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Board 270: Evaluating Implementation of Hands-on Learning Modules Considering Social Cognitive Theory

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Progress in Evaluating Hands-on Learning Module Implementation and Considerations of Social Cognitive Theory

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Over the course of a five-year study, our NSF IUSE team created and disseminated several Low-Cost Desktop Learning Modules (LCDLMs) used to teach college students difficult engineering principles. The goal of this project is not only to allow students to experience the engineering concepts they are learning about in a hands-on manner, by lowering the associated cognitive load, but to allow them an opportunity to work in interactive groups. This approach is inspired by Bandura's Social Cognitive Theory (Bandura, 2011), which posits learning is a social process, and thus complex ideas are learned best collaboratively. LCDLMs are thus meant to help students visualize the concepts to be learned and create an environment where students can make observations and test hypotheses together, sharing and evolving their understanding through their differing perspectives. Afterwards, students are asked to participate in pre- and posttests to assess learning of the associated concepts, and a survey to gauge their motivation inspired by using the LCDLMs.

Now that the project has been running for several years, and data have been collected in several classrooms at universities across the country, it is worth examining whether instructors have embraced this approach to enhance their own learning strategies as well as for us to assess student learning within the classroom. The LCDLMs were disseminated to instructors who agreed to participate via a "Hub and Spoke" model, where workshops were held in different regions at various "hubs" across the US to instruct professors on appropriate uses of LCDLMs. Feedback was gained through post-implementation forms with written feedback submitted semesterly. The hope is to remove any barriers instructors may have in implementing LCDLMs effectively, such as lack of funds, poor technical support, insufficient how-to information, as well as to include their suggestions about more effective strategies for using the LCDLMs and collecting test scores and survey information from their students.

In the past year, greater attempts have been made to increase transparency with participating instructors and incorporate their feedback collected during workshops and throughout the school year. Instructors have asked that the pre- and posttest results from the LCDLM activities be shared with them outside of workshops, not only to support the validity of use of the LCDLMs, but so the activities can be incorporated into their grade books. Additionally, we have compiled a list of "best practices" from both the researchers working on the project and the participants in the study to implement the LCDLMs more efficiently. However, steps need to be taken to evaluate professor implementation strategies and their perceptions on how interactions with student teams can maximize the effects of using LCDLMs to teach and learn fundamental engineering concepts. We also want to assess qualitatively our workshop interactions to ensure the LCDLMs are used in a way that maximizes their effectiveness based on the data we have collected thus far. Hence, in the present study we seek to collect feedback from instructors through personal interviews as well as post-implementation forms.

Finally, new LCDLMs are under development to incorporate additional engineering topics not yet covered by the current set. A glucose analyzer LCDLM is being produced, tested, and prepared for implementation, while a recently developed fluidized bed will be used for a second time in the classroom. Results from implementations will be analyzed based on pre- and posttests and motivational surveys.

INTRODUCTION

Hands-on and active/interactive learning continues to show efficacy in terms of cognitive and motivational gains and does so across demographic differences. Our team and others have shown this time and again over the years through studies on use of dresser-sized modules (Golter et al., 2005), growth in Fink's cognitive dimensions of foundational knowledge, implementation of the 7 Principles of Good Practices in undergraduate education (Abdul et al., 2011; Chickering & Ehrmann, 1996), application and integration while using Desktop Learning Modules (DLMs) (Abdul et al., 2016), cooperative learning (Authors, 1998), a meta-analysis of active learning (Freeman et al., 2014), correlating visualization with reduction in cognitive load and enhancement of interrelatedness resulting in greater gains at the higher levels of Bloom's taxonomy (Burgher et al., 2016), greater intrinsic motivation (Hunsu et al., 2017), and better equalization of learning across demographics (Ajeigbe et al., 2023; Knight et al., 2002). All of this shows that much of the modern emphasis on innovative educational practices is working.

