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Work-In-Progress: Enhancing Engineering Education: A Comparative Analysis of Low-Cost Desktop Learning Module Impact on Student Engagement and Outcomes

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Enhancing Engineering Education: A Comparative Analysis of Low-Cost Desktop Learning Module Impact on Student Engagement and Outcomes

ABSTRACT

There is a growing emphasis on enhancing student engagement and comprehension in the dynamic landscape of engineering education. To address this critical need, we developed evidence-based activities to go along with Low-Cost Desktop Learning Modules (LCDLMs). These LCDLMs and associated activities were developed to bridge the gap between theoretical knowledge and practical application related to learning of fundamental engineering concepts in heat transfer and fluids mechanics. In prior research we investigated the impact of LCDLMs on student learning, with a focus on how different delivery modes, ranging from in-person to virtual environments, affect educational outcomes. In these studies, we also delved into demographic influences, analyzing how factors such as race, ethnicity, and gender may play a role in learning efficacy while using LCDLMs. Furthermore, our investigations have extended to assess how LCDLMs can bolster intrinsic motivation and the adoption of effective learning strategies. Our current study seeks to investigate the effects of different Low-Cost Desktop Learning Modules (LCDLMs) on students' post-test score and cognitive engagement score - measured using the Interactive, Constructive, Active, and Passive (ICAP) framework). Preliminary findings suggest that, hands-on instruction with LCDLMs enhances students' interactive engagement more than traditional lectures, as measured by ICAP scores. Our results also showed that the hydraulic loss module was more effective than the other two types of LCDLMs (shell and tubes and venturi) in enhancing students' learning. While these results indicate a potential for more interactive, hands-on methods in teaching complex engineering concepts, they also highlight the need for further research to understand the broader implications for educational practices.

Keywords: *Engineering Education, Low-Cost Desktop Learning Modules (LCDLM), Student Engagement, Active Learning, Instructional Methods.*

INTRODUCTION

Over the past decades, researchers in engineering education have continuously explored and proposed innovative instructional methods and approaches to enhance learning effectiveness [1], [2], [3], [4], [5]. These explorations have contributed profoundly to reshaping our understanding of instructional methods and approaches, emphasizing the need for diverse and adaptive teaching strategies. A notable contribution by Johnson and Johnson [4] highlights the effectiveness of cooperative learning, where students work in small groups to achieve learning goals, demonstrating improvements in academic achievement and interpersonal relationships. Furthermore, research by [6] on concept mapping and learning highlighted the effectiveness of this approach in improving student comprehension and retention of complex concepts. Nesbit and Adesope [6] emphasized the importance of integrating cognitive theories and technology-enhanced tools in educational practices to promote meaningful learning

There is increasing evidence to suggest that learning improves with student-centered learning practices and engagement according to the Interactive, Constructive, Active, and Passive (ICAP) framework developed by Chi and Wylie [7]. This framework is a comprehensive model that categorizes different types of cognitive engagement into four distinct levels: interactive, constructive, active, and passive [7]. Active learning regardless of the level is generally characterized as any educational activity that fosters student interaction and involvement with the subject matter, as opposed to merely a passive reception of information [8].

One of the promising active learning practices used to foster learning in engineering education is the Low-Cost Desktop Learning Modules (LCDLM). The LCDLM was developed to provide undergraduate and graduate students with a dynamic active learning experience in engineering subjects, aiming to boost engagement within the engineering classroom setting. A significant aspect of the LCDLMs is their affordability and accessibility as highlighted in [8]. These scholars emphasize how LCDLMs provide cost-effective alternatives to conventional laboratory equipment. This accessibility is particularly crucial in STEM fields, where experiential learning is essential for grasping complex concepts. LCDLMs have been researched to promote active learning in engineering education. For example, a study by [9] examined how the low-cost desktop learning modules (LCDLM) facilitated direct student engagement with educational materials, fostering deeper comprehension through interactive participation.

Despite significant advancement in educational research and the effectiveness of specific instructional types, such as online learning, hands-on, and traditional lecture approaches [10], much remains unknown about the effect of different instructional types on student learning and engagement. This current study seeks to increase understanding on how various instructional types impacts diverse student learning outcomes.

