Exploring Students’ Perceptions of an Innovative Active Learning Paradigm in a Fluid Mechanics and Heat Transfer Course*

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Students-centered paradigms have been proposed as beneficial to promoting enriching learning experiences. In an attempt to improve student learning experience in engineering classrooms, instructors often employ innovative strategies to foster learning engagement. One such approach is Cooperative Hands-on Active Problem-based Learning (CHAPL). CHAPL combines the characteristic benefits of some existing research-proven active learning pedagogies. This study reports responses from a survey that assessed the perspectives of chemical engineering students who were taught fluid mechanics and heat transfer concepts using both traditional classroom lecture and the new student-centered paradigm—CHAPL. Analysis of responses to closed and open-ended survey items indicates that CHAPL could differentially influence measures of significant learning and may be beneficial to enriching the learning experience. Limitations and recommendations for future implementations are discussed.

Keywords: cooperative; hands-on; active; problem-based learning; CHAPL; cognitive outcomes; affective outcomes

1. Introduction

In response to national reports about the inadequate preparation of engineering graduates to face workplace challenges, ABET initiated the Engineering Criterion 2000 (EC2000) standards for accrediting engineering programs [1]. Unlike pre-EC2000, the current requirements shift the focus of accreditation away from ‘what is taught’ towards ‘what is learned’ [2]. Many engineering programs responded to the EC2000 by restructuring existing curriculum to privilege student-centered learning pedagogies, such as: problem-based learning, hands-on and collaborative learning that teach good communication, problem solving and life-long learning skills [1, 3].

While the EC2000 is an auspicious initiative to improving engineering graduate preparedness for the workplace, it seems clear that a teacher-centered mode of instructional delivery is sub-optimal for achieving its objectives [4]. The conventional engineering classroom has been characterized by lethargic passivity on the side of students that detracts from meaningful learning engagements. More than often, students are less cognitively engaged with their learning, and as well are minimally engaged in peer learning as they depend so much on the sage-on-the-stage [5, 6]—resulting in students who are ill-prepared to engage with the workplace’s multifaceted expectations. In a bid to revamp existing curriculum, engineering educators are adopting established inquiry-based and student-centered pedagogies that are grounded in education literature that promise enriched student experience, as well as equipping graduating engineering students in attaining the learning outcomes specified by the EC2000 Criterion 3 a–k.

Unlike teacher-centered instructional approach, student-centered learning shifts the responsibility for learning to the students, giving the instructor a new role as a guide-by-the side [7]. Taking ownership of their learning, students are more cognitively engaged in knowledge construction and are emotionally invested in the learning process. This is perhaps demonstrated by studies that have compared lecture-type learning with such pedagogies that foster student engagement as active learning: cooperative learning, project-based learning, and inquiry-based learning among others [8–10].

Review of education research literature has shown that learning approaches that encourage student engagement promote meaningful learning [11]. Lattuca and colleagues also indicated in their evaluation report that curriculum and instructional methods that encourage active learning were one of the programmatic changes that many colleges have

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made to meet the EC2000 accreditation Criterion 3 requirements. Their report suggests that these shifts might have resulted in significant changes in at least seven out of ten measures of student experiences examined in their cross-sectional evaluation of engineering programs and graduates over a ten-year period, although observed changes were small. Improving the quality of students’ learning experience and all associated learning outcomes is a crucial objective of engineering educators, and the focus of engineering education research has been to identify innovative ways of raising the bar in teaching excellence and enhancing those learning outcomes [4].

While diverse factors may be responsible for the quality of students’ learning experiences in engineering programs [12], enriching student learning experiences would require multi-faceted innovative efforts that extend beyond professional development that instructors of engineering courses get—especially when they consider the limitations of teacher-centered learning. Extending the potential of student-centered learning to ensure an enriching experience might include a rich integration of different active learning paradigms. In light of this, we have been working to fine-tune a pedagogy that incorporates features and attributes of some research-proven student-centered learning approaches. Cooperative Hands-on Active Problem-based Learning (CHAPL) incorporates features of cooperative learning and problem-based learning while using hands-on learning aids in engineering instruction. This article reports on an exploratory study that compares students’ experience in traditional lecture sessions to a CHAPL-augmented classroom.

