ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37951

The Effects of Prior Knowledge on Learning with Low-Cost Desktop Learning Modules

Carah Elyssa Watson

Carah Watson is a rising senior in general engineering with a chemical/pharmaceutical concentration at Campbell University. She has been working as an undergraduate research assistant for Dr. Jacqueline Gartner on the Educating Diverse Undergraduate Communities with Affordable Transport Equipment (EDUC-ATE) project through Washington State University (WSU) and Campbell University since the spring of 2021.

Jacqueline Gartner (Assistant Professor)

Jacqueline is an Assistant Professor and founding faculty at Campbell University School of Engineering. As part of her role, she teaches many of the chemical engineering courses for students in the middle years.

Bernard J. Van Wie (Professor)

Prashanta Dutta (Professor)

Olusola Adesope (Professor)

Heidi Curtis

The Effects of Prior Knowledge on Learning with Low-Cost Desktop Learning Modules

Abstract

Hands-on experiments using the Low-Cost Desktop Learning Modules (LCDLMs) have been implemented in dozens of classrooms to supplement student learning of heat transfer and fluid mechanics concepts with students of varying prior knowledge. The prior knowledge of students who encounter these LCDLMs in the classroom may impact the degree to which students learn from these interactive pedagogies. This paper reports on the differences in student cognitive learning between groups with low and high prior knowledge of the concepts that are tested. Student conceptual test results for venturi, hydraulic loss, and double pipe heat exchanger LCDLMs are analyzed by grouping the student data into two bins based on pre-test score, one for students scoring below 50% and another for those scoring above and comparing the improvement from pretest to posttest between the two groups. The analysis includes data from all implementations of each LCDLM for the 2020-2021 school year. Results from each of the three LCDLMs were analyzed separately to compare student performance on different fluid mechanics or heat exchanger concepts. Then, the overall pre- and posttest scores for all three LCDLMs were analyzed to examine how this interactive pedagogy impacts cognitive gains. Results showed statistically significant differences in improvement between low prior knowledge groups and high prior knowledge groups. Additional findings showed statistically significant results suggesting that the gaps in performance between low prior knowledge and high prior knowledge groups on pre-tests for the LCDLMs were decreased on the posttest. Findings showed that students with lower prior knowledge show a greater overall improvement in cognitive gains than those with higher prior knowledge on all three low-cost desktop learning modules.

1.0 Introduction

It is widely accepted that engineering students can improve conceptual understanding of material with active learning pedagogies compared to traditional lecture-based pedagogies (2). There are many different active learning pedagogies that are implemented in classrooms including hands-on activities, demonstrations, labs, and peer led groups. These different pedagogies are all considered active learning; however, some may be more effective than others at keeping students engaged and teaching the material. A previous study found that interactive and constructive learning activities lead to better scores than active and passive learning activities (5). This study also states that students learned progressively more from passive to active to constructive to interactive activities which aligns with the ICAP hypothesis (5). The interactive pedagogies were most impactful on overall student learning, and this suggests that active learning pedagogies should focus on an interactive implementation to improve student learning.

Another consideration is if students with low prior knowledge of the subject or high prior knowledge of the subject are most helped by the hands-on learning pedagogy. While many studies suggest active learning is beneficial to students in general, some studies suggest it may be more beneficial to students with low prior knowledge of the material or those who are lower performing students overall. A previous study at North Carolina State University showed that students with a lower GPA in an active learning sophomore chemical engineering course were more likely to remain in the chemical engineering program (1). The active learning caused a significant difference in retention of students with lower GPA while students with higher GPA were unaffected by classroom pedagogy. Studies have also shown that different prior knowledge levels can affect the final conceptual understanding of topics (4). A study done in middle schools showed that an animated pedagogical agent helped low prior knowledge students increase cognitive gains. The high prior knowledge students exposed to the same pedagogy did not show the same cognitive gains as the other students (4). This suggests that pedagogies may be best suited for students with specific levels of prior knowledge. Targeting the students who find active learning pedagogies most beneficial is useful when looking at an equitable approach to education instead of an equal approach. While students are all given access to an equal education in a traditional lecture style pedagogy, active learning pedagogies may be more equitable in the classroom because lower performing students improve more without negatively impacting those students who normally do well.

