Open Source Gamified Remote Labs in Photonics Education

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Abstract

Remote Labs are nowadays a widely used educational resource in curriculums of a wide range of scientific fields. The growing technological advances and progressing digitalization of education provides an ecosystem of possibilities to experiment with new means of communicating science. In this paper, we will present an approach to combine remote laboratories with gamification and storytelling all in one.
Although, the development and implementation is usually associated with costs and resources, we provide a framework solely based on open technology. From 3d-printing and off-the-shelf components on the hardware side to free software libraries and technology for implementing web applications and endpoints for augmented (AR) and virtual reality (VR) – open source enables reducing costs while developing platform and device independent applications.
Based on this technological implementation, we also developed a best practice for embedding learning content in an attractive and state-of-the-art manner directly within the 3D visualization of the experiment. Our method particularly relies on sequential storytelling for historical and research narratives, as well as gamification for an abstract, interactive visualization of the experiment itself.
With the integrated educational content, remote experiment applications offer a comprehensive, holistic learning experience for self-paced learning.

Keywords: *Remote Lab, Open Source, Gamification, Photonics*

1. The Potentials of Gamified Remote Labs

Remote labs and virtual labs are well-proven instruments to enhance online lab training. Whether based on a remotely accessible physical experiment or a plain software implementation of a simulated experiment, these environments offer a wide range of possibilities in the curriculum of various scientific fields and educational levels [1]. According to [2], there is no significant disadvantage in learning success by using digitally accessible experiments of any kind. They actually can improve achievements in various aspects.
During the last year, we experimented with the implementation of remote labs in an international MSc Photonics program. The goal was to provide an easy-to-use and customizable framework to adapt existing experiments and provide them as open educational resources (OER). Besides the development of the framework, we especially targeted two main scopes: First, we wanted to provide a maximum level of immersion, so the lab experience feels as real as possible. Our approach here was to rely heavily on the implementation of interactive 3d-representations, augmentations, and virtual reality applications. According to studies [3] [4], virtual (VR) and augmented (AR) support is widely accepted and again promotes learning success.
The second approach is to implement means of gamification directly into the lab environment. These allow an interesting interrelationship between a real experiment with measurements and a more abstract explanation of the same object. Here, we especially experimented with contemporary ways of communicating educational content directly through the promising utilization of comics. [5]
In the following paper, we will introduce our approach based on a self-developed software and hardware framework for remote labs and illustrate it based on a demonstrator application of a virtualized Michelson interferometer.

2. Virtual Remote Lab Environment

Our approach, as shown in figure 1, of openly accessible experiments as educational resource is based on real and virtual experiments at its core, framed by layers for gamification concepts and storytelling. Every resource and module implemented here works also on its own and can be applied individually, depending on the learning context and application.

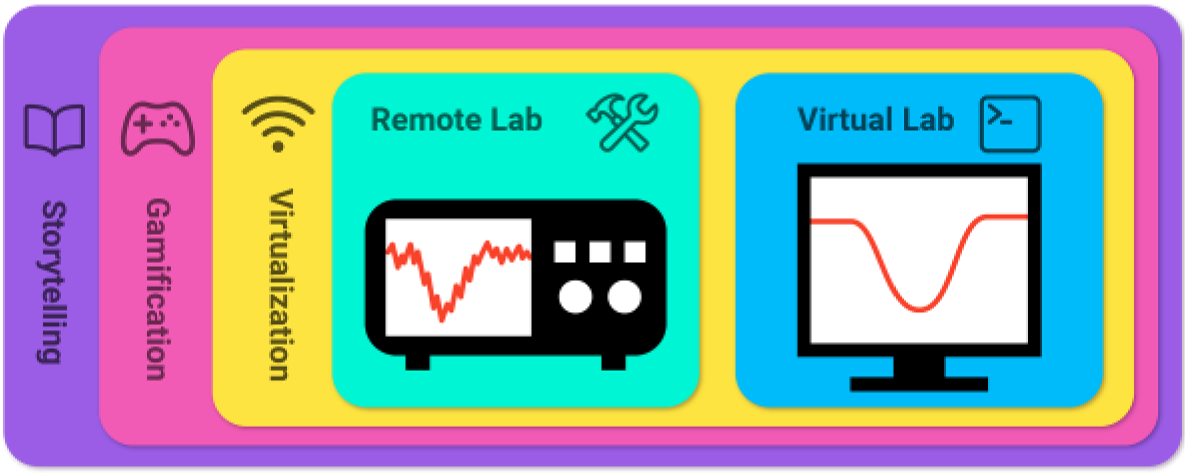

Figure 1: The conceptual approach of integrating hardware and software labs or simulations into a publicly accessible platform and framing these by gamification and storytelling layers for self-paced explorative learning

