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Progress in the Nationwide Dissemination and Assessment of Low-Cost Desktop Learning Modules and Adaptation of Pedagogy to a Virtual Era

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Biosketch

Khan completed his B.S. and M.S. degrees in mechanical engineering from Bangladesh University of Engineering and Technology (BUET) in 2011 and 2014, respectively. He worked as an Assistant Professor at mechanical engineering department, BUET for 6 years. Currently, Khan is a Ph.D. candidate at Washington State University with multidisciplinary research including hands-on learning for STEM education, drug transport across blood-brain barrier, inverse techniques, deep learning and plans to pursue a teaching career upon earning his Ph.D.

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Progress in the Nationwide Dissemination and Assessment of Low-Cost Desktop Learning Modules and Adaptation of Pedagogy to a Virtual Era

The development of tools that promote active learning in engineering disciplines is critical. It is widely understood that students engaged in active learning environments outperform those taught using passive methods. Previously, we reported on the development and implementation of hands-on Low-Cost Desktop Learning Modules (LCDLMs) that replicate real-world industrial equipment which serves to create active learning environments. Thus far, miniaturized venturi meter, hydraulic loss, and double-pipe and shell & tube heat exchanger DLMs have been utilized by hundreds of students across the country. It was demonstrated that the use of DLMs in face-to-face classrooms results in statistically significant improvements in student performance as well as increases in student motivation compared to students taught in a traditional lecture-only style classroom. Last year, participants in the project conducted 45 implementations including over 600 DLMs at 24 universities across the country reaching more than 1,000 students.

In this project, we report on the significant progress made in broad dissemination of DLMs and accompanying pedagogy. We demonstrate that DLMs serve to increase student learning gains not only in face-to-face environments but also in virtual learning environments. Instructional videos were developed to aid in DLM-based learning during the COVID-19 pandemic when instructors were limited to virtual instruction. Preliminary results from this work show that students working with DLMs even in a virtual setting significantly outperform those taught without DLM-associated materials.

Significant progress has also been made on the development of a new DLM cartridge: a see-through 3D-printed miniature fluidized bed. The new 3D printing methodology will allow for rapid prototyping and streamlined development of DLMs. A 3D-printed evaporative cooling tower DLM will also be developed in the coming year.

In October 2020, the team held a virtual implementers workshop to train new participating faculty in DLM use and implementation. In total, 13 new faculty participants from 10 universities attended the 6-hour, 2-day workshop and plan to implement DLMs in their classrooms during this academic year. In the last year, this project was disseminated in 8 presentations at the ASEE Virtual Conference (June 2020) and American Institute of Chemical Engineers Annual Conference (November 2019) as well as the AIChE virtual Community of Practice Labs Group and a seminar at a major university, ultimately disseminating DLM pedagogy to approximately 200 individuals including approximately 120 university faculty. Further, the former group postdoc has accepted an instructor faculty position at University of Wisconsin Madison where she will teach unit operations among other subjects; she and the remainder of the team believe the LCDLM project has prepared her well for that position.

In the remaining 2.5 years of the project, we will continue to evaluate the effectiveness of DLMs in teaching key heat transfer and fluid dynamics concepts thru implementations in the rapidly expanding pool of participating universities. Further, we continue our ongoing efforts in creating the robust support structure necessary for large-scale adoption of hands-on educational tools for promotion of hands-on interactive student learning.

Introduction

The goal of this NSF IUSE is to catalyze inter-institutional STEM community transformation to create more experiential, effective, and engaging hands-on interactive learning environments. Our specific objectives are to: (1) implement a multi-hub and spoke model with dissemination hubs around the US reachinng out to approach regional instutitions (spokes) to facilitate the adoption of light-weight, portable, ultra-Low-Cost Desktop Learning Module (LCDLM) Equipment to enable understanding of the fundamentals of momentum, heat and mass transfer. The goal is to allow students to engage in an experiential hands-on systems to illustrate the physics that underlie transport processes and to understand how such thermal energy and momentum transfer concepts enable the development and use of associated equipment; (2) examine robustness of evidence surrounding improved learning and motivation, while also considering demographic factors, and community change associated with using hands-on interactive exercises, and to do so in a variety of instructional settings including a virtual mode of instruction during COVID-19 restrctions to academic content delivery; and (3) Reformat and develop new LCDLMs for testing and dissemination.

