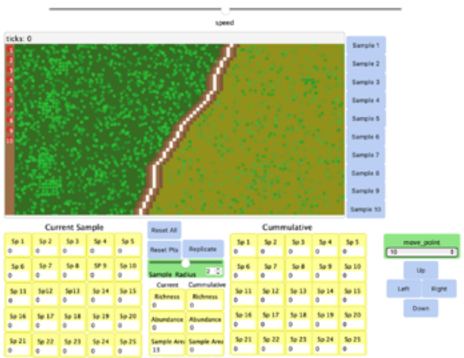
11. Virtual experimentation in biology with realistic data

https://virtualbiologylab.org **link**

Virtual Biology Lab is a free educational resource that simulates natural environments with the way life responds to changing conditions. It allows students to learn by experimentation: parameters and conditions can be easily changed for observable effects and consequences. The data generated are realistic and displayed numerically and graphically. Students can design experiments, conduct them using models, and collect data that can be analyzed using different software.

The Virtual Biology Lab includes:

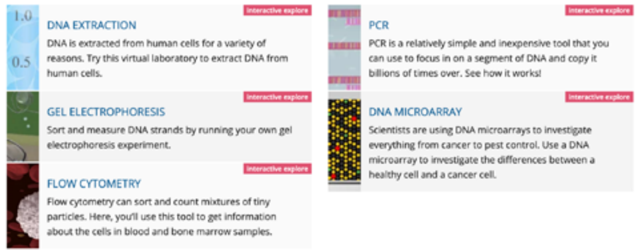
1. ecology models (population ecology, community ecology, behavioral ecology, conservation ecology, biodiversity ecology);
2. evolution models (population genetics, selection); and
3. cell biology models (membranes).



12. Interactive lab practices in genetics

https://learn.genetics.utah.edu/content/labs/ **link**

Learn.Genetics developed by the University of Utah includes virtual labs about several topics: e.g., DNA extraction, gel electrophoresis, PCR and DNA microarray.



13. Interactive simulations on food safety

https://virtuallabs.nmsu.edu/index.php **link**

The Virtual Labs help students to learn basic laboratory techniques and practice methods used by lab technicians and researchers in a variety of careers related with food science lab processes.

14. PhET Interactive Simulationsfor Science and Math

https://phet.colorado.edu/en/simulations/browse **link**

The University of Colorado Boulder offers a collection of numerous interactive simulations for science and math, the PhET interactive simulations. These simulations are very suitable for a flexible use in many teaching situations, and help students explore the different fields of physics, chemistry, mathematics, earth science, and biology. Students can run the simulations online or download them to their computer. The interactions are intuitive to use and allow students to analyse the effects of the changes they make immediately. By exploring the simulations, the students can answer scientific questions. In addition, students can use measurement devices that allow quantitative observations within the simulations.

Materials for teachers on how to use the simulations are available on the site, including tips on remote learning with PhET and virtual workshops (https://phet.colorado.edu/en/teaching-resources/tipsForUsingPhet **link**). Many of the interactive simulations are available in multiple languages. (https://phet.colorado.edu/en/simulations/translated **link**) This supports e.g. international cooperation of different schools or the active participation especially of foreign students in the class, who do not speak the national language very well yet. In the link of a specific simulation, only the two-digit country code has to be changed accordingly.

PraxiLabs

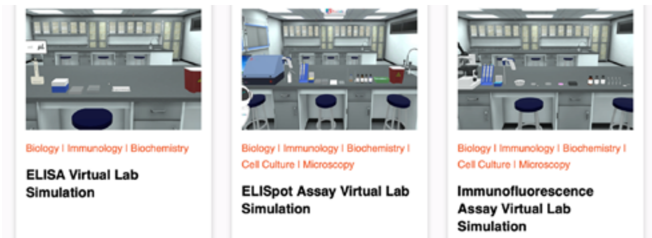
15. 3D interactive virtual labs on biology, chemistry and physics

https://praxilabs.com link

PraxiLabs allow students to conduct science experiments anywhere via 3D interactive virtual labs. It includes immersive virtual experiments on three main subjects:

1. biology (from DNA extraction and genetic cloning to tissue culture and protein electrophoresis);
2. chemistry (general, analytical, and organic); and
3. physics (nuclear physics, thermodynamics, electricity, and more).

