Hands-on Tabletop Units for Addressing Persistent Conceptual Difficulties in Continuity and Frictional Loss in Fluid Mechanics

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Abstract

The difficulty in covering chemical engineering concepts using traditional lectures and whiteboard teaching approaches means today's students' learning demands are unfulfilled, so alternate methods are needed. Desktop learning modules (DLMs) are designed to show industrial fluid flow and heat transfer concepts in a standard classroom so students can immediately gain an intuitive understanding of processes and combine mathematical models with physical reality. In a previous engineering class on open channel flow concepts, a large average effect size, d=0.98, between the experimental and control group shows a statistically significant gain. In this paper, we build on this approach by the design of two simple classroom DLMs to demonstrate continuity and pressure drop. Our approach consists of a take home quiz, worksheet, pretest and posttest assessments, and an end of semester survey. Pretest and posttest results show there were no significant differences between the DLM and lecture groups; however, both improved their performance on posttests. Survey assessment results show both DLM and lecture students strongly favor a mix of DLM with lectures rather than having one predominant approach.

Introduction

With the rapid development of science and technology, and the increasing influence of modern chemical industry in economic development, how to foster excellence in chemical engineering education is becoming a primary focus. Chemical engineering courses contain descriptions and analyses of three-dimensional equipment components and processes which educators can visualize in their mind's eye, however, teaching in the traditional classroom using textbooks and whiteboards without showing students actual examples or physical models to illustrate engineering concepts is no longer appropriate (Philpot & Hall, 2006). There is a need for use of alternative learning strategies particularly for conveying concepts involving application of scientific principles to physical systems. To address this issue some instructors have used computer-animated instruction to create a better learning environment and present fluid mechanics concepts in three-dimensional forms (Faleye & Mogari, 2010). Other instructors have shown that the combination of electronic classroom communication systems with a series of questions and feedback related teaching methods can increase understanding and enthusiasm for the subject (Gerace, Dufresne & Leonard, 1999; Mazur, 1997). Recent results of an implementation that includes a computer simulator connecting students with more realistic engineering experience indicate that simulators increase student motivation, improve student grades, provide interactive learning environments, increase effective problem solving skills, and provide a deeper understanding of engineering concepts (Lee, McNeill, Douglas, Koro-Ljungberg, & Therriault, 2013). These methods help students visualize the principles, enhance understanding and participation, but do not let them experience real chemical engineering operation processes because there is a lack of simple classroom hardware componentry to aid in teaching the subject.

The Fluid Mechanics and Heat Transfer course at hand is a compulsory professional course for students in chemical engineering. Through interviews we identified persistent gaps and difficulties in understanding several fluid mechanics and heat transfer concepts including those related to flow regime, the mechanical energy balance, venturi meters, straight pipes and bends/fittings, and non-circular channels, even among seniors who have already had the junior level course covering these topics (J. K. Burgher, Finkel, D., Van Wie, B. J., Adesope, O., 2014). Most students either struggled with continuity and pressure drops and associated calculations or were confused about how to apply these concepts.

To address these gaps our approach is to develop miniaturized industrial equipment for use in the standard class room. The equipment has been coined as desktop learning modules (DLMs) and demonstrates many fluid mechanics and heat transfer concepts associated with fluidized beds, orifice meters, venturi meters, tubular, shell and tube and cross flow heat exchangers, and evaporative coolers (Abdul, et al. 2011; J. K. Burgher, Finkel, Adesope, & Van Wie, 2015; Coon, Golter, Thiessen, Adesope, & Van Wie, 2011; Schlecht et al., 2011; Van Wie et al., 2012). An assessment focused on use of the shell and tube heat exchanger, and evaporative cooling DLMs shows in terms of attitude, students prefer the hands-on DLM over lectures (J. K. Burgher et al., 2015; Coon et al., 2011).

Other classroom research has shown success in introducing DLMs in other disciplines and at other universities. For example, our group has extended the approach to civil engineering water resource undergraduate engineering classes at Washington State University and found enhanced understanding of selected open channel flow concepts (Brown et al., 2014). Compared with a control group taught with lectures having a 0.26 gain between pre- and posttest results and 39% competency, students who used DLMs registered a gain of 0.57 out of 1.0 possible with 70% of the students achieving minimum competency (Brown et al., 2014; J. K. Burgher et al., 2015). Furthermore, our DLMs have been used in a Heat Transport course in the Chemical Engineering Department at Ahmadu Bello University in Zaria, Nigeria, and even though students register improvement in both the DLM and lecture groups, surveys show the DLM is in better alignment with the 7 Principles of Good Practice in Undergraduate Education (Abdul, et al. 2011). Meanwhile, Minerick while at Mississippi State University showed Desktop Experiment Modules can be used in conjunction with traditional heat transfer lectures as useful tools to introduce students to heat transfer concepts (Minerick, 2009). She stated that the advantages of classroom hands-on experiences were that including them is independent of laboratory space availability and students have the unique experience of immediately linking chemical engineering principles to real systems thereby promoting enhanced understanding (Minerick, 2009). Nevertheless for the continuity and pressure drop issues no widely available hands-on devices to date have been developed to specifically address gaps in this area. While processes like these can be simulated in programs such as COMSOL Multiphysics® there is a learning curve for programming and the approach requires significant computing power. Our approach with DLMs circumvents the need for computers and helps the students to observe immediately and visually what happens to physical parameters such as flow rate, static pressure heights, etc. as a result of changing of the input variables. This is especially needed for pipe flow analysis as concepts are counter-intuitive as many students believe either velocity increases when flowing through a constant diameter tube as flow continues downhill or flow velocity slows down in horizontal pipes due to friction.

