BIOSPACE – A low-cost platform for problem- based learning in biophotonics

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BIOSPACE – A low-cost platform for problem-based learning in biophotonics

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***Abstract*— Advanced instrumentation and versatile setups are needed for understanding interaction of light with biological targets. However, conventional biophotonic instruments and laboratory equipment are often bulky and expensive. Therefore, we designed the Biophotonics, Imaging, Optical, Spectral, Polarimetric, Angular, and Compact Equipment (BIOSPACE) as both a pedagogical tool and a platform for conducting research. Here we report the design and capabilities of the platform, as well as its implementation in a graduate physics course.**

***Index Terms*—biophotonics, problem-based learning, hands-on exercise, 3D-printing, open-source hardware, goniometer, pedagogy**

I. INTRODUCTION

Experiential learning (ExL) emerged as a part of pedagogical terminology in the early 20th century, promoting hands-on learning as an alternative to didactic learning, where the student assumes a more passive role [1], [2]. ExL includes the sub-area problem-based learning (PBL), popularized in modern graduate engineering education [3].

In postgraduate education, terms such as 'research questions' and 'theoretical and conceptual frameworks' are seen as a natural part of the scientific research process. Posing a question, defining a hypothesis, and testing that hypothesis are part of tried-and-true research methodology. Nevertheless, such methodology does not solve societal problems, which is the ultimate purpose of an engineer. The differences in the scientific and the engineering method of conducting research (see Fig. 1, adapted from [4]) have been discussed in recent decades, sometimes with fierce advocacy of the latter [4], [5]. The engineering discipline is sometimes referred to as "engineering arts", a terminology that clearly states its polarity with science and highlights that engineering is the *art* of solving a problem efficiently.

Another recent development is the emergence of open-source hardware coupled with the exponential growth of availability of 3D printers [6]-[8]. This aids in the process of making the engineering method available for researchers and teachers with limited funds. 3D-printing technology is also reported to have significant educative value [9].

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In this paper, we have developed a biophotonics platform for teaching physics and biology. Our pedagogical tool follows the principles of PBL, promotes the engineering method, and both uses and expands upon the open hardware movement.

II. THE BIOPHOTONICS PLATFORM

A. Components and construction

BIOSPACE is inspired by earlier efforts [10], [11], which describe more simple platforms with a similar purpose of facilitating low-cost science. The more sophisticated BIOSPACE has the capability of capturing multispectral images of a biological sample. These images can include polarization and light scattering angle information, and the studied sample can also be rotated around two axes. This versatility opens up great possibilities in experiment design and enables the examination of the samples physical principles and optical properties.

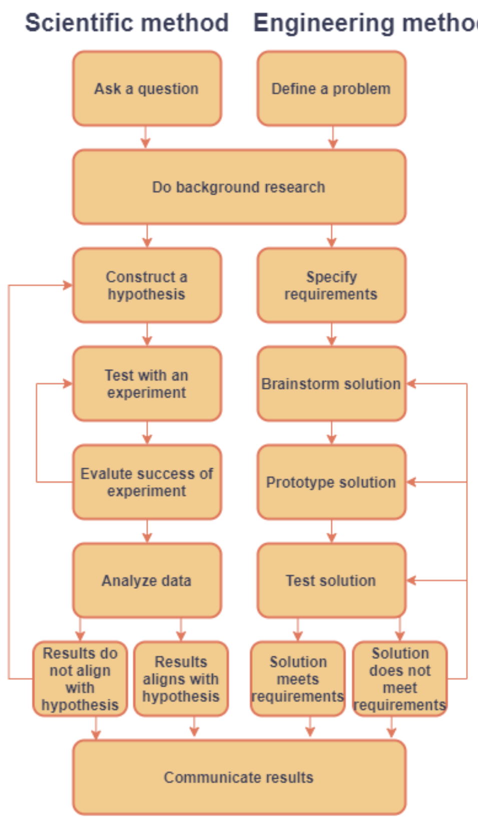


Fig.1. The scientific vs the engineering method of conducting research.

