Miniature Low-Cost Desktop Learning Modules for Multi-Disciplinary Engineering Process Applications

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ASEE 2015: Miniature Low-Cost Desktop Learning Modules for Multi-Disciplinary Engineering Process Applications

Abstract

To transform the STEM learning environment and make it more effective, exciting and experiential, hands-on learning needs to be implemented in the classroom. This is the long term goal in a set of NSF projects, one a new IUSE project and a continuing TUES/CCLI project enhanced through a USAID/NSF PEER and TUES supplement. The objectives are to build and disseminate light weight, low-cost Desktop Learning Modules (DLMs), with interchangeable Fluid Mechanics, Heat Transfer and Biomass Conversion cartridges. The TUES laid a foundation resulting in a marketed technology being used in classrooms around the world in universities, community colleges and high schools, while the IUSE seeks to extend the technology to an ultra-low-cost format through design-for-manufacture with 3D printing and vacuforming.

Studying the impact of these DLMs is crucial to the success of this research to determine educational effectiveness. Assessment strategies are being refined, and we have now added a pre-/post motivation survey to add to our technical assessment centered on pre-/posttest written explanations to provide a more subjective grading rubric.

DLM cartridge options are also being expanded to include biofuels options. However, gasification is highly exothermic resulting in high temperatures that can create high pressure if gases are confined in small spaces. Therefore, the biogasifier DLM design requires special safety specifications so class demonstrations do not pose risks for students and instructors. Considerations include gasifier placement into a polycarbonate shielded container for easy visualization, reducing reactor size to mm-diameter quartz tubes to create a classroom safe system that limits total thermal energy, directed thermal heating through electrical resistance wires, and providing unique conversion measurement means such as a small syringe cylinder / piston unit where the piston expands along a graduated strip to read volumes of reaction gases while holding pressures at near atmospheric levels. Syngas cleanup will be accomplished by passing products through a fiberglass filter to reduce tar, bubbling through olive oil to remove any remaining tar and cool the gas stream, absorption of acidic CO_2 and H_2S gases in mono-ethanol amine, and collecting final product gas in the syringe. Gas production from specified products will be pre-determined through GC analysis and relating conversion to final gas volumes, after knowing reaction conditions, and the nature of side-product removal processes. To make such systems relevant to educating students about gasifier design in resource limited environments, the team is working internationally with Ahmadu Bello University and the National Research Institute for Chemical Technology in Zaria, Nigeria. This enhances the education of US students by providing experiences with a transnational collaborative team.

In this paper we will present technical aspects surrounding development of a number of new learning cartridges, both low-cost vacuformed models already fabricated and classroom tested and those in the planning stages including a Solid Works image and COMSOL model of a new simplified Shell and Tube Heat Exchanger and the Biomass cartridge explained above. We will

also focus on our new pre-/post motivation survey and planned implementations of the hands-on learning modules to undergraduate and high school students at a small number of institutions.

Introduction

Hands-on teaching methods have a long history, but generally these are in the form of science-based laboratory classes that accompany lecture courses or capstone laboratory courses such as the chemical engineering unit operations laboratory.

While STEM instruction is considered mature, engineering students graduate with a surprising lack of understanding of core concepts, even though seasoned professors teach the material. A marked reversal occurs with team activities as Washington State University (WSU) students who used miniaturized desktop learning modules (DLMs) registered a gain of 0.57 (1.0 possible) with 70% of the students achieving minimum competency.[1] This is compared to a respective 0.26 gain and 39% competency for a control group taught by lecture, with an average effect size of d = 0.98. Substantive affective gains accompany results every time DLMs are implemented, whether in the US,[2] or internationally, e.g., at Ahmadu Bello University.[3] DLMs are designed to demonstrate industrial *fluid flow and heat transfer* concepts within a standard classroom[4] allowing students to visualize how processes work and immediately tie mathematical models to physical realities. However, a recently commercialized DLMX costs $18,000 per station, albiet with 7 interchangeable cartridges for various fluid mechanics and heat transfer learning applications. These, however, are not affordable for every institution, and certainly not for an individual student, nor are they light and compact enough to be taken home. What is needed now is to offer alternatives for these special cases in the form of ultra-Low Cost LC-DLMs, affordable by every student, to broadly disseminate DLMs and demonstrate efficacy in enhancing conceptual understanding, recruitment and retention at universities, community colleges and high schools across the US.

