Nationwide Dissemination and Critical Assessment of Low-Cost Desktop Learning Modules for Engineering: A Systematic, Supported Approach

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Biosketch

Aminul Islam Khan has received BSc and MSc in Mechanical Engineering from the most regarded and reputed engineering university of Bangladesh, Bangladesh University Engineering and Technology (BUET). In his BSc degree, he had received the department Gold medal because of his outstanding results.

Aminul Islam Khan has joined to BUET in 2011 as a Lecturer in Mechanical Engineering Department. In 2015, he has become an Assistant Professor in the same department of BUET. In 2016, he has joined to School of Mechanical and Materials Engineering of WSU as a PhD student. From that time, he has been working as a Research Assistant. As a research assistant, he has been working to improve learning in undergraduate engineering education along with his scientific research.

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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 36 years and for the past 22 years has focused on innovative pedagogy research as well as technical research in biotechnology. His 2007-2008 Fulbright exchange to Nigeria set the stage for him to receive the Marian Smith Award given annually to the most innovative teacher at WSU. He was also the recent recipient of the inaugural 2016 Innovation in Teaching Award given to one WSU faculty member per year.

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Abstract

Effective, organized dissemination and assessment of learning tools designed to address common misconceptions and foster learning in engineering courses is crucial. It has been widely shown that students engaged in active learning perform significantly better than those learning passively. Thus, there is currently a movement toward the use of active learning in the classroom. In the current paper, we report on an NSF Improving Undergraduate STEM Education (IUSE) project that seeks to complement the national efforts. We have developed Low-Cost Desktop Learning Modules (LC-DLMs) which replicate industrial equipment on a small scale and can be used in traditional classroom settings to display fundamental mass and heat transfer concepts in a highly visual format. Studies with existing venturi meter and hydraulic loss LC-DLMs show statistically significant improvement in performance, especially at higher Bloom's levels of evaluate and create, as well as positive impacts on motivation and self-efficacy for students exposed to the LC-DLM intervention versus those taught fluid mechanics concepts in a lecture-based format. This supports the hypothesis that use of LC-DLMs fosters deeper conceptual understanding.

Based on these results, we are continuing to explore the benefit of LC-DLMs by engaging in a national dissemination effort which will allow a more critical assessment of LC-DLM impact across a wide demographic base. We have begun distributing existing LC-DLM cartridges to institutions nationwide, including minority serving colleges and those located in Established Program to Stimulate Competitive Research (EPSCoR) states, and will continue to expand the dissemination effort over the next several years. Dissemination will be supported with a web-based hotline structure, video tutorials, and worksheet and assessment materials. Additionally, seven regional hub-based workshops over five years, beginning with a workshop for hub coordinators in March 2019, will serve to educate faculty on appropriate use and implementation of LC-DLMs in the classroom, foster local interest, and catalyze the spread of LC-DLMs. Finally, additional LC-DLM cartridges including a miniature fluidized bed and cooling tower are in development. Through these efforts, we hope to gather and critically assess a multitude of evidence supporting the ability of LC-DLMs to improve undergraduate student performance as well as provide the complex support structure required for large-scale adoption of hands-on learning tools encouraging active, collaborative learning in engineering classrooms.

Introduction

It is well-established that teaching pedagogies which foster engaged, active learning result in students who outperform those taught using teaching styles which encourage purely passive learning [1-3]. Learning can be categorized into several distinct modes of engagement including interactive (I), constructive (C), and active (A) learning, as well as passive (P) learning according to Chi's ICAP hypothesis [4]. The ICAP hypothesis suggests that interactive engagement, which encourages students to interact with their peers or technology in a constructive, discussion-based manner, results in the largest learning gains, though all active modes of learning lead to improved student performance compared to passive learning [1, 4]. Further, use of visual aids allow students to form a permanent mental image of systems, freeing up working memory processing space for other, more complex conceptual interactions and keeping overall cognitive load low [5]. Considering both these theories, there is a clear need for an increased number of visual, interactive modules in chemical engineering (ChE) and mechanical engineering (ME) classrooms to aid in student understanding of fundamental concepts.