PraxiLabs promote learning and understanding through experimentation without any hazard or high costs.



4. Practice-oriented advices on developing remote hands-on experiments and promoting the sense of community among students'

The development of remote hands-on experiments can represent a challenge for both students and teachers not used to this kind of activities. While some obstacles and difficulties cannot be easily surpassed (e.g. unreliable internet connection and unstable home situations), others can be solved with an adequate planning and specific strategies.

During the implementation of remote hands-on experiments students can feel disconnected from their colleagues. This feeling can be quite common. In order to reduce it, it is important to propose situations (coordinated by teachers) to foster students' interaction and to develop the sense of community among them. Providing contexts for students' presentation and discussion of the experiments can be effective in decreasing this sense of isolation and, at the same time, increasing the chance to think about the science concepts and to promote higher-order learning. These contexts can be synchronous (e.g. through on-line conferences using tools such as Zoom – https://zoom.us link, Google Meet – https://meet.google.com link, and Skype – https://www.skype.com link) or asynchronous (resorting to on-line platforms where students can discuss in chats or discussion forums).

The interaction and the sense of community can also be promoted through the collaborative development of documents, such as:

a. concept and mind maps about specific scientific topics, allowing the detection and the discussion of alternative conceptions (e.g. using Popplet – https://www.popplet.com/ – or Padlet – https://padlet.com/ link);

b. activity plans or reports through virtual bulletin boards and post-it walls (e.g. using Padlet – https://padlet.com/ **link**);

c. reports and presentations articulating the findings and results obtained by different students (e.g. using Google Docs - https://docs.google.com/ **link** that allows the creation, storage, real-time edition and sharing of web-based documents, spreadsheets, and presentations).

This collaborative development of on-line materials can be done in real-time (synchronously) or asynchronously (respecting students' different schedules and work speeds and allowing the later participation of those students who have to share just one computer with several brothers and/or sisters).

Some students can have difficulties in organizing their activities at home and to work in teams without the teachers' supervision in presence. To help students in these tasks, teachers should provide detailed scheduling milestones and assessment/deliverable information for the activities, offering guidance for effective student progress. Team-work in remote settings works better with groups of 3–4 students where each one is responsible for specific tasks/roles. This helps introducing accountability to the process and allows students to allocate their energy to thinking and learning, instead of being constantly worried with finding an appropriate plan.

Regular short on-line meetings with the teacher allow for the early detection of difficulties and the necessary support to overcome them. The teachers' responsiveness to questions and strong presence in the on-line environment (providing feedback on the collaborative tasks) are important factors for the success of educational proposals involving remote hands-on experiments.

5. The "Hands-on-Remote" modules

5.1. The rationale behind the modules

Teachers themselves were involved as co-creators of resources. Implementation support will not only helped in the uptake through the teachers, but also at the same time allowed a continuous quality enhancement of the teaching modules. To enhance the sustainability of the intellectual outputs, the teaching modules are accompanied by step-by-step instructions that enable independent implementation of the concepts.

The development of practical learning units that enable the use of hands-on-experiments in online-, hybrid- and on-site face-to-face-learning is key to our project. Due to COVID-19 and the multitude of uncertainties that the pandemic comes along with there is a need for flexible solutions that teachers can use to support their students in each of the possible scenarios (virtual, hybrid, presence learning). So far, there is little evidence of COVID-compatible, tailor-made solutions for vocational schools to assist them in the continuation of their lessons under corona-conditions. Practical work and experimentation are part of general school practice in vocational schools and are essential for learning technical, IT, and scientific methods. Therefore, the main goal of the project is the development of directly applicable teaching concepts for the use of hands-on experiments at vocational schools in different COVID-related scenarios and the documentation of these teaching concepts in a training module for teachers. Corona-related reduction of contacts is hard to endure, especially for young people. Therefore, a special focus was given to the generation of community experiences which are a creative and innovative element of the emerging concepts.

