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BOARD # 45: Work in Progress: Classroom Glucose Spectroscopic Analyzer Prototype Learning Module

Riley Jackson Fosbre, Washington State University

Riley Jackson Fosbre is a graduate student at Washington State University, Pullman. He is pursuing his PhD in Chemical Engineering, and currently possesses a MS without a thesis. His research interests involve engineering education and technology.

Dr. Prashanta Dutta, Washington State University

Prof. Prashanta Dutta has received his PhD degree in Mechanical Engineering from the Texas A&M University in 2001. Since then he has been working as an Assistant Professor at the School of Mechanical and Materials Engineering at Washington State Universit

David B. Thiessen, Washington State University

David B.Thiessen received his Ph.D. in Chemical Engineering from the University of Colorado in 1992 and has been at Washington State University since 1994. His research interests include fluid physics, acoustics, and engineering education.

Prof. Bernard J. Van Wie, Washington State University

Prof. Bernard J. Van Wie received his B.S., M.S. and Ph.D., and did his postdoctoral work at the University of Oklahoma where he also taught as a visiting lecturer. He has been on the Washington State University (WSU) faculty for 42 years and for the past 27 years has focused extensively on novel team-interactive hands-on learning with miniature Desktop Learning Modules that represent physical equipment used in industry. Bernie and his cross-disciplinary team have shown markedly enhanced learning of concepts at higher Bloom's levels and student motivation through use of these modules. He has about 100 publications in the areas of biotechnology and engineering education and about 70 ASEE full-length publish-to-present publications.

Work in Progress: Classroom Glucose Spectroscopic Analyzer Prototype Learning Module

Introduction:

Over the course of 28 years, our group has strived to provide chemical engineering students with active, hands-on learning opportunities to enrich their education and better prepare them for their chosen careers (1-3). Chemical engineering is a multidisciplinary field of study with a large depth and breadth of material to cover in just four short years, so learning should be both efficient and reinforcing of basic concepts to maintain student retention and success.

To better facilitate better learning outcomes in our current NSF sponsored work, our team developed several ultra-low-cost desktop learning modules (LCDLMs) which can serve as a full, unit operations experiment without need for a full laboratory budget and set up to facilitate (4-6). The more recent kits are on the order of 10” x 4” x 1” (1) meaning they can be used on an auditorium chair tablet arm desktop, hence the name. There are currently four main kits in circulation at universities across the country, two covering the topic of fluid mechanics and momentum transfer, and two covering heat transfer (7,8).

The two fluid mechanics LCDLMs include a hydraulic loss kit, meant to show pressure loss over length, and a venturi meter, which demonstrates the conversion from flow work to kinetic energy. The second set of kits includes a concentric or double pipe and a shell and tube heat exchanger, which are meant to introduce students to the basics of heat transfer, system geometries and flow paths within those systems.

In addition, we have three other LCDLMs used at our university due to the currently small number of available units. This includes a fluidized bed column, a bead sedimentation process, and an evaporative cooler. These kits cover more complex mechanical principles than the previous four. The first demonstrates the pressure trends for a bed of fluidized beads. The second simulates cell separations in dense suspensions using beads of variable size and color. The third provides an example of the impact of phase change, humidity and air velocity on thermal energy transport.

Since the project started in 2018, we have collected data on student comprehension of the LCDLM topics by disseminating the modules to universities across the US and assessing student knowledge via a set of pre- and posttests. Students were provided with worksheets to complete prior to taking the posttest for consistency across different implementations. After implementation, student comprehension was judged based on their improvement between assessments, which were compared with a control group, who only received the normal lesson plan from professors prior to taking the posttest exams (9).

Our next step is to expand the number of topics covered through our project by developing new LCDLMs, leading us into the topic of this report: The Classroom Glucose Spectroscopic Analyzer, an LCDLM designed to introduce students to the field of analytic chemistry, enzyme kinetics and the topic of microfluidics. Unlike the previous examples, this module is one of the first to incorporate liquid phase chemical reactions (10). It is the topic of this paper and we will present its description, usage, improvements made and future directions.

Lab Module Description:

The Classroom Spectroscopic Glucose Analyzer (CGSA) is a 12 x 12 cm square unit made of three acrylic panels approximately 0.3 cm thick. The center panel features a y-shaped channel with two component reservoirs at the top and one large collection reservoir at the bottom cut into it via laser cutter shown in Fig. 1. This is to accommodate a channel width approximately 3 mm in width, 4.8 cm in length, and with fourteen 0.5 mm thick alternating baffles lining the sides, forming a serpentine path for the reagent and sample to follow to the bottom. Four holes are drilled into the topmost panel, one for each upper reservoir and two at the collection reservoir, for the injection of chemicals and the free flow of liquids through the module and ejection of air, and ease of reagent and sample mixing and device cleaning.