Given preliminary success with commercialization of the DLMX we have moved to design-for-manufacture efforts using 3-D printers to make molds used to vacuform matching halves of fluid flow and heat transfer equipment that are then assembled, tested and introduced into the classroom. Our objectives are to build and broadly disseminate light-weight, portable LC-DLMs with interchangeable Fluid Mechanics and Heat Transfer cartridges with a per-unit cost about that of a textbook ($100 – $200), and study their longitudinal impact on educational effectiveness, recruitment from high schools and community colleges, and retention in engineering programs. We also are developing biomass conversion systems, though not amenable to vacforming, that are inexpensive and light-weight and which consist of miniature, safe, low-energy content pyrolysis and gasification units. In this paper we highlight recent progress on the LC-DLMs, a Solid Works image and COMSOL model of a shell and tube heat exchanger, a new motivational survey and near term plans for implementing sets of the hands-on learning modules within programs at branch campus, a nearby private university and regional high schools.

LC-DLM system with base and hydraulic system

We demonstrate a new approach to introduce low-cost experiments into engineering classes to enable active learning by students to help them master concepts in fluid mechanics and heat transfer. The approach is based on previous work by our group on developing in-class engineering experiments called Desktop Learning Modules or DLM's.[5,6] More recent work on applying a design-for-manufacture approach that leverages flexible manufacturing tools such as CAD, 3-D printers and vacuforming machines has resulted in the possibility of producing an array of simple and easy-to-use experimental hardware at very low cost.[7,8] The present work introduces several sets of experimental hardware that have been developed and implemented in undergraduate engineering courses. We have developed Venturi Nozzle experiments designed to exercise students understanding of the Bernoulli equation and Pipe Flow experiments designed to help students master principles of head loss. The experimental devices to be demonstrated here have been fabricated using a four step approach as shown in Figure 1. First, commercial CAD software is used to define the geometry of an experiment. Second, a rapid prototyping machine is used to 3-D print a plastic mold of the design. Third, a vacuformer is used to form thin plastic sheets around the 3-D printed mold. Finally, the vacuformed sheets are assembled together to produce multiple copies of the experiment. The Venturi (Figure 2) and Pipe Flow/Head Loss experiments have been implemented in a junior-level Mechanical Engineering Fluid Dynamics course as well as a junior-level Chemical Engineering Fluid Mechanics and Heat Transfer Course. To date, more than 150 students have tried out these low cost experiments in active learning experiences. The results of these first implementations indicate the value of this approach for making possible a wide variety of experimental activities for classroom use, for take home homeworks, and for distance education.