To ensure a good fit with the teaching in vocational schools, a compact analysis assessed the actual demands of schools and teachers to define the key features of the program. Teachers themselves were involved as co-creators of resources. This took place through counseling, as well as direct inclusion in the development process. As it is well known in professional teacher education, that the implementation in class after a successful training is still a huge hurdle, implementation support is provided for the teachers trained. Since the project is based on a digital system, it is easy for the partners to join e.g., the video call and support the teacher running the sessions for the first time in class. This not only eases the uptake through the teachers but at the same time allows a continuous quality enhancement of the teaching modules.

Under the responsibility of the Deutsche Museum, a basic formative evaluation system was installed to accompany the development and implementation process and gain comparative insights into the different use scenarios and countries. This allowed collecting feedback from the teachers, as well as the students using the learning system.

All teaching modules cover a longer time span in class, e.g., a plan of roughly six subsequent lessons. This secures that there is enough time to get familiar with the new learning approach and gain a deeper knowledge of the digital system, allowing the students to use it in multiple ways. On the other hand, it provides the possibility to run more complex experiments, that need more elaborate skills. Students then could use the digital system in their prep time and fulfill self-determined tasks with it. Additionally, the longer time span allows integrating tasks related to the socio-scientific challenges novel science and technology almost always has. For us, this connection between technology and society is crucial for understanding our current world (and especially the transnational factor) – it enables students to get a broader view on the topics and be empowered to take action.

The core elements of the resulting training module are:

1. A framing for the teacher to ease integration into curricula/teaching
2. An introductory unit to the topic
3. Step-by-Step-Instructions for each of the hands-on teaching concepts in different settings (virtual, hybrid, presence)
4. A closing unit with reflecting tasks
5. Details on promoting the community experience
6. Documentation of possible difficulties with technical settings and feasible solutions
7. Documentation of tests and the results of the evaluation of these concepts

All materials are organized in an appealing, interactive way, including interactive multimedia web files. The training module should enable teachers to apply the teaching concepts themselves at their vocational schools. The teachers can expand their digital competence, gain a stronger self-confidence in dealing with digital media, and conducting hands-on experiments with digital support. In combination, this should support increasing digital education readiness. Indirectly and in the long term, sectors with a shortage of skilled workers – for example in STEM-related vocations – will benefit if STEM education content can continue to be put into practice even under difficult conditions (like a pandemic) and interest in STEM topics can be awakened. A transfer of the teaching methodology and the learning content to other schools, as well as areas of non-formal education, is feasible and highly interesting.

5.2. Brief description of the different modules

Automation in Miniature – Teaching module from Germany

This module is recommended for 10th to 13th grade students (age 16–20 years old) and its expected duration is 3 hours for the main part and 5 or more hours for additional units. The teacher can select the order of activities to be performed by the students.

The teaching module "Automation in Miniature" enables students to program a small production plant themselves and set it in motion. A traffic light module as status indicator, a light barrier and a turntable serve as hands-on elements, which together with various moving functional parts become a mini production plant. The teams program their plant using the Arduino microcontroller and a text-based programming language. The students can control the turntable as a filling system – in which the light barrier detects a container on the turntable, the status display indicates a change of state by changing from red to green and a dispenser is used to fill something into the corresponding container.

Scheme with the activities' sequence

Teaching module
Automation in miniature

Students program a small production plant and set it in motion. The automatic filling system is made of simple materials and can be taken home by the students. Students can work together as a team, even in remote situations.

Main teaching module

Unit 1a
Brief introduction to the topic
Aim: Establishing references to everyday life and professional environments
Task: Showing videos of various applications of turntables in automation

Unit 1b
Introduction to the Arduino
Aim: Introduction to programming with Arduino IDE, using a first circuit design
Task: Programming of different-colored LEDs, learning basic commands and common programming errors

Unit 2a
Online-Simulation
Aim: Getting to know the online simulation environment "Wokwi", which enables the exchange of code even in distance learning
Task: Finding mistakes in a Wokwi-debugging file and observing the effects on simulated LEDs

Unit 2b
Servomotor
Aim: Learning about the characteristics and functions of servomotors
Task: Using servomotors to move functional parts of the production plant