Major Accomplishments in Dissemination

Multi-hub Dissemination. We continue to complete our participation map illustrated in Fig. 1 propagating LCDLM use. A third dissemination workshop led by the PIs, three PhD candidates, a Master's student, and postdoctoral associate was conducted in October 2020 to cover the central and southern regions of the US east of the Mississippi with additional faculty participants who could not make prior dissemination hubs or whose hub was canceled because of Hurricane Dorian hitting North Carolina on the day of the scheduled workshop. Due to COVID-19 restrictions the hub was held virtually for two afternoons (Eastern time) and in total 13 new participants were added. Hub coordinators are now being given more responsibility and authority to coordinate efforts with their "spoke" participants, making contacts for the workshop, following up with e-mails and Zoom meetings held every semester to encourage greater interactions and discuss logistical issues. They solicit pre- and post-implementation forms and provide notifications for obtaining stipends. They do additional follow ups to make sure participants have done pre-assigned homework to set up and test the DLMs in preparation for the workshop – a requirement to receive a stipend for attending the virtual workshop. PhD students are taking responsibility for assistance during implementations and for collecting and analyzing data collected including pre- and post-test results and class motivation surveys. The workshop agenda is presented in Fig. A1 of the Appendix.

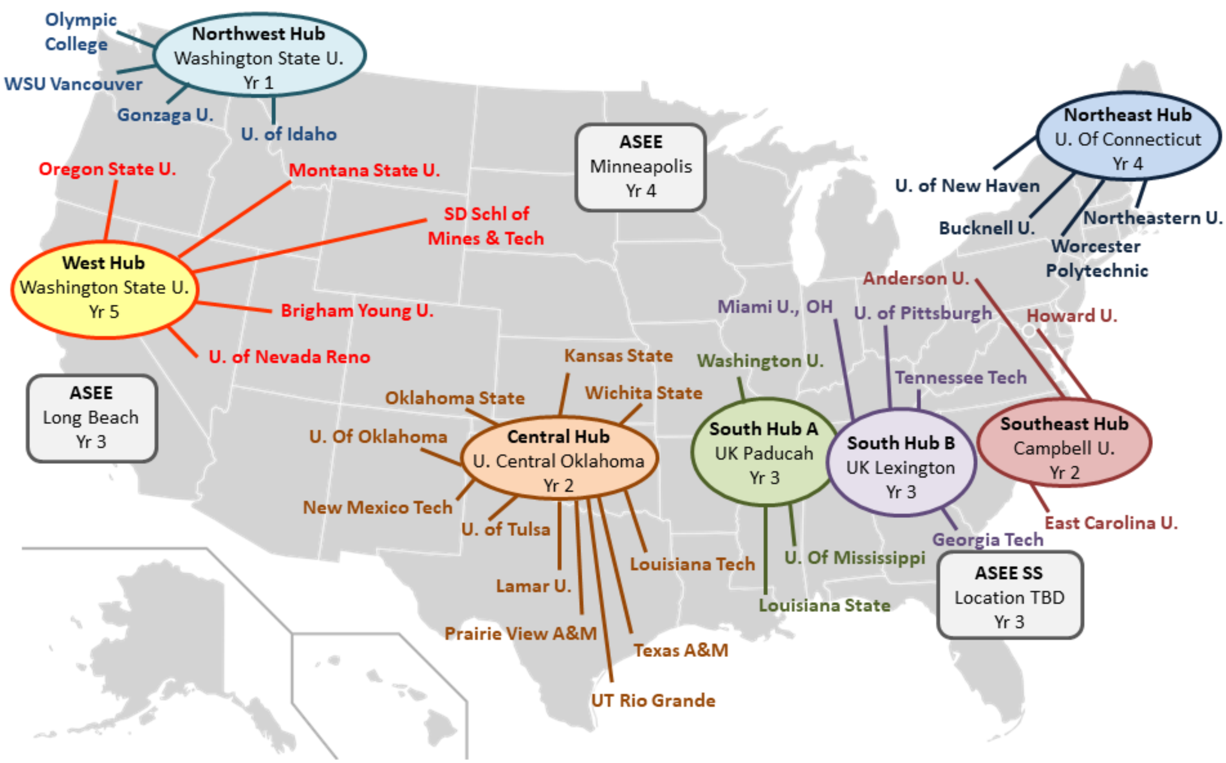

Fig. 1. Multi-year hub-based dissemination strategy. The Year 3 South A and B hubs and Southeastern hub participants were oriented during a October 2020 virtual workshop with new institutions implementing throughout the 2020-2021 academic year. WSU and Central hub participants introduced in Year 2 continued implementing through the year.