Our team's goal for the EDUC-ATE IUSE project is to disseminate hands-on learning devices to improve students' conceptual understanding and interactive gains. Learning modality and prior knowledge are important aspects of overall learning gains in students. In the study reported in this paper we aimed to investigate the effects of learning modality and prior knowledge on overall cognitive gains in students who use low-cost desktop learning modules (LCDLMs). Data from groups of students who used three different LCDLMs has been analyzed to see if LCDLM exposure does result in different magnitudes of improvement between groups with low or high prior knowledge. The posttest scores are also analyzed on their own to compare how well students in the two groups understand the concepts taught with each LCDLM. Results from use of each module are analyzed separately to understand which concepts taught with the modules are most understood by students in each prior knowledge group. Our analysis will answer whether or not use of the LCDLM pedagogy has an impact on lower prior knowledge student improvement and understanding of the concepts at the time of the posttest in comparison to students with higher prior knowledge.

2.0 Methods

2.1 LC-DLMs

LCDLMs have been created to implement in engineering classrooms across the United States. The modules are manufactured by undergraduate students at Washington State University. Each module is made from injection molded plastic, polycarbonate tubing, and standard fittings. They are accompanied by a kit with extra attachments, stands, thermometers and pumps to operate the devices for implementation. The injection molded plastic is durable and affordable to make the devices at low-cost and is clear, so students can see fluid flow within the device. Adding dye to the water pumped into the devices can also aid in the visual nature of the engineering concepts being taught. The modules are implemented in groups of four students using guided experiments and worksheets. The LCDLMs provide a visual representation of fluids concepts such as the relationship between velocity and pressure and heat transfer concepts like driving force. Data such as velocity, temperature, and pressure can be collected from the devices.

2.2 Pre- and Posttests

During an implementation, students take a pre-test to establish a baseline of knowledge and a posttest aimed at collecting what the students learned during their interaction with the LCDLM. The pre- and posttests consisted of online surveys composed of several multiple-choice questions related to key concepts for the fluid mechanic or heat exchanger devices. For some questions, partial credit was awarded to students who choose answer choices with partially correct explanations. Questions on the pre- and posttests were designed to target different concepts related to the modules and worksheet and questions were repeated between the two surveys. The double pipe heat exchanger LCDLM shown in figure 1A was implemented to teach students key concepts about driving force, velocity, and surface area in relation to heat transfer. Figure 1B shows a hydraulic loss LCDLM and 1C the Venturi meter, both used to teach fluid mechanics concepts like those relating how velocity and pressure change as fluid flows through the throat of the venturi and then through the gradually expanding section.

