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Gender-Related Effects on Learning with Hands-On Modules in Engineering Classrooms

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Work in Progress: Gender-Related Effects on Learning with Hands-On Modules in Engineering Classrooms

Abstract

Numerous studies have endorsed hands-on learning as an effective way to transform science, technology, engineering, and mathematics (STEM) education. More specifically, advocates of hands-on learning in STEM suggest that such active learning strategies have been found to increase engagement and learning. Indeed, numerous studies have been conducted on the effects of low-cost desktop learning modules (LCDLMs) on students' learning experiences in engineering classrooms as part of a comprehensive research program to promote hands-on learning. We have reported on the effects of LCDLMs on students' motivation and learning strategies skills in past publications. However, little is known about how different students learn with LCDLMs. Such studies are needed to further establish the robustness of LCDLMs for improving different students' learning and motivation to learn. The present study begins to fill this gap by examining if LCDLMs offer differential benefits or effects based on the gender of participants who used these LCDLMs. If LCDLMs are equally beneficial for men and women, this could suggest that they are effective for all genders. This would be a valuable contribution to the existing research on gender inequality in STEM, which has shown significant gender gaps in retention and workforce development in engineering. This underrepresentation of females in science-dominated fields is a major concern for researchers and policymakers. This study aims to investigate the differences between males and females in affective and motivational engagement forms. A total of 232 survey responses from students enrolled in fluid mechanics and heat transfer, a junior-level chemical engineering course at eight universities in the United States of America, were used in this study. More specifically, the study used these survey responses to assess differences in learning and engagement between male and female participants. Results show no significant differences between the gender groups, which suggests that using LCDLMs is beneficial for females as they are for males. The paper concludes with implications and recommendations for researchers to develop hands-on interventions.

Introduction

Across numerous studies, researchers have examined how gender impacts achievement motivation and its influence on educational and occupational choices [1]–[5]. These studies utilized achievement motivation theories to understand why men and women pursue different career paths. In recent years, there has been significant progress toward achieving gender equality in academic achievement across different educational levels.

Nevertheless, women continue to be significantly underrepresented, particularly in STEM fields, according to the National Science Foundation's report from 2021 [6]. As a result of these inequalities, among other learning barriers in STEM classrooms (e.g., cognitive engagement, affective engagement, etc.), many STEM instructors in higher education have since proposed active learning as a promising way to improve student engagement and learning experience.

Notably, advocates of active learning in STEM posit that active learning strategies increase students' engagement in their learning environments [7]. Extant research has shown that active learning can be fostered through low-cost desktop learning activities [8]–[10]. The LCDLM was designed to offer postsecondary students (i.e., undergraduate and graduate) an active learning experience in engineering. Students can use these LCDLMs to investigate heat transfer and fluid mechanics phenomena directly.

While most active learning strategies (pedagogies) have since been developed to improve student's experience in the classroom, there is still a lot of research literature that suggests that these strategies are not equally engaging to all students, particularly considering that there is still a plethora of evidence that suggests that women are still underrepresented in STEM classrooms, [1], [6], [11], [12].

The present study aims to bridge the research gap in the literature by investigating whether there are varying advantages or impacts of LCDLMs depending on the gender of the participants. The main objective is to determine if both men and women benefited equally from using the LCDLMs. These findings could add to the current pool of knowledge on gender inequality in STEM, particularly in the engineering sector, where there is a significant gender disparity in workforce development and retention.

Methods

Participants and Design

The study involved 232 postsecondary undergraduate students enrolled in similar heat transfer and fluid mechanics courses in 8 schools (9 classes) in the United States. The participants comprised 74 females and 158 males. Of the total participants, 6 identified as "non-binary," and 6 other participants preferred not to answer the gender identity question. Due to the small sample size, we could not include these participants in our analysis. The racial/ethnic composition of the participants was White (67.8%), Asian (10.3%), Hispanic (8.1%), Black (9.1%), Middle Eastern (1.7%), and Other (3%). The data for the study was collected from various universities, including three research universities (R1): Howard University, the University of Kentucky, and The University of Dayton, which are well-known institutions with strong engineering programs. Including research universities in the sample allowed us to evaluate the generalizability of the findings to a wider range of students.

Materials and Measures

Low-Cost Desktop Learning Modules

Low-Cost Desktop Learning Modules (LCDLMs) are small, affordable models of industrial equipment that can be used to teach engineering concepts. They are helpful tools for learning abstract concepts in the classroom because students can interact with them and see how they work. The LCDLMs used in our studies were made from simple, inexpensive materials and could be used to simulate different flow rates and observe how temperature and pressure change, for example. By interacting with LCDLMs, students can solidify their understanding of abstract engineering concepts taught in the classroom. LCDLMs and older versions have been used in previous studies in various settings [8]–[10], [13]–[15].