As stated, the workshop effort originally scheduled at [redacted] University for the Southeast Hub was re-envisioned. Our Campbell co-PI met with some of the regional participants and discussed key aspects for implementation. In many cases, she traveled to meet with the participants, and she met with one at the AIChE National Conference. For others she arranged to defer their attendance to the South Hub at the University of Kentucky as mentioned above. This highlights the strength of the regional hub approach and the ability for the regional host to adjust to unforeseen circumstances.

LCDLMs have now been successfully used in nearly 45 implementations at universities from five of regional hubs over the past three years. LCDLMs are now being used at 24 universities including the University of Kentucky Lexington and Paducah campuses, Washington University, Louisiana State University, the University of Mississippi, Georgia Tech. University, Tennessee Tech. University, the University of Pittsburg, Anderson University, Howard University, East Carolina University, Miami of Ohio University, Wichita State University, the University of Tulsa, the University of Dayton, Campbell University, UC Berkeley, Prairie View A&M, the University of Texas Rio Grande Valley, the University of Oklahoma, Lamar University, Central Oklahoma University, Texas A&M, Oklahoma State University, and the University of Connecticut. Well over 600 LCDLM sets have been distributed including hydraulic-loss cartridges, venturi meter and double-pipe heat exchangers. A shell & tube heat exchanger has been designed for near term manufacture to begin late spring and summer 2021.

Virtual Alternative Adjustment for COVID-19 Restrictions. The transition of all participating universities to virtual classrooms because of the COVID-19 pandemic afforded us the opportunity to conduct a comparative analysis between face-to-face vs. online implementation of DLMs which 10 of our faculty participants took part in. We note an NSF supplement request was granted for this effort. Graduate PhD candidates [redacted] and [redacted] developed implementation videos shown in Fig. 2 demonstrating the data collection process with the DLMs. Postdoc [redacted] supplemented these with additional videos covering key concepts that can be learned from using the DLMs. Videos were specifically designed to address common misconceptions and highlight the visual aspects of the DLMs. The videos were uploaded to the group website [redacted] and a group