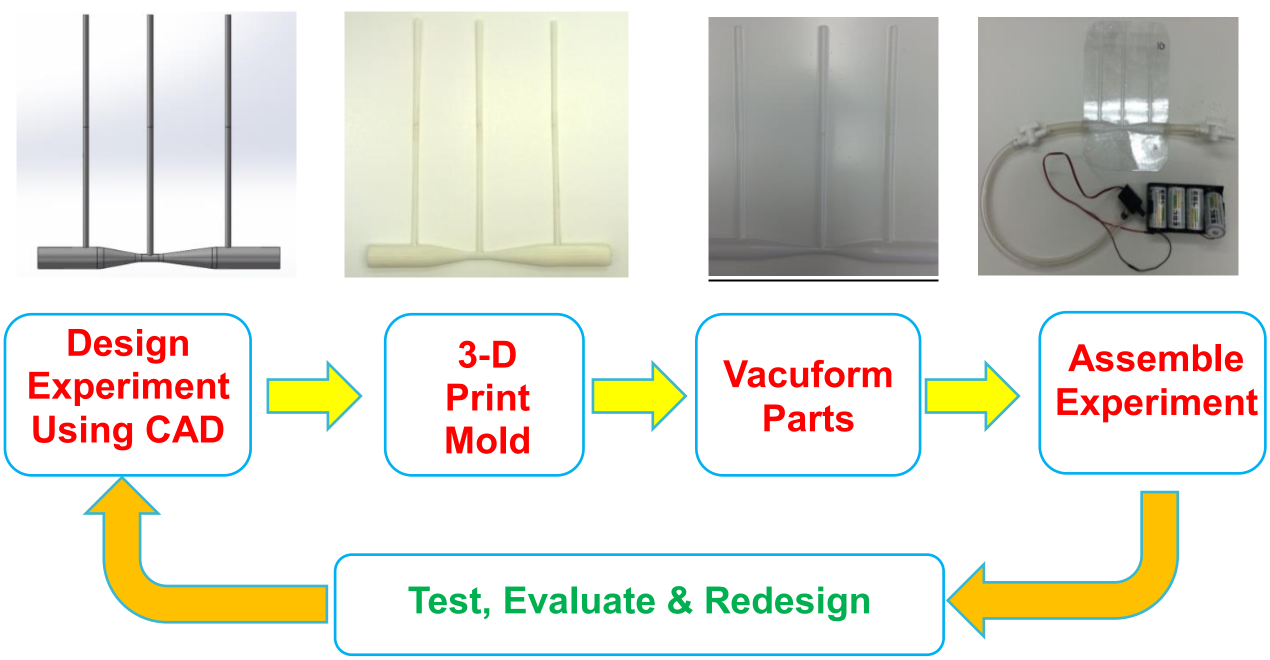

Figure 1. Design for manufacture process for LC-DLMs.

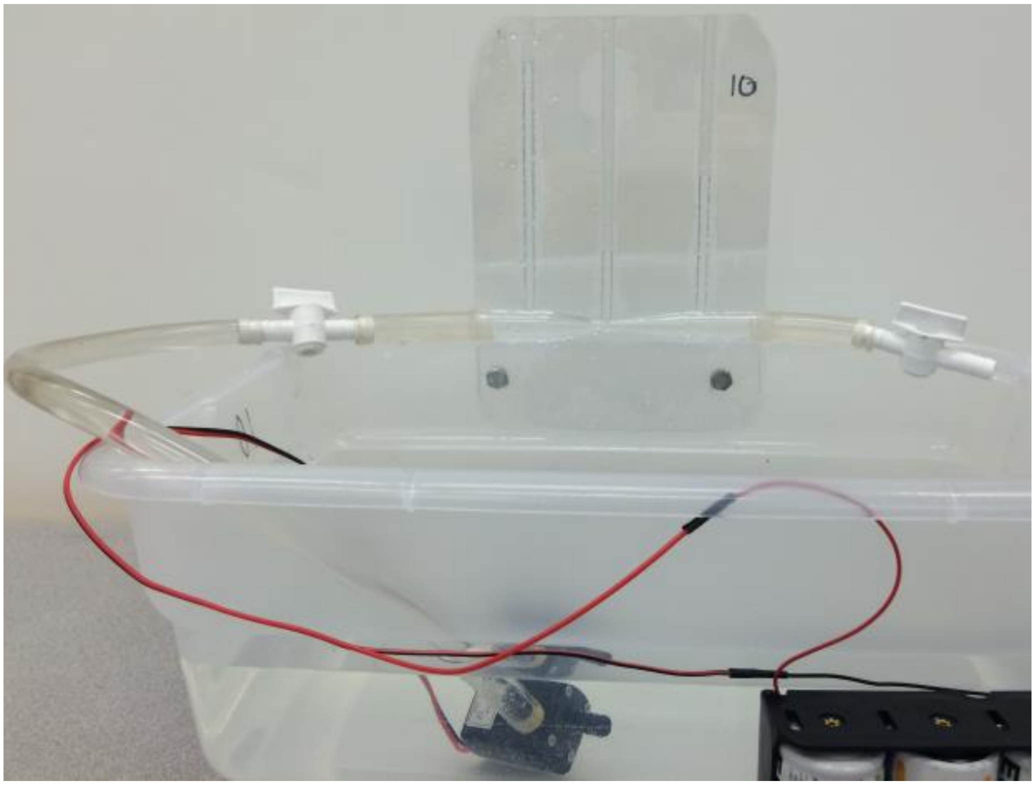

Figure 2. Venturi DLM.