With all that has been done it will be of benefit to distill a set of best practices toward uniform implementation strategies. Our team is engaged in a dissemination strategy to propagate use of our hands-on learning with Low Cost Desktop Learning Modules (LCDLMs) for use in fluid mechanics and heat transfer courses across chemical and mechanical engineering disciplines (Z. Durak et al., 2023). After five years of implementations in some 50 institutions and with 70 plus professors using the LCDLM innovations along with interactive learning we realize there are differences in outcomes with some professor implementations resulting in better results than others. This raises the research question about whether there are effective strategies, that if used more uniformly, the results would be more consistent.

Therefore, our team is evaluating input from implementers to extract what we deem to be the best practices, in our context. In this paper we provide a summary of what we have found to work well to date. At present a smaller set of professors have agreed to use practices as described in a more homogeneous fashion. Since the study is continuing and is expected to do so over the next 1.5 years or more it is too early to draw concrete conclusions. Nevertheless, we will describe the process in coming to a consistent set of best procedures, how we are assessing this and preliminary results from a small set of institutions. Moreover, we realize that the LCDLM concept can be expanded and therefore include explanations on preliminary efforts to expand the use of packed and fluidized beds (D. Durak et al., 2023) and to develop a miniature glucose analyzer (Fosbre et al., 2023).

Best Practices and Meta Analysis

Summary of best practices

After nearly 5 years of collecting data from classrooms across the US, we have compiled a list of best practices based on high scoring posttest classrooms. We recommend that for all four LCDLMs, a professor gives the consent form and pretest 3-4 days before the in-class implementation and incentivize taking the exam by assigning points for completion. To assist in this process, we have agreed to grade the pre and posttests for faculty, as they will not have direct access to the online surveys on the backend to collect student responses. We also suggest equipment checks be done during this period as well. Participating instructors are recommended to practice with the LCDLMs by running through the worksheet provided with them, to ensure replacement parts and equipment can be ordered and to prepare instructors to actively participate in implementation. During the in-class portion, we recommend groups of 4-5 students using the worksheets we provide (which align with our assessment questions). During class the instructor should walk around and engage with the groups, offering advice, asking questions, and helping to troubleshoot any areas of confusion with the use of the LCDLMs and worksheets. The posttest should be done outside of class to maximize time on the LCDLMs and completed after submitting associated worksheet homework during a subsequent class period. We recommend the due date for the posttest be placed within the next 48 hours, to give students ample time to complete the additional assignments as well as discuss the results of their implementation before taking the examine, without delaying other topics in the curriculum. It is worth noting that collection and grading of the worksheets and homework sections we provide with the LCDLMs is left up to the instructors' discretion. In addition, we recommend assigning the short YouTube channel videos for each LCDLM that we made to clarify conceptual understanding, and which were originally developed as an add-on while offering alternative synchronous and asynchronous use of LCDLM exercises during the COVID-19 pandemic.

Workshop changes

Over the past several years, our methodology for mentoring faculty to implement LCDLMs in their classrooms has continued to improve. When we started in late 2018, we prepared a full-day onsite training for directors of regional hubs from across the US and local implementers. After an initial workshop in early 2019, we focused less on our historical development, instructional and motivational philosophy, and more time on the actual implementations. In 2020, because of the COVID-19 pandemic we did a virtual one-day workshop that was about 6 hours long. Feedback from participants indicate this time online was too long, so in 2021 we continued with the virtual and shortened the workshop to 3 hours. Beforehand, we sent faculty the LCDLMs and asked them to experiment on their own and become familiar with the units. Feedback from faculty showed they liked the virtual rather than the on-site option as it gave them more flexibility in their schedules.

Alignment with ICAP Hypothesis

Student participant responses regarding their level of engagement with the various LCDLMs were classified according to the Chi and Wylie (2014) levels of engagement: Interactive, Constructive, Active, and Passive (ICAP) framework. Represented in Figure 1 are data collected from 2,452 participants, dating from fall 2019 through to spring 2023 who had interacted with the LCDLMs. The distribution shows 69% of the participants agree or strongly agree that LCDLMs fostered the interactive level of engagement. A moderate number of participants, specifically 47%, agree or strongly agree that the LCDLM helped them to be constructively engaged. In addition, 40% of participants claim the LCDLMs helped them to be actively engaged while only a very small number of students, 15%, report being passive while using the LCDLM. Following the ICAP framework responses, more than 80% of participants indicated the LCDLM activities foster meaningful forms of engagement, i.e., Interactive, Constructive, and Active, making them more engaged in the classroom.