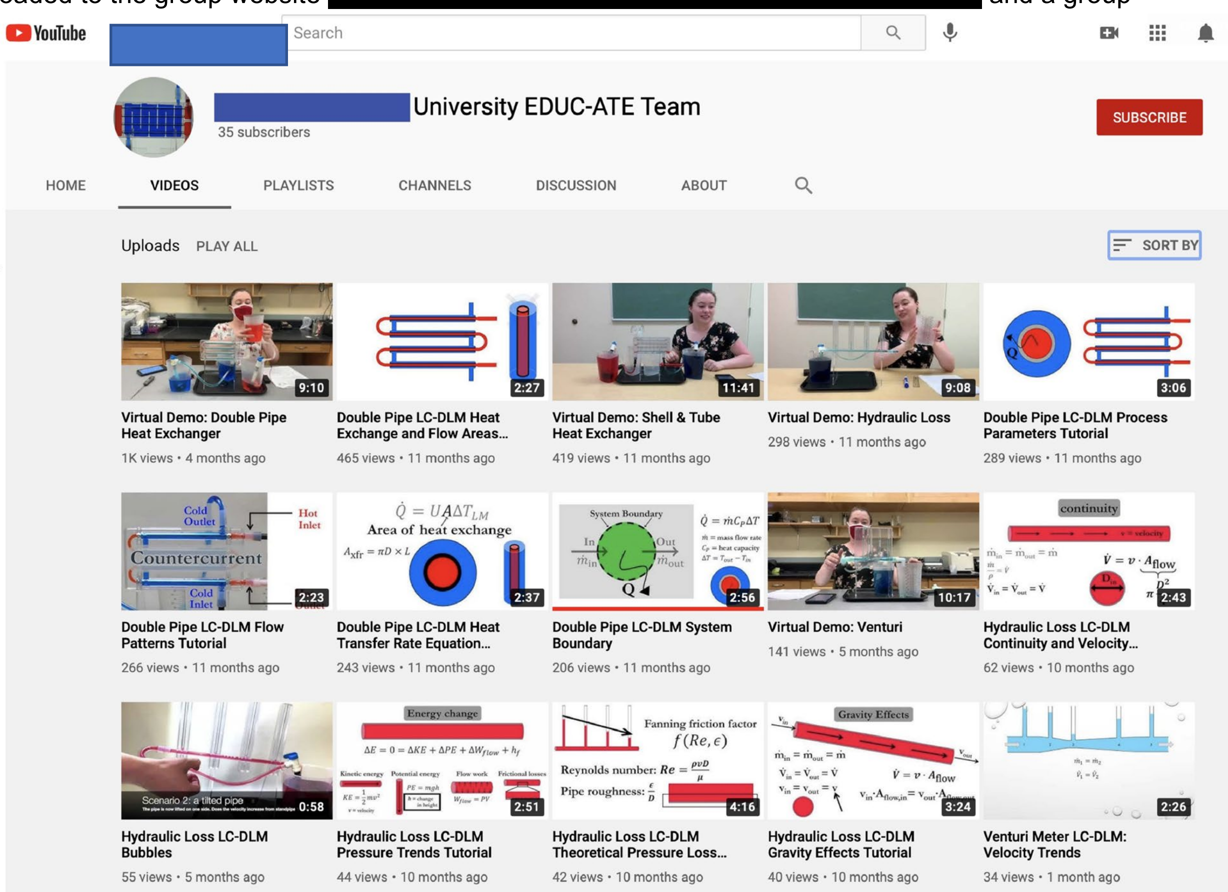

Fig. 2. YouTube channel virtual alternatives involving LCDLM demonstration videos and short 1-2 min narrated conceptual video supplementary materials to replace or augment the LCDLM pedagogy in this case for the hydraulic loss and double-pipe heat exchanger cartridges.

YouTube [redacted] was created to provide easy access of the instructional videos to all students and participants. We collected data from spring, summer and fall of 2020 and are collecting data in spring 2021 for a comparison manuscript.

Enhancement of Conceptual Learning Worksheets. Given assessment data, we redesigned worksheets in to enhance associated learning. Fig. 3 shows an example where instructions were clarified for use of the double-pipe heat exchanger showing clearly where entrance and exit ports are to be connected for quick assembly.

Experiment 2: Effect of Flowrate on Heat Transfer Rate

a) Rearrange the LCDLM setup to recycle the hot and cold water as shown below. Ensure the hot water outl tube is not submerged in the beaker
b) Position the thermometer so it will reach ***into the hot water exit stream,*** near the end of the exit tube.
c) Start flow for the hot and cold water (valves fully open). ***Note the temperature of the hot stream.***
d) Pinch the cold inlet tubing for ~5 sec to slow the cold flowrate. ***Note the temperature of the hot stream.***
e) Release the tube and ***note the temperature change*** after ~5 sec.
f) Turn off the pumps.

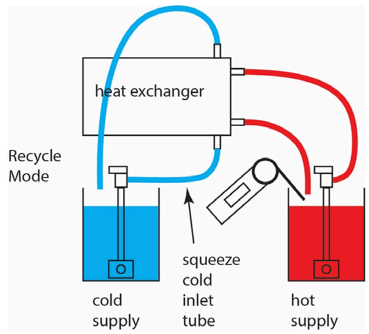

Fig. 3. Enhanced pictorial for arrangement of the double-pipe heat exchanger connections, pumps, and reservoirs, and taking of temperature readings.

