

# Designing a LEGO-based microscope for an educational setting

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**Abstract:** Here we present the design of a high-resolution, high-magnification microscope using LEGO® bricks and easily-available lenses. With the provided workflow and suggested experiments, we show that 9-to-13-year old students significantly increased their understanding of microscopy. © 2021 The Author(s)

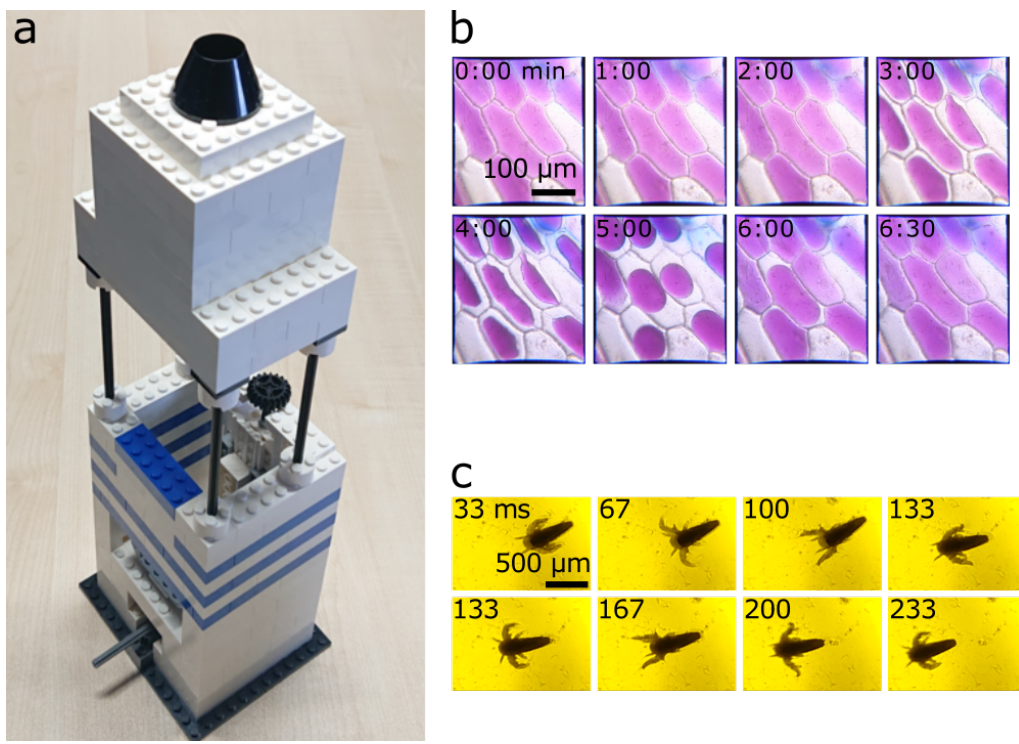
Microscopy is an essential tool in many fields of science. However, despite the simplicity of a basic light microscope, the fundamental working principles are beyond everyday intuition. While this lack of insight into simple optics might be partially due to the perception of microscopes as complex research instruments, hands-on experience promises to drastically improve the understanding for the working principles of microscopes by any interested person, including children.

Here we introduce a LEGO microscope as a scientific tool to access the micro-world and to understand the fundamental principles of the optical components of a microscope in a playful and motivating, yet precise approach. By basing the design on LEGO, we aim to make the microscope modular, cheap and inspiring. The only non-LEGO components are the two optical parts, which can be purchased off-the-shelf at approximately €4 each. We design a number of experiments that can be carried out using the LEGO microscope and applying it on easily accessible materials. The provided step-by-step workflow is designed for a school setting or for helping parents and children to discover microscopy in an autonomous way. Finally, we demonstrate that this LEGO microscope can be used in an educational setting by letting a group of 9- to 13-year-old students build the microscope and demonstrate their progress in understanding of microscopy with a questionnaire. All materials, including a list of parts, building plans, the workflow and experiment suggestions are found in Ref [1] and on Github [2].