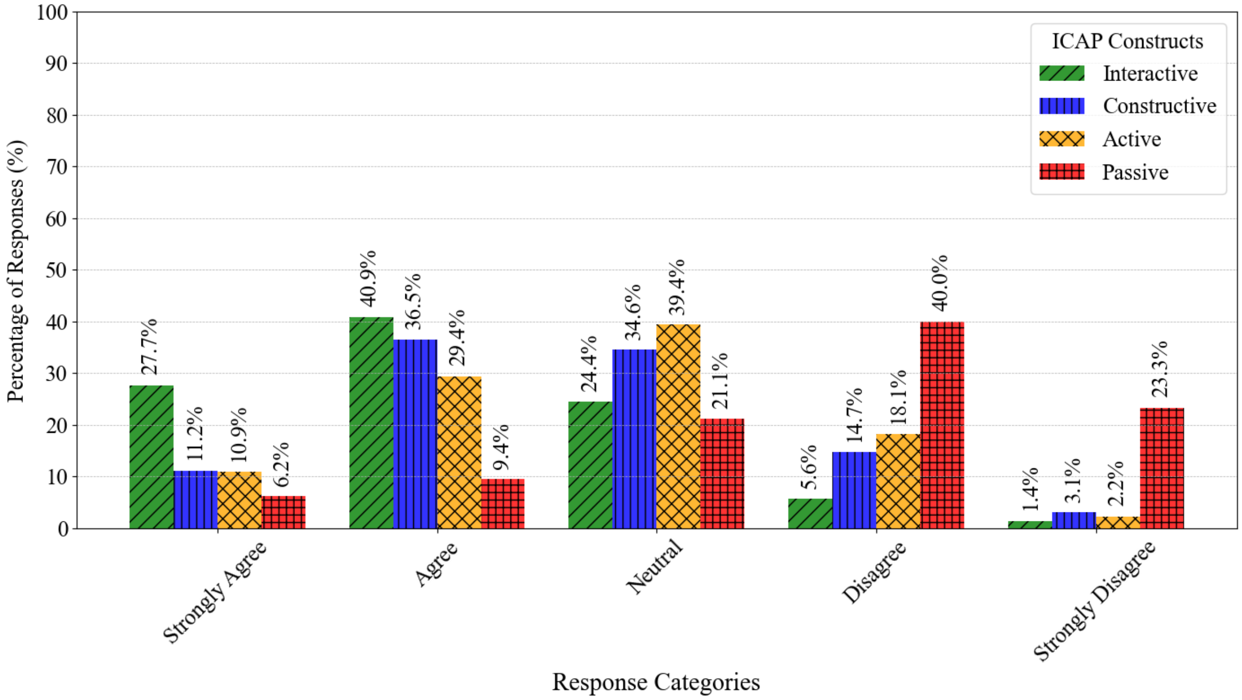

Figure 1: Student's self-report responses on use of the LCDLMs related to I.C.A.P.