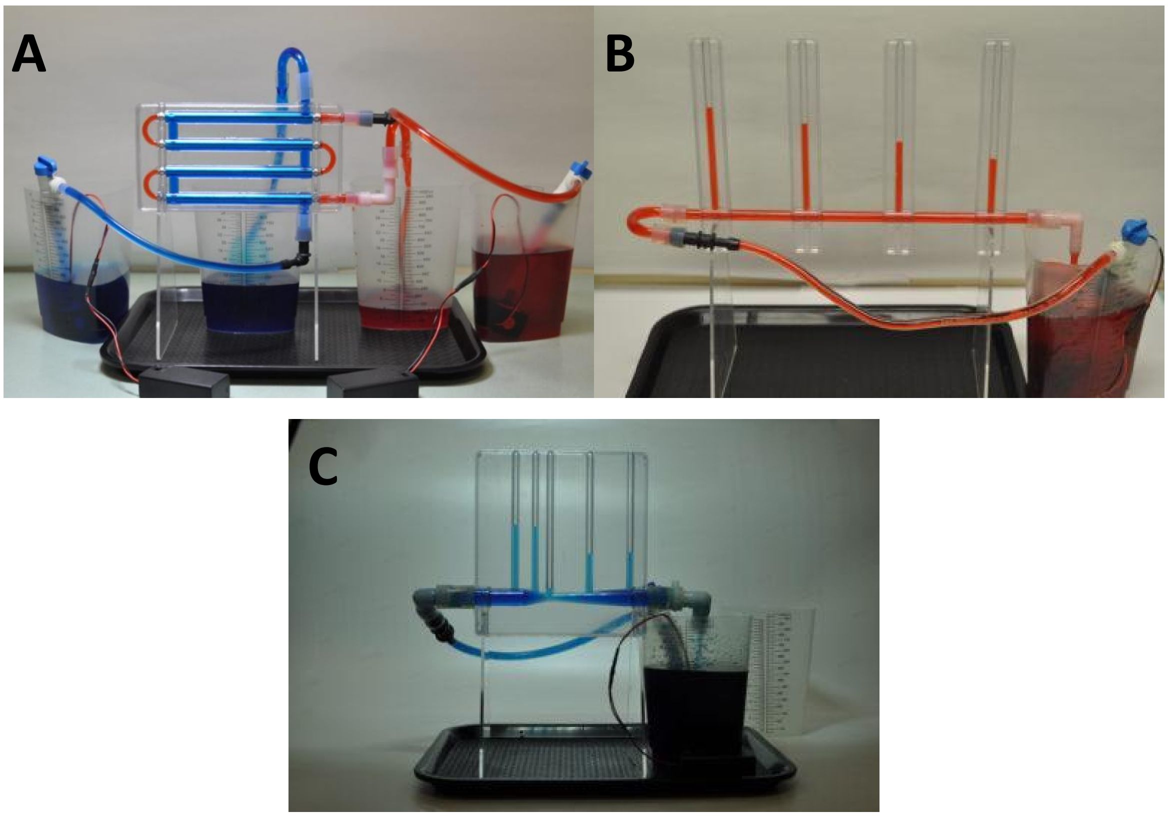

Figure 1: Double pipe heat exchanger (A), hydraulic loss (B), and venturi meter (C) desktop learning module setups

2.3 Implementation

The LCDLMs were disseminated to universities across the country using a hub system based on location. A new hub consisting of approximately half a dozen universities is added each year to train professors on classroom implementation of the modules and foster a sense of community between professors participating on the project. A yearly workshop for each subsequent hub is held in late summer to allow professors to gain hands-on experience, background information on the manufacturing and educational benefits of the modules, and best practices of implementation. Professors work through the experiments outlined in our worksheets provided to help teach specific concepts for fluid mechanics or heat transfer. The worksheets are designed to allow coverage of topics included in the pre- and posttests. For instance, students must identify and formulate an equation for the area of heat transfer in the worksheet for the double pipe module and then answer a conceptual question on the posttest about the area in the module where heat transfer occurs. Professors are not required to use the exact same worksheets in their classroom, but the worksheets provide an example of conceptual topics each LCDLM can be used to illustrate and the calculations that correspond to the concepts. In a typical implementation, the students fill out a consent form then a pre-test for the LCDLM they are using in class that day. Then the professors implement the LCDLM in lecture or lab. After the LCDLM session, the posttest is taken by the students.

2.4 Data Collection and Analysis

The data collected from all classroom implementations for the 2020-2021 school year were grouped and analyzed based on pretest scores. The population size of the double pipe LCDLM was 167 students, hydraulic loss 103, and venturi meter 190. The total population for all LCDLMs was 460 students from universities across the U.S. in 10 mechanical and chemical engineering programs. The two groups compared were students who scored 50% or below on the pre-test, indicating a lower prior knowledge, and those who scored above 50% on the pretest, indicating a higher prior knowledge. The JMP program was used to analyze the data using t-test connecting letters reports. Results from these tests were compared to examine differences in score increases for those with lower vs. higher prior knowledge for each of the three LCDLMs and then for the collective scores of all three together. It should be noted that the mode of implementation, virtual, hybrid, or in person, were not separately considered in this analysis.

