Modular Open-Source Toolbox for Optics Education (openUC2)

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Abstract: We present a modular open-source toolbox compiled into comprehensive educational kits. The hardware is supported by manuals and documentation that together provide an accessible tool and lower the entry barrier of studying optics and microscopy. © 2021 The Author(s)

1. Introduction

Increasing complexity and high price of standard equipment lead to an entry barrier in microscopy and a gap between study and practice. The STEM (Science, Technology, Engineering, Mathematics) education movement attempts to bridge this gap, but the right tools are not always at hand. With openUC2 (You.See.Too.), a general-purpose framework for building optical projects, we aim to provide a solution to this issue. Building a microscope using openUC2 becomes as easy as building a Lego© house, since the toolbox relies on commercially obtainable components and 3D-printed building blocks. The toolbox offers an alternative for both education and research, and it is therefore ideal for bringing the two fields closer together. It is available online [1] and fully open-source, so that anyone can use it, reproduce it, and adapt it to their purposes. Even though the toolbox is already accessible, the time and resources are often very limited in the sphere of education and a compact and to-the-point solution is needed.

2. Methods

The recently introduced modular optical toolbox UC2 [2] utilizes a simple yet universal cube ($50\times50\times50$ mm^3) as the basic building block. A cube can host a variety of 3D-printable inserts that adapt off-the-shelf optical and electronic components to the framework. A growing collection of modules (cubes with inserts), which enable different functionalities, helps to realize common applications not only in microscopy. Each setup consists of a set of modules on baseplates, that serve as the backbone of the system. The growing demand for cubes and the necessity to form stable and reproducible optical setups led us to produce parts of the system, namely the cubes and the baseplates, using large scale injection moulding methods. During the design transfer from the entirely 3D-printable design to the mouldable parts, we ensured that both schemes remain compatible to preserve the ability to have them produced by anyone, anywhere, with commercially available 3D-printers. Scaling up the production dramatically improved the systems stability and availability of the parts [3].

Fig. 1. Left: openUC2 MiniBOX prototype (injection moulding/ laser cutting); Right: Example from the MiniBOX booklet – manual to build a Keplerian telescope.

In order to enable scaling of the inserts as well, they were redesigned and optimized for production using a laser cutting machine. The MiniBOX (Fig. 1. left), the basic education kit as described later, can be now completely

Sixteenth Conference on Education and Training in Optics and Photonics: ETOP 2021,
edited by A. Danner, A. Poulin-Girard, N. Wong, Proc. of SPIE Vol. 12297, 122970Z
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produced by injection moulding and laser cutting. This way it is more suitable for outsourcing the manufacturing process and mass production. Especially the latter is necessary for bringing the toolbox to a broad audience of pupils and students. However, many schools and universities nowadays have 3D-printers or access to makerspaces, and the toolbox still exists in an open, fully printable version.

Along with easy-to-use hardware it is crucial to provide instructions on how to use it. The documentation has become an essential part of the project, as this makes the difference in an open-source project being just available or truly accessible. Aside from giving everyone the chance to build their own box by providing detailed assembly manuals, we also designed the MiniBOX booklet (Fig. 1. right) that leads the user through a series of experiments while explaining the underlying theory.

3. Results

We have developed a comprehensive educational kit, called TheBOX, to be used for teaching optics, microscopy, and potentially other fields of science. It is compact, cost-efficient, and meant to be used even by people who are not professional in any of the fields. It currently comes in five versions to serve different levels of education and purposes.

The FullBOX, equipped with a Raspberry Pi computer, can be used to build for example a brightfield transmission or a light sheet fluorescence microscope, as well as many other systems and all the simple experiments of the MiniBOX. The openUC2 software provides all the necessary hardware control via included electronics and a user interface for image acquisition. This version, however, proved to be too complex for many applications. The use of electronics and the focus on more advanced experiments of this box does not lower the entry barrier enough for secondary education or courses aimed at microscope users rather than microscope developers. This led to the classification of the following boxes.

The CourseBOX is meant for demonstrations and offering hands-on experience of the standard brightfield microscope alignment, Abbe diffraction experiment and basics of some commonly used microscopy methods. It was developed in collaboration, for an introductory course of an imaging facility, and it fulfills the common demands on these courses. The already mentioned MiniBOX and the SimpleBOX cover the experiments from the ray optics chapters of secondary and high school education, with the SimpleBOX featuring some extra components, like an eyepiece. Additionally, there is the PolarBOX, which works as an add-on to the other boxes, and deals with the experiments that show the polarization effects of light.

The MiniBOX prototype is a product of iterative optimization with the aim to lower the price and effort for manufacturing while the experiments that can be performed with it remain the same as for the SimpleBOX. Thanks to the employment of injection moulding and laser cutting the production time has decreased from 36 hours of 3D-printing to under 10 minutes.

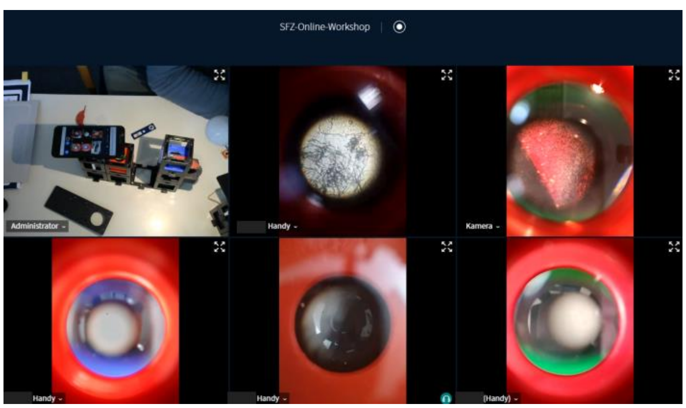

Fig. 2. Screenshot of the online workshop on the topic of microscopy done with SFZ Jena witelo e.V. (Schülerforschungszentrum; Wissenschaftlich-technische Lernorte in Jena)

We tested these BOXes in workshops at schools, universities, and out-of-school educational institutions. In the light of the pandemic situation, we also started testing the MiniBOX for the use in a flipped classroom concept, where the course is held via an online platform or a video call (Fig. 2.) while the participants borrow the BOX beforehand or build their own at home. All the types of workshops yielded positive feedback from the participants and helped us to improve the toolbox to the current state.

4. Conclusion

We built open-source educational kits to support in-person and remote teaching. It is supported by detailed documentation and guidelines that open the field to anyone. Therefore, it provides an affordable, accessible, and independent tool for education that can be used anywhere, as long as there is access to internet and a 3D-printer. We also optimized the toolbox for mass production and tested it in STEM context so it can hopefully find its way to schools on a large scale.

The latest results of the flipped classroom concept tests show that TheBOX could be a welcomed option for universities and imaging facilities that are currently unable to offer practical courses and it could also support the development of international study programs, which are taught online and attended by students worldwide.

5. References

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