In this paper we highlight a means to extend DLM instructional concepts by building two simple classroom units to demonstrate continuity and pressure drop. One system has flow through a tube beginning in one reservoir and transferring to another at lower elevation. The system is ideal for explaining continuity as graduated markings indicate the same level of rise in fluid in the second reservoir as that lost in the first. In the second system flow exits the bottom of a reservoir and travels through a tube, with hydrostatic head tubes to measure pressures, and exits into a second reservoir. The system shows characteristically linear pressure drops as flow continues along the tube with a higher pressure loss through valves. We designed a controlled study in which one section had hands-on learning while the other involved lectures on these topics. We designed assessments using pretest and posttest questions with the pretest at the beginning of the semester including questions about continuity and pressure drop. Then just before the semester's end, students took the posttest on the same topics and we evaluated their performance. We also designed end-of-semester survey questions for students to self-report about the perceived efficacy of the implementation. We report on the system design features, outcomes in conceptual gains, and student comments.

Methodology

Implementation

Fifty nine (59) Washington State University junior chemical engineering students in a ChE 332 Fluid Mechanics and Heat Transfer class were split into two sections, taught by the same instructor, each alternating between lecture and hands-on learning for different topics. Each section had subgroups of 4 to 5 students all consisting of an equal balance of GPAs, with a mix of gender, nationality and ethnicity while maintaining an effort not to isolate a single person of one gender, international status or ethnicity. The groups were divided like this to create an atmosphere in which every individual student was more likely to collaborate with group mates and participate in assignments especially those who generally prefer to work independently (Jones, Antonenko, & Greenwood, 2012; C. Thomson et al., 2003). For continuity and pressure drop, Section I with 30 students had hands-on group learning while Section II with 29 students only received lectures on these topics based on material from two standard textbooks (McCabe, Smith, & Harriott, 2005; Thomson, 2000). The hands-on learning groups used specially designed hands-on tabletop units to experience the continuity and pressure drop concepts by watching and doing experiments.

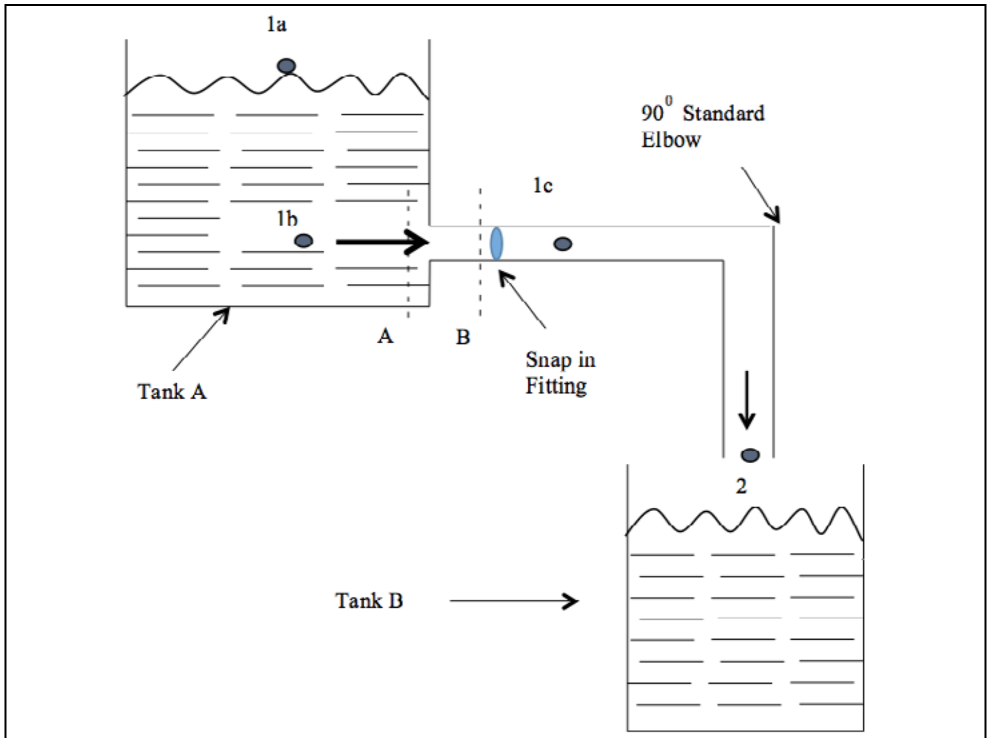

Figure 1: Diagram of system A for studying continuity.