Unit 3a
Turntable
Aim: Construction of the central part of the production plant
Task: Setting up the turntable, adjusting the drive motor and letting the turntable move by a quarter

Unit 3b
Light barrier
Aim: Using sensors for automated production, discussion of measurements with sensors
Task: Using the lightdependent resistor (LDR) as a sensor in a reflex light barrier to control the production process

Additional / optional units

Unit 4
Extensions to the automation process
Aim: Transfer of previously acquired knowledge to new elements, Scope for students' own projects
Task: Free choice for the installation of other functional parts like
- LED status indicator
- Entrance Slide
- Ejector

Unit 5 / 6
Collaboration / Digital Collaboration
Aim: Promoting collaboration among students, including teamwork and a sense of community even in distance learning
Task: Coupling of turntables of different teams; Using light transmission to induce effects in remote situations

Unit 7
Automation in its social context
Aim: Exploring and discussing the impact of automation processes on society
Task: Discussing advantages and disadvantages of automation using an Online-Whiteboard, and considering aspects like energy demand, waste, etc.

Unit 8
Other uses of the turntable
Aim: Encouraging further engagement with the turntable
Task: Using the turntable as a sorting machine detecting differences in brightness or color; Using the turntable as light-induced sound player, measuring brightness

Teachers can change the sequence of the units and start with 3a/3b and follow-up with 2a/2b.

The six teaching units build on each other, but allow for a division into a beginner and an advanced program. At the beginning, some motivating insights into the industrial application of turntables put the school class in a fictional factory. For their mini-manufacturing plant, teams can choose what they “produce” with their own fictional scenario. As an introduction to programming with the Arduino, the students first switch the LEDs of the status display on and off. They work with both a real and a virtual traffic light module for this purpose. An Internet-based simulation environment facilitates collaboration and the exchange of the programming created, so that close cooperation remains possible even in distance learning. The teams set the turntable in motion with a geared motor. Other functional elements of the system are moved back and forth between two positions by servomotors. Students first program the servomotor for the dispenser: they turn two gears to open a passage and drop something into a container. After that, teams can program other elements (passage for feeding parts, swivel arm for the ejector).

The difficulty level can also be set at the programming level: If a teacher wants to use the module for an entry level, students enter only a few programming commands in a largely predefined programming. If a teacher wants to use the module for advanced programming, students have additional tasks, such as defining classes. An interactive instruction page allows teams to work largely independently, according to their own needs and at their own pace. In vocational schools for computer science, object-oriented programming is an important teaching topic. The designed module offers the chance to understand abstract principles of this programming style by means of real objects. The teams program servomotors for three real objects (passage for the dispenser, passage for the feeder, swivel arm for the ejector). In this way, the students can learn that different real objects of the same type are, in programming terms, different objects of the same class – an important insight in object-oriented programming.

The topic of automation and its societal consequences affect many vocational students directly – as computer scientists, they will possibly program such systems, as automation technicians they might build them and in other branches – such as food technology – they will work with such production systems. In a final lesson, students are encouraged to discuss and reflect on societal issues related to automation in order to consider their own future careers in a broader context.

The module aims primarily at vocational schools, but can also be used in other types of schools. The presented scenario of the mini production line is only one example of many possibilities for the uses of the turntable and the material kit. If you place a (self-designed) black and white pattern on the turntable, the light sensor can convert this brightness information into tones and simple rhythms for a sound output device – thus creating a simple sound machine. There are few limits to creativity…

Sound – Teaching module from Portugal

This module is recommended for 8th-grade students (age 13-14 years old) and its expected duration is 18 hours in total. The teacher can select the activities to be developed by the students.

Scheme with the activities' sequence

Teaching module
Sound

Students build different type of musical instruments, measure the sound level , measure the rate of reduction of the sound intensity of a model, and build a microphone

Main teaching module

Unit 1

Musical instruments

Aim: Learning about sound production, transmission and sounds attributes
Task: Constructing musical instruments and getting to know the online simulation

Unit 2

Sound level

Aim: Learning about sound level
Task: Using an APP, students measure the sound level in different stations of their homes or school.