LC-DLM Shell and Tube Heat Exchanger

To manufacture an ultra-low-cost shell and tube heat exchanger, based on the calculations done using Kern's method, two halves of the shell were designed in SolidWorks and 3-D printed in ABS plastic, with grooves on each mold prepared for insertion of baffles. Tube plates were also 3-D printed using ABS materials; however, to reduce expense all baffles were made by laser cutting PETG plastic of 0.02" thickness. Then, using a vacuforming machine and the two 3-D printed molds, each half of the shell was formed from a PETG thermoform plastic sheet. After passing the tubes through the tube plates and baffles, the two halves were glued together with adhesive to form the final assembly (Figure 3).

The first design of the ultra-low-cost shell and tube heat exchanger was made with 5 tubes per pass (10 tubes total). The entire system, including pumps, tubing, batteries, etc. cost less than $80. To reduce the cost even more, our plan is to re-design the heat exchanger into a smaller geometry with fewer tubes. A summary of calculations for the second generation design with just 3 tubes per pass is found in Table 1. As shown in this table, the most cost-effective design, which also allows for a turbulent tube side velocity, may be made using 0.25" OD / 0.12 ID" tubing.

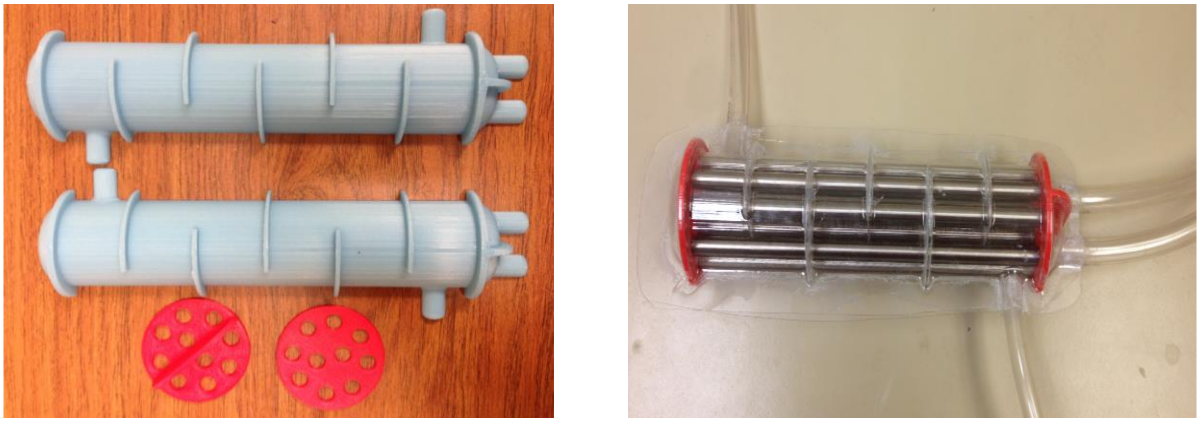

Figure 3. Shell and tube heat exchanger.

LC-DLM 2D Heat Exchanger

The goal in this aspect of the project is to design a very simple shell and tube heat exchanger which clearly shows the flow pattern on the shell side, again of small size and with low cost materials. This instrument will help students to have a better understanding of heat transfer and fluid mechanics principles. We began by designing the heat exchanger in SolidWorks, shown in Figure 4, as a system with 4 tubes of 0.25" diameter and 6" in length. The tubes are arranged linearly in 4 rows, and the shell is rectangular, 2" in height and 5" in length. COMSOL modeling was used to model the system in counter-current mode. We set the inlet temperature for the tube and shell sides to be 320 K and 290 K, respectively. The flow rate was set at 500 ml/min on the shell side, and for tube side we applied different flow rates from 100 to 600 ml/min with COMSOL results shown in Figure 5 for the highest tube side flow rate.

