Digital Teaching in Photonics – new possibilities for Labwork Training Programs

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Abstract: New technologies rapidly lead to many new possibilities for digital teaching concepts of labwork training programs, which might be on-site or remotely. Mixed Reality is a promising candidate to meet the learning goals. © 2021 The Author(s)

1. Challenges for Digital Teaching the the laboratory

Digital Teaching has been a backbone of academic education in the recent 1.5 year due to the Corona pandemic. Due to the meeting restrictions, classical educational concepts that require a physical presence in some room were no longer possible. This was particularly true for laboratory training programs in Photonics, which typically require physical presence of working teams in tiny spaces where strong air flow in counterindicated.

For classical course formats like lectures, there were already well-established tools and concepts that were ready to be used when the instant switch to all-digital teaching became necessary in the pandemic. Learning management systems like moodle and others or video conferencing solutions, authoring software and digital production tools are just the most prominent examples. Most of these tools were technically already fully developed at the beginning of the pandemic, although not always widely used by teaching faculty in Photonics at that time.

For training programs in the laboratory, the situation was and still is vastly different. The reason lies in the different learning goals. Lectures, tutorials and seminars typically address the first three levels of the learning taxonomy (Fig. 1) in their core. A main focus lies in transporting knowledge, creating comprehension of the underlying concepts and applying these skills to solve given problem sheets.

Labworks, in contrast, typically build upon these steps and do often *not* primarily create new knowledge, but serve the three higher levels. An analysis of the prior theoretical knowledge is necessary to understand the technical requirements for an experimental realization. The own experimental results require an evaluation in order to be interpreted. This process can then lead to the modification or even creation of new experimental setups which can serve to answer self-proposed research questions.

These points, typically summarized loosely under the term ”hands-on-experience”, require massively more *action* of the learner. Any Digital Teaching concept for labwork in Photonics experiments has to serve the learning goals listed above in order to be sufficiently useful in any Photonics teaching program. In contrast to classical

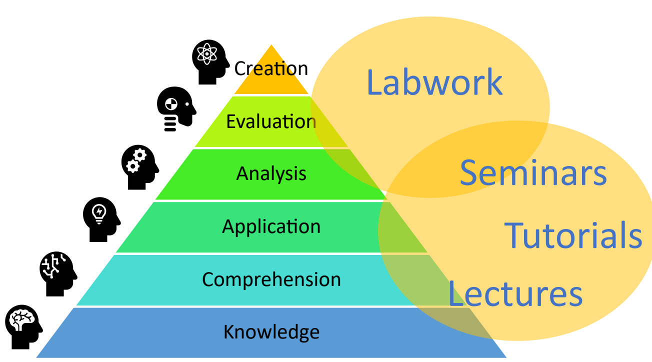

Fig. 1. (left) Labwork typically addresses the upper three levels of the learning taxonomy for which no standardized digital teaching concepts exist. (right) Our AR app in ”preparation mode”. A 3D model of the real lab setup can be explored on an empty desk from home.

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teaching elements, no well-established and standardized solutions are available for that task. Technological advance has, however, brought many possibilities into reach.

2. Mixed Reality in on-site Photonics education

An interesting new technology that is not yet used wide-spread in academic education is *Mixed Reality*. A rough distinction can be made into Augmented or Virtual Reality, differentiating if any interaction with the real environment is present or not. The technology seems particularly promising for digital lab concepts, since activity is required from the user. This is an enabling property for reaching higher levels of the learning taxonomy.

In Jena, we are currently investigating different types of technologies and approaches. In a first project, we use Augmented Reality on tablet devices to explore the possibilities of combining and linking the lower and higher level groups of the taxonomy scheme. Our tablet app (Fig. 1) has two possible modes of usage: a ”preparation mode” for the student to use at home, and a ”lab companion” mode for the student to use on-site. The lab setup is a horizontal infinity-corrected microscope with Koehler illumination and the possibility for optical filtering, *i.e.* a classical setup for exploring Fourier Optics. In ”preparation mode”, the students work on interactive learning elements explaining the physical background of Fourier Optics. Learners can augment their empty desk at home with a 3D representation of the actual setup they will later find in the lab, walk around it and explore the functionalities of components they will find. In ”lab companion mode”, augmentations are directly placed where the real components are. They help students performing the experiments. Instructors then reflect the findings together with the learners. The approach combines different digital learning concepts like inverted classroom or just-in-time teaching and tries to explore the best practice case for using AR technology for on-site lab experiments.

A second project explores the possibilities of augmented and virtual reality in situations completely without physical presence. A nanofabrication facility in the cleanroom is simulated completely in virtual reality. This includes a scanning electron microscope, a focused ion beam device and several other parts of the fabrication chain like spin coaters. The program is run with a VR goggle and serves the purpose of emulating a training situation for the complex machinery in the cleanroom for beginners. When coming out of the lecture hall, students in microstructure technology typically have no idea how being and working in a cleanroom is actually like. It is usually also surprising to learners how much auxiliary machinery has to be operated, like different valves of the vacuum system or micromanipulators to handle the samples. The VR training program is supposed to lower the temporal resources instructors have to spend with low-level basic training in the cleanroom significantly.

3. Site-independent Photonics education

The technological hurdles become much higher if teaching concepts for the laboratory have to work completely without the physical presence of the learner [1]. One attempt we have developed is the ”digital twin” model. This involves a real lab setup and an off-site digital representation. The interconnection between the two determines the level of immersion that can be reached. We have tried live streams of 360°-cameras on a lower technological level. This allows the learners to choose their viewing angle in the laboratory freely and see all simultaneous processes in real-time. Interaction, however, is just possible via communication with on-site personnel, which might suffer from latency issues or be in general limited to text chat.

Another approach we are investigating is the augmentation via high-tech AR glasses like the Microsoft HoloLens. This allows the learner ”to see through the eyes” of an instructor whose task it is now to ”be the hands” of the learner. Parts of the setup can be automated to be operated remotely by the learner directly wherever possible. Undoubtedly, these approaches are highly experimental and redefine what ”hands-on-experience” can mean in teaching. Once fully operational, they need to be evaluated thoroughly with respect to their effectiveness in the learning process.

The last approach we take is ”receive-your-own-device”. Being the logical continuation of the ”bring-your-own-device” approach, simple lab components are shipped to the learners for them to build their own setup. Interaction with instructors can be just by video conference or with any of the more sophisticated augmentation methods above. This underlines strongly the importance of open educational resources. In Jena, we rely on the locally developed open system ”UC2” [2] that makes use of low-cost, 3D printed components. Using these building blocks, users are able to realize an impressive number of even sophisticated Photonics setups.

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