Unit 3

Acoustic insulation

Aim: Learning about sound-insulating
Task: Using an App, students measure the rate of reduction of the sound intensity of a model to conclude that some materials are more sound-insulating than others.

Additional / optional unit

for students aged 16 to 18 years old

Unit 4

Microphone

Aim: Learning about Faraday law (or electromagnetic induction), sound waves, magnetic and electric fields.
Task: Using an App or a video, students build a microphone with everyday materials. From this artifact, they explain the function of the materials used, as well as the operation of their own microphone.

Sound module includes four units, entitled: Musical instruments, Sound level, Acoustic insulation, and Microphones. 'Musical instruments' is a hands-on activity. During the unit, students construct their musical instruments with everyday materials, and they study the sound waves associated with their instruments. Then, students open a 'Sound Waves' simulator and using a 'Listen from a single source', recreate sounds and associate a musical instrument constructed. In the unit 'Sound level', students are invited to measure the sound level in different stations of their homes or school. So, students should define different measurement stations in different locations at home or school, and use their cell phones/tablet with the application that allows them to take measurements. During the unit 'Acoustic insulation', students must solve the following problem: 'What will the two brothers do to soundproof the bedroom wall to reduce the noise produced at the festival?' For that, using an app, students measure the rate of reduction of the sound intensity of a model to conclude that some materials are more sound-insulating than others. Finally, in the unit 'Microphones', students build a microphone. Before that, students can visualize a video about microphones and their construction using simple materials.

Sensors and Measurements – Teaching Module from Poland

This module is recommended for 9–13th grade students (age 15–19 years old) and its expected duration is 14–16 hours in total.

Most research work involves observation, analysis, and interpretation of results. When planning to get students interested in scientific research, it is worth supplementing their activities with these components as an essential part of the experimentator's work. Due to the limited equipment conditions of schools and the pandemic necessity of conducting experiments at remote locations, often without the possibility to use specialized equipment, we suggest using materials and tools available in the household.

Scheme with the activities' sequence

Teaching module
Sensors and Measurements

Students perform different experiments involving making DIY sensors. They investigate basic physics phenomena like elasticity, acceleration and electromagnetism. Students can work individually, or as a team. Remote collaboration is also possible.

Optional unit

Unit 1
Measurement error
Aim: Learning about measurement errors
Task: Measuring diagonal of a sheet of paper and calculating coarse/systematic errors

Teachers can change the sequence of the modules or use only one as an independent unit

Main teaching module

Unit 2a
Slingshot
Aim: Investigation of the distance of a fired object – stretched rubber band
Task: Building a simple slingshot model to make some experiments

Unit 2b
Rubber band drive
Aim: Using the potential energy of elasticity to design a simple drive
Task: Building a car model with rubber band drive

Unit 2c
Experiment results analysis
Aim: Presenting to the group the analysis of the collected measurement data and comparing the results with other students
Task: Presentation of collected data by student groups

Unit 3a
Building the pendulum
Aim: Using the pendulum to make some measurements e.g. oscillation period
Task: Building a model of mathematical pendulum using simple tools and materials

Unit 3b
Making a measuring tool
Aim: Making a remote sensor to collect data from the pendulum
Task: Using Arduino Science Journal or NodeMCU to make simple sensor and collect data

Unit 3c
Comparison of results
Aim: Presenting to the group the analysis of the collected measurement data and comparing the results with other students
Task: Presentation of collected data by student groups

Unit 4a
Building an electromagnet
Aim: Building a simple electromagnet model to investigate electromagnetism phenomenon
Task: Measuring strength of an electromagnet using a compass and board with scale

Unit 4b
Building the sensor
Aim: Finding the way of measuring electromagnetic field strength
Task: Measuring electromagnetic field strength using a smartphone or DIY sensor (NodeMCU + Hall sensor)

Unit 4c
Sorting device
Aim: Using newly acquired knowledge to design simple coin sorting device
Task: Building sorting device using an electromagnet

The activity scenarios proposed in unit 1 ("Measurement Errors") deal with the simplest of measurements, allowing students to understand that obtaining different results is normal in the world of measurement. For example, as a class we can measure the diagonal of an A4 sheet of paper using a variety of school rulers, tape measures and carpenter's tape measures to find out about gross, systematic and random errors. Students can also note the differences in the accuracy classes of instruments used. They can indicate their use in class-appropriate measurements and suggest ways to obtain results that are more accurate. It is also valuable to discuss and answer the question of the "true" length of the diagonal of a measured sheet of paper.