Best Practice Impact on Conceptual Understanding

Double Pipe

Preliminary data on improvement in conceptual understanding for the best practice use of the double pipe heat exchanger show considerable growth in contrast to previous results. Data in Figure 2 were collected from students (N = 83) from four different universities. There were 8 questions in the pre- and post-tests, which are meant to address student misconceptions of the topic, such as where to place the system boundary, the area over which heat is transferred, and how the heat transfer rate will change based on the dimensions of the heat exchanger. The results show a clear improvement in performances in the post-tests. Based on these data, a paired t-test shows significant p-values and small to medium effect sizes for six of seven questions and are in sharp contrast to previously reported data showing such improvements on only two of five questions (Authors, 2022). A further question-by-question analysis will be conducted once data is collected from more participating institutions. Although the p-value varies for different questions, the overall results show significance at $p < 0.01$ which is highly encouraging. Moreover, the effect size for the average of all questions is 0.50 showing the average score increasing from an average pre-test value of 54% to a posttest value of 64%. The largest increases reported are for Questions 6 and 7 on whether the temperature gradient driving heat transfer changes through the module and which difference in fluid temperatures (inlets, outlets, hot and cold) drive heat transfer. These are two related questions, and they measured the ability of the students to identify the most relevant temperatures for heat transfer.

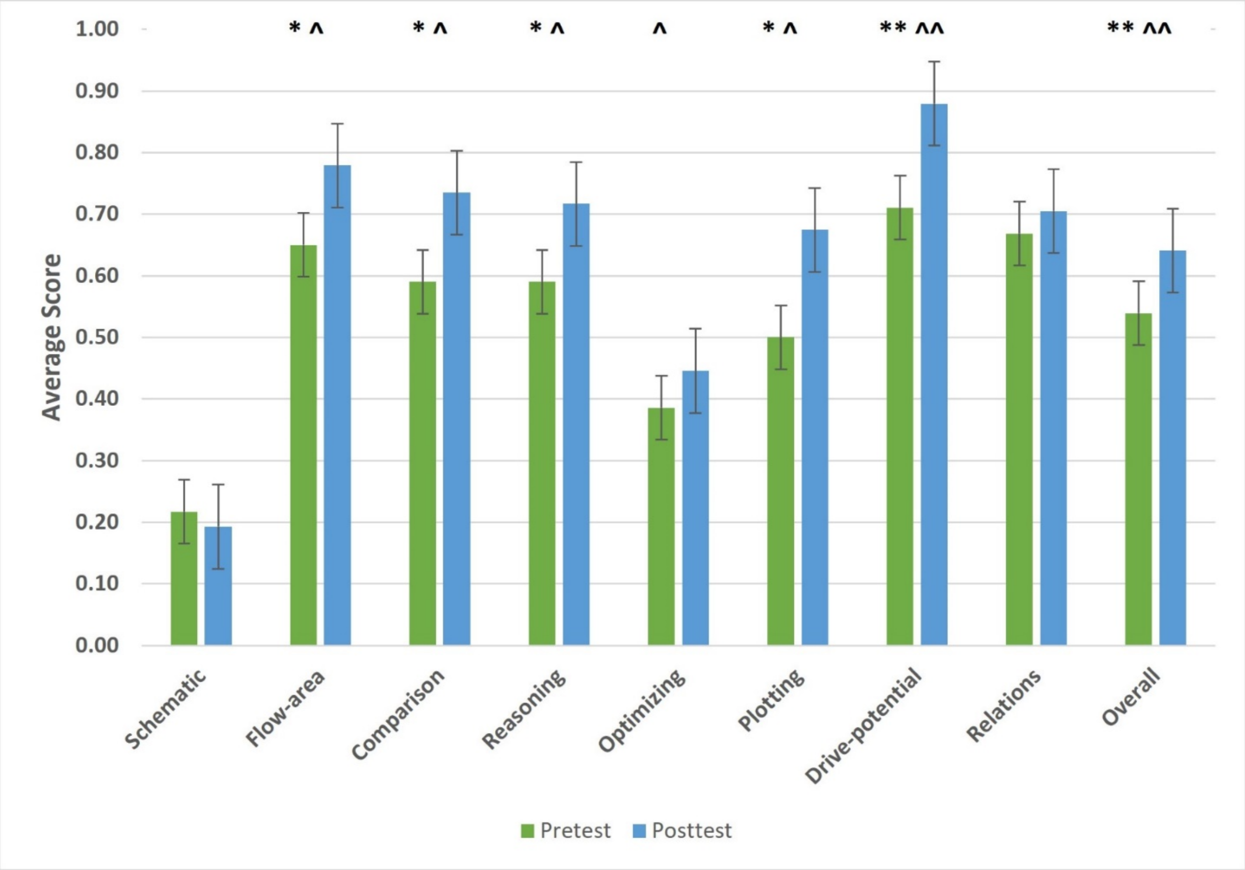

*Figure 2: Comparison of double pipe pretest and posttest scores with statistical analysis (N = 83). Improvements are in sharp contrast to previous implementations. * $p < 0.05$; ** $p < 0.01$A; ^ small effect sizes where $0.1 <$ effect size < 0.4; and ^^ medium effect sizes where $0.4 <$ effect size < 0.8.*