Major Accomplishments in Learning and Motivational Assessment

Summary of Comparative Results for Virtual vs. Face-to-Face Hands-on Implementations. Fig. 4 illustrates, through average scores for responses on a five-question concept test, that learning through virtual implementations of the hydraulic loss LCDLM is on par with that for hands-on face-to-face implementation in the three cases studied so far. Results are both significant with p<0.005 and have medium to large effect sizes and more importantly averages are in the 75-80% correct range. Further analysis of fall 2020 and spring 2021 data will be presented at the ASEE Conference given there will be sufficient time post-spring 2021 semester to fully review and assess the comparative data gathered over the academic year.

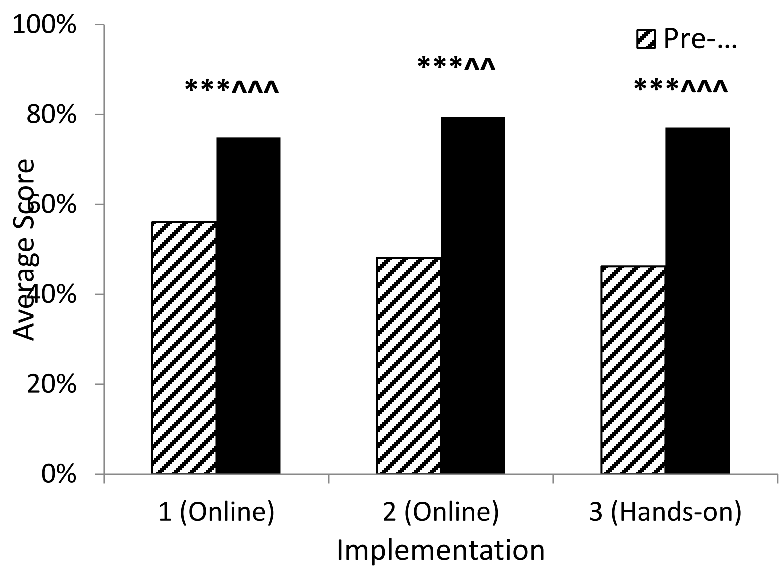

*Fig. 4. Posttests for the hydraulic loss LCDLM show improvements to an average 75-80% over pre-test scores in the 50-60% range on a five-question concept test with similar results for both virtual online LCDLM demonstrations or a face-to-face format. *** indicates p<0.005. ^^ and ^^^ indicate medium and large effect sizes.*

Motivational Assessment. Fig. 5 illustrates the overall percentage frequency of responses across all LCDLM implementations using the ICAP Framework. The results show that a high percentage of the participants remarked that the implementations promoted Interactive (62%), Constructive (69%) and Active (57%) forms of engagement. While 65% of the participants responded that exercises were not Passive. A breakdown of the frequency for each LC-DLM also showed similar results. While the face-to-face implementation responses were higher than virtual implementation, findings showed no significant difference between the face-to-face group and the virtual group.

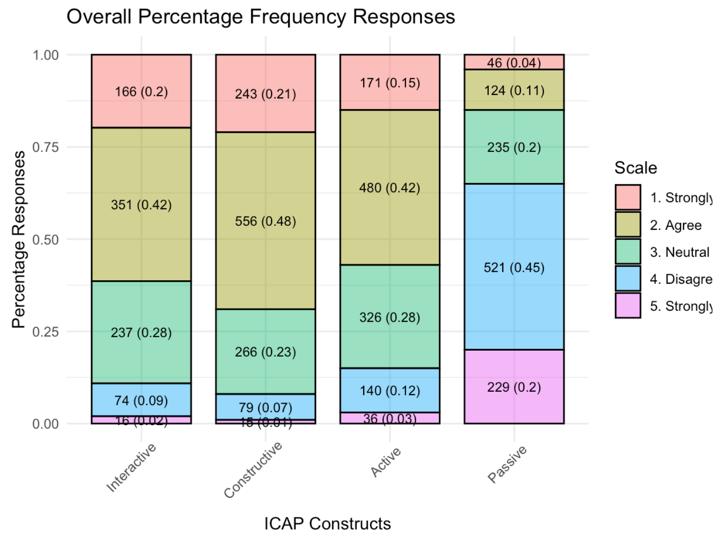

Fig. 5. Motivational Assessment using the ICAP framework for all LC-DLMs.