Our group has therefore designed numerous ultra-low-cost, hands-on learning instruments called Low-Cost Desktop Learning Modules (LC-DLMs) including a hydraulic loss pipe system, venturi meter [6, 7], a double pipe and a shell and a tube heat exchanger [8], and a boundary layer visualization system [9]. The LC-DLM cartridges were constructed using inexpensive vacuum-forming and 3D printing techniques and are highly visual and interactive, allowing students to see trends in pressure, flowrate, and fluid paths, as well as manipulate and measure flow rates and temperatures while collaborating with their peers. Due to their compact size, less than 10 by 10 inches for most modules, LC-DLMs have been employed in a variety of classroom orientations including traditional classrooms containing tablet arm chair desks and larger laboratory spaces. Compared to traditional laboratory teaching equipment, LC-DLMs are simple to transport, construct, and deconstruct. Examples of current vacuum formed LC-DLM cartridges formed over 3D printed molds are shown below in Figure 1.

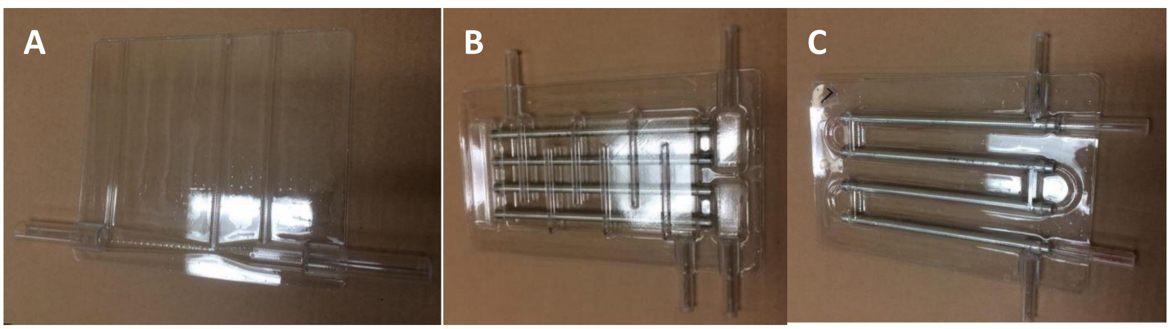


Figure 1: LC-DLM cartridges including the A) venturi meter, B) shell and tube heat exchanger, and C) double pipe heat exchanger all constructed via 3D printing and vacuum-forming techniques.

Previous implementations with LC-DLM cartridges indicate that significant improvements in conceptual understanding and, thus, student performance, occur after exposure to LC-DLMs. For example, after using venturi meter DLMs, students enrolled in a junior level Fluid Mechanics and Heat Transfer course showed statistically significant improvements in performance on several assessment questions addressing velocity and pressure profiles in a venturi meter compared to their peers, who learned concepts in a traditional lecture-based setting [10]. The current IUSE project, initiated in fall 2018 seeks to expand the use of LC-DLM cartridges to other universities and colleges as well as continue to evaluate the effectiveness of LC-DLMs for addressing common misconceptions and improving student performance. The following four major areas are addressed in the project:

1) ***Dissemination*:** Provide existing LC-DLM cartridges to a diverse pool of universities and colleges throughout the United States through a regional hub-based workshop approach;

2) ***Support*:** Develop a web-based hotline and an LC-DLM video tutorial series accessible to students and professors, and provide LC-DLM worksheets and rigorously vetted assessment materials;
3) ***Assessment*:** Evaluate the effectiveness of LC-DLM cartridges by comparing student performance before and after intervention, and assess implementer attitude towards modules and success using them in their classrooms;
4) ***Module Development*:** Improve the LC-DLM manufacturing process and develop new LC-DLM cartridges including a fluidized bed and evaporative cooler to expose students to additional fluid mechanics and heat transfer concepts.