The quantities obtained as a result of direct measurements are often included in further calculations by applying formulas. The considerations involved in such activities can be examined using the example of building a pendulum proposed in unit 1 and determining the value of the acceleration of gravity with it. In this case the students use a thread, a weight and a stopwatch to create the pendulum. It allows to investigate the influence of individual variables (e.g. length of the thread, period of oscillation) on the result and possible accumulation of errors, and also to notice the influence of the human factor and the value obtained by automatic measurements, which will be part of subsequent scenarios.

The main theme of the scenario activities proposed in unit 2 ("In Motion") is the potential energy of elasticity represented by the example of a stretched rubber band. Both the introductory experiment to investigate the distance of the bottle cap launch as a function of the rubber band tension deflection and the final vehicle race challenge address the same issue. Getting students interested in the transformation of potential energy to kinetic energy and understanding the relationship defined by, for example, Hook's Law can be made easier just by using elements from the environment rather than a specialized physics lab.

Unit 2 scenario involves the construction of a vehicle in which the role of propulsion is played by a stretched, twisted rubber band. Pupils can freely determine the method of transmission to the wheels and propose their own construction, but for the purpose of standardization of the challenge we have developed a model based on 3D printing. Students will receive printed components ready to assemble or they will print their vehicles themselves using the files provided to them (perhaps making interesting modifications), developing digital competence.

It is of course possible to organize competition between individual teams and constructions based on standard challenges, e.g. maximization of the distance travelled by the vehicle. But to broaden the construction and IT competences of the students, we suggest to extend the elements of the competition by using a smartphone with preloaded application such as Arduino Science Journal, which has the ability to record, for example, acceleration. The phone placed on the built vehicle (as a support platform) can record changes from the built-in accelerometer, which after appropriate mathematical transformations will allow to determine the speed of the vehicle; This can be adopted is the proposed challenge "who is faster".

In the following sections we offer teachers the possibility to choose the measurement tools which they will use in the experiments, based on to the level of familiarity with programming (exhibited by their class as well as by themselves) so that they can feel confident with the implementation. The experiments described in the scenarios can be carried out using either a smartphone or a dedicated sensor operated by a microcontroller.

The focus of unit 3 ("Pendulum") is the motion of a pendulum. The experiment consists in measuring the period of oscillation of a mathematical pendulum, which will be built by students themselves. Measurements will be done using built-in sensors in a cell phone and a special application, or in a more advanced way, which consists in building a measuring device based on a light sensor and a microcontroller. The course will cover topics such as harmonic motion, acceleration, vibration theory, and data analysis.

In unit 4 ("Electromagnetism") students will construct a simple model of an electromagnet. With the help of an application in a phone or a self-made sensor (based on the Hall's effect), experiments will be carried out in order to determine the dependence of the intensity of the electromagnetic field on the parameters of the electromagnet (e.g. the material of the core or the number of coils). On the basis of their observations and conclusions, the participants will build a simple device for sorting coins.

6. "Hands-on-Remote" Training/ Dissemination Scheme

6.1. Introduction

The training and dissemination events are the key feature to make the Hands-on-Remote teaching program available to the wider community in Europe. The half-day workshops primarily address teachers and headmasters of vocational schools, but as well are open to teachers from other schools as well as people from informal science education who are interested in using the modules.

6.2. Different phases for a teacher training/ dissemination workshop

The teacher training/dissemination workshop is a crucial component of the "Hands-on-Remote" project, promoting the teachers' capacitation for the modules' implementation at their own classes. Typically, this kind of workshop will involve the following phases:

1. Presenting "Hands-on-Remote" project: the rationale and the modules – Using the guidebook to introduce the participants to the "Hands-on-Remote" project's rational and modules.