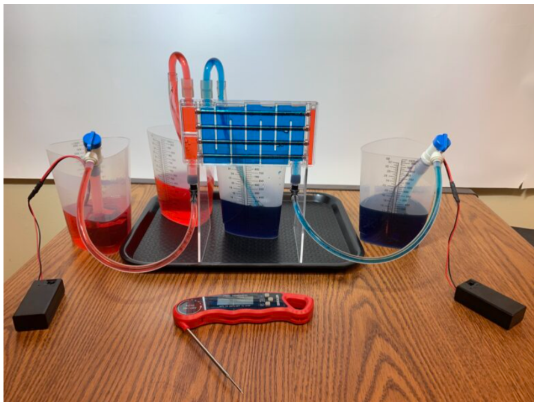

Fig 1: Shell and Tube (Heat Transfer Kit).

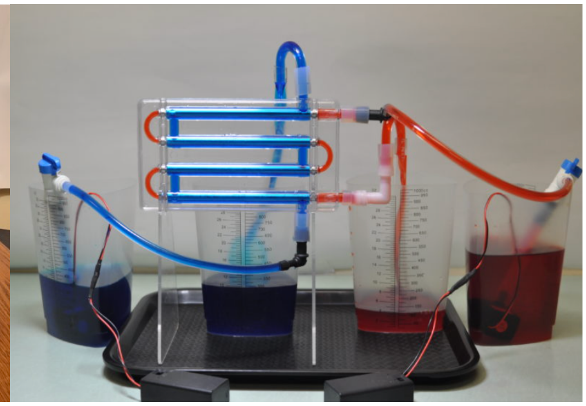

Fig 2: Double Pipe (Heat Transfer Kit).

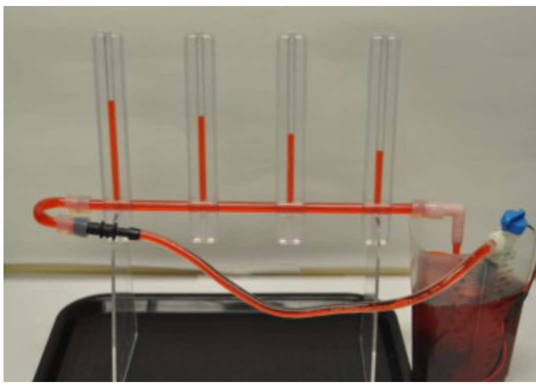

Fig 3: Hydraulic Loss (Fluid Mechanics).

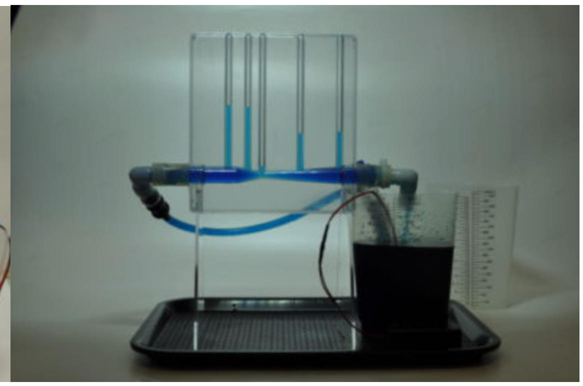

Fig 4: Venturi Meter (Fluid Mechanics)

Figures 1,2, 3, & 4 are all samples of the LCDLMs used in this study. Fig 1 has standpipes that participants could use to observe different flow rates and how temperature and pressure change as fluids pass through the system [15]. Each module served as a teaching aid that provided visual reinforcements to substantiate many abstract concepts taught in the classroom as participants interacted with the modules.

Survey

This research employed a descriptive survey design, a blend of quantitative and qualitative data. Data was collected using a survey instrument administered with the Qualtrics online survey tool. The motivational survey had sixteen questions (four questions for each category of the ICAP framework: Interactive, Constructive, Active, and Passive) with close-ended Likert-type items to examine how cognitively engaging the concepts they learned with the LCDLMs were. The questionnaires were adapted from the ICAP [16] framework using a 5-point Likert scale (1 = Strongly disagree, and 5 for Strongly agree). The ICAP model, as proposed by [16], connects various observable student behaviors to potential cognitive actions and subsequent learning outcomes.