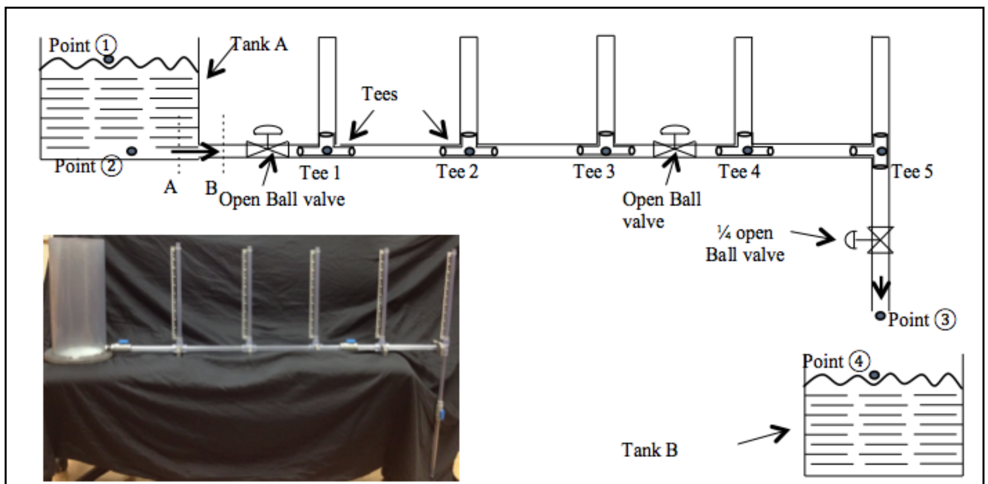

Figure 2: Diagram of system B for studying pressure drop for flow through a straight pipe.

The course was held in a semi-lab classroom with benches, sinks, shelves with racks for experimental DLM instruments, and whiteboards, but no chairs. Instructors, TAs, and students could gather around the lab tables with DLMs for viewing and instruction. During the hands-on implementation, group members were required to stay close around their DLM and work through the worksheet together. This special setup allowed all group members to participate in hands-on experiments (Easley, 2012), and pay attention during group discussions while facilitating more direct communication between the instructor and TAs who circulated to coach individual groups.

DLM System, Class Implementation and Assessment Design

Over many years of teaching experience, fluid mechanics courses have always been described by students as containing difficult and challenging topics. It often happens that due to superficial learning, some students in final year courses are still confused about the concepts and techniques learned in the previous years (Dempster, Lee & Boyle,2002); so we designed two simple classroom units to demonstrate continuity and pressure drop concepts to hopefully address the problem.

In system A, fluid moves under gravity, from Tank A to Tank B via tubing. As is shown in Figure 1, a snap in fitting connects the tubing to Tank A, and a 90° standard elbow allows transition to flow in the vertical direction. The system is ideal for explaining continuity as graduated markings indicate the same level of rise in fluid in the second reservoir as that lost in the first. This is counter intuitive to many students as they either believe that velocity

Concept	Questions asked
Mechanical Energy Balance	• Explain how energy conservation applies to flow in a pipe. • How would you choose your reference points in a system for applying the Mechanical Energy Balance equation?
Hydraulic losses in pipes	• What are the contributions to head loss associated with a piping system that consists of various fittings? And how do they depend on pipe diameter?

Table 1: Summary of Concepts Covered in Take Home Quiz

Initial condition	Time elapsed ~ 20 sec	Change in height of water in Tank A [in]	Change in height of water in Tank B [in]	Flow Rate [GPH]
Tank Full				

Table 2: Experimental observations noted for system A

in. H_2O [gauge]	Point 1	Point 2	Tee 1	Tee 2	Tee 3	Tee 4	Tee 5	Point 3	Point 4	Time [sec]	Change in water height in Tank 2	Flow rate [GPH]
Pressure Reading												

Table 3: Experimental observations noted for system B

0 points	1 point (Low)	3 points	5 points (Medium)	7 points	9 points (High)
No Answer	Correct with no explanation	Explanation is strongly flawed	Explanation relates to fundamentals	Explanation relates to fundamentals strongly	Provides clear explanation
OR	OR	OR	OR	OR	OR
No Reasoning	Correct/ Incorrect w/incorrect logic	50-75% critical mistakes/ incorrect	25-50% critical mistakes/ incorrect	25% critical mistakes/ incorrect	1 simple mistake

Table 4: Generalized rubric for pre- and posttest scoring

increases in a constant cross-section pipe as flow continues downhill or that flow velocity slows down due to friction.

For system B in Figure 2, fluid exits the bottom of a reservoir through a two-foot long half-inch diameter tube with five hydrostatic head tubes equally spaced along its length. The tube terminates with a 90° vertical bend emptying into a second reservoir. Three valves were positioned along the tube, one just outside the first reservoir, and another just before and one just after the 90° bend. The system shows the anticipated linear pressure drops as flow continues along the tubes with a higher pressure loss through valves.

Assessment

Take home quiz

The take home quiz was given out before students had the topic on continuity and pressure drop, and it was expected students would find the solutions in textbooks and come to class prepared to enhance their understanding of related concepts. There were three questions, as summarized in Table 1, about mechanical energy balance and hydraulic losses in pipes. To ensure the students would finish the take home quiz as a preparation for the activity they were collected at the beginning of class and students received full credit if it appeared they had done preparation and supplied answers to all questions.

Worksheets

The worksheets were developed by the instructor and graduate students to specifically address persisting misconceptions, such as "the flow speeds up in a pipe as it travels downhill", by adding exercises, for example, to measure inlet and outlet flow rates to show they are the same. The best way to remove any bias gained by the more physically representative experiential learning is to emphasize these aspects in lecture through verbal communication and this was done. Our aim in designing worksheets was to help students understand fluid mechanics concepts thoroughly through careful observation, guided hands-on experiments, and simple calculations including discussions within groups and with the instructor and TAs in one class period.