PRESENT STUDY

The present study aimed to explore the relationship between instructional approaches and student learning outcomes. Building on the conceptual framework that hands-on learning may enhance cognitive engagement, we examined how the type of instructional approach — specifically, a hands-on method versus a traditional control approach — influences students' ICAP scores. The ICAP framework suggests that deeper cognitive engagement through interactive and active activities leads to more effective learning outcomes. Furthermore, we assessed the impact of educational technology by investigating the effects of different Low-Cost Desktop Learning Modules (LCDLMs) on students' post-test scores. These modules represent an intersection of affordability and practicality in educational tools, yet their influence on learning retention and comprehension remains underexplored. The study, therefore, sought to answer the following research questions:

- Research Question 1: How does the type of instructional approach (Hands-On vs. Control) influence the average ICAP scores among students.
- Research Question 2: What is the impact of different Low-Cost Desktop Learning Module (LCDLM) types on students' learning outcomes?

METHODS

Participants

We recruited instructors from eight different universities in the U.S. who taught fluid mechanics and heat transfer courses to undergraduate engineering students. These instructors were recruited to either use LCDLMs in their teaching (Hands-On group) or to teach using traditional lectures (Control group). One hundred and sixty-five students consented to take part in our study. The participants consisted of 45 females, 114 males, 4 others (including non-binary, gender-fluid, agender), and 2 who preferred not to answer. The mean age of the participants was 20.3 years (SD = 2.1), ranging from 18 to 36 years.

The ICAP Survey

To measure the students' cognitive engagement with the LCDLMs, we used the ICAP survey, which is based on the framework proposed by [7]. The designed ICAP survey questions consisted of 16 questions, four for each ICAP category, that asked the students to rate how much they agreed or disagreed with statements about their learning activities with the LCDLMs. The questions were adapted from previous studies that used the ICAP framework to assess engagement in different contexts [7], [11]. The survey used a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The ICAP survey has been shown to have good validity and reliability in measuring cognitive engagement [7]. The Cronbach's alpha reliability estimates for interactive score was 0.89, constructive was 0.89, active was 0.84 and passive was 0.91.

Materials

Low-Cost Desktop Learning Modules

The low-cost desktop learning modules (LCDLMs) were created to aid in student comprehension of a variety of engineering concepts. The LCDLMs are hands-on tools that can be used to represent the theories behind the many process units seen in the industry. LCDLMs have been found to be effective within a classroom setting [12], [13]. More specifically, LCDLMs are innovative desktop experiments that are designed to facilitate hands-on learning of fluid mechanics and heat transfer concepts for engineering students. They are low-cost, miniaturized, lightweight, transparent, safe, and user-friendly. The LCDLMs also come with instructional materials, such as videos, readings, worksheets, and homework assignments, that guide the students through the learning process. In this study, we used three different LCDLMs, each focusing on a specific concept within fluid mechanics and heat transfer: shell & tube, hydraulic loss, venturi meter [12], [13].

Measures

Learning Performance

We assessed the students' prior knowledge and learning performance for each LCDLM using multiple-choice tests. The tests consisted of 6 pretest and 8 posttest questions with Cronbach's alpha reliability estimates = 0.74. These questions covering the main concepts and principles related to each of the LCDLMs. The questions were designed to test the students' conceptual understanding, rather than their factual recall or procedural knowledge. The questions were aligned with the learning objectives and outcomes of the LCDLMs. The tests were administered online via Qualtrics before and after the students engaged with the LCDLMs. The tests were scored by awarding one point for each correct answer and zero for each incorrect answer.

Procedure

First, a pre-test was presented to the participants to evaluate their prior understanding of fluid mechanics and heat transport concepts. A worksheet was given to each participant for use by them during the experiment. The experiment's steps were outlined in the worksheet for the participants to follow. The worksheet gave the participants a chance to consider and deliberate about the ideas being covered. Afterward, each participant was given a post-test to examine how much they had learned during the instruction. They were then required to respond to the cognitive engagement survey. Participants received links to the online surveys administered via Qualtrics© at the end of the LCDLMs sessions. The cognitive engagement survey prompts asked participants to reflect on their LCDLM facilitated instructions and report how well they believed experiencing LCDLMs instruction helped them to engage in learning or how LCDLMs engendered affective responses that we intended would capture situational interest. Students also completed an assessment focused on self-reported engagement and the usefulness of various physical features of the LCDLMs for enhanced learning. Figure 1 illustrates the distribution of participants' responses regarding their engagement with the low-cost desktop learning module (LCDLM) based on the ICAP framework.