Shell & Tube

We are seeing similar results from preliminary best practice implementations for the shell and tube heat exchanger. Data to date (N = 75) are from 3 different universities. Figure 3 shows results from paired t-tests and effect sizes again with significant improvements over pre-tests answers and overall scores improving to a 65% average from 55% for the pre-test with $p < 0.01$ and an effect size of between 0.5 and 0.8. As with the previous LCDLM, students were assigned a series of questions (seven each) meant to test their knowledge of the system and relevant trends. This included how average flow velocity affects the outlet temperatures, identifying what types of flow patterns were featured by the model, and providing an explanation for these trends using their knowledge of fluid mechanics, such as how the Reynolds number effects heat transfer. The result for question 3 shows the highest improvement with $p < 0.01$ and ES > 0.4). Again, there is an apparent improvement in the results in contrast to prior implementations (Khan et al., 2022). We will continue to collect such data for more best practice participants and expect the noted improvements to be robust.

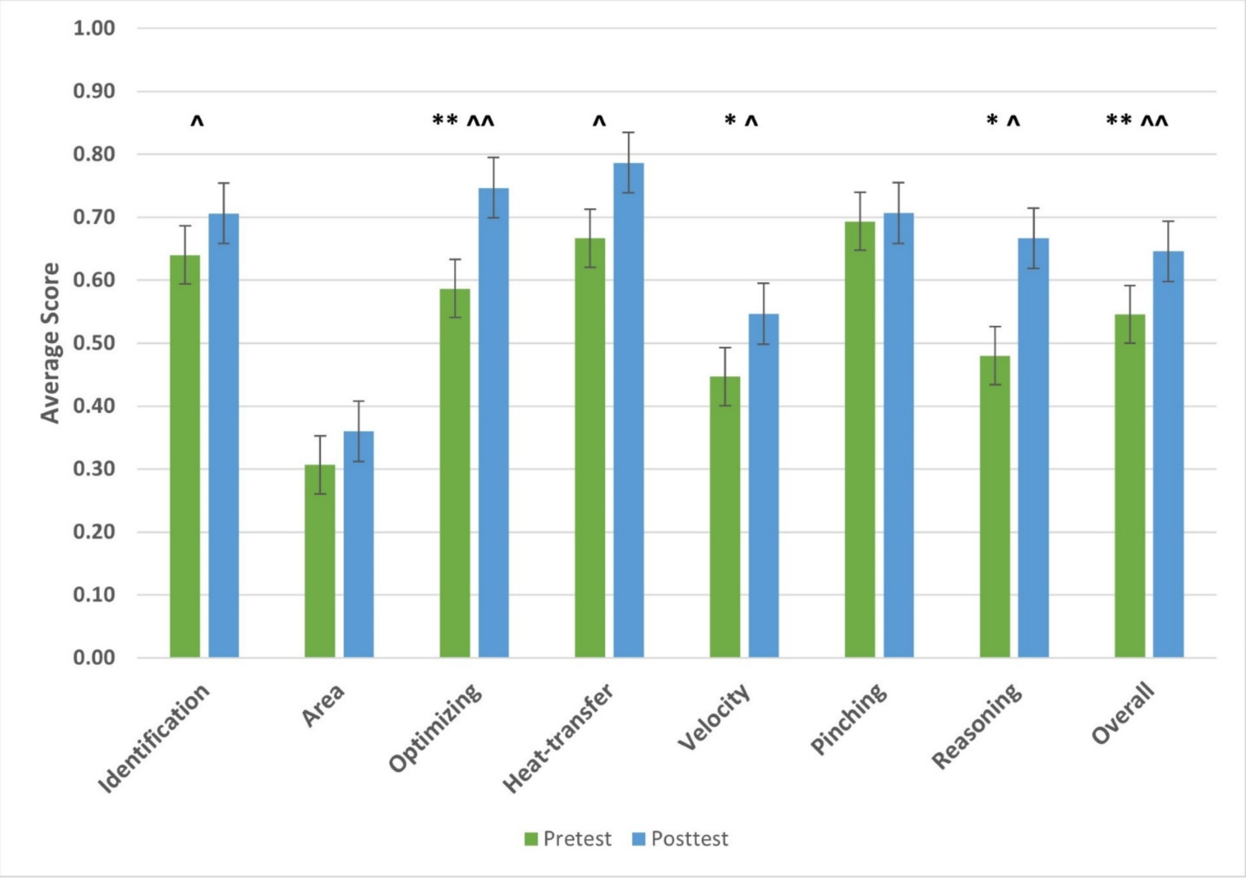

Figure 3: Comparison of pretest and posttest scores with statistical analysis (N = 75). '' means 0.05 < p-value < 0.01 and '**" means p-value < 0.01. '^' means 0.1 < effect size < 0.4 and '^^' means 0.4 < effect size < 0.8.*

Fluidized Bed Progress

When theoretical engineering principles seamlessly intertwine with real-world applications, a deeper comprehension of concepts emerges, facilitating more effective task performance. Consequently, the establishment of an interactive learning environment proves instrumental in enhancing student efficiency in acquiring