For system A, before students started the experiment, a few questions needed to be answered and discussed. The questions were: what do you think will happen to the velocity of water in the tube i) as water flows horizontally out of Tank A down the tube, ii) as water flows vertically down to Point 2, iii) as water leaves the tube at Point 2 and falls into Tank B. After the discussion, they run the experiments with observations and notes are taken as indicated in Table 2. Then the in-class experiment was run by each group and observations made after which they went back to the answers to the questions, making corrections or confirming and explaining their reasoning. The last question for system A was to determine flow rate and discuss results within the group.

For system B, students needed to answer the same questions as for system A, although the experimental setup and observations were different and are listed in Table 3.

Pretest and posttest

The pretest and posttest consisted of four questions with figures about continuity and pressure drop including: 1) describe energy types in the mechanical energy balance, 2) how do velocity and pressure change as flow proceeds from a reservoir down a straight pipe, 3) how do velocity and pressure change when entering and exiting a centrifugal pump, 4) how does velocity change when liquid flows from a reservoir through a tube don that necks down to a very narrow tube. Students took the pretest at the beginning of the semester, and the posttest on the same topics before the semester's end. Results were evaluated to assess improvements in performance.

The rubric in Table 4 was used to standardize ratings of the pre- and posttests and was adapted from earlier collaborative work where question ratings are assigned a value of 0-10 (Brown et al., 2014). It is possible that students who participated in pre- and post-assessments could be assigned a score of 0 if there was no answer or 10 if their justification and fundamentals were 100% correct.

We invited three researchers to rate the pretests and posttests individually by using the rubric. After the grading, we set up a meeting to examine the reliability of the scores. For each student's test score, if all three researchers' scores were within 1 point, the average score was registered for that student. If there was a difference of more than 1 point, a discussion was undertaken to understand the rationale behind each person's score and a common more refined set of criteria for rating was agreed upon. Then the raters would adjust their score based on the updated criteria though it was not required they agree within 1 point.

We evaluated statistical significance and effect sizes for the relative gains achieved for the DLM and lecture groups. We applied a standard 'gains' (G) formula, Equation 1, to normalize the increase or decrease between each student's pretest and posttest scores.

$$G = (\text{Post Score} - \text{Pre Score})/(10 - \text{Pre Score}) \quad (1)$$

End of semester survey

To obtain student feedback about the perceived efficacy of the implementation, we designed end-of-semester survey questions. The survey design was adapted from Burgher's paper (Burgher et al., 2015). The survey included two components: Likert multiple choice questions specific to student attitudes and self-identified conceptual understanding for hydraulic energy loss and pressure loss concepts as well as a free-response question asking students about their feelings toward lecture or hands-on learning. These were designed to determine student perceptions about the learning activities they experienced in the class, and also to seek to discover if students felt they would have benefited more from the other group's pedagogical implementation.

We used an online Skylight system to conduct the survey. All pre- and posttests as well as the survey were allocated an individual code from the beginning of the semester to maintain individual confidentiality and promote freedom to convey honest impressions about hands-on learning and lectures. The online survey has no time limit for students to respond so that they could answer questions after careful consideration.

There were four questions from the survey that were pertinent to the study in this paper. The DLM group for example received a question that began with "Continuity: Hands-on group activities with flow from one reservoir downward into a second reservoir of equal volume helped more than if I had lecture to understand and apply the principle of continuity, e.g., velocity in a uniform diameter tube is constant even when flowing downhill." The answer choices for the hands-on learning group were "Strongly agree (90-100% hands-on active is best for me)", "Agree (75% hands-on active – 25% lecture is best for me)", "Equal (50% hands-on active – 50% lecture is best for me)", "Disagree (25% hands-on active – 75% lecture is best for me)", and "Strongly disagree (90-100% lecture is best for me)". The same style of questions was used for the lecture group on these topics only beginning the question with "Lecture about . . ." and response choices in reverse order. Finally, the students were asked for free responses of the type "What components of 1) Lecture or 2) Hands-on active learning helped/would have helped you to understand and apply basic principle(s) of continuity, e.g., velocity in a uniform diameter tube is constant even when flowing downhill? Please be as specific as possible." Responses were then analyzed for trends, categorization, frequency, and impact on shaping future implementations.

Results and Discussion

Observations on Instructional Implementation

Key observations were made about the suitability of the instructional design. The first was the design of the take home quiz. We expected students to review the concepts they had learned from previous courses and have a general understanding about what they were going to study in the classroom. From the hands-on learning group performance on the worksheet, the take home quiz showed its effectiveness, especially in applying the mechanical energy balance and finding reference points. Secondly, during class, students made several comments to indicate that the continuity and pressure drop systems helped them. This was most evident in comparing responses before and after seeing the DLMs in action. For example, questions were asked by the instructor about what would happen to the velocity of water as it flows past different points. These were usually answered incorrectly. Most students thought when fluid flows from a higher level to a lower level, the velocity increases due to gravitational acceleration. This was the most common mistake the students made. Our systems allowed students to visualize what really happens to the velocity and pressure head. Furthermore, the accompanying worksheet group discussion questions were designed to guide students doing hands on activities to consider logical reasoning about the real physical phenomena taking place in front of them. Through applying the mechanical energy balance in Equation 2 (Bernoulli equation accounting for frictional loss and presence of a pump along with pump efficiency), groups were led to answer correctly the questions about continuity and that the pressure is the dynamic term rather than the velocity when considering flow through a tube of constant diameter.