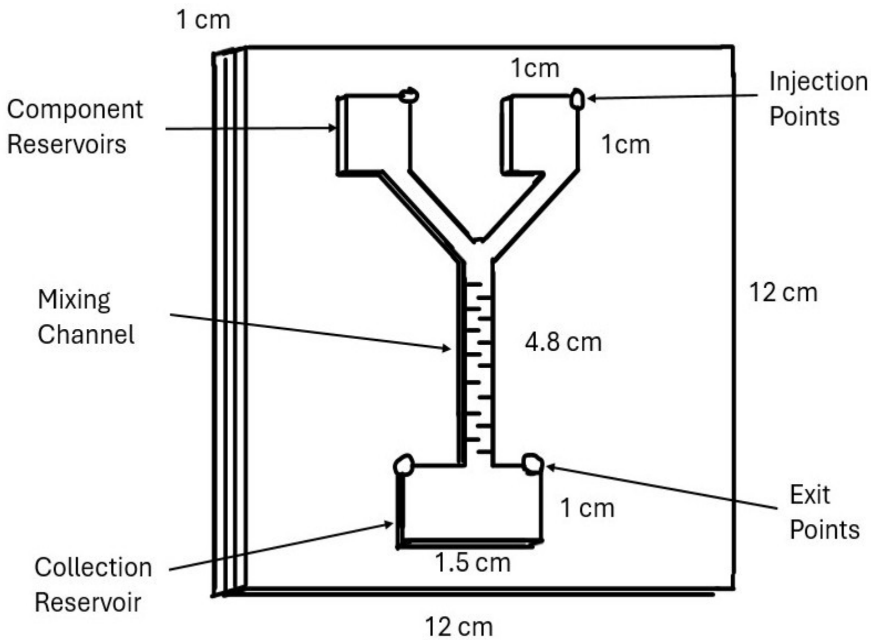

Fig. 1. Rough schematic of the module with exact dimensions. The channel shown is cut into the middle layer of the module with holes hand-drilled into the top for free flow of liquids from the top to the bottom reservoir and ejection of air initially contained within the system.

Samples and reagent solutions are gravity fed to the top of the module. The two components are mixed via diffusion and fluid folding due to the baffles as fluids flow along the main channel, stretching the interface between the two solutions (11). This mixing method is necessary due to the low quantities of fluid involved and limitation of usage within the laminar regime, some things which students will be asked to discuss. The collection reservoir only holds approximately 1 mL of fluid total, the two upper reservoirs subsequently hold equal 0.5 mL amounts in volume. This is meant to reduce costs and minimize the use of potentially irritating chemicals in the classroom. Once the solution reaches the bottom, data is collected via a cellphone camera with a resulting image shown in Fig. 2.

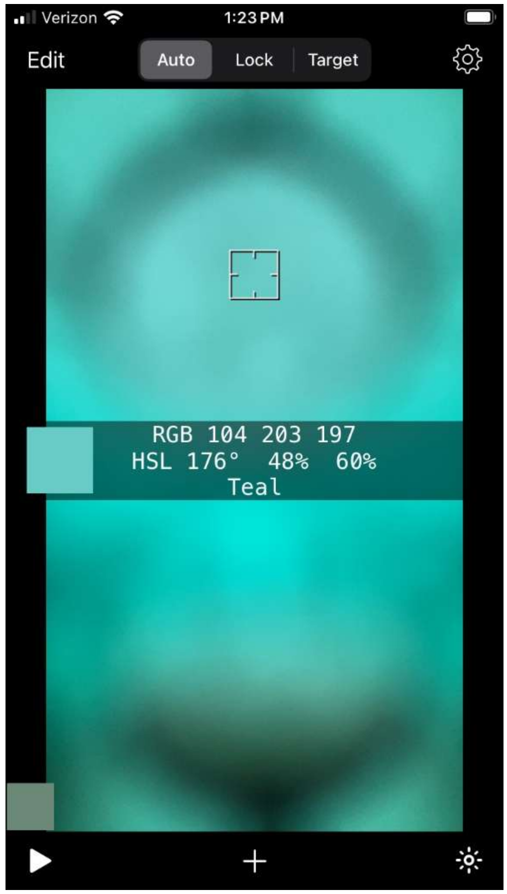

Fig. 2. Screenshot of the ColorAssist Interface used to collect quantitative data. The middle number counts the number of green pixels in the target area on screen which corresponds to the transmittance of green light through the sample.

Quantifiable measurements of intensity from the collection reservoir are taken using an RGB saturation app, such as ColorAssist for iPhones (12). The saturation of green in the photo correlates to the intensity of green light allowed to pass through the red sample. Intensity can then be used to find the absorbance and concentration of the sample via Beer's Law.

$$\ln\left(\frac{I_0}{I}\right) = A = \varepsilon C l$$

$$\boldsymbol{I = \frac{G}{R+G+B} * 100}$$

I = Sample intensity, I_0 = blank intensity, $\boldsymbol{R}$ = red value, $\boldsymbol{G}$ = green value, $\boldsymbol{B}$ = blue value,

A = absorbance, C = concentration, l = pathlength, ε = molar absorptivity

This module was made with fourth year undergraduate students in mind, either to supplement learning in an engineering course like reaction kinetics or biochemical engineering or it may be used as an introductory experiment for a wet lab like that associated with a unit operations or an analytic chemistry course. The experiment features a common spectroscopy test for determining blood glucose concentrations in biomedical blood analysis labs with two reactions in sequence, the first and rate determining step (13) being a reaction between glucose, oxygen, and the enzyme glucose oxidase to produce peroxide for a second, much faster probe reaction with the enzyme peroxidase to oxidize dye present in the reagent solution, turning the sample red. Students will be asked to construct a full calibration using five prepared stock solutions with known concentrations, and then determine the concentration of an unknown sample by measuring the absorbance and placing it on the curve.