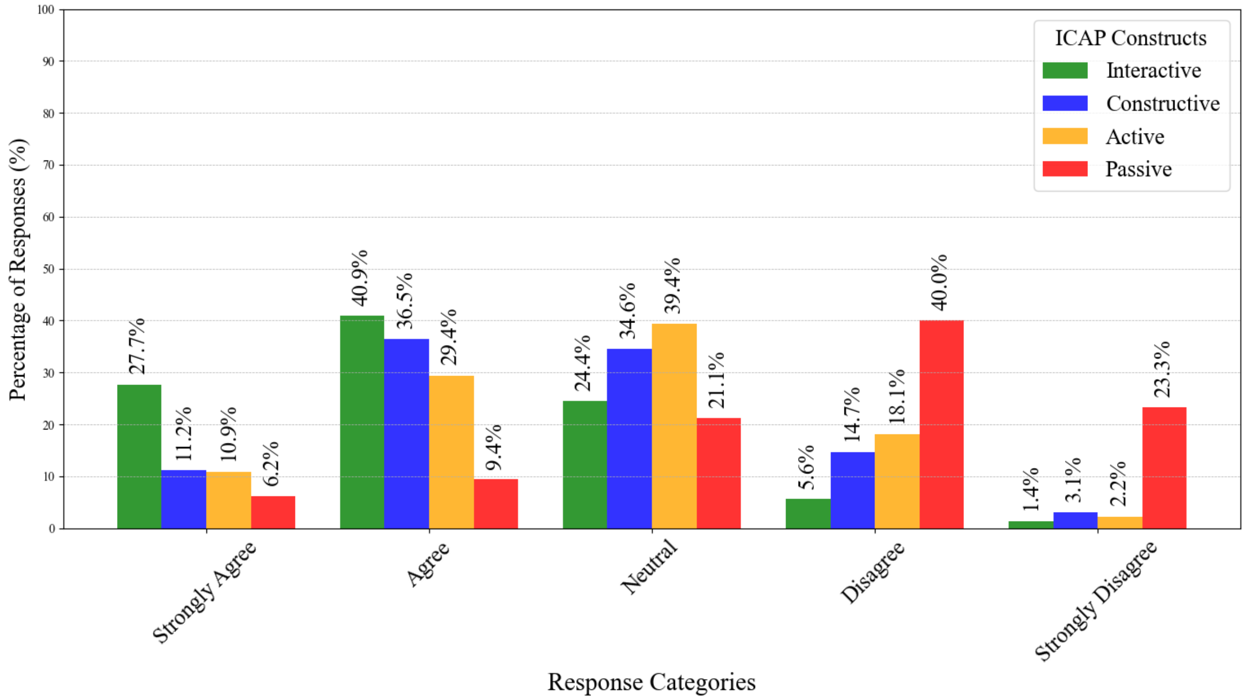

Figure 1: Participants' endorsements of the LCDLM (ICAP)

RESULTS

Instructional Approach and ICAP Scores

Prior to data analysis, all variables were examined for accuracy of data entry, outliers and normality of distributions. All assumptions were met. The data were normally distributed within acceptable levels of skewness and kurtosis [14]. A one-way multivariate analysis of variance was conducted to evaluate the impact of the type of instructional approach on the ICAP scores among students. The instructional approach was classified into two learning groups: the hands-on and control. The dependent variable was the average ICAP average score, categorized into four types: interactive, constructive, active, and passive. The univariate ANOVA results revealed differential effects of instructional approach on the interactive mode of engagement $(F(1, 163) = 4.184, p = 0.042)$ and the active mode of engagement $(F(1, 163) = 6.078, p = 0.015)$ ICAP scores, indicating that the type of instruction significantly influenced these aspects of student engagement. No significant effects were found for constructive *(F(1, 163) = 0.295, p = 0.588)* and passive *(F(1, 163) = 0.927, p = 0.337)* scores. Post hoc analyses using Tukey's HSD test indicated that the hands-on approach led to significantly higher interactive scores compared to the control approach (4.09, SD = 0.73, M = 3.82, SD = 0.81). Conversely, the hands-on approach resulted in significantly lower Active scores than the lecture condition (M = 3.60, SD = 0.703, M = 3.89, SD = 0.57).