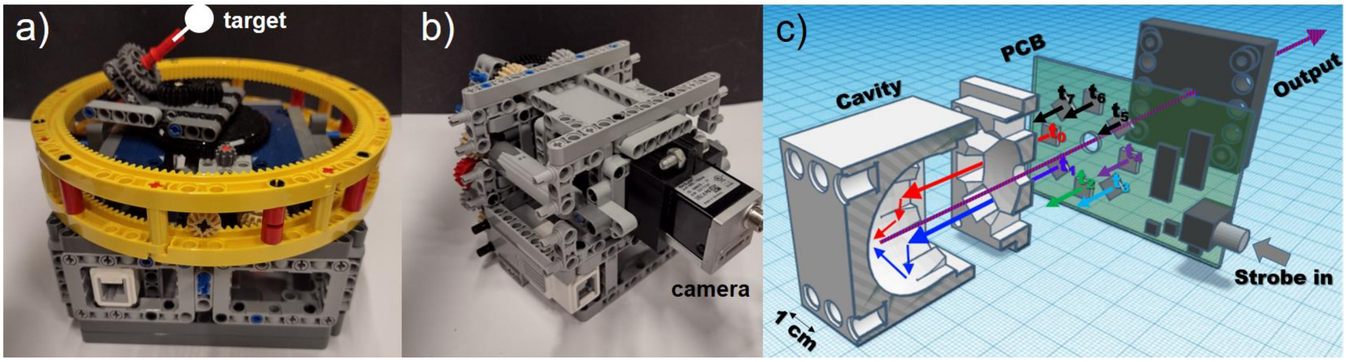


Fig. 2. a) The mechanical structure of BIOSPACE, including the 3-axis rotation stage where the biological target is mounted. b) The imaging receiver unit of BIOSPACE. The receiver camera is mounted with Lego® Technic such that it can focus with Lego® motors, the rotatable polarization analyzer is placed in front of the camera. c) Exploded view of the illuminator of BIOSPACE, illustrating the light paths originating from the LEDs.

The structure of BIOSPACE is made of Lego® technic, and it has 3D-printed adaptors for installing optical elements (see Fig. 2). This design significantly reduces the cost compared to commercial counterparts. The instrument consists of different modules; an illuminator, a receiver unit, and a target rotation stage. Four Lego motors control the angles of the parts: the illuminator can change its incidence angle around the target to achieve a goniometric scan; rotation stage where the target is mounted can rotate around two axes to image the target from all angles; and a polarizer on the receiver unit can be rotated to study the polarization properties of the target.

The illuminator consists of eight LEDs with emissions at different wavelengths mounted on a custom-made printed circuit board. Each LED is multiplexed in synchronization with the active exposure of the camera in the receiving unit. Combining multiple exposures of the same target with different wavelengths of light illuminating it results in a multispectral image.

Three copies of BIOSPACE were made to prove the reproducibility of the platform. The bill of materials was US$ 2000 apiece.

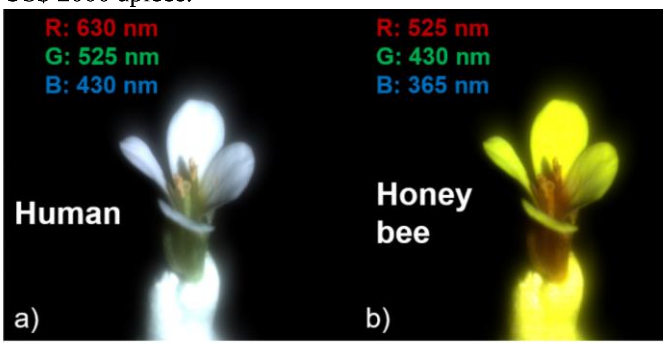


Fig. 3. a) The alpine rock-cress (*arabis alpina L*) as seen by humans. b) A presentation of how the Alpine rock-cress might appear for a honey bee. Here the color channels are shifted toward the UV spectral region.