<u>Enhancement of Concept Pre- and Post-tests</u>. Based on results from the first two years of implementation we found several concepts for which we were not seeing improvements in performance for students using the LCDLMs. Much of this correlated to instances where there was a lack of visual representation of the concepts inherent in the equipment. To address this, we improved the worksheet exercises to clearly illustrate the concepts to be learned. An example is on student understanding of the areas important in double-pipe heat exchanger calculations. Fig. 6 (left) shows how we changed the worksheet so students can easily discern which areas should be used for determining fluid velocities, those of the annular (cold side) and those of the tube-side (hot side) cross sections, as well as the external tube area for through which thermal energy is transported. A corresponding test question is being used (right) to assess the impact of the improved worksheet. These results are being analyzed and will be presented at the 2021 ASEE Annual Conference in Long Beach, CA. All pre- and posttests are given on Qualtrics with specific links for each instructor implementing to make data analysis straightforward. Data are de-identified before analysis and for most institutions the data are exempt from needing IRB approval though on-line consent forms are still provided so that deidentified data can be published.

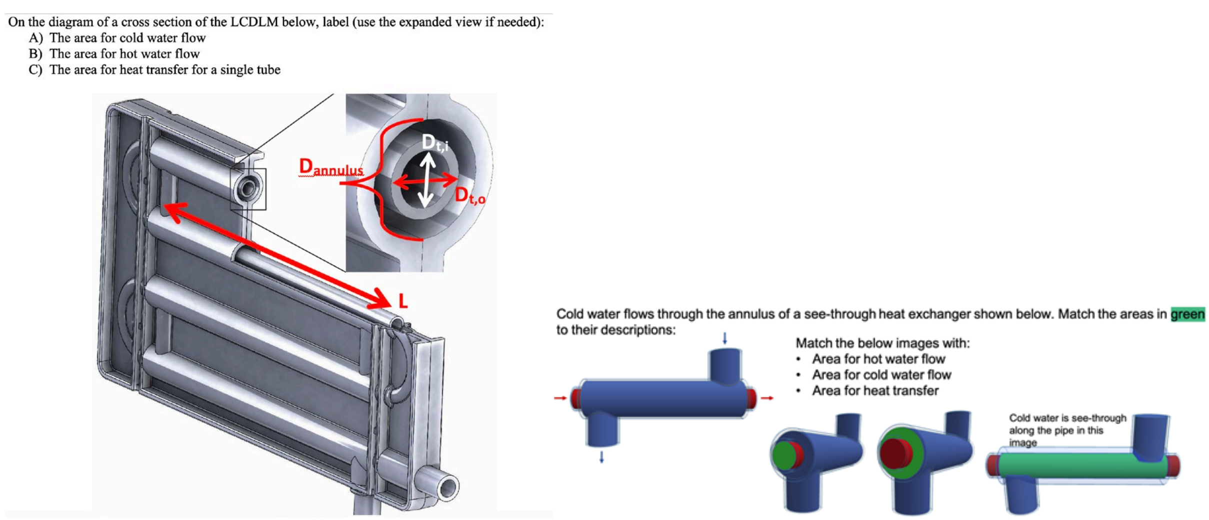

Fig. 6. Left: Enhanced pictorial for determination of the correct cross-sectional areas tube and annular side flows and for the heat transfer area. Right: Modified posttest question to assess the understanding of the varied areas used in double-pipe heat exchanger calculations.