1.1 XR Twin Lab (XRTL)

We developed a framework for remote access of experimental setups with a focus on photonics. The framework is solely based on open technologies, so research groups and educational institutions can reproduce and adapt their remote experiments at low costs. As described in [1] and shown in figure 2, actuators and sensors are attached via 3D-printed parts to physical components of the experiment and controlled by a microcontroller. These controllers communicate via Websockets with a server, which runs an Internet-of-Things (IoT) message protocol. One way to control the experiment is a ReactJS application, which runs in any browser on desktop computers and mobile devices as well. The JavaScript application shows a WebGL-rendered 3D representation where the user can select components and generate commands in a user-friendly interface. The advantage of JavaScript is that besides the platform- and device-independent operation, various libraries support modern augmented and virtual reality environments. These applications run in standard commercially available VR and AR headsets or smartphones. Furthermore, JavaScript is one approach to integrate further educational content and implement games into the virtual layer. On the other hand, the open message-based protocol of XRTL allows client implementations in other game development and authoring tools like Unity, Unreal or Godot.

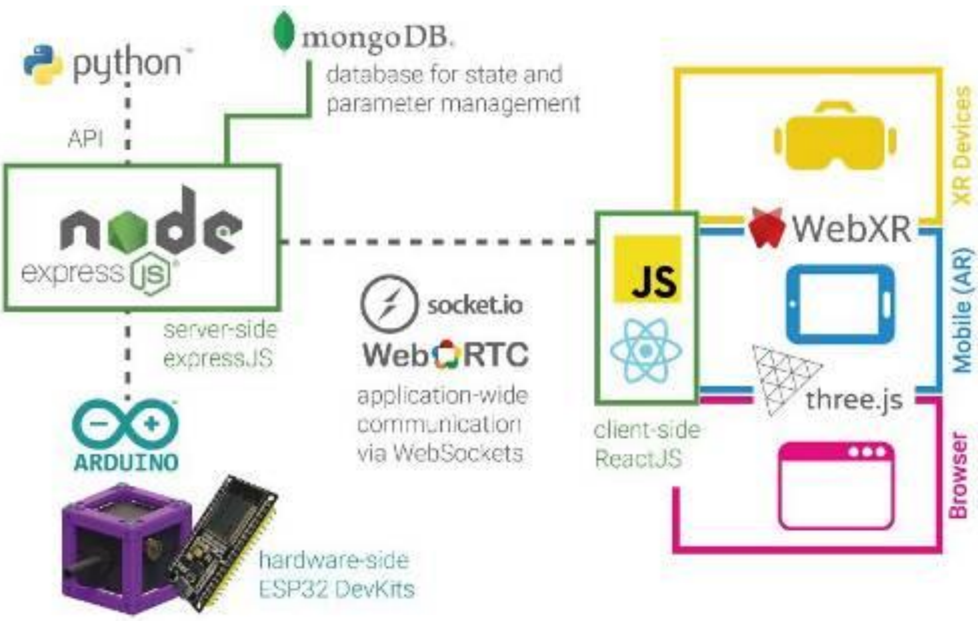

Figure 2: Architecture of the XRTL framework as introduced in [1] .The experiment, controlled by ESP32 microcontrollers and the user endpoints communicate via a nodeJS express server.

1.2 Gamification and Narration

To enhance the learning experience with a remote experiment, real-time simulations can supplement the virtualization. The goal is to integrate more abstract models of the experiment to facilitate the learning process. This whole virtualization is then framed in a gamification and narration layer.
Gamification is a method to connect simulations with measurement data from the experiment to create an interactive and entertaining way to communicate natural scientific models and relationships. There is a wide range of possibilities here: starting with simple quizzes or puzzles to contemporary game genres like flight simulation, adventure role gaming, first-person involvement, and strategy. Our objective is not just to communicate facts and methods on a meta-level but to allow the user to become a part of the experiment in an immersive way and experience science from a different perspective.
To communicate the context and content, the gamification is capsuled in a narration layer. Here, we experimented in particular with the sequential art (comic) medium. Comics allow splitting narration into small chunks, which can be temporally and spatially arranged [7]. This is beneficial since the explanation of an experimental process and underlying methods have temporal and spatial aspects as well. Additionally, comics have a high appeal for young readers and inherently allow the communication of complex interrelationships in an attractive graphical manner. We will show the implementation of the gamification and narration layer based on an experiment in the next chapter. An example of the integration of comics and gamifying and experiment is illustrated in the chapters 2.2 and 2.4

2. Gamification and Narration of a Remote Michelson Interferometer

One of the fundamental and canonical experiments in physics or photonics is the Michelson Interferometer. It became well known for its use by Michelson and Morley in an experiment to detect the earth's motion through a "luminiferous eather" at the end of the 19^{th} century. The ether was an assumed medium for light to be propagated in. Although the experiment disapproved of its existence, it is still a common setup to show the wave nature of light and is implemented in a wide range of modern optical devices for fine vibration and distance measurements.