$$\Delta\frac{\bar{v}^2}{2} + \frac{1}{\rho}\Delta P + g_z\Delta H + h_f - \eta W_p = 0 \qquad (2)$$

In summary, the hands-on activities allowed students, through visualization in the DLM systems, to experience applications of theories in the textbooks within a real system, to discuss concepts in groups with peers and to ask instructors and TAs questions to clarify their understanding. This is consistent with literature findings on how an interactive learning environment is effective in enhancing learning when students work in groups to physically and/or verbally complete a common task (Chi, 2009; Salomon & Perkins, 1998). There was just one issue of concern in that some student groups could not finish the worksheet discussions in class. The reasons for this could be that students took too much time in actually performing the DLM experiments, spent too much time on discussion of questions earlier in the worksheet without moving on or that the worksheet covered too much information for one class.

Pretest and Posttest assessment

Inter–Rater Reliability (IRR)

To assure accuracy and uniformity in pretest and posttest ratings, a rating rubric and reliability exercise was undertaken. In total 58 out of the 59 students from Section I and Section II participated in both the pretest and posttest. First, after one professor and three raters discussed the test questions, we established a set of correct answers. Then the three raters established a norming process in which each rater took 15 student pretests and posttests and rated them with a 0-10 score based on the solution. There were four main questions 1a, b, c and d, each with sub-questions except for 1d. We rated every sub-question with a score of 0-10. We then compared ratings and found an Inter-Rater Reliability (IRR) of 26.7-100% for the percentage of times scores for all raters agreed within 1 point. We then discussed the answers, improved our understanding of the correct answers and adjusted ratings. After the norming process a 93.3-100% IRR resulted and then one rater proceeded to rate the remaining 43 pretests and posttests. Table 5 shows the IRRs for both the pretests and posttests. Because the thorough understanding of the correct answers was derived from our discussions, and raters were all familiar with the field and well trained in use of rating rubrics, the high IRR indicates that we created an objective, repeatable and dependable scoring process.

Comparison of Pretest and Posttest Results

Assessments of conceptual learning show nearly equivalent gains for both the lecture and DLM groups. After rating the pretests and posttests, we averaged scores for subquestions and analyzed the data statistically. Charts

Question	IRR - Pretest		IRR - Posttest	
	Before %	After %	Before %	After %
1ai	80	100	40	100
1aii	100	100	86.7	100
1aiii	86.7	100	66.7	100
1aiv	93.3	100	60	100
1av	80	100	46.7	100
1bi	46.7	100	66.7	100
1bii	73.3	100	66.7	100
1biii	40	100	26.7	100
1ci	73.3	100	86.7	100
1cii	60	100	80	100
1d	40	93.3	86.7	100

Table 5: Inter-Rater Reliability (IRR)

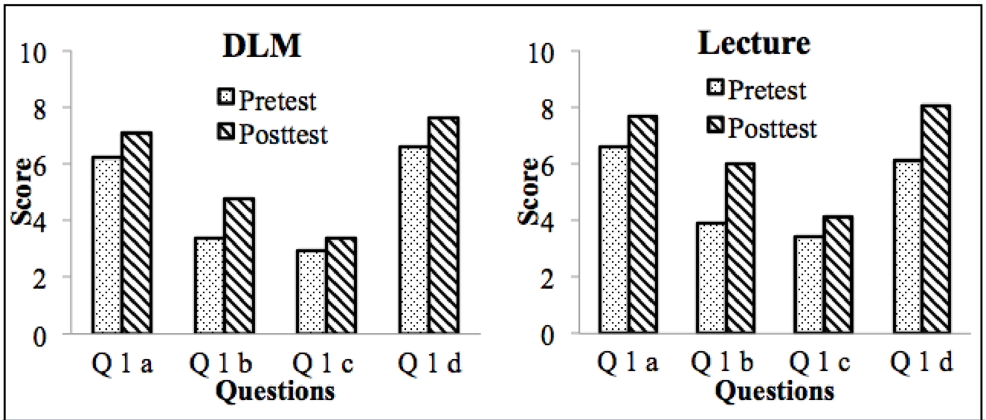

Figure 3: Comparison of the average pre- and posttest scores for DLM group and lecture group