3.0 Results and Discussion

Results from average assessment scores show significantly greater impact on understanding of concepts for those with low pre-test scores, especially for the hydraulic loss LCDLM, compared to marginal gains for those with high pre-test scores as illustrated in Table 1. Students with low prior knowledge had average pre-test scores ranging from 23 to 37%, just 31% overall, for all three LCDLM implementations. The double pipe implementation resulted in an average posttest score of 55%, and corresponding averages of 65% for both the hydraulic loss and venturi cartridges amounting to 25, 42 and 27% gains and a 31% gain when taking all three LCDLM data sets collectively. This is in strong contrast to those with high 68 to 84% pre-test scores, 72% on average, whose scores show gains of 1 to 3% for the double pipe and venturi meter units, respectively, and even a reduction by 2% for the hydraulic loss system. Importantly, students in the low prior knowledge hydraulic loss group improved 36% - 41% more than those in either the venturi or double pipe group on the posttests! Interestingly, the hydraulic loss data for those who scored above 50% on the pre-test showed pretest scores were 10% higher on average than those for other LCDLMs. This population was the only group that showed a negative percent difference of -2% in the analysis. All mean values included in Table 1 showing comparisons between the low and high pre-test performance groups are significant, based on student's t-tests, where the connecting letters report showed different letters for all groups. The connecting letters report does not generate p-values and instead simply states whether the difference in means between the pairs were significant or not using an alpha value, or significance level, of 0.05.

Table 1: Average pre- and posttest scores and average improvement for populations above or below 50% on pre-test scores (indicates significance based on t-test connecting letters report)*

Pretest Score Less than or Equal to 50%			
	Average Pretest Score	Average Post Test Score	Average Improve ment
Double Pipe	30%*	55%*	25%*
Hydraulic Loss	23%*	65%*	42%*
Venturi Meter	37%*	65%*	27%*
All LCDLMs	30%*	61%*	31%*

Pretest Score Greater than 50%			
	Average Pretest Score	Average Post Test Score	Average Improve ment
Double Pipe	68%*	70%*	1%*
Hydraulic Loss	84%*	82%*	-2%*
Venturi Meter	71%*	74%*	3%*
All LCDLMs	72%*	74%*	1.9%*

The pre-test averages connecting letters report shows that for each individual LCDLM type the groups perform at statistically different cognitive levels. Each mean for the categories of pre-test, posttest, and improvement were compared between the high and low prior knowledge group and found to be significantly different. The difference in means for the improvement between the pre-test and posttests shows that use of the hydraulic loss LCDLM resulted in a greater difference in improvement between the two prior knowledge groups than for when the venturi and double pipe LCDLMs are used. As shown in Table 2, the difference in means for improvement for the venturi and double pipe were identical at 24%. The posttest difference in means were all 23-43% less than the difference in pretest means for the two groups. Furthermore, the difference in improvement for all three LCDLMs was positive which indicates those with lower prior knowledge improved more than those with higher prior knowledge. The two groups had a difference in means of -39% for the double pipe pre-test, however, the difference between groups shrunk to -15% on the posttest. The venturi meter groups had a difference in means of -34% on the pre-test which shrunk to a difference of only -9.9% for the posttest. Importantly, the hydraulic loss had a large difference in means on the pre-test of -61% which shrunk to -17% on the posttest. This suggests the gap in knowledge between the low prior knowledge and high prior knowledge was closed for all LCDLMs between the pre-tests and posttests. We observe that use of the hydraulic loss module had a greater effect on student cognitive gains than either the double pipe or venturi modules as the improvement in results for the hydraulic loss is nearly double that of either the venturi or double pipe cartridges.

Table 2: Difference in means when subtracting the above 50% group from the below 50% group

LCDLM	Double Pipe	Hydraulic Loss	Venturi Meter	All LCDLMs
Pretest	-39%	-61%	-34%	-42%
Posttest	-15%	-17%	-9.9%	-12%
Improvement	24%	44%	24%	29%