2.1 Experiment

In the Experiment, light from a coherent source is split into two paths by a beam splitter, reflected back, and thereby overlaid which generates an observable interference pattern on a screen. Moving one of the mirrors changes the path length and therefore the interference pattern. By observing and counting the fringes, the student can conclude the path length changes and wavelength of the light source. We based our remote experiment on an educational kit provided by Thorlabs. As shown in figure 3a, every adjustable kinematic component was motorized as described in chapter 1.1. The interference pattern is observable by a camera feed in the web application (figure 2b).

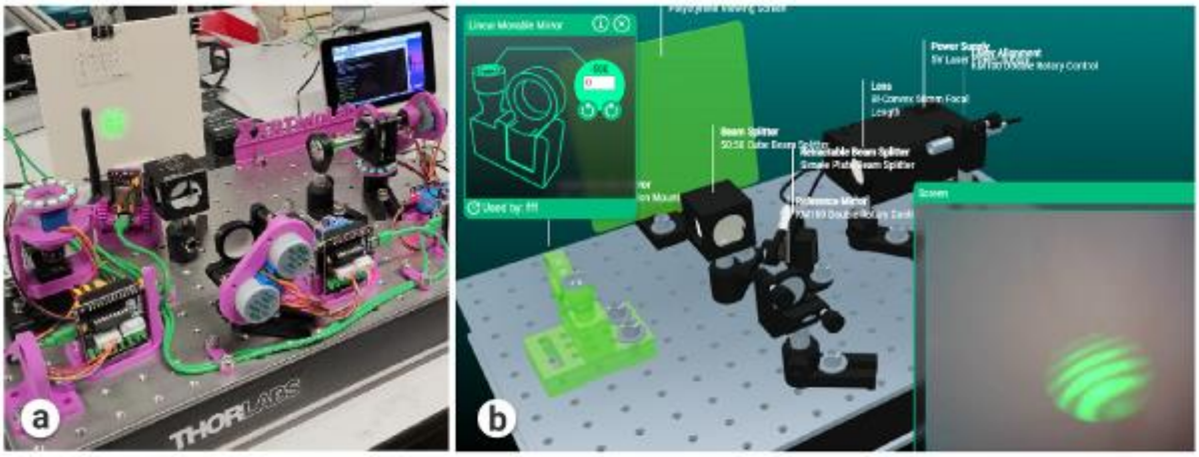

Figure 3: a) Remote version of Michelson interferometer educational Thorlabs kit with 3D-printed attachments (pink) for motors and status LEDs and the server running on a RaspberryPi in the background b) ReactJS web application for remote control of the experiment with 3d rendering and component windows for controlling motors and viewing the interference fringe pattern on the screen

2.2 Storytelling

The Michelson interferometer plays a pivotal role in the history of physics. It stands between the ancient conception of classical nature elements, critical thinking in the Age of Enlightenment and led into the revolution of physics beginning of the 20th century. Therefore, the interferometer offers a wide playground to embed stories about the experiment context such as historical, social background, scientific context, and contemporary research like gravitational waves or quantum mechanics.
We decided on comics and illustrative work to visualize and tell the story of world models involving the aether as shown in Fig. 4 and Fig. 5a. The experiment components hereby act as a backdrop for the augmented storytelling. While explaining the experiment itself, components get faces and become characters besides Michelson and Morley. So even without referencing the setup in particular, it is always a part of the narrative and becomes a steady rememberable constant for the audience.

Figure 4: a) separated comic elements to be integrated into b) a virtual 3D environment based on an experimental setup (here in Unity Game Engine)

2.3 Advanced Narratives

We further experimented with how the sequential stories are actually read by the audience. The experiment itself is no comic book and just imitating pages is not considered attractive and maybe even discouraging. Depending on the viewer orienting the view in the web application or using a mobile device and moving around a virtual or real experiment, there is always a user interaction between the experiment, its representation, or a 3D model. We utilized this mechanism by revealing story elements (panels) according to the view changes. By doing so, the viewer can “scroll” and progress the story by moving the viewing device. This is especially beneficial while explaining a process or a method based on experiment components (see Fig 5c)
We also not only implemented illustrations as story elements, but experimented with 3D models, visualizations, and alembic animations as shown in Fig 5b. Contemporary game development environments like Unity, Unreal, or Godot as well as the JavaScript frameworks used by us all provide a wide range of technological possibilities to embed complex multimedia content into scenes, which bridge the gap between reality and virtual environment. In interaction with a real-world experiment, and the processing of real measurements results, these methods open a completely new world into experiencing and communicating science and research.