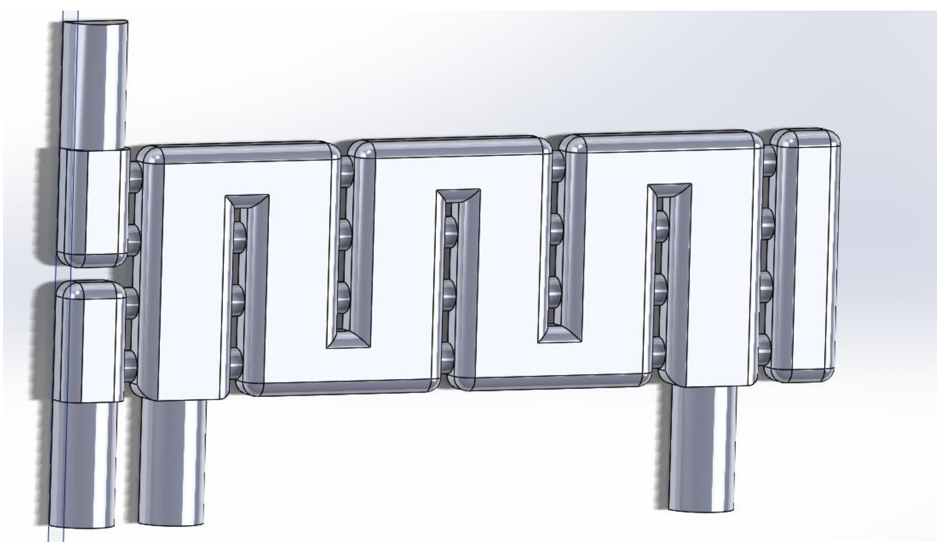

Figure 4. SolidWorks Model, Shell and Tube Heat Exchanger (2 pass tube-side). The tubes have an outer diameter of 0.25" and length of 6", and are located in 4 rows. The shell is a rectangle 2" in height and 5" in length. Four baffles are mounted with a 0.75" baffle spacing.