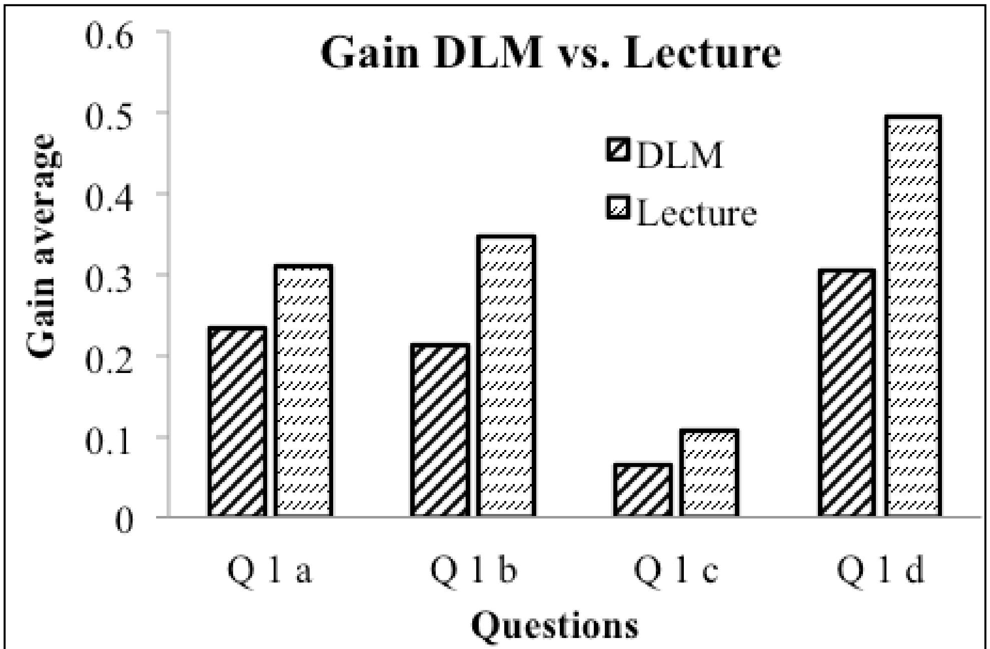

Figure 4: Comparison of the Gain for DLM and lecture

in Figure 3 show, for both the DLM and lecture groups, growth in conceptual understanding by increases of 15-55% from the pretest to posttest scores for each question while Figure 4 shows the relative gains and Table 6 summarizes the mean scores and effect sizes, which are a measure of the fractional gain relative to the composite standard deviations around a gain. All gains were positive, most with small 0.2 – 0.5 effect sizes. Effect sizes of 0.5 – 0.8 are considered medium in size, for which there are only two instances, both for lecture, but when compared to the DLM group, which also shows gains on the same questions, there are no instances in which more than a small net effective gain would be calculated for the performance of the lecture group over and above the DLM group.

Moving on to specific questions, 1a was a theoretical question about mechanical energy balance terms. The concept was taught in many other chemical engineering courses before this class. The pretest results showed that students knew at least half of the content. The posttest results showed there were improvements for both groups. Question 1b was a continuity question which asked about how velocity and pressure changes when incompressible fluid flows from a reservoir down a long straight horizontal smooth or rough pipe. Students answered this question by writing their explanations. The posttest showed a small improvement as well. The only concern about this question is that when the rater graded it, most student answers showed they either did not know how to answer the question or they did not understand the question. For example, in Question 1b the question was asking what happens to the velocity and pressure as flow continues down the pipe. Students' answers showed that they were confused about how to determine the point or region at which the velocity and pressure changes. The way this question was asked made it difficult to express the educators' intentions and also hard to reflect the students' level of understanding.

Where the physical nature of the concepts associated with a new process is important our study suggests the imperative of having a hands-on component. For example, let's consider Question 1c about the centrifugal pump, a control question, the answer for which was given in lecture for both sessions and students were supposed to realize that the velocity of a liquid stream entering a pump had to be the same as that exiting the pump due to continuity if diameters are constant and the fluid is incompressible, and that instead it is the pressure head that changes. One would expect all students to correctly answer this question as they all have had four previous courses dealing with this topic. On the other hand, we could understand that this is the first course where practical aspects of how pumps work are introduced, and even then little is said about how the centrifugal pump pictorially displayed in the test question really works; hence, there may be issues with cognitive load in terms of getting all the pieces of the puzzle in mind before doing an analysis. Indeed the pretest results with a 3-point average did reflect that they did not know the concept well. The posttest results show, though both groups improved marginally, students still had a poor understanding of the concept of continuity as it relates to pumping. This also illustrates the negative side of lectures. If students don't see how a real centrifugal pump actually works, that inlet fluid, entering through a pipe at the center of rotation of the pump blades though thrown outward by centrifugal force, still must have the same flow rate and velocity if entrance and exit tubes have the same diameter. Nothing can be more discouraging for an instructor, feeling a concept is relatively simple and obvious, than to see students "just not get it", and likewise, nothing can more entice considering a hands-on component where entering and exiting flows and velocities are unmistakably the same, and pressures quite different.

We now move to Question 1d and begin drawing other important conclusions. In 1d a diagram was shown with fluid flowing out of a reservoir through a tube that bends downwards vertically and flattens out horizontally again into a very narrow tube. We asked what happens to the velocity in the narrow tube. We covered this topic in both lectures and DLM activities and both groups showed improvement. Relative gains shown in Figure 4 tell us both groups for all questions improved on posttests, with lecture groups showing a slightly higher gain. Again, after we determined effect sizes, shown in Table 6, we see all gains are small to medium for both groups indicating little difference between performance in the two comparative sessions. We also found the p-statistic values for the gains between the groups indicated insignificant differences between groups which may be due to the large standard deviations around the means as reported in Table 6. All this is likely due to the small sample sizes for both groups. However, we note the average gains would amount to a grade increase from a D to a C and D+ to a C+ for the respective DLM and lecture groups on Question 1a, and a

Concept		Pretest		Posttest		Effect Size
		Mean	Std Dev	Mean	Std Dev	
Q 1a Mechanical energy balance	Experimental-DLM	6.2	4.3	7.1	3.5	0.22
	Control-Lecture	6.6	4.1	7.6	3.5	0.28
Q 1b Continuity	Experimental-DLM	3.3	3.8	4.8	4.3	0.35
	Control-Lecture	3.9	4.2	6.0	4.4	0.50
Q 1c Centrifugal pump	Experimental-DLM	2.9	3.8	3.4	4.1	0.12
	Control-Lecture	3.4	4.0	4.1	4.4	0.16
Q 1d Velocity changes reservoir to tube end	Experimental-DLM	6.6	3.4	7.6	3.5	0.30
	Control-Lecture	6.1	3.5	8.0	3.6	0.54