Work has begun on each of the four major areas described above. The first LC-DLM dissemination workshop was held in March 2019 and we expect to collect the first set of preliminary results from LC-DLM classroom implementations outside our own institution in fall 2019. This paper addresses the work completed, in progress, and planned for each of the four project areas.

Dissemination

Broad dissemination across geographically, academically, and culturally diverse universities is critical for accurate evaluation of the overall effectiveness of LC-DLM cartridges and their ability to promote learning gains. To facilitate effective dissemination to a large number of institutions, a unique hub-based system has been devised. Dissemination of the LC-DLM modules is focused around seven national hubs, all of which have faculty members experienced with LC-DLM technology and implementation. To date, 46 universities and programs represented by 48 faculty members, excluding the project PIs, have been recruited to participate in the LC-DLM dissemination effort. This includes one two-year college, 13 universities in EPSCoR states, and three minority serving institutions.

In a study by Hazen, et.- al., logistical issues were identified as one of the most common dissemination challenges during a systematic content review of over 400 poster abstracts of projects funded through the NSF Course, Curriculum, and Laboratory Improvement (CCLI) or the Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES) programs [11]. Approximately 8% of the dissemination projects were negatively impacted by logistical issues which arise due to communication or participation problems stemming from geographical separation between technology developers and implementers. The dissemination strategy utilized for this project uniquely overcomes this challenge by organizing dissemination by separate geographical hubs; in this way, implementers will receive critical local support and encouragement from trained regionally embedded champions during implementation. Figure 2 shows a map of the current hub locations, participating institutions (color coordinated by hub) who have already committed to participating in the LC-DLM dissemination study, and ASEE workshop locations.