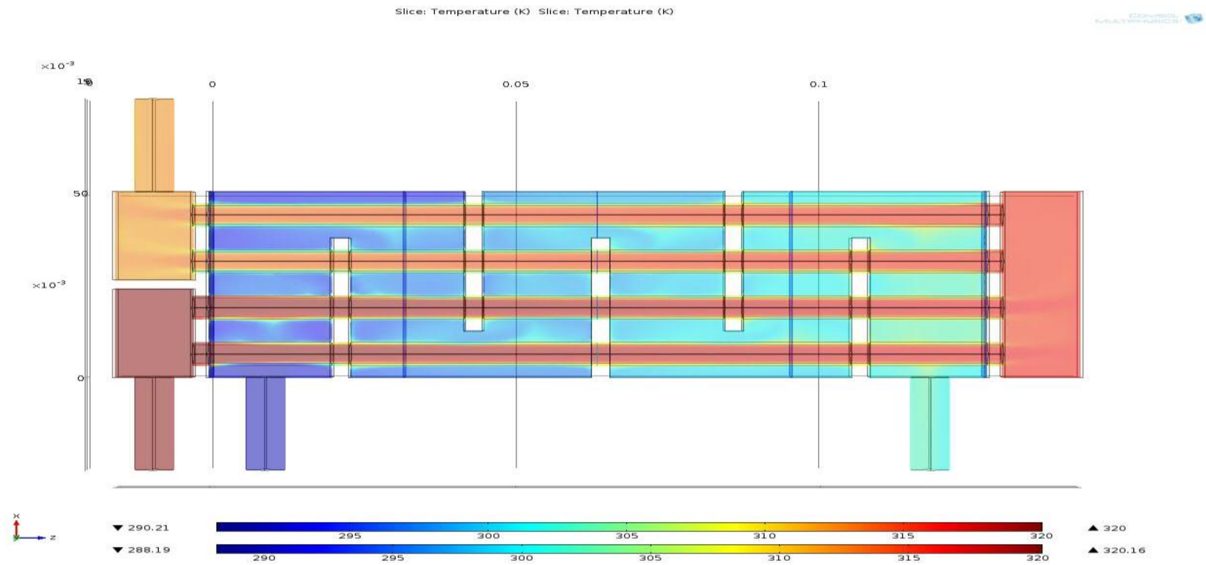

Figure 5. COMSOL 3-D Model with temperature distribution in the Shell and Tube Heat Exchanger with hot fluid in the tube side and cold fluid on the shell side with a flow rate of 600 ml/min on the tube side and 500 ml/min on the shell side. The inlet flow temperatures were set at 320 K and 290 K for the tube and shell sides, respectively. The out flow temperatures obtained were 312 K for the tube side and 301 K for the shell side which shows an 8 degree decrease on the tube side and an 11 degree increase on the shell side.

Table 1. A summary of calculations for second generation design with just 3 tubes per pass.

$U_{o,\ assumed}$ $\left[\frac{W}{m^2K}\right]$	Tube	Price	U_t $\left[\frac{W}{m^2K}\right]$	Re_t	ΔP_t $[mm\ Hg]$	U_s $\left[\frac{W}{m^2K}\right]$	Re_s	ΔP_s $[mm\ Hg]$	$U_{o,cal}$ $\left[\frac{W}{m^2K}\right]$	Error
1026	5/16" OD 0.243" ID	6 ft: $11	0.33	2586	640	0.05	422	289	577	43%
1282	1/4" OD 0.194" ID	6 ft: $29	0.52	3239	1740	0.08	524	872	958	25%
1465	7/32" OD 0.188" ID	28 in: $19	0.55	3343	2000	0.1	597	1686	1010	30%
1282	1/4" OD 0.12" ID	6 ft: $19	1.36	5237	15,000	0.08	524	872	988	22%

Gasification reactor and syngas cleanup system

A miniaturized biogasification system for use in resource limited environments and for applications in the engineering classroom is being developed through collaboration between WSU, and the National Research Institute for Chemical Technology (NARICT) and Ahmadu Bello University both in Zaria, Nigeria. The current system uses a resistance wire to provide energy to a quartz reactor of 1mm ID, 3 mm OD, where air acts as the gasifying agent in the reaction. The current biomass being used in the reaction consists of toothpicks, and the syngas from the system is collected and analyzed with a gas chromatograph. A syngas cleanup system (Figure 6) consisting of two flasks, one with olive oil to remove tar, and a second with MEA to remove carbon dioxide was designed by the NARICT, fabricated in the US, and is currently being tested. The system will be implemented in a thermochemical conversion classroom, highlighting concepts surrounding the changing syngas composition from pyrolysis and gasification reactions with the volumetric syringe at the outlet, noting the change in volume from the solid biomass to the gaseous vapors.

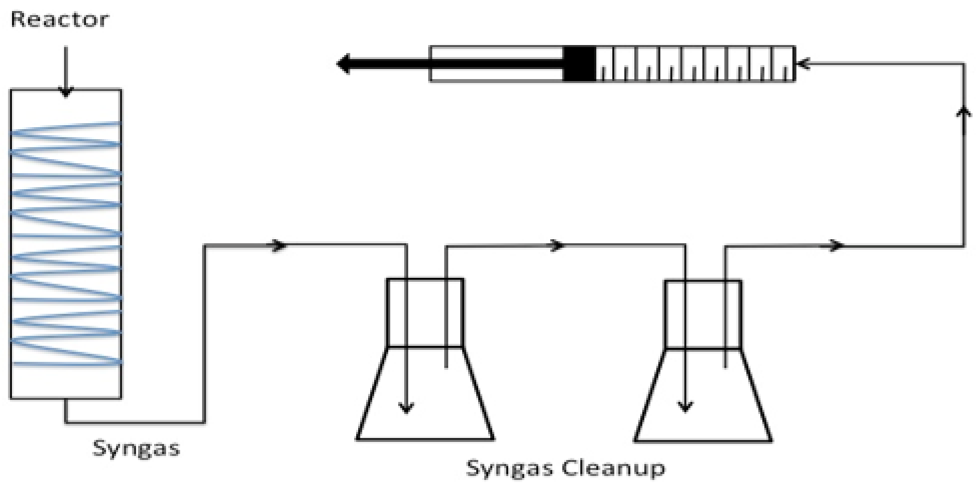

Figure 6. Gasification reactor and Syngas cleaning system.