knowledge. In undergraduate STEM education, the amalgamation of hands-on tasks with lecture content proves particularly advantageous. This integration proves invaluable in elucidating concepts related to fluid mechanics, fluidization processes, heat transfer, biomedical engineering, transport phenomena, and reaction engineering.

Fluidized bed processes play a crucial role in various industries, offering efficiency in chemical reactions, drying, and heat transfer. These dynamic systems involve the suspension of solid particles, transforming them into a fluid-like state when subjected to a gas or liquid at an adequate velocity. The resulting fluidized state enhances mixing, heat transfer, and contact between solid particles and reactants, leading to heightened reaction rates and overall process efficiency. Noteworthy characteristics include the capacity to regulate temperature uniformity, mitigate hotspots, and accommodate diverse particle sizes. These processes find application in combustion, catalysis, drying, and chemical synthesis, showcasing their versatility in industrial contexts.

In our ongoing efforts, we are developing an LCDLM focused on fluidization processes. Use of this educational tool is aimed at enhancing student understanding of the phenomena inherent in fluidization processes within classroom settings. Our focus began with our current simple fluidized bed process shown in Figure 4 where students work with packed and are fluidized beds. This year we shifted our focus to include designing fluidized beds with reactions that produce a color change to vividly illustrate the industrial utility of fluidized beds. In doing so we are prioritizing classroom safety through development of a non-toxic low temperature processes beginning with efforts to include enzyme reactions.