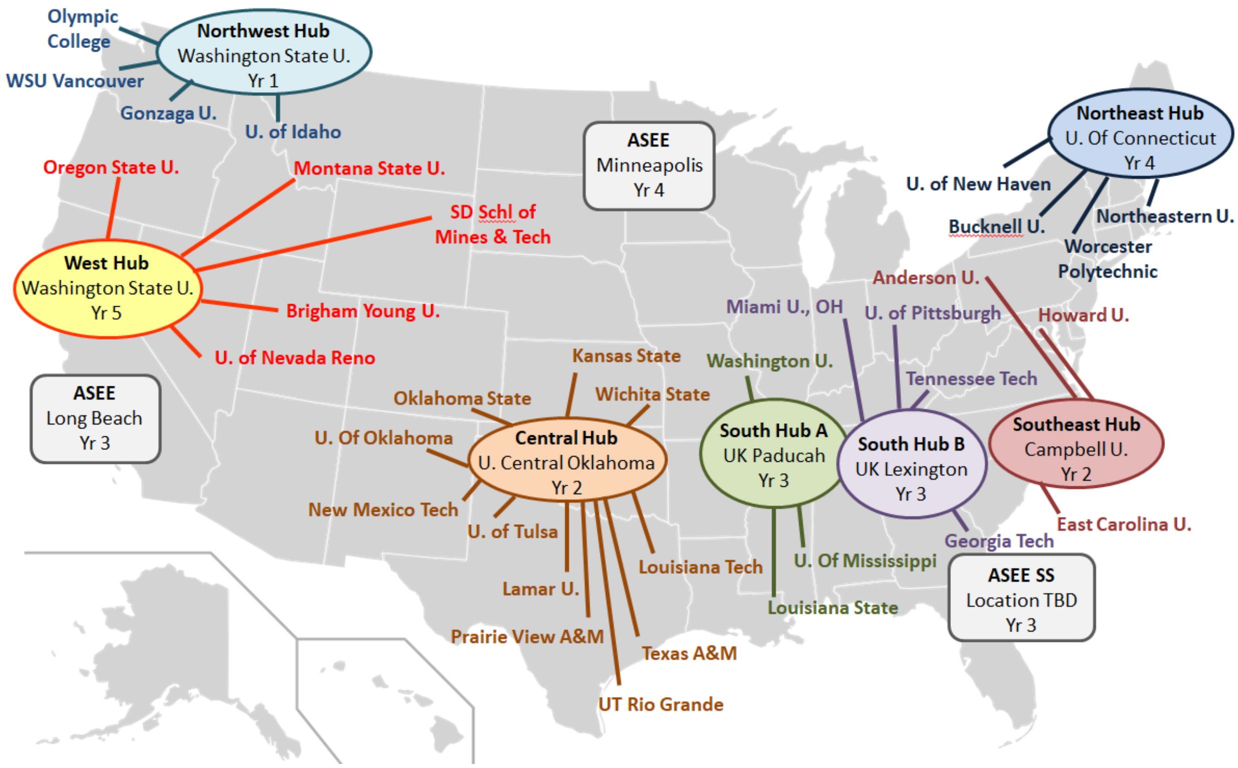


Figure 2: Current hub locations, committed institutions participating in LC-DLM dissemination and assessment efforts, and ASEE workshop locations. Hubs, shown as ovals, include hub institution, grant year in which dissemination workshop will occur, and local institutions connected to the hubs. Workshops to be held at ASEE conferences are also shown

The LC-DLM modules will be distributed through dissemination workshops held at each national hub over five years and directed by local hub coordinators. The first modules will be distributed after the Year 1 workshop for hub-coordinators which occurred in March 2019. Attendees will be among the first implementers of LC-DLM cartridges including head loss, venturi, and double pipe and shell and tube heat exchanger modules in spring 2019. The hub-coordinators will therefore become highly experienced implementers before transferring their knowledge to the second wave of implementers at other participating institutions in their respective hubs, and they will also drive the expansion of local interest in LC-DLM use. In this way, dissemination of the LC-DLMs will be organized and highly effective given that all implementers will receive extensive hands-on training before implementation. Workshops will also be held at the ASSE National Conferences in 2021 and 2022 and ASEE CHED Division Summer School (ASEE SS) in 2021 where faculty not previously committed to the project may receive training, find out how to build their own modules, and learn about ways they can purchase LC-DLM modules as we expect there will be a commercial supplier by then. In summary, dissemination efforts are focused on regional distribution efforts to 48 institutions and/or programs through a workshop-based approach where we will seek to train all implementers before LC-DLM implementation.

Support

LC-DLM module support is divided into two major areas. First, pre- and post-test assessment materials are provided to implementers in a web-based format using the Qualtrics platform to allow them to quantitatively evaluate differences in student performance on key course concepts before and after LC-DLM implementation. To provide quality questions at various Bloom's levels, our team used the multi-step question development process shown in Figure 3. Briefly, questions and answers were developed by individual team members; pooled and evaluated by the team for quality and relevance to course concepts and sorted by Bloom's taxonomy level; vetted in a survey taken by junior and senior undergraduate students who were asked to answer the questions, rate how well they understood what we are asking in the question on a Likert scale, and participate in a discussion where they put forth proposed improvements to the questions and answer choices; and finally, edited based on student feedback.

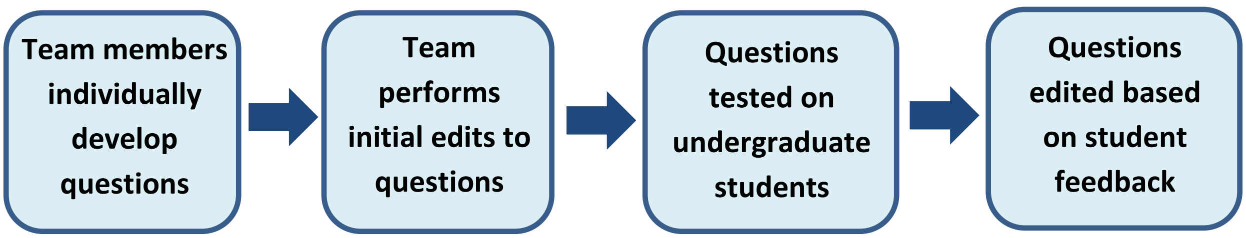


Figure 3: Question development process used for pre-and post-test assessment creation.