Major Accomplishments Regarding New LCDLMs and Reformatting

Shell & Tube Heat Exchanger. An mold has been designed and fabrication process developed for an injection molded shell & tube heat exchanger that will consist of two adjacent halves in which a vertical set of four tubes will be laid into one half and the top half glued into place, sealing around the ends of the tubes. Prototypes made from machined halves show the fabrication technique will succeed. Undergraduate students are being employed to perform the fabrication work.

Fluidized bed. We have a SOLIDWORKS and preliminary 3D printed version of a fluidized bed design as shown in Fig. 7. Discussions are underway with a community college with considerable emphasis on 3D printing technology training to make a transparent waterproof version.

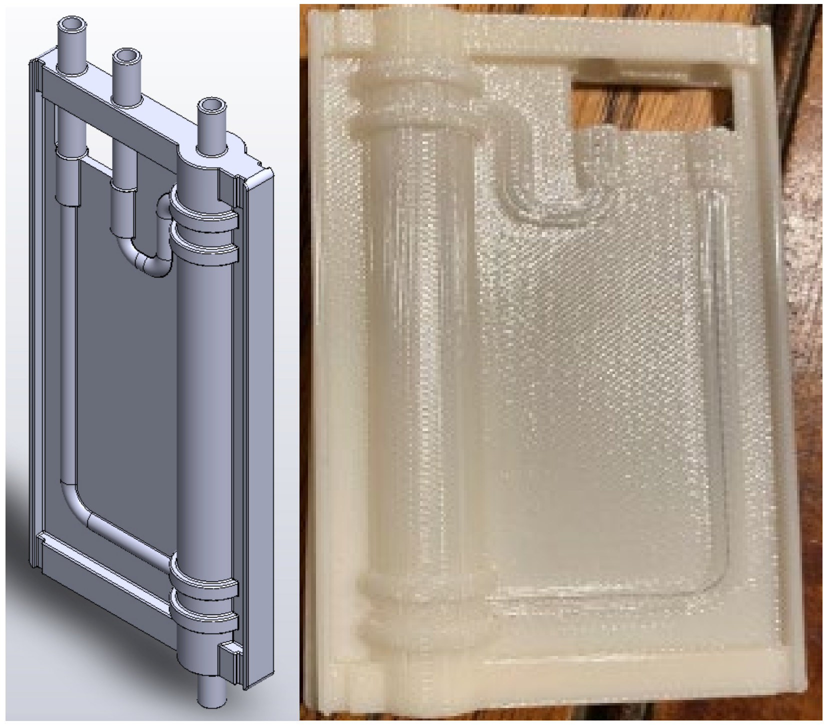

Fig. 7. SOLIDWORKS CAD of a fluidized bed and preliminary 3D printed version.

Biomedical Engineering Applications. A university supplement grant was acquired by two female PhD students on the project to extend LCDLM use into a medical context. Two biomedical engineering LCDLMs are being designed, each shown in Fig. 8, one for representing cell separations and another for an aneurysm in a blood vessel. The aneurysm design is not showing enough of a pressure increase at the center due to flow stream jetting in the system; therefore, we are designing an aneurysm around a bend to make sure that a stagnation pressure is reached for one of the entrant flow streams of high kinetic energy. The current fidget spinner is being replaced by a longer column so students can better visualize the differential sedimentation patterns. As anticipated the larger beads, which represent white blood cells, settle fastest in a dilute suspension, however, in a dense suspension due to hindered setting their settling velocities are on par with those of the simulated red blood cells (red beads). These two units will be implemented in freshmen engineering classes and are intended for assessment of piquing the interest of female chemical engineers who may have a more compassionate orientation such as the application of chemical engineering principles in the field of medicine.