1.1 An overview of pedagogical components of CHAPL

Extant literature has suggested that students have a variety of learning styles [13, 14]. Felder and Silverman [15] argued that professors soon bore students in engineering classes when there is a mismatch between instructors’ teaching styles and their students’ learning styles, which results in learning disengagement, poor tests scores and possible attrition. Some instructors however explore different constructivist paradigms to foster student involvement and learning engagement. Because students learn differently however, no single unblended instructional design may guarantee optimal engagement. A learning paradigm that integrates multiple learning opportunities might be helpful in engaging learners. As such we combined features of Cooperative and problem-based learning using Desktop Learning Modules (DLMs) that bring experimentation into the classroom.

1.1.1 Cooperative learning (CL): refers to an instructional strategy where learners work together in small groups to achieve shared learning goals [16]. Unlike learning in groups, a cooperative learning group is structured to foster social inter-dependence [17, 18]. Copious reviews of studies have reported on the effectiveness of cooperative learning for promoting positive achievement outcomes. In a meta-analysis of 37 studies comparing the learning benefits of cooperative learning and individual learning in STEM education, Bowen [19] found cooperative learning yielded a mean effect size of 0.51, indicating that cooperative learning is more beneficial than individual learning.

1.1.2 Problem-based learning (PBL): is an instructional approach in which students learn the material by working collaboratively to resolve real problems [20]. The instructional goal of PBL is to develop students’ problem-solving skill simultaneously as they acquire the intended domain knowledge [21, 22]. Besides, it is argued that PBL promotes self-regulated learning and bolsters learning motivation because learners are working on contextually meaningful problems.

CHAPL sessions are designed so that students work in cooperative learning groups to resolve a domain problem while using hands-on teaching aids. In our chemical engineering course, students use DLMs specifically designed to illustrate similar industrial processes. The DLM units bring experimentation into the classroom. Students are divided into jigsaw cooperative learning groups. In jigsaw groups, each member is assigned specific learning responsibilities for which s/he works individually to learn, and then with an ‘expert group’ to harmonize learning. Becoming an ‘expert’ in assigned tasks, s/he in turn teaches what is learned to his or her cooperative learning group [23, 24]. Hence the success of the group depends on the commitments of its individual members. Group efforts are guided by worksheets provided for the lesson, and each group unites to formalize their findings through homework submissions. To prime students for each session, they are expected to complete assigned class readings and take-home quizzes. While still working to standardize the approach, the CHAPL may afford students the privilege to develop skills that align with the ABET Criterion learning outcomes. Besides gaining domain knowledge, students could improve on problem-solving, teamwork and communication skills among others. Teaching more engineering courses using the CHAPL approach may afford multiple opportunities to hone desired life-long learning skills. However, assessment and documentation of the evaluation of CHAPL implementations in engineering classrooms is crucial to ascertaining its viability.
1.2 Purpose of this study

In light of this, we conducted an exploratory study to assess the potential benefits of the CHAPL approach to teaching engineering concepts. The study evaluated perceptions of learning gains and learning experiences for students taught similarly with cognitively challenging concepts in CHAPL and lecture class sessions. We assessed student perceptions of meaningful learning using constructs of significant learning proposed in Fink’s taxonomy. Besides this, we assessed participants’ perceptions on social and motivational benefits associated with group learning. Some studies have indicated that students may resist a cooperative learning approach as a result of their commitments to competition and individuality, lack of social skills, and avoidance of failure among others [25]. In order to assess potential apprehensiveness towards the CHAPL approach, we evaluated participant’s self-reported comparisons of their experiences in the lecture and CHAPL sessions. In the subsequent sections of this paper, we described the methods used in conducting our study, and then followed by how we analyzed the data obtained from the study. This is followed by a succinct discussion of the result of our analysis, study limitations and recommendation for future research.

2. Methods

2.1 Participants and design

The participants were twenty nine students enrolled in Fluid Mechanics and Heat Transfer (FM and HT), a junior level Chemical Engineering course, at a research university in the Pacific Northwest. The majority of students were male with only six female participants. All participants had fulfilled all prerequisites for the course and had cumulative grade point averages ranging between 2.29 and 4.0 at the time of this study. Course topics were taught in two distinct manners, either through a traditional lecture or as a CHAPL activity and all participants attended each session because it was not logistically possible to have a control group. In the place of a control group, equivalent pairs of topics were taught in lecture and CHAPL sections. Participants’ responses to a perception of interests survey were taken as a measure of learning outcomes.