2. Trying out "Hands-on-Remote" experiments – Trying out some Hands-on-Remote experiments from the teaching modules, guided by developers and/or experienced teachers and discussing possible implementation challenges. This phase introduces teachers to each module and promotes the development of the pedagogical knowledge necessary for their implementation in the classroom.

3. Adapting "Hands-on-Remote" modules to participants' contexts – Hands-on activity of adapting/developing individual (or small group) proposals for implementation in each teacher's

working context. This phase is critical in order to increase the probability of teachers' utilization of the modules with their students. They will use the modules only if they correspond to their competences and perceived needs.

4. Discussing the different proposals – Sharing of proposals among participants and giving feedback to 2 colleagues (at least). This phase allows the improvement of the activities' educational potential and a better adaptation to each teacher's working context.

5. Implementing the proposals – Implementation of the proposals in each participant's school/context. This phase reinforces the development of the pedagogical knowledge necessary to the modules' implementation in the classroom.

6. Reflection on the implementation – Reflective report (individual) on the experience: positive and negative aspects, suggestions for improvement. Group discussion of the different reports. This formative phase fosters the activities' educational potential and the teacher's pedagogical knowledge about their implementation in a specific context.

Since we believe that for the users of the new teaching modules it is really important to get support for the implementation in class, we will provide digital support for the first time use in class for each teacher. This can easily be done through videoconference in order to ease the implementation significantly. Further, the collection of feedback from real classroom scenarios will allow to improve the teaching modules.

7. Evaluation of modules

In addition to the direct exchange with teachers during development, summative evaluation methods were used to optimize the development of the modules. In the following, the focus is on student feedback on the one hand, and on the other hand, the assessments of the application possibilities by the teachers who participated in dissemination events.

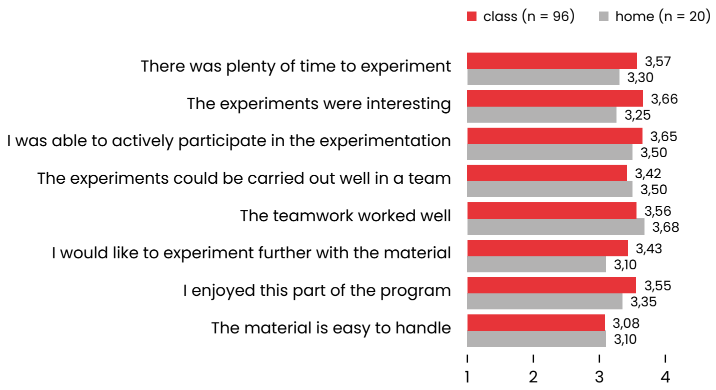
For both studies, participants were surveyed with an online questionnaire immediately after the activity: for students, after completing the last learning unit of the module; for teachers, immediately after the dissemination event.

Feedback from the students

A total of 116 students participated in the study. Due to the slightly eased COVID situation, 83% of the students participated in a classroom setting, whereas 17% attended the module at home. The hybrid situation with part of the class being at school and the other part staying at home was tested only twice with no students participating in the survey.

The feedback on the teaching was rather positive. All scales were to be rated on a 4-point Likert scale, with 1 = strongly disagree to 4 = strongly agree (plus option 5 = not applicable). The average ratings for all items in the scale "Hands-on Experiments" (Fig. 3) range between 3.08 and 3.68, i.e. between the options agree and strongly agree. However, comparing the data of the student's perception of the hands-on experiments in a classroom vs. an at-home teaching situation shows clear differences for both situations: experimenting in a remote session was judged less positive than in class. However – and this is interesting – the teamwork situation seemed to work slightly better in an online collaborative work situation than in the classroom. The stimulation to want to continue working with the material, as well as the enjoyment of the program were again more pronounced in the onsite module.

