My First Biolab - an Inquiry-Based Learning System for Microbiology Exploration

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Abstract

Understanding microbiology concepts is highly relevant for everyday life, with wide implications on health and environment. It is believed that these concepts should be taught at high-school level. Inquiry-Based Learning (IBL) is a recommended approach for learning scientific concepts, that includes hands-on investigation, performing experiments, and gathering data. IBL is rarely applied in biology learning at schools, mostly due to three aspects: (1) Lack of immediate feedback as microorganisms are invisible; (2) costly equipment; (3) safety regulations. We present "My First Biolab", a novel and accessible system enabling safe and sterile hands-on experimentation with microorganisms, for microbiology concepts through IBL. The system includes a custom-designed nylon bag containing the experiment's biological materials, a magnetic peristaltic pump for circulation, a spectral sensor that monitors bacterial growth, a heat transfer plate for temperature control, and a smartphone UI for setting and monitoring the experiment in real-time.

Author Keywords

Microbiology; Inquiry-Based Learning; Youth; Education; Hands-On Experimentation

CCS Concepts

•**Human-centered computing** → *Interactive systems and tools;*

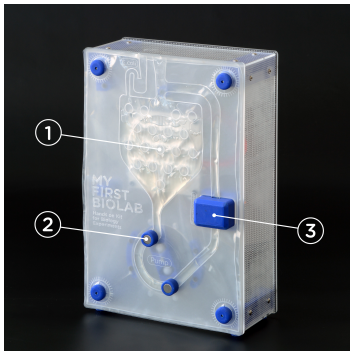

Figure 1: The MFBbox
1. Heat transfer plate; 2. Magnetic peristaltic pump; 3. Spectral Sensor.

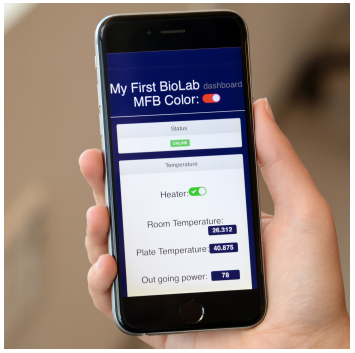

Figure 2: The MFBUI
The user can control multiple systems, set different parameters, and monitor experiments.

Introduction

Core principles in microbiology are highly relevant for better comprehension of human health [10]. Understanding such principles can impact the public's behavior, especially in the health and environment domains. One approach is to introduce microbiology already in school years [10]. Traditional biology activities in high-school classrooms (and sometimes middle-school) typically involve frontal teaching [11], online educational materials [6], and demonstrations of experiments performed by educational staff [9]. These methods commonly lead to minimal engagement and are considered to be less effective for learning biological processes [13]. Inquiry-Based Learning (IBL) that involves hands-on experiences is considered to be more appropriate for exploring biological concepts [14, 1]. IBL involves hands-on investigation, performing experiments, and gathering data [3]. Teaching microbiology concepts to youth using IBL is challenging due to three main reasons: (1) The learning materials are invisible to the human eye and students cannot simply observe the bacteria without specialized equipment. The bacterial processes may last from a few hours to a few days and students do not receive immediate feedback [8]; (2) Handling microorganisms requires expensive equipment which is commonly beyond the reach of most schools and after-school centers [2]; (3) Safety regulations limit youth's participation in the learning experience [4], preventing hands-on learning that is known to contribute to understanding and engagement. In this demo we present My First Biolab (MFB), a novel system enabling IBL of microbiology concepts in a safe, sterile, and accessible way. The MFB was implemented according to IBL principles, supporting hands-on experimentation with microorganisms.

Related Work

Hands-on IBL-based technologies are not common in the field of microbiology, probably due to the limitations discussed above. One alternative are IBL-based simulation systems, for example the CRYSTAL ISLAND web-based computer game: a narrative-centered learning environment for middle-schools in which students are asked to investigate an illness spreading on an island. The activity includes asking questions, generating hypotheses, collecting data, testing hypotheses, consulting with a microbiology field manual, and conducting tests [12].