Table 6: Means, standard deviation and effect size for pretest and posttest

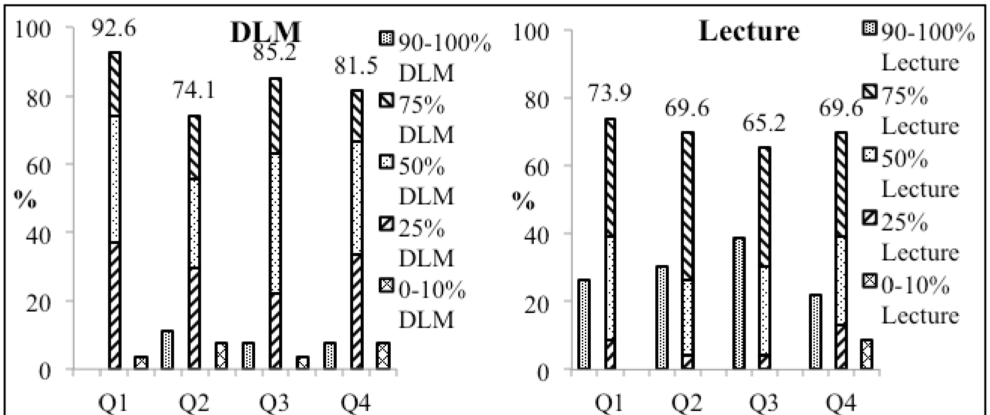

Figure 5: Students attitudes towards hands on DLM and lectures

Comments	DLM Group	Lecture Group
Lecture only	4	1
Prefer Lecture	9	29
Mix of DLM with Lecture	27	11
Prefer DLM	11	5

Table 7: Summary of numbers of student comments about pedagogical approaches

D+ to a C+ and a D to a B for Question 1d. The majority of professors will claim that going from an unsatisfactory low average on a pretest before instruction to a passing and above average rating on a posttest after instruction was due to the instruction no matter what the comparative statistics tell us. More importantly, it is intriguing that the students who had the DLM and very little if any companion lecture improved as well or nearly as well as those who had just the lecture. This supports the premise that well designed hands-on interactive learning will be as effective or nearly so as lecture, with the important benefits of visualization, improved attention, teamwork and stronger interactions with professors and TAs as they circulate among groups.

The results from pretests and posttests are not only telling us how students reflected their understanding of knowledge through their scores, but also tell us how to improve the assessment. It could be that the questions in the pretest and posttest were not the most appropriate questions, or that the way we asked them may not have been best for students to convey their actual knowledge or that the rubric we used for rating was not suitable for all the questions. From this study the data analysis did not tell us which group did better or which method was better for students. In the future, we plan to improve the tests by asking more precise questions that can help students better convey their thoughts. We will also administer the pretest right before students start the study on the topic proceeding to the posttest right after students finish studying the topic. We believe taking the pretest and posttest when students still have the information fresh in their minds will help us to assess the implementation efficiency as well as reduce compensating factors of multiple homeworks, discussions, preparatory sample exams, cross discussions between the two separate courses sections and further discussions with the professor and TAs during office hours.

End of semester survey discussion

One may ask why use the DLMs, since concept tests analyses show similar gains as for lecture, there is an associated financial cost, and there is a barrier in adopting and preparing for the new pedagogy. However, there is encouraging information about the usefulness and need for a hands-on component as will be seen in the survey responses. The response rate on surveys was excellent for both sections and there were abundant comments to support the results. There were 30 students in hands-on learning groups and 26 students completed the survey, an 87% response rate. There were 29 students in lecture groups and 23 students completed the survey, a 79% response rate.

In Figure 5, the self-report survey results show students strongly support some combination of lecture and hands-on activities while relatively few supported use of just one pedagogy, be it DLM or lecture. In the case of those who had DLMs on the topics discussed in this paper, 74-92% preferred use of DLMs for 25-75% of the time with less than 10% wanting DLMs only or lectures only. The same is true for those that had lectures on the same topic with 65-74% wanting 25-75% DLMs mixed with lectures. The data are clear that the lecture groups, by the totals wanting a mix being on the order of 10-15% less than the DLM group, indicated they thought the DLM activities would be less helpful than lecture. This is corroborated by the fact that 25-37% said they wanted the course to be 90-100% lecture. The interesting thing is that this section having had lectures on systems A and B did not have the benefit of using DLMs for the relevant concepts and therefore may not have realized the benefits, though they later used DLMs for other topics not discussed here. Notably those who wanted 75% lectures in the lecture group, 30-43%, were similar in number to those in the DLM group who wanted 75% lectures and 25% hands-on activities, 22-37%. However, a larger number of the DLM students, 25-40% wanted a 50:50 mix of DLM and lecture compared to the lecture section, 21 – 30% depending on the question to which we refer.