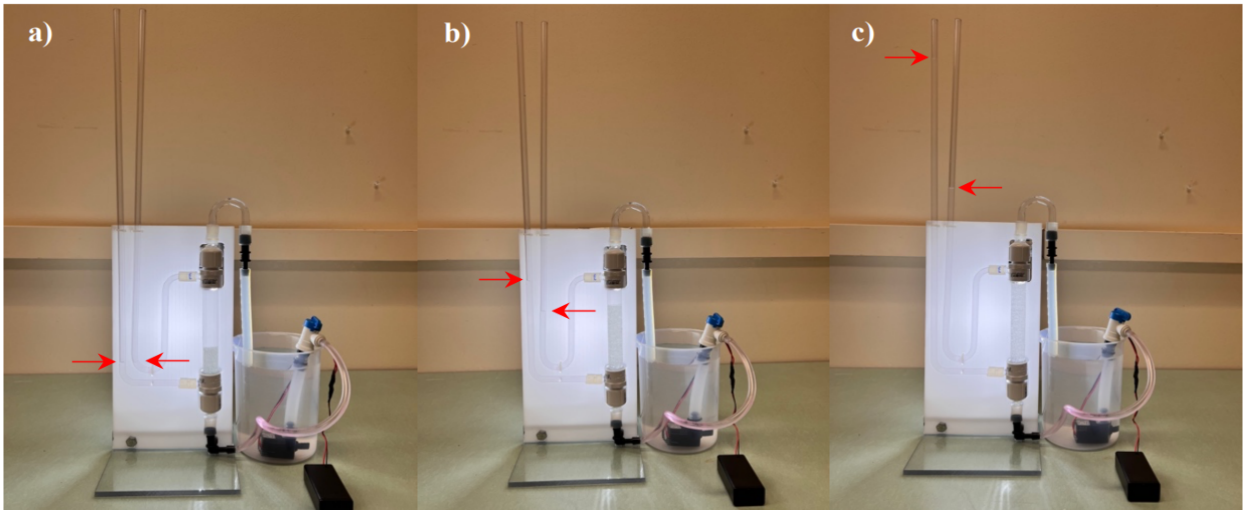

Figure 4: Fluidized bed prototype. The three frames show how the pressure changes across bed as the beads go from packed to fluidized states via the differential water heights in the manometer tube.

Glucose Analyzer Work in Progress

In addition to the fluidized bed and continuing the trend of incorporating chemical reactions into the LCDLM implementations, a recently proposed module is currently under development, with hopes moving toward a working prototype with anticipation of it being running by Summer 2024 ready for classroom implantation during the 2024-2025 academic year. The new module is meant to showcase the basic principles of spectrometry alongside introducing students to more complex topics like microfluidic flow behaviors and reaction kinetics. We expect to do this using a chemical reaction common in biomedical practice, the glucose oxidase reaction, which is used to show the concentration of glucose in blood samples for diabetics.

Figure 5 shows how the device will work in theory. Students will mix the sample of glucose with a reagent which will induce a color change related to the concentration. The colored sample will then be exposed to a light source, and the amount of light that gets through can be measured with a cellphone camera in the form of a color saturation value. Finally, using Beer's Law, students can construct a calibration curve, using the saturation values of an unknown provided in the kit.

The innovation with this LCDLM is that chemical solutions can be kept in low amounts, with only a few milliliters at most used per each measurement. To accomplish this, a single pass, microfluidics mixing chamber will be included in the kit to mix the sample and reagent together before exposure to the light source for measurement. The mixing mechanism will be included in the accompanying material, so students are aware of the differences between macro and micro-scale mixing.