Motivation Survey

Various reports published during the past decade highlight a wide range of problems with engineering curricula, especially the lecture-dominated form of transmitting core engineering concepts to students.[9-13] These reports also indicate motivation for learning engineering concepts is waning among college students. To enrich student learning experiences, instructional methods need to be engaging and should seek to promote meaningful learning. While cognitive outcomes, such as recall and transfer measures, etc., might be indicators of success in such endeavors, non-cognitive variables are proxies that provide a more holistic picture of the students' learning process.[14,15] Hence, we are exploring a program of research to examine how the use of DLMs in classrooms influences student motivation and learning strategies. Preliminary investigations have used the Motivation Strategy for Learning Questionnaire (MSLQ) [15] assess differences in motivation and learning strategy due to learning with the DLMs. The MSLQ is comprised of 81 items measuring six motivational and nine learning strategy constructs on a 7-point rating scale. We administered 43 items covering eight constructs measured by the instrument with a question sample set shown in Table 2. We plan to use the data to make group comparisons, as well as to model predictors of cognitive learning outcomes. Our findings are expected to provide insights for the evaluation of DLM implementations. Our long-term goal is to improve future implementations to maximize the teaching and learning benefits of DLMs in engineering and science classrooms.

Table 2. Sample Motivational Survey Questionnaire.

Sample Questions	Target Construct
The use of DLMs could encourage me to try and work with other students from this class to complete the course assignments.	Peer Learning
Despite the use of DLMs I often missed important points because I'm thinking of other things.	Metacognitive Self-Regulation
I work hard to do well in this class even if I don't like what we are doing.	Effort Regulation
I try to apply ideas from course readings in other class activities such as lecture and discussion.	Elaboration
Getting a good grade in this class is the most satisfying thing for me right now.	Extrinsic Goal Orientation

Institutions Involved

Table 3 lists the institutions involved as well as expansion sites where LC-DLMs are expected to be implemented.

Table 3. Institutions involved in LC-DLM effort.

Institute	Department	Class	Term
WSU-Pullman	Mechanical Engineering	Fluid Mechanics	Fall 2014
WSU-Everett	Mechanical Engineering	Fluid Mechanics	Fall 2014
WSU-Bremerton	Mechanical Engineering	Fluid Mechanics	Fall 2014
WSU-Pullman	Mechanical Engineering	Fluid Mechanics	Spring 2015
WSU-Pullman	Mechanical Engineering	Thermal System Design	Spring 2015
WSU-Pullman	Chemical Engineering	Fluid Mech. & Heat Transfer	Spring 2015
WSU-Everett	Mechanical Engineering	Heat Transfer	Fall 2015
WSU-Bremerton	Mechanical Engineering	Fluid Mechanics	Fall 2015
Gonzaga University	Mechanical Engineering	Fluid Mechanics	Fall 2015
Gonzaga Prep. High School	Mechanical Engineering	Heat Transfer	Fall 2015
Pullman High School	Science	Physics and Basic Science	Fall 2015

Conclusions

Our goal as stated is to develop ultra-low cost hands-on learning equipment affordable to every student. To date, we have made a base unit, vacuformed Hydraulic Loss and Venturi cartridges and implemented them initially in mechanical and chemical engineering classrooms. A simple, safe and inexpensive biomass conversion unit also is in progress, as well as a vacuformed shell and tube heat exchanger for which a preliminary design has been built. Pre-/post quizzes have been implemented as well as a motivational survey. As continual efforts are underway for implementation and assessment in various chemical and mechanical engineering classes, more details will be reported at the 2015 ASEE meeting.

Acknowledgements

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