Procedures
For this study, we recruited instructors from diverse schools that offered courses in fluid mechanics, heat transfer, and related topics. These instructors were provided with LCDLMs to incorporate into teaching these concepts. The participants were first instructed to go through a pre-test to assess prior knowledge of fluid mechanics and heat transfer concepts. The instructor in each school then used LCDLMs to facilitate instruction while teaching heat transfer and fluid mechanics concepts. Participants were provided with a worksheet to guide them during the experiment. The worksheet contained steps for the participants to perform during the experiment. The worksheet allowed the participants to think and reflect on the concepts being taught. 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 motivational/engagement survey. Participants received links to the online motivational survey administered via Qualtrics© at the end of the LCDLMs sessions. The 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.

Data Analysis
A One-way MANOVA was then conducted to examine differences between male and female participants' perceptions of their cognitive engagements with the LCDLMs. Each student's cognitive engagement was measured on an interval level scale variable where each level corresponds to the four ICAP levels [16]. Each participant's average ICAP score served as the dependent variable used in this study. The independent variable in the study is a categorical demographic variable that classified the students into two groups, one for female and the other for male students. An alpha value of .05 and SPSS version 24 was used to check for statistical significance. There was no statistically significant difference between males and females.

Table 1: *A comparison of overt attention focusing on students' affective and motivational engagements by gender.*

	Male (n = 158)		Female (n = 74)			
	Mean	*SD*	*Mean*	*SD*	*F*	*Sig.*
Interactive	4.02	0.63	4.07	0.54	0.32	0.56
Constructive	3.89	0.61	3.99	0.53	1.44	0.23
Active	3.59	0.56	3.68	0.63	1.09	0.29
Passive	2.34	0.89	2.29	0.95	0.15	0.69

Results
A one-way multivariate analysis of variance was run to examine if LCDLMs offered differential benefits or effects based on the gender of participants. Four modes of engagement were assessed: Interactive, constructive, active, and passive scores. Participants were grouped by their gender: male and female. First, we checked preliminary assumptions, and results revealed that data was normally distributed, as assessed by inspecting the Normal Q-Q plots. There were no univariate

and multivariate outliers, as assessed by boxplot; there were linear relationships, as evaluated by scatterplot, and no multicollinearity; and variance-covariance matrices were homogeneous, as assessed by Box's test of equality of covariance matrices *($p = 0.473$);* variances were homogeneous, as assessed by Levene's Test of Homogeneity of variance *($p > .05$)* The differences between the genders on the combined dependent variables were not statistically significant, $F(4, 227) = 0.461$, $p = 0.765$; $Wilks' \Lambda = 0.992$; $\eta^2 = 0.008$

Limitations

When interpreting the results, it is important to consider the several limitations of this study. The sample size was relatively small, which may limit the applicability of the findings to a broader student population. Self-reported data were used, which could be influenced by response biases and social desirability biases. Additionally, the study solely focused on affective and motivational engagement forms and did not investigate other learning outcomes, such as conceptual understanding. The study was also restricted to male and female gender categories, with inadequate representation from non-binary and gender-fluid individuals, resulting in limited generalizability of the findings to a more diverse population. Furthermore, the study only examined undergraduate fluid mechanics and heat transfer courses, and the results may not be relevant to other STEM fields or academic levels. Despite these limitations, this study offers valuable insights into the potential benefits of LCDLMs in STEM education, particularly in promoting similar levels of engagement for male and female students in STEM classes. However, further research is necessary to address these limitations and investigate the effects of LCDLMs on student learning.

Discussion

As part of a more extensive NSF-funded research program, this study examined whether the use of LCDLMs promoted similar levels of engagement for male and female students. As briefly described in the introduction, gender differences still exist in educational outcomes, particularly in STEM classrooms [6]. To reduce the gender gap in STEM, attention should be given to addressing the contributory cognitive and motivational factors, primarily maximizing the number of career options women perceive as attainable and compatible with their abilities and goals. Results of this study show no significant differences between the gender groups, which suggests that using LCDLMs is beneficial for females as they are for males. This is good because extant literature shows gender differences in STEM, suggesting that gender gaps still exist between male and female students, especially in STEM. Given these findings, we intend to extend this study by investigating why LCDLMs fostered similar forms of engagement for males and females. LCDLMs are inexpensive miniature prototypes of industrial equipment; participants interact with the LCDLMs without fear of damaging the equipment. Researchers [17] hypothesize that men are more likely to take risks than women. Although preliminary, we predict that the female participants in our study were as comfortable using the LCDLMs as the male participants because the modules are inexpensive. Future studies will carefully examine this hypothesis.

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