2.2 Material and measures

2.2.1 Learning activities: For each learning approach, content delivery was designed around ‘equivalent’ topic pairs based on the principles of backward design and guided inquiry [26]. The desired learning outcomes were first established, acceptable evidence of the achievement of these outcomes was then determined and learning activities were built around these. Both learning approaches, lecture and CHAPL, included five paired topics. Topics in the lecture approach were paired with those of the CHAPL based on the similarities between their contents, concepts and principles, and their complexity, to ensure that participants experienced comparable cognitive challenges.

Although the study lacked a control group, all participants had the privilege of experiencing the new learning intervention. Lecture topics were presented using a deductive learning approach, while students learned topics in the CHAPL sessions using the DLMs. Table 1 lists topics covered in each learning approach.

2.2.2 Desktop learning modules (DLMs): Our portable DLMs pictured in Fig. 1 provide access to small desktop-scale replicas of some common equipment used in industry involving fluid flow and heat transfer. They consist of a base unit containing two fluid reservoirs, a rechargeable battery, pumps, tubing and receptacle ports to which a detachable equipment cartridge can be inserted.

On the front of the base unit and above the insertion point of the cartridge are located two cell phone display read-outs for differential pressure and stream temperatures, respectively. The rotameter for controlling and reading flow rates from the pumps is located at the lower left hand corner. These DLMs or older versions of the same have been used in previous studies in various contexts by our group [27, 28, 29]. Fig. 2 shows the cartridges employed in this study, each of which can be installed interchangeably on the DLM base unit shown in Fig. 1. The venturi, orifice and packed/fluidized bed cartridges were used to study the design and analyses of fluid flow equipment while the shell and tube and evaporative cooling cartridges were used to study the design and analyses of heat exchange equipment.

<table>
<thead>
<tr>
<th>Serial #</th>
<th>Lecture topic</th>
<th>Equivalent CHAPL topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pressure drop with fittings (second)</td>
<td>Reynolds experiment (first)</td>
</tr>
<tr>
<td>2</td>
<td>Pitot tube (first)</td>
<td>Venturi and orifice (second)</td>
</tr>
<tr>
<td>3</td>
<td>Packed bed (first)</td>
<td>Fluidized bed (second)</td>
</tr>
<tr>
<td>4</td>
<td>Double pipe heat exchanger (first)</td>
<td>Shell and tube heat exchanger (second)</td>
</tr>
<tr>
<td>5</td>
<td>Pool Boiling (second)</td>
<td>Evaporative cooler (first)</td>
</tr>
</tbody>
</table>
2.2.3 Survey: We developed a survey to assess students’ perceptions about how comparable their learning experiences in the two educational modes were. The survey comprised of two sections that used both closed-ended Likert-type items intended to capture students’ thoughts about the CHAPL learning approach and open-ended items that allowed respondents to express their experience in short sentences. Items were framed to assess how well each session helped participants to achieve cognitive and affective learning outcomes identified as objectives of significant learning in Fink’s taxonomy of significant learning. According to Fink, the objectives of significant learning include: (a) foundational knowledge—measured by understanding and retention of the main information and ideas; (b) application—assessed by measures of critical, practical and creative thinking; (c) integration—assessed by the ability to connect ideas across domains; (d) human dimension is demonstrated if students learned more about themselves and others; (e) caring—if students found interest value in the course material; and (f) learning how to learn—measured by the ability to become self-directed learners [30]. Items on the survey were in two categories: those assessing students’ perceptions of CHAPL, and those contrasting their experience in the CHAPL and lecture sessions. Four items asking students to contrast their experiences in lecture to CHAPL sessions, referred to as comparison items,

Fig. 1. Shows the base unit of the DLM.

Fig. 2. Some of the plug-in cartridges: (a) venturi, (b) orifice, (c) shell and tube heat exchanger, (d) packed/fluidized bed and (e) evaporative cooler.
were also reversed to have students contrast CHAPL to lecture sessions, making eight comparison items in all.

e.g. ‘‘Hands-on group learning helped more than lecture to understand basic principles in this class’’ and ‘‘Lecture helped more than hands-on group learning to understand basic principles in this class’’