Together, these findings show that the hydraulic loss clearly impacts low prior knowledge learners more than that of the venturi or double pipe. Thinking about the concepts associated with the module, the hydraulic loss emphasizes fundamental fluid mechanics concepts like continuity and skin friction. Meanwhile the venturi meter operates similarly with standpipes, a foundational understanding of the mechanical energy balance and how application of the balance to the inlet and throat will represent the exchange of energy between flow work and kinetic energy is required to excel in a posttest on venturi-related concepts. The hydraulic loss has fewer elements of these pre-requisite concepts as the constant diameter tubing reduces the energy balance to the ΔP and skin friction terms, involving a simpler set of concepts required for student understanding. Similarly, understanding phenomena related to the double pipe heat exchanger requires an understanding of impact of the cross-sectional area of the annulus on fluid velocity, the difference between a ΔT thermal energy driving force and a ΔT associated with an energy balance, the difference between surface area for thermal energy transport and the area normal to the flow streamlines for calculating velocity, and how liquids flow co- or countercurrent relative to each other through the serpentine geometry of the heat exchanger. The simplicity of the hydraulic loss pipe flow experiment may have assisted in the additional learning gains and retention as illustrated in the posttest scores of low prior knowledge learners. As for the high average pretest scores of 84% for the high prior knowledge group on the hydraulic loss concepts, much of the understanding may carry over from a transport course which serves as a pre-requisite for fluid mechanics courses in many curricula. Still, those with low pretest scores on the hydraulic loss concepts, are the lowest overall, averaging 23% demonstrating that even students entering with presumed pre-requisite knowledge are markedly divided between those who “got it”, and those who may have passed exams, but never fully internalized the concepts.

The dramatic increase in improvement for the lower pre-test compared to high pre-test students, not only for the hydraulic loss, but also for the venturi and double pipe heat exchanger modules offers strong supporting evidence that the hands-on, very visual and tactile components of the LCDLM exercises are of assistance to overcome prior intellectual challenges. The use of LCDLMs at least does not negatively impact the performance for the higher pre-test scoring students on average; though improvements are smaller in size there is also a smaller potential for gain as the scores already are nearer to 100%. Figure 2 illustrates the overall trend of greater improvement for those who score lower on the pretest across all DLMs. We might ask the question in a future study correlating GPA among low vs. high pre-test scoring students whether hands-on learning instruction in pre-requisite courses may have more of an equalizing effect on conceptual gain and perhaps more importantly on motivation to learn.

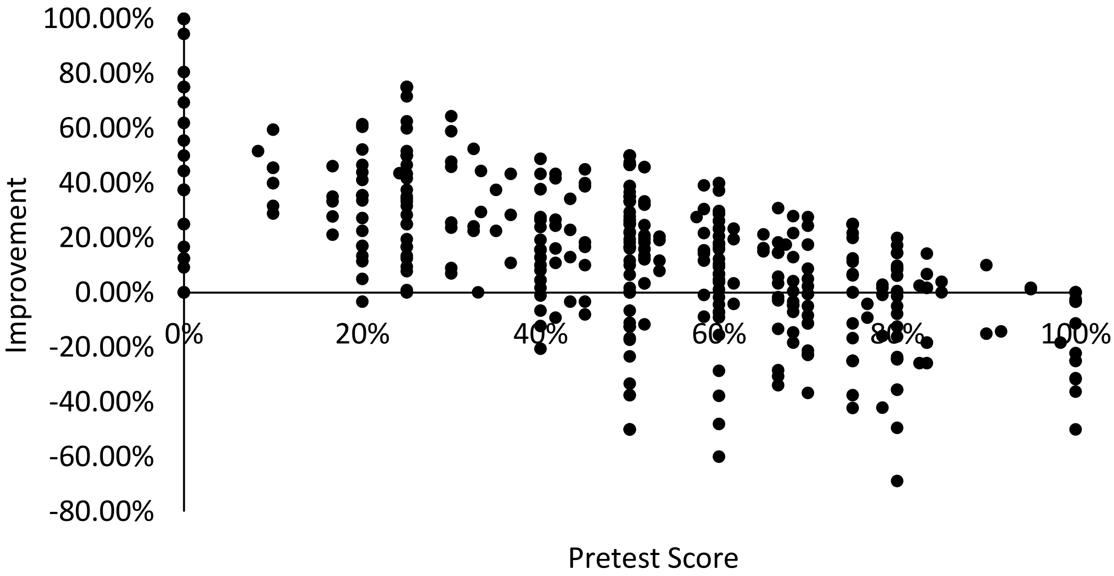

Figure 2: Improvement between pre- and posttest scores for each pretest score across all LCDLMs