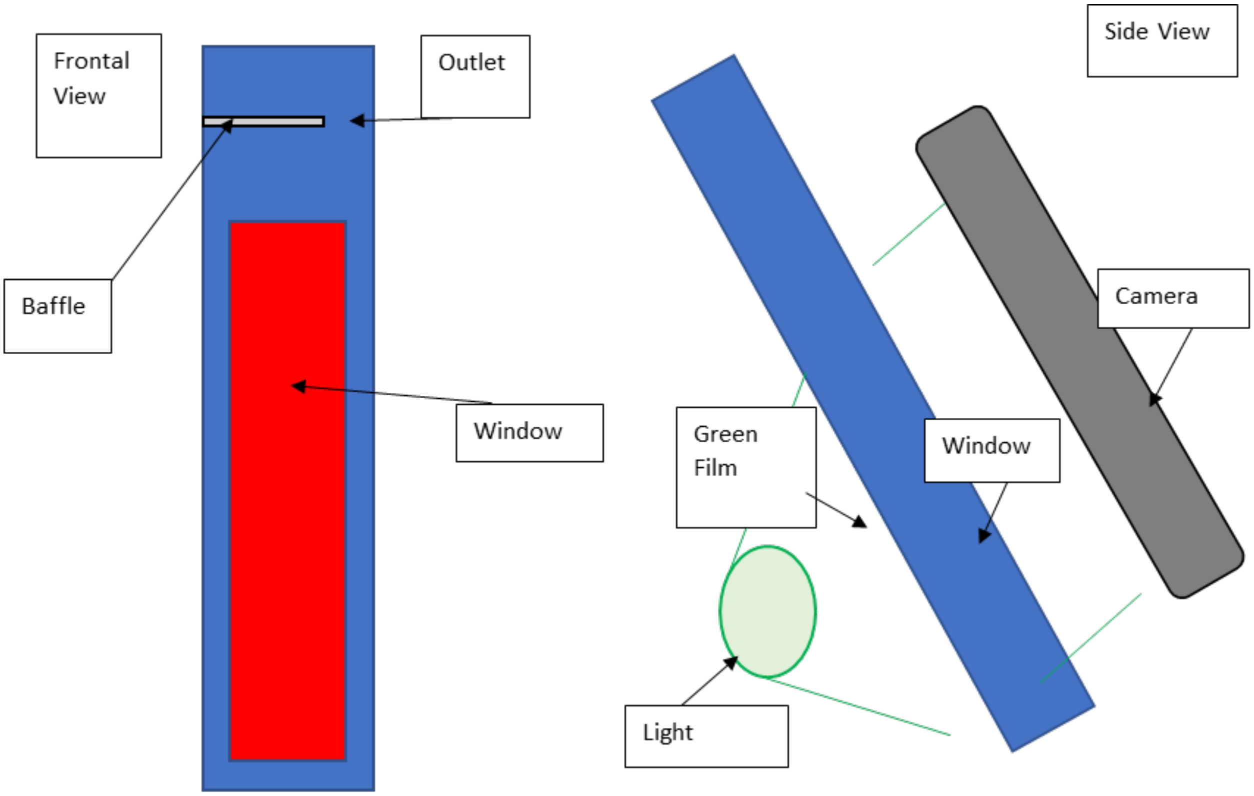

Figure 5: Glucose Analyzer overall concept. A cellphone camera is placed over a watch glass with sample inside. A green light is shown through the sample and absorbance detected.

Experiments and questions will also be included for students to discuss reaction kinetics, so students are aware of test limitations. Since the reaction is oxygen dependent, for example, the procedure will either need to include a dilution scheme such that the glucose in each sample does not consume all the available oxygen or an alternative kinetic reading, where students measure the rate at which the color change takes place over a given time interval.

CONCLUSIONS

The intention going forward with the project is to provide implementing instructors with the data and related debriefings showcased above, as well as to continue branching out to include other engineering topics with LCDLMs. It cannot be understated how critical the topics covered by the current LCDLMs are for prospective engineers to learn, as they are all meant to showcase mechanisms and concepts used in various industries today, from petrochemicals manufacturing to biopharmaceuticals. Thus, it is important to address any misconceptions students may have about these processes early on, such that they do not need to spend time relearning older topics during the later stages of their academic and industrial careers. The overall hypothesis behind this study is that providing students with a method of visualizing phenomena and working in groups to test and share hypotheses back and forth will enhance learning over and above that instilled by standard lectures. Thus far the data collected supports this hypothesis.

Project success is not solely dependent on the development of the LCDLMs but also how they are used in the classroom. While the efforts made by collaborators from other universities is greatly appreciated, going forward a more uniform approach to implementation is necessary not only to lower variability across different groups but to improve outcomes for students. In testing the LCDLMs, our aim is to assist students in learning the material, so through reasonable effort they will improve their learning experience. The intention in providing teachers with test results, trends, and feedback is to provide them with tools to implement the LCDLMs and incorporate the LCDLM activities into the larger curriculum more effectively, while also providing evidence of study credibility through transparency of information collected from their students. In the future, we would like to make this method of teaching more widespread with plans for mass production of LCDLMs for purchase by schools and institutions across the US and internationally. With that larger goal in mind, attempts to fine tune the implementation process are even more critical.

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