This question development process allows us to distribute high quality questions at a variety of Bloom's levels, focused on concepts addressed when using LC-DLMs. Structuring the assessment by Bloom's level, where low levels correspond to aspects of non-abstract learning such as remembering and understanding and high levels correspond to complex and high level learning aspects such and evaluation and creation [12] will allow us to discern where use of LC-DLMs has the greatest advantage over lecture. We hypothesize that use of vigorously vetted assessment questions will allow more significant differences between pre-and post-test performance to be observed, due to the fact that vague, confusing, and visually or textually overwhelming questions will have been eliminated from assessments. More details and results from our question development and validation process will be provided in a second ASEE paper, "Development of Bloom's Level Graduated Instrument for Assessing Transport Concepts in Hands-on Learning" by IUSE team co-authors.

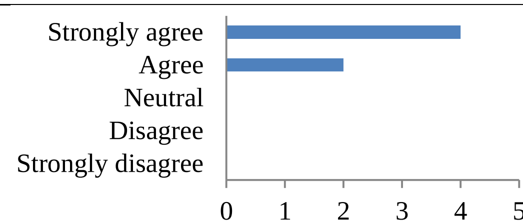
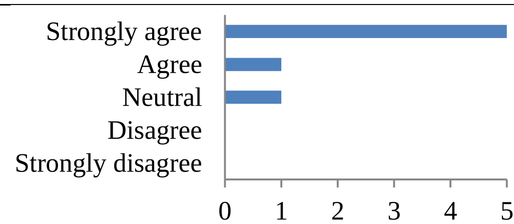
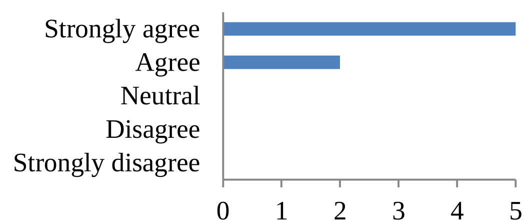
Pre-and post-test materials will be provided through a detailed website containing other support materials, including video tutorials demonstrating module use, a frequently asked questions page, and worksheet materials that can be used during LC-DLM implementations. Our rationale is that students who use the website to familiarize themselves with the LC-DLM modules before arriving to class will be prepared for module use and associated learning. We will encourage faculty to utilize the website to obtain worksheet material and obtain real-time support via the hotline system should any problems arise during LC-DLM implementation. Worksheets will be specifically written to allow completion within a 50 minute class period and will be geared towards encouraging interaction and discussion between peers as well as manipulation of the

LC-DLM systems. Work has begun on website development and preliminary materials are posted online for faculty, workshop attendees, and students.

Assessment

This project is focused on several assessment strategies for identifying the effectiveness of LC-DLM technology. Broadly, we wish to evaluate faculty and student attitudes towards the use of modules as well as determine technology impact on student performance related to core engineering concepts such as heat and mass transfer and fluid mechanics. The impact of LC-DLM implementations on faculty will be evaluated by the following methods: 1) surveys and focus groups following implementation workshops, 2) post-course surveys addressing detailed aspects of LC-DLM implementation and possible barriers to effective dissemination, and 3) logs and records documenting implementation strategy and time spent outside of the classroom preparing for LC-DLM implementation. Using these three approaches, we will thoroughly evaluate faculty attitudes towards the use of LC-DLM modules, discern whether any barriers exist which discourage faculty from adopting the technology, and improve implementation guidelines to optimize faculty workloads and use of class time. Faculty who have already implemented the LC-DLMs recently completed a 13 question survey containing Likert-scale questions focused on factors identified as some of the most common barriers to implementation including adaptability, relative advantage, management support, and complexity [11]. Table 1 below shows several examples of responses to questions on the faculty survey.