4.0 Conclusions

In this study we investigated the performance of low prior knowledge students and high prior knowledge students in classes with LCDLM implementation. The low prior knowledge groups, measured by a pretest score below 50% improved on the venturi meter, hydraulic loss, and double pipe LCDLMs statistically significantly more than the high prior knowledge groups. The group that had the highest gain from pre-test to posttest was that for the hydraulic loss, which we suggest is because fundamental fluid mechanic concepts were targeted that require less prior knowledge for understanding than concepts related to the venturi meter or double pipe modules. The knowledge gap between the low prior knowledge and high prior knowledge group was closed with all three LCDLMs shown by a decrease in the difference of means between the pretest scores and the posttest scores. The different response and improvement between the two groups after using the LCDLMs shows that these modules could be implemented as an equitable approach to education. All modules studied show that groups with lower prior knowledge were able to understand more of the related concepts than before they used the LCDLMS and those who already had a higher prior knowledge of the concepts were not significantly negatively impacted by the use of LCDLMs.

Overall, the active learning pedagogy supported by use of the low-cost desktop learning modules shows there is a significant difference in improvement in the student population whose scores are 50% or lower on pre-tests than the student population whose scores are above 50% on the pretest. There is a statistically significant difference in pre- to posttest concept scores for students with low prior knowledge than for students with high prior knowledge on all three LCDLMs. Use of the hydraulic loss LCDLM, in particular, resulted in the largest improvement in scores for the lower prior knowledge group and the largest difference in improvement between the high and low prior knowledge groups. We postulate that the differences noted have to do with the greater complexity and interrelatedness of concepts for the venturi meter and double pipe heat exchanger modules.

Acknowledgements

The authors are grateful for NSF support through IUSE #1821578 and acknowledge support from the WSU machine shop, Dr. David Thiessen, and undergraduate LCDLM fabricators Connor Backman, Jose Becerra Fernandez, Andrea Garcia, Julio Gaspar, Carter Grant, Chase Llewellyn, Anthony Mendoza, Sara Moore, Johnathan Powell, Aline Uwase, Carah Watson, and Chandler Young, and the students and professors at Brigham Young University, Campbell University, Oklahoma State University, Prairie View A&M University, Texas A&M University, University of Central Oklahoma, University of Dayton, University of Kentucky-Lexington, University of Kentucky-Paducah, University of Oklahoma, University of Tulsa, and Washington University in St. Louis who participated in or directed the implementation.

References

[1] L. Bullard, R. Felder, D. Raubenheimer, "Effects of Active Learning on Student Performance and Retention", in *2008 Annual Conference & Exposition Proceedings*, 2008, pp. 13.473.1-13.473.8.

[2] S. Freeman *et al.*, "Active learning increases student performance in science, engineering, and mathematics", *Proceedings of the National Academy of Sciences*, vol 111, no 23, pp. 8410–8415, Jun 2014.

[3] S. Ghanat, J. Kaklamanos, S. I. Selvaraj, C. Walton-Macaulay, M. Sleep, "Assessment of Students' Prior Knowledge and Learning in an Undergraduate Foundation Engineering Course", in *2017 ASEE Annual Conference & Exposition Proceedings*, 2017, p. 27642.

[4] A. M. Johnson, G. Ozogul, M. Reisslein, "Supporting multimedia learning with visual signaling and animated pedagogical agent: moderating effects of prior knowledge: Learning with signaling and APA", *Journal of Computer Assisted Learning*, vol 31, no 2, pp. 97–115, Apr 2015.

[5] M. Menekse, G. S. Stump, S. Krause, M. T. H. Chi, "Differentiated Overt Learning Activities for Effective Instruction in Engineering Classrooms: Differentiated Overt Learning Activities", *Journal of Engineering Education*, vol 102, no 3, pp. 346–374, Jul 2013.

[6] O. Reynolds *et al.*, "Transition of an Interactive, Hands-on Learning Tool to a Virtual Format in the Covid-19 Era", 2021.

[7] B. J. Van Wie *et al.*, "Progress in the Nationwide Dissemination and Assessment of Low-Cost Desktop Learning Modules and Adaptation of Pedagogy to a Virtual Era", in *NSF Grantees Poster Session*, 2021.