Additionally, students will be asked to account for reaction stoichiometry when working with higher sample concentrations. Oxygen serves as a limiting reagent due to the finite amount of dissolved oxygen in water and minimal diffusion of atmospheric oxygen into the solution within the enclosed module. When oxygen is in excess, the reaction produces a proportional amount of oxidized dye for a given amount of glucose, but students will be shown what happens when the glucose exceeds the initial oxygen concentration. This will be shown during the experiment with an undiluted solution and through supporting materials, including a worksheet students will use to complete the experiment and record their data and observations prior to taking an assessment on their comprehension.

Improvements:

One of the main complications with this experiment is acquiring consistent measurements using a cellphone camera. Measuring samples manually invites human error into the pathlength between the sample and the camera lens. To mitigate the issue, a cardboard box is now being used as a holder for the phone and the module as shown in Fig. 3. The box serves a dual purpose, holding the camera in place at a fixed distance of 10 cm with the camera lens aligned with the collection reservoir, shown below.

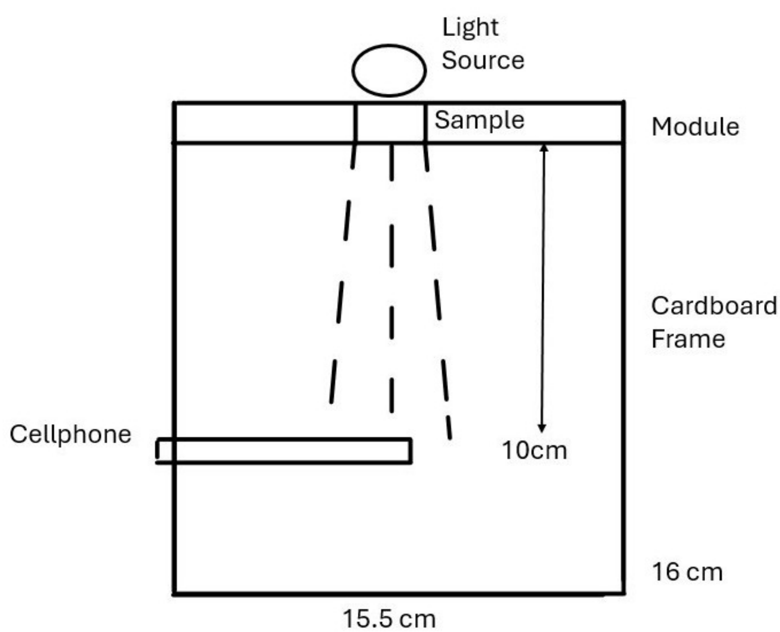

Fig. 3. Inside view of the cardboard holder. A slit cut is made into the right side for a cellphone to be inserted for measurements, and a flashlight attached to the back to serve as a light source.

We have also moved away from the use of a valve or pump system in favor of a simple, gravity fed design to remove the need for additional parts. As shown in Fig. 5 to accomplish this, the module's upper reservoirs are offset from the channel so they can hold liquids in place while the module is on its side, allowing students to load the chemicals and rotate the module upright to create gravity induced flow to mix the reagent and sample together when ready. The module can then be loaded into the holder from the bottom to collect readings.

Fig. 5. Demonstration of the module's gravity fed passive mixing mechanism using dye. The module depicted is an earlier version with the component reservoirs set in the middle, relying on surface tension to hold components in place.

Future Work:

We intend to collect cognitive data from students who use this module before the end of the semester in our reaction kinetics and biochemical and biomedical engineering courses. To accomplish this, we will need to manufacture enough modules to comfortably accommodate groups of 3-5 students for a total class size of approximately 15-20 students. Students will be tested on their prior knowledge of stoichiometry and spectroscopy, specifically the creation of a calibration curve, using a pretest survey online. Students in a control group will take the posttest after viewing material on the topics provided by the participating faculty but before using the LCDLM, while students in the test group will take the posttest afterwards. Our hypothesis is that students in the test group will show greater levels of improvement between assessments, as well as report higher levels of engagement in their subsequent feedback as with what was observed with prior LCDLMs.

Additionally, we are currently working in collaboration with West Virginia University on the development of a new version of the module. This one is made using microscope slides and silicone paper which will be bound together using a laminator. The equipment needed to manufacture this version is available on site, unlike the current acrylic version we are using, which requires the assistance of a third-party laser cutting service to manufacture. Due to the cheaper and more readily available materials, we plan to go forward with implementations using our partner's design as well.

Acknowledgements:

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