B. *Example measurement*

The number of different experiments possible with BIOSPACE is only limited by the creativity of the operator. One example presented in Fig. 3 is a white flower called alpine rockcress (*arabis alpina L*), which was investigated using the spectral capabilities of the platform. Multiple exposures of the flower were acquired with wavelengths ranging from ultra-violet 365 nm to near-infrared 940 nm. The flower was then presented with human color vision, selecting the spectral bands where humans have distinct spectral receptors. The flower was also presented with spectral bands corresponding to a honey bee with spectral sensitivity to the ultra-violet. The white (for us) flower looks yellow for the bees (see Fig. 3).

III. BIOSPACE AS A PEDAGOGICAL TOOL

BIOSPACE has been used in a graduate course at the faculty of Engineering of Lund University as a tool to implement PBL. In the course Biophotonics (FBRN10), a significant focus was a project where the students designed unique scientific experiments using the versatile BIOSPACE. The project was designed to make the students follow each step in the engineering method seen in Fig. 1, from defining a problem to communicating the results.

In the project, the students could choose what kind of sample they were interested in studying and in which measurement domain they wanted to analyze their sample. The possible samples were divided into three categories and the measurement domains into four, giving the students the option to choose among twelve alternatives (see Table I).

Fig. 4. Students conducting experiments in the course Biophotonics at Lund University.

In the course, students were free to design their experiment with BIOSPACE. Their task was to come up with a research question that interested them. Some examples were, “how do flowers look for bees?” and “can we estimate rice quality with a goniometric measurement?”. The steps of the project included: 1) conducting a literature review, looking for similar experiments done previously. 2) Designing the experiments; students discuss ideas and the feasibility with the supervisors of the course. 3) Acquiring of samples, where rice was bought, and flowers picked (for the

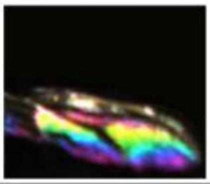
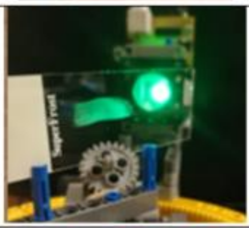
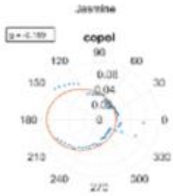
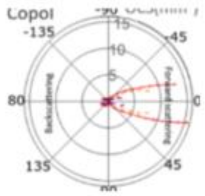
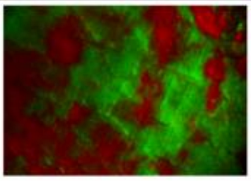
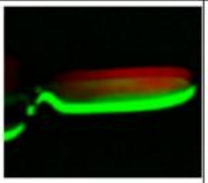
	Medicine	Organic products	Ecology
3D-imaging, projections (spatial)			
Spectroscopy (wavelength)			
Goniometry (scatter angle)			
Ellipsometry (polarization)			

Table I. The available options of sample selection and measurement domain in the biophotonics course project. Sample images are inserted into each table cell, providing inspiration for the experiments for the specific sample and measurement domain combinations. The samples include:

- Textures and inhomogeneity in pharmaceutics and organic products.
- Optical projection tomography of small animals
- Tissue spectroscopy
- Fruit quality control
- Thin films measurement of insect wings
- Scatter phase functions of blood smears, grains, and insects
- Polarimetric imaging of muscle tissue, rice grains and bark beetles.

example cases). 4) Conducting experiments with BIOSPACE, adjusting and calibrating the platform as needed for the measurements. 5) Analyzing and visualizing the data into publish-worthy images. 6) Presentation and peer review of the projects at a seminar. A photo of students performing their experiments on campus with BIOSPACE is shown in Fig 4

IV. Conclusion

Three prototypes were successfully manufactured and used in a graduate course at Lund University. The aspiration toward low-cost and open-source permeated the whole design process resulting in a platform with Lego® and 3D-prints as the mechanical structure and open-source software for controlling the experiments. The software, the assembly instructions, and the necessary files for 3D printing the mechanics and milling the printed circuit board are all made available for interested parties.

In the future, multiple copies of the BIOSPACE are planned to be sent to partner research groups members of the African Spectral Imaging Network (AFSIN). These collaborators reside in six countries, predominantly in West Africa.

BIOSPACEs low cost and high versatility present great opportunities for implementing PBL-projects in research projects in low-income countries and in university teaching.

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