The design of the microscope is shown in Fig. 1a. The main components that provide the functionality of the microscope are the illumination, the objectives, the objective holder and the ocular. The illumination is provided by a special LEGO brick integrating an orange LED. As the light source is positioned close to the sample, no special condenser lens is included, which helps reducing the optical parts to a minimum. The objectives consist of a LEGO casing with an optical element. For a high-magnification objective (with a total magnification of  $254\times$ ), the lens of a replacement iPhone5 camera module with a focal length of 3.85 mm is used. Despite the low cost, this lens has an outstanding optical performance compared to glass or polymer beads and is suitable for high resolution microscopy that approaches the diffraction limit [3]. For the low-magnification objective (a total magnification of  $27\times$ ), a glass lens with a focal length of 26.5 mm was used. Other lenses or lens systems can be easily integrated, as long as such adapted objectives position the optical elements in the same position, to keep the alignment of the microscope. The objective holder allows sub-millimeter precision adjustment of the objective position. This is possible by combining a gear rack with a gear worm screw which results in approximately 3 mm of travel for every full rotation. This is sufficient for precise adjustment of the focus, even when looking at samples of only several  $\mu\text{m}$  in size. The ocular is essentially a classical magnifying glass, consisting of a LEGO case that holds two acrylic lenses with a focal length of 106 mm each, with one flat and one convex side. Placing the two lenses with their flat sides on top of each other, the focal length is reduced to 53 mm. Finally, the microscope can be used both for direct observations by eye, or images can be recorded with a smartphone camera.

To support the usage of the LEGO microscope and to optimize the learning experience, we designed a detailed workflow that can be followed at the individual level but also in a classroom environment [2]. Since the help of an experienced adult is not guaranteed, the workflow includes help sections, to ensure that certain steps are successful before a next steps is initialized and to reflect on the learning progress. Besides an understanding of optics, we suggest a series of experiments that can be conducted with the microscope and readily available samples (Fig. 1b-c). These experiments demonstrate some important concepts from the natural sciences, such as the drastic effects of osmotic pressure on plant cells or the motion of microswimmers.

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**Fig. 1. Design of the LEGO microscope and images from suggested experiments. (a)** A photograph of the microscope, **(b)** Time lapse of an osmotic shock in red onion cells. After approximately 30 seconds, a 1M NaCl solution is flowed in. Subsequently, water leaves the cells, causing the cell membranes to detach from the cell walls. After approximately 5 minutes, distilled water is flowed in, washing away the 1M NaCl solution, and the cells return to their original volume. Images are recorded using the high-magnification objective featuring the smartphone camera lens. **(c)** Time lapse of the movement of an Artemia shrimp in water. Images are recorded using the low-magnification objective featuring the glass lens.

In a preliminary attempt to quantify the effectiveness of the LEGO microscope as a learning tool, 8 students in the age range of 9 to 13 years were tested before and after following the provided workflow instructions. The tests were identical and contained 5 questions on the subject of microscopy as well as 5 general questions related to natural sciences. Although the subject of the microscopy questions was discussed in the workflow instructions, the answers were not included and had to be obtained by working through the different steps. After having finished the workflow, the second test was taken, asking the same questions as the initial test. The general questions served as a benchmark, and the fraction of correct answers to these control questions changed only marginally from  $78 \pm 21\%$  to  $83 \pm 21\%$  correctly answered questions after the students had worked with the microscope. The fraction of correct answers on the microscopy questions however, almost doubled from  $50 \pm 17\%$  to  $83 \pm 12\%$  correct answers. Although the group size was relatively small, the effect is significant.

In conclusion, using LEGO and low-cost, easily available lenses, it is possible to construct a microscope that can resolve micrometer-sized objects, with a resolution that is close to the diffraction limit of light. A series of experiments that can be conducted with household ingredients is suggested, covering different fields of natural sciences. The modular design of the microscope itself also lets it easily be incorporated in a curriculum on optics. A preliminary study with 8 students in the age range of 9 to 13 shows that the understanding of microscopy increases after working with the LEGO microscope.

## References

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