My First Biolab System

The MFB system is designed according to IBL principles, to allow for introducing basic concepts of microbiology and performing iterative experimentation with live microorganisms by manipulating biotic and abiotic variables and monitoring bacterial growth. The MFB addresses the needs of middle-school students with no prior knowledge in biology, and high-school biology students who conduct iterative scientific projects in microbiology. The system includes three main components: a lab in a box (MFB_box), an experiment in a bag (MFB_bag), and a User Interface (MFB_UI).

The MFB_box

The MFB_box case is constructed from laser cut acrylic sheets with custom 3D printed connectors. The technical components include an ESP8266 D1 mini board that controls the 2D magnetic peristaltic pump, the spectral sensor, and the heat transfer plate (See Figure 1).

The MFB_bag

The MFB_bag is a custom-designed nylon bag, with specific fluidic structures required for a single experiment. The MFB_bag (See Figure 1) is a novel solution, holding all biological materials and enabling a sterile experiment setup in one container. The bag is created using two sheets of Polyacrylamide-Polyethylene (PAPE), welded together using a laser cutter that accurately forms "Macrofluidics" by

Figure 3: Hands-On
The user can manually transfer the bacteria to the growth substrate in a safe and sterile way.

Link to video

shorturl.at/biEX6

channeling the liquids via pre-defined paths. This novel technique offers several advantages: safe and sterile experiment, flexibility and accuracy in the Macrofluidics path design; transparency that reveals both the biological experiment processes and the system's mechanisms; Hands-on liquid manipulation by the student (See Figure 3).

The MFB_UI
The MFB_UI enables remote operation and continuous monitoring of the experiment's parameters and the bacterial growth (See Figure 2). The UI is a simple online interface accessible by smartphones and PCs. It allows control of temperature and motor speed, and presents a real-time graph of bacterial growth.

MFB and IBL Design Guidelines

The MFB was designed to support IBL principles and to overcome the known challenges in microbiology school-based teaching. The system provides a safe and sterile hands-on introduction to bacterial growth, which is a basic subject studied in microbiology courses in high-schools [7]. Students can conduct experiments in a safe and sterile way, while controlling temperature and speed of circulation, and then monitoring the bacterial growth remotely using their smartphones [5]. The IBL principles involved in the activity include: (1) Studying through performing a scientific process; (2) Active participation; (3) Self exploration; and (4) Experimentation (including hypothesis generation, planning investigations, gathering and analyzing data, and proposing answers, explanations, and predictions) [3].

Studying Through Performing a Scientific Process: The MFB is designed as a simple and accessible research tool, allowing students to conduct scientific experiments with live organisms and monitor bacterial growth. Similar to gold-standard microbiology lab equipment, MFB enables students to generate hypothesis concerning the optimal parameters for bacterial growth; plan investigation by setting the temperature and speed of circulation; gather and analyze data by monitoring the experiment results remotely (using the UI); propose explanations for the experiment results, and suggest future experiments.

Active Participation: The system's transparency encourages students to participate in an active and self-directed activity. Students are able to manipulate the system by setting temperature and circulation speed values, move the bacteria to its growth substrate (See Figure 3), and monitor the bacterial growth curve throughout the UI using a mobile app in their private cell-phone or using their personal computer.

Self Exploration: The learning activity is fully performed by the students with minimal involvement of the teacher (or researcher). The system provides a safe and sterile environment where students are able to conduct their own experiments. All biological materials are sealed in the bag, and all electronic components are secured inside the box. The students are able to set the experiment's parameters by themselves, allowing them to derive hypotheses while investigating which factors influence bacterial growth.

Experimentation: The students experience the full experiment cycle: First, they generate hypotheses concerning bacterial growth; Second, they set the experiment's parameters by controlling temperature and speed of circulation; Third, students monitor the experiment's progress through observing the bacterial growth curve presented in the UI; Forth, they interpret the findings presented at the curve as a function of the parameters they defined and draw conclusions.

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