Hands-on Experiments



Motivation

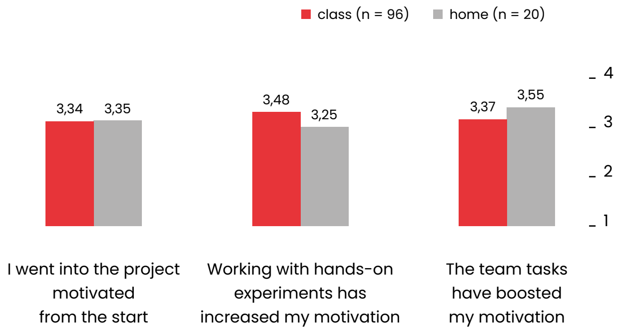


Figure 3: Comparison of the perception of hands-on experiments and student motivation in classroom vs. home teaching situations (both Likert scale with 1 = strongly disagree to 4 = strongly agree).

The motivation was assessed by three questions targeting the motivation at the start, working with experiments, and the teamwork in the module (student self-evaluation). The impact on student motivation is quite equal for both learning settings, however, it seems to make a difference when it comes to working with the hands-on experiment: at home, this is perceived as less motivating – which is in line with the findings on judging the experiments mentioned above. The team tasks, i.e. working together, seem to have boosted motivation, especially for those working from home.

However, it should be borne in mind that these data originate from the first round of testing of the modules and are therefore subject to greater variation. In addition, the numbers of participants for the two situations are considerably different (96 vs. 20). Nevertheless, the trends provide interesting indications for the further development of the modules and methodological approaches.

Assessment of the teachers

By the time the Guidebook was printed, a total of 36 teachers had taken part in the study. One of the basic ideas of the Hands-on Remote project was to support teachers in teaching practical tasks remotely – on the one hand through ready-made modules that can be used directly, and on the other hand through teaching concepts that encourage them to develop and use their own content. In this respect, the stimulation of the teachers was an important aspect of our project outcomes and the dissemination events. 29 of the 36 teachers (85%) stated that they were more motivated to use remote experiments with their students after the event. In general, the usability of the concepts presented was rated very positively, ranging from 3.22 (remote teaching) to 3.36 (hybrid teaching) to 3.69 (face-to-face), depending on the field of application. (Likert scale from 1 = strongly disagree to 4 = strongly agree, cf. Fig. 4).

The concept can be used well in ... teaching

Figure 4: Usability of the teaching concept in different teaching situations, judgment by teachers taking part in dissemination events. (Likert scale with 1 = strongly disagree to 4 = strongly agree, N=36)

It can be seen, however, that despite the design for different fields of application, the classic scenario receives the best rating. Looking more closely at the more differentiated feedback (open responses), the concerns become clearer: One of the hurdles is the technical framework conditions for remote and hybrid teaching, both in terms of digital devices and the supply and distribution of materials for the experiments. The individual support of the single (remote) student is seen as an obstacle – the teachers name the difficulty to recognize problems/mistakes and the high expenditure of time to support many students of a class individually and thus the difficulty to make progress within the class.

Nevertheless, the teachers are mostly convinced that the Hands-on-Remote experiments can promote the team spirit of the students even in remote teaching: 16 teachers fully agree (39%), 13 agree (34%), while 7 are rather critical and disagree (18%).

Since the course units can not only be used in different teaching scenarios (remote, hybrid, face-to-face) but can also be used with a different timing structure in class, the teachers were asked which organizational form of the courses they would prefer. 42% indicated that their preferred form would be continuous use (over several weeks) in the classroom, 34% would rather prefer a project day for the activities, while 24% would want to use an entire project week for this purpose.

8. Get in touch

In case you have any questions, suggestions or need to discuss your own implementation, feel free to contact either the coordinator or the local partner in your country.

Coordinator: Lorenz Kampschulte, Deutsches Museum, Munich, Germany – https://www.deutsches-museum.de/forschung/person/lorenz-kampschulte **link**

Pedro Reis, Instituto de Educação, Universidade de Lisboa, Portugal – http://www.ie.ulisboa.pt/docente/pedro-reis **link**

Wojciech Karcz, Copernicus Science Center, Poland – wojciech.karcz@kopernik.org.pl **link**

Hands-on-Remote Website:

https://sites.google.com/campus.ul.pt/hands-on-remote-en/home **link**

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All materials are available at

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The Hand-on Remote project was funded in the Erasmus+ KA226 Partnerships for Digital Education Readiness program (2020-1-DE02-KA226-VET-008295)

Co-funded by the Erasmus+ Programme of the European Union

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