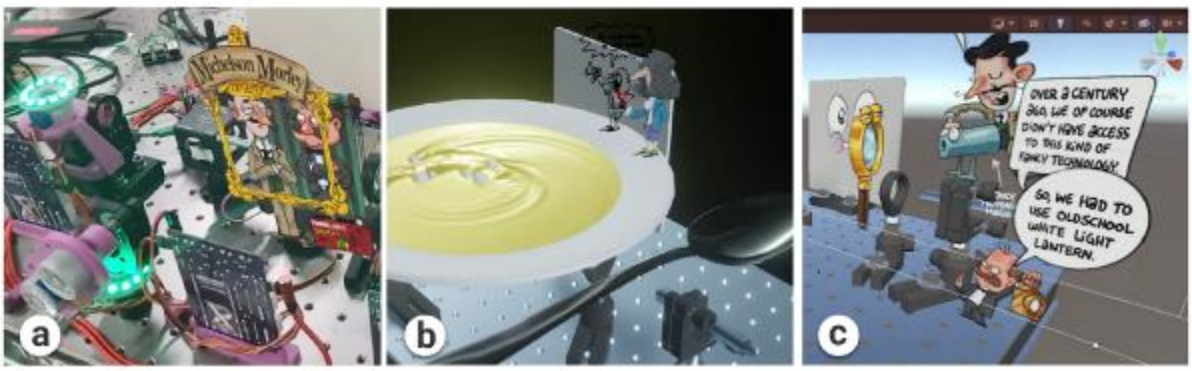

Figure 5: a) augmenting illustrations and comic elements on real or virtual experiments b) integrating 3D models and alembic animations for visualization and story elements and c) showing panels and story elements interactively depending on view direction and changes

2.4 Gamification

Finally, we also integrated a variety of gamification approaches into our remote lab environment. The focus here is to complement the explanation and contextualization of the experiment. Especially hard-to-grasp concepts are being boiled down to an abstract simulated approach which is playfully. We hereby tried to integrate games as seamlessly as possible into the virtual environment, for example by exploring an optical setup from the point of view of a photon in the style of a flight simulator as shown in Fig 6a. Another example is the Augmented Layer of the Hanbury-Brown-Twiss-Interferometer (HBTI) shown in figure 6b. To comprehend a single photon and correlation measurement, the user can introduce interactively their own virtual photons from the single photon source and therefore build up a personal more abstract measurement. By comparing these to the real-world data, these simplified results offer an approach to the topic of particle-wave duality of photons.

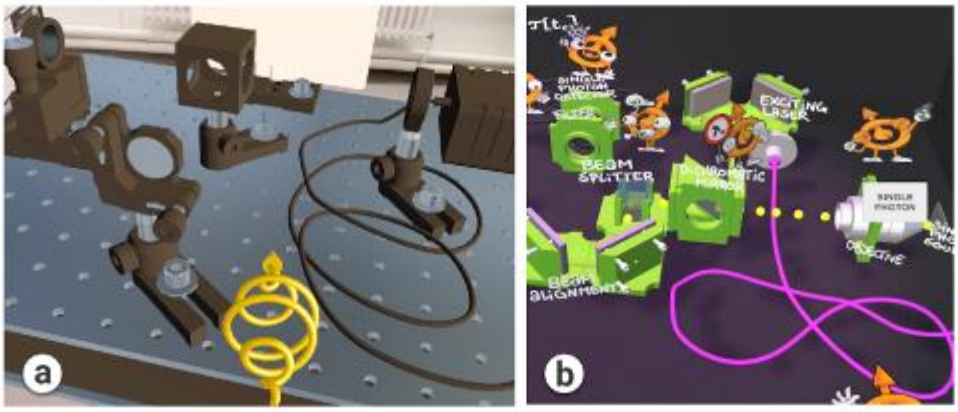

Figure 6 a) ReactJS implementation as a flight simulator, guiding a photon through an experiment b) HBTI implementation with abstract model photons activated by the user to generate simulated results

3. Conclusion

We have shown that lab experiments can be virtualized and remotely controllable with open-source technology. DIY manufacturing tools like 3D printing, off-the-shelf electronic components, and extensive software environments offer a wide toolset of virtualizing lab experiments with integrated educational content and gamification approaches. This integration of creative science communication offers a holistic approach to self-paced, explorative learning with perseverative and sustainable learning success.

By now, there are various experiments implemented with remote access and used in a practical lab-training course of a MSc Photonics program at the Friedrich Schiller University in Jena, Germany. In the future, we will concentrate more on the integration of educational and gamification layers as introduced in this paper. By doing so, the applications and resources are adaptable to various user groups, allowing us to offer state-of-the-art research from the lab to non-university curriculums and science communication.

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