Table 1: Examples of questions used on faculty survey, dissemination barrier addressed by question, and faculty response

Question	Barrier(s) Addressed	Response (N = 7)
LC-DLM ease of use helps with the understanding of course concepts*	Complexity Relative advantage	
Flexibility in how a faculty member chooses to use the DLMs, e.g., in the classroom, lab, or as a take-home unit makes the system adaptable to philosophy of teaching	Adaptability	
I have support for the use of novel teaching practices such as using DLMs from my administrators	Management support	

*One faculty member provided no response to this question, therefore *N=6* for this question only.

As can be seen from Table 1, faculty members responded positively to the use of LC-DLM cartridges in their classroom with the majority agreeing that the modules are easy-to-use, offer students a valuable tool to understand course concepts, are adaptable to a variety of uses inside and outside the traditional classroom, and are supported by their university administrators. Future surveys will continue to address the most common barriers to implementation to identify whether faculty feel that the technology could be improved to allow for easier adoption. We recently collected responses from surveys and focus groups conducted during the first implementation workshop. We will use these results to tailor future workshops to better suit faculty needs and expectations. We also expect to collect log notes and data on faculty workload for the first implementations which will be completed by fall 2019, but preliminary data will be available by spring 2019. Portions of this data will be included in the poster presentation.

While we are focused on optimizing the LC-DLM implementation and assessment strategies for widespread adoption using results from faculty assessments, we wish to instead focus on evaluating to what extent the LC-DLM modules improve student academic performance and motivation during student assessments. During each implementation, students will participate in pre-tests, taken before LC-DLM implementation or lecture-based introduction of course concepts, and post-tests, taken after implementation. We seek to evaluate performance improvements after LC-DLM use as well as compare the performance of students exposed to LC-DLMs to students taught the same concepts in a traditional lecture setting. A recent study with DLMs suggests that performance is most improved at higher Bloom's levels of learning including the levels of analyze, evaluate, and create for groups exposed to LC-DLMs, while performance at the basic levels of remember, understand, and apply is generally comparable to students exposed to lecture only [10]. We seek to examine the robustness of these findings at multiple, diverse universities in several courses in the current project. Additionally, student motivation and self-efficacy will be evaluated using the Motivated Strategies for Learning Questionnaire (MSLQ) after LC-DLM use to determine whether the modules foster improved motivation to learn engineering concepts and improved self-efficacy, defined as one's beliefs about their ability to perform engineering-related tasks. We hypothesize that LC-DLMs, because of their interactive nature, will result in increased student motivation and improve student confidence in their ability to solve engineering problems by allowing them to explore complex physical phenomena in a visual format. We expect to collect the first results from motivation surveys and pre-and post-test assessments at exterior universities in fall 2019.

Module Development

The final focus of this project is to improve the manufacturing process for existing LC-DLM cartridges as well as design and manufacture two new modules: an evaporative cooler and fluidized bed. Work has begun on the improvement of the manufacturing process. Previously, 3D printing was used to form a solid mold of fluid mechanics or heat exchangers modules; then thin plastic was vacuum-formed over both sides of the mold, creating two mirrored pieces. Finally, the pieces were glued together using a two-part adhesive. Several problems existed with the previous manufacturing technique. Most two-part adhesives have a very short working time of approximately five minutes. Thus, for more complex modules such as the double pipe and shell and tube heat exchangers containing both plastic shells and metal tubes, applying the required adhesive to all portions of the module within the adhesive working time is extremely tricky. Therefore, even experienced assemblers often applied an incomplete layer of adhesive which led to leaks or failures in nearly 50% of assembled modules. Due to these shortcomings, we have developed a new technique for LC-DLM manufacture which makes use of injection molded parts and UV-cured adhesives. The use of injection molding allows more precise control of module size and shape compared to vacuum-forming, which sometimes results in deformed plastic shells due to varying vacuum pressure along the length of the mold. Additionally, the use of UV-cured adhesives will allow assemblers to spend as much time as required applying the adhesive before adhesive curing via UV light. In addition, UV adhesives fluoresce under UV light, allowing assemblers to identify any gaps in the adhesive coating before curing the adhesive. A comparison of an old shell and tube heat exchanger module and a new molded double pipe heat exchanger assembled with UV adhesive is shown in Figure 4. Circled on the old module are areas where gaps in adhesive often occurred that resulted in leaking sections.