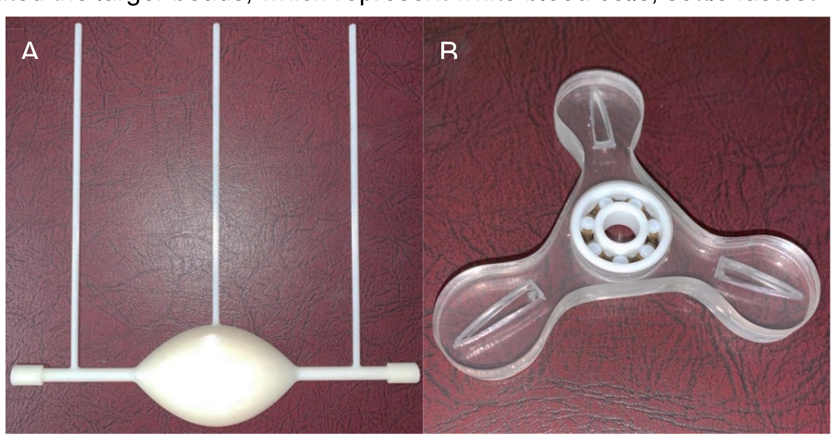

Fig. 8. Biomedical engineering cartridges. A) 3D printed mold for vacuum forming over the top to make a representation of an aortic aneurysm. Fidget spinner to hold small micro centrifuge tubes containing red and white beads to represent differential separation of blood cells.

Broader Impacts

Use of LCDLM and associated activities will transform engineering education in the momentum, heat and mass transfer realm. We are disseminating the pedagogy through a regional hub-based approach with five workshops at five institutions across the US as well as through ASEE Workshops and the ASEE Chemical Engineering Division Summer School. Our target audience is middle year undergraduate students spaning a broad range of institutions including those with a strong research focus to those serving predominantly undegraduates. We are including major public, HBCU, Hispanic serving and private institutions to include at least seven EPSCoR states. A hub-cordinator, web-based, campus visit, and hot-line support structure are in place to ensure quality and uniform implementation. Findings are intended for dissemination in in the top-tier journals, e.g., the *Journal of Engineering Education*, *International Journal of Engineering Education*, *Instructional Science*, *Chemical Engineering Education*, and through national and international conferences, e.g., ASEE, FIE, AICHE and ASME. Two female PhD candidates are being trained, as well as two interantional students, a PhD candidate from Bangladesh and an MS student from Nigeria. One ethnic minority and one female professor are intimately involved in the research.

Acknowlegements

The authors acknowledge support through the NSF IUSE #[redacted] and supplement for contrasting the impact of virtual vs. face-to-face implementations. The efforts of undergraduate team to manufacture the LCDLMs, students and faculty implementers are also greatly appreciated.

Appendix – Figure A1

AGENDA

EDUC-ATE Educating Diverse Undergraduate Communities – Affordable Transport Equipment Workshop Outline

OCTOBER 1, 2020

START TIME	END TIME	ITEM	SPEAKAER
2:00pm	2:30pm	Welcome; Introductions	[redacted]
2:30pm	2:45pm	Orientation	[redacted]
2:45pm	3:15pm	DLM Construction & Implementation Design Philosophy and Q&A	[redacted]
3:15pm	3:45pm	Instructional Philosophy	[redacted]
3:45pm	4:00pm	Break	
4:00pm	4:55pm	LC-DLM Set I: Breakout groups based on hub	Hub Coordinators
4:55pm	5:00pm	Closing	[redacted]

*Note: For day 2, please come with DLMs setup and prepared

OCTOBER 2, 2020

START TIME	END TIME	ITEM	SPEAKER
2:00PM	2:10PM	Welcome to Day 2 – brief discussion of activities	[redacted]
2:10PM	2:35PM	Fluids DLMs Session	
2:35PM	2:45PM	Debrief / Questions	
2:45PM	3:05PM	LC-DLM Data: The kinds of data you can take / logistics	[redacted]
3:05PM	3:15PM	Break / setup DLMs	
3:15PM	3:40PM	Heat Transfer DLMs Session	
3:40PM	3:50PM	Debrief / Questions	
3:50PM	4:20PM	Student Motivational Interest	[redacted]
4:20PM	4:40PM	Support: FAQs & Faculty/Student RA Hotline;	[redacted], Hub Coordinators
4:40PM	4:50PM	Post workshop survey	[redacted]
4:50PM	5:00PM	Closing	[redacted]