Table 1: Effects of Instructional Approach on ICAP Scores

Means, Standard Deviations, and One-Way Analysis of Variance in instructional approach on the ICAP scores among students.

Measure	Hands-On (N = 120)		Control (N = 45)		F (1,163)	p-value	Cohen′s d
	M	SD	M	SD			
Interactive	4.09	0.73	3.82	0.81	4.184	0.042*	0.3
Constructive	3.94	0.78	3.87	0.81	0.295	0.59	
Active	3.6	0.70	3.89	0.57	6.078	0.015*	0.5
Passive	2.325	0.83	2.47	0.87	0.927	0.34	

*** p < .005

Table 2: A Tukey’s HSD pairwise comparison revealed the significant differences between G1 and G2 (p <0.05) for interactive, and between G1 and G2 for active (p <0.05).

G1	G2		Lower Bound	Upper Bound	p-value
Hands-On	Control	0.27	0.01	0.53	0.04
Hands-On	Control	-0.29	-0.52	-0.06	0.0147213

*** p < .005

Impact of LCDLM Types on Post-Test Scores

To determine the impact of different types of Low-Cost Desktop Learning Modules (LCDLMs) on students' post-test scores, an ANOVA was conducted. The LCDLMs types assessed were Venturi, Shell & Tube, and Hydraulic Loss, with the dependent variable being the students' post-test scores. The analysis revealed a significant effect of LCDLM type on post-test scores ($F(2, 117) = 10.81$, $p < .001$). Post hoc analyses showed that Hydraulic Loss post test score outperforms Shell & Tube were associated with significantly higher post-test scores compared to Hydraulic Loss and Venturi ($M = 80.63$, $SD = 21.69$, $M = 54.11$, $SD = 29.04$, $M = 67.27$, $SD = 20.09$). However, no significant difference in post-test scores was observed between Venturi and Shell & Tube.

Table 3: Analysis of Variance (ANOVA) results for the impact of LCDLM types on students' learning outcomes.

Measure	Hydraulic Loss (N = 46)		Shell & Tube (N= 22)		Venturi (N= 52)		F (2,117)	p-values	η^2
	M	SD	M	SD	M	SD			
Post Tests	0.80	0.21	0.54	0.29	0.66	0.21	10.81	<0.05	0.16

*** p < .005

Table 4: A Tukey's HSD pairwise comparison revealed the significant differences between shell and tube and hydraulic loss and between venturi and hydraulic loss.

Comparison	M	95% CI	p-value
Shell & Tube vs. Hydraulic	-0.2614	(-0.4017, -0.1211)	< 0.001
Venturi vs. Hydraulic	-0.1446	(-0.2541, -0.0351)	0.0061
Venturi vs. Shell & Tube	0.1168	(-0.0208, 0.2544)	0.1132

*** p < .005

DISCUSSION & CONCLUSION

The present study provides evidence on the effectiveness of hands-on instructional methods using Low-Cost Desktop Learning Modules (LCDLMs) in engineering education. In line with the ICAP framework, hands-on methods enhanced interactive engagement scores significantly. Our result supports the cognitive engagement theory proposed by Chi and Wylie [7], which implies that interactive learning activities facilitate deeper cognitive processing, leading to improved learning outcomes. However, the hands-on method seemed to reduce active engagement scores compared to traditional lecture methods. This might suggest that students may prefer other forms of active learning, such as note-taking or summarizing, which are more aligned with their learning styles or goals. This result might call for a reassessment of hands-on methods to ensure they encompass all active learning aspects. The study also revealed that the type of LCDLM influenced learning effectiveness, with the hydraulic loss module resulting in higher post-test scores. This implies that some modules may be more efficient at conveying complex engineering principles, possibly due to the nature of the concept or the design of the module itself. Our study has not only provided evidence for the effectiveness of hands-on learning modules over traditional lectures but also lays the groundwork for future research into optimizing instructional designs to enhance student engagement and learning outcomes in engineering education.

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