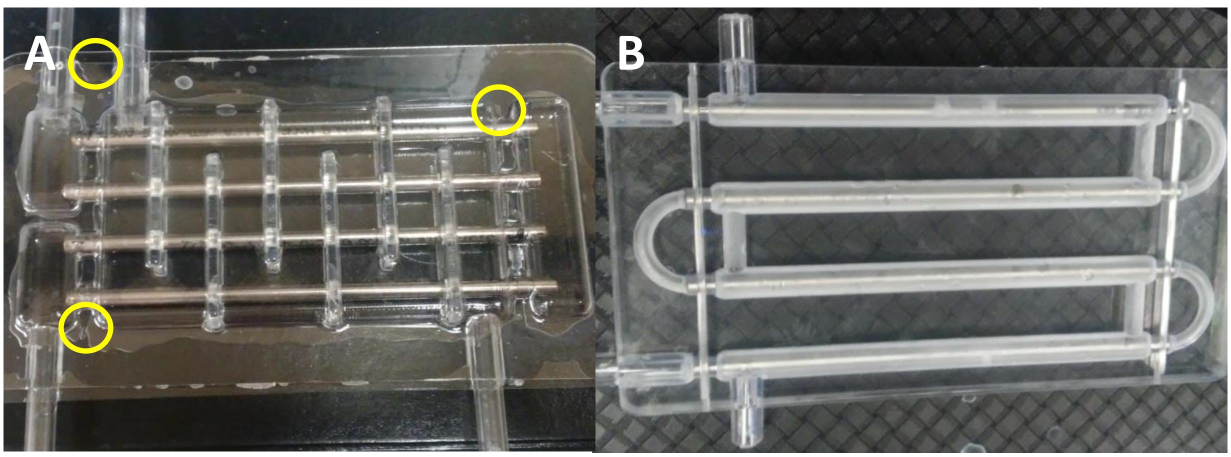


Figure 4: A) Shell and tube heat exchanger assembled with vacuum-formed parts and two-part epoxy with leaky, problem areas circled in yellow; and B) double pipe heat exchanger assembled with injection molded parts and UV-cured adhesive.

As can be seen in Figure 4, the new assembly technique results in a cartridge with a cleaner overall appearance as well as evenly applied adhesive. We expect therefore, that the new technique will result in far fewer defective LC-DLM cartridges. In initial trials using machined module parts identical to those expected to be created with injection molding, adhesive was applied appropriately to all modules, resulting in no assembled LC-DLMs with leaks. We plan to begin manufacturing the improved, injection molded LC-DLMs in summer 2019 and expect to manufacture 300 cartridges by fall 2019.

The final portion of this project involves the design and manufacture of two new LC-DLM cartridges using the injection molding technique. We plan to create a fluidized bed allowing use of different sized particles and fluid flowrates as well as an evaporative cooler. Work has not yet begun on these modules as we are first focusing on optimization and efficient mass-production of existing cartridges.

Conclusions

In conclusion, the NSF IUSE project described herein focuses on wide-scale dissemination and assessment of ultra-low-cost, hands-on engineering learning instruments, LC-DLMs, to 46 universities and/or programs through an innovative hub-based workshop approach. Significant work has been and is being done and will be reported in the June 2019 ASEE Conference including completion of the first dissemination workshop, initial LC-DLM classroom implementations, creation of improved assessment materials, preliminary website development, and refinement of LC-DLM manufacturing techniques. Work will be ongoing for the next several years and will include six additional dissemination workshops, three workshops at ASEE events, continued website development, analysis of results from student and professor surveys and assessments, and the development of two additional LC-DLM cartridges. Through this project, we expect to successfully provide LC-DLMs to a wide, diverse student group to improve student understanding of core engineering concepts through the use of interactive, visual learning tools.

Acknowledgments

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