That the majority of students believe a mix of lectures and DLMs is most beneficial is further supported by survey comments summarized in Table 7. There were 5 DLM group students who stated they wanted lectures only and only 1 from the lecture group. There were some strongly preferring DLMs based on their comments: 11 were from the DLM groups and 5 from the lecture group. This indicates most of the students who had a particular learning activity tended to prefer the treatment they had. This would explain why there were only 9 comments from the DLM group saying that they preferred lectures on these specific topics, but 29 comments from the lecture group sharing the same opinion. A selected student comment from the lecture group supports this, "Lecture presented the material in formulas that were critical to problems. This allowed for me to fully understand the methods associated with them." Another student, also from the lecture group, suggested that the lecture was better by saying "The lecture demonstration and notes were much more helpful for me to understand the underlying concept."

Yet, the vast majority expressed a desire to have a mix of DLMs and lecture in class, with lectures giving a thorough and accurate description of fundamental concepts and with DLMs creating a mental picture that undergirds and clearly demonstrates the concepts. Selected example comments support this where one student said, "seeing DLMs in lab just put a picture in my mind, but the lecture gave me the crucial fine print underneath the picture to give me understanding of what is happening." Another student suggested, "Doing lecture first to understand the technical aspects would provide a more effective DLM experience." A third further emphasized this point by saying, "I feel like having lecture first and then doing the hands-on activities would help more. This way, I would be able to better understand what is going on and what I should be paying attention to during the hands-on activity." This is supported by Bligh in his book "What's the Use of Lectures?" where he concludes lectures are not intended to promote ideas or offer deep learning experiences, but still provide a good basis of content before a better teaching method is found (Bligh, 2000).

There were some students of course who provided strong comments indicating they preferred the very mode of instruction to which they were exposed over the other to which they were not exposed for the topics we are discussing. There were those who had been exposed to DLMs for example that greatly appreciated the hands-on learning activities, believing they helped them more than any other method. Selected comments include that from one student who said, "Hands-on group activities helped more because I am a very visual person." Another responded, "To be honest, the hands-on activity(ies) help(ed) me understand this material a lot better than lecture." Those who had lectures on these topics that believed lecture to be the only mode in which they learned well had equally weighty comments. This is reinforced by one student who said, "Not easy to translate something you see into an equation, so lecturing on the math was more helpful." Another student responded, "Lecture would probably be the easiest to see all the components." A third replied that, "Lecture seemed like the best option for this topic. They gave a clear and precise method for choosing the proper terms." This would indicate that students slightly favor the treatment that they received, thinking that was the best for their learning having seen it tried and proven effective for their learning.

Another factor that came into play was implementation. Some of those who had the hands-on activities gave constructive criticism on how the implementation could be improved and where it would be most beneficial. From the DLM improvement comments, we not only find reasons why students thought learning with DLMs was problematic, but also ways to improve them. In most student comments, they wanted "a small lecture" before the hands-on activities. Kirschner made clear conclusions that students need strong instructional guidance rather than minimal guidance (Kirschner, Sweller, & Clark, 2006), and hence favors a mix of short lectures and hands-on activities with instructions. One student suggested we "make a video demonstration about DLM(s) and let students watch (them) ahead of time", while another thought lectures should be interspersed with hands-on activities to provide more guidance. There are many other similar comments all saying that they want a clear demonstration and/or instruction before hands-on learning.

To improve DLMs, some students suggested altering the DLM valve set-up, so when they adjust the flow rate by changing valve positions, they can see the pressure drop corresponding to what their calculations would give. Many suggested building a larger-sized DLM system presumably so they could see them better, a particular problem with 4 or 5 people crowding around a single 1 foot wide system – this could also be addressed of course by having smaller group sizes of 2 or 3, something we are just beginning to change. Also the comment when taken collectively with others may be indicative of students' desire for more real physical phenomena – since the systems were of very small scale, students likely realize that engineers in industry are usually dealing with very large scales and it would be helpful to be exposed to this. One said the "Hands on activities would be better if the machines worked a little better". Such a comment could be related to problems with other DLM hardware not associated with the analysis in this paper, however, we recognize the need to provide better valving instructions or to preset some of the valves to control flows within a certain workable range. There were some comments about improving the implementation set-up effort. This could be done by having water tanks filled beforehand. Some students complained that worksheet questions took up too much time in class causing the hands-on learning to be rushed. This could be addressed as already suggested by more lecture preparation and as one student suggested, use of a video demonstration to be watched ahead of time. Some students wanted to have a smaller group for closer observation of System B – being our first implementation of this system we only had one station and half the class was involved in the activity at a time while the other half worked in groups of 4 to 5 on a number of System A setups. Some students wanted to have fewer hands-on learning sessions per week, and more time for lectures. Some suggested that worksheets needed to be modified by providing a chart for recording pressure head data at each point. All these comments are helpful and being considered for future implementation improvements.

Conclusions and Recommendations

Using hands-on learning units to demonstrate continuity and pressure drop concepts in the classroom shows promise in teaching and learning aspects of chemical engineering courses. Dividing students into groups, having instructors and TAs available to rotate among groups in a special classroom setting provides a novel interactive approach, which creates a better communication environment. Our hands-on implementation creates a typical interactive learning environment which we expect will enhance student learning efficiency.

Based on the implementation and assessment of continuity and pressure drop in hands-on learning units, while performance on posttest uniformly improved almost to the same extent as for those who had lecture, most students prefer to have a short lecture about the complexities of the DLM system and to build a theoretical foundation before using DLMs. The combination of DLMs with lectures in the classroom will be considered as a next step implementation and we anticipate improvements in outcomes.

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