2.3 Procedure

The course was taught in two modes alternating between two professors and the participants took part in all class sessions. Topics were divided among the professors, with one teaching exclusively by lecture and the other directing use of the DLMs with the first professor present to observe and participate in discussions. Equivalent topic pairs were on different days to allow students to experience the topic pairs in separate course sessions. While in the first session type topics were presented in deductive lecture format, the professor employed questioning techniques and the use of visual aids to foster critical thinking and learning engagement. The second session type was presented using DLMs and the CHAPL approach. Students were divided into seven groups of three participants, and two groups of four participants. Participants were allowed to choose their preferable group partners, but to ensure group diversity females and international students participants were not allowed to be in isolated groups. The CHAPL section began with an introductory session after which participants worked in their assigned groups on short worksheet based experiments, while the instructor or a teaching assistant provided cognitive scaffolding, in the form of Socratic dialogue [31], to support group activities. Group activities were halted to provide clarifications where the instructor observed pervasive learning misconceptions among participants. The experimental session is either preceded or followed by other cooperative learning activities, depending on whether or not a group began with the DLM. For example, we used the jigsaw cooperative learning pedagogy where each group member mastered an aspect of the learning material, and taught other group members the aspect of their ‘‘expertise’’ [40]. At the end of all the topic sessions, participants took a survey via the university survey system. Survey participation was voluntary—contingent upon participants consenting to be included in the study.

3. Data analysis and findings

Twenty three participants consented to completing the end-of-session survey of students’ experiences and their responses are included here for data analysis. It was not possible to conduct an exploratory factor analysis of the survey items because of the limited sample size [32]. In order to ensure a thematically structured data-analysis however, items were coded into themes that reflected the purpose of each survey item. Table 2 lists the themes that emerged from item coding. Some themes had multiple closed-response items e.g., Motivation and Social Learning; as a result we performed reliability analysis to explore how closely items are measuring constructs to which they were associated. Based on Cronbach’s alpha values of the analysis, items that were not closely related were dropped from the theme. Open-response items were analyzed based on themes emerging from participants’ responses about their experience in the CHAPL sessions that may not be examined by quantitative methods.

3.1 Contrasting participant experience

To assess how participants’ perception of their experiences in lecture and CHAPL sessions compare, four pairs of survey items contrasting experience in both sessions were analyzed using a
Wilcoxon signed-rank test. We compared participants’ response on four of Fink’s indicators of significant learning: foundational knowledge (understanding), application, integration, and learning how to learn (motivation). Each survey item asking participants to contrast their experience in CHAPL to lecture sessions also had an equivalent item contrasting lecture to CHAPL. For example, a survey item “Hands-on group learning helped more than lecture to understand basic principles in this class” was countered with another item “lecture helped more than hands-on group learning to understand basic principles in this class”. A Wilcoxon signed-rank test showed no statistically significant difference between participants reported experiences in the CHAPL and lecture sessions on all four comparisons: Understanding ($Z = –1.577, p = 0.115$); Application ($Z = –0.454, p = 0.65$); Integration ($Z = –1.126, p = 0.26$); Motivation ($Z = –0.395, p = 0.693$).

3.1.1 Participants’ perceptions of CHAPL on indicators of significant learning

While participants varied in the comparisons of their experiences in both sessions, results showed more respondents tended towards a positive perception of CHAPL. While some students were very displeased with their experience, some other students showed appreciation for the CHAPL approach and provided constructive reflections about CHAPL and how it could be improved. We report below our findings on participants self-report on the indicators of significant learning assessed by the survey.

3.1.2 Understanding, integration and application

The first three items on the survey assessed what participants think about how CHAPL sessions impacted their learning of engineering concepts taught using DLMs. Most students (about 70%) thought CHAPL activities could aid basic understanding of engineering concepts while 26% do not think CHAPL is beneficial for basic understanding, and 4% were undecided. Similarly 74% of respondents agreed that CHAPL activities might hone their ability to apply principles learned in the FM and HT course both in creative and practical thinking, and in aiding integration of ideas across different domains, with 13% and 17%, respectively dissenting (please see Table 3 for summary of survey responses). Participants reported that CHAPL is least effective in teaching for basic understanding and most effective for developing such application skills as creative and critical thinking.

3.1.3 Motivation

Six items were coded into the motivation theme because they were assessing to what degree the activities in CHAPL sessions induced participants to care about topics taught using the approach and to challenge them to self-regulated learning. However we performed reliability analysis to ensure the items were closely measuring a similarly related construct. The analysis yielded an acceptably high internal consistency (Cronbach’s alpha = 0.83) on three of the initial items. The items assessing if CHAPL was motivating asked if students were encouraged to seek answers to questions they had on the topics using DLMs, use their unique abilities and skills to learn, and learned in a new way. Most students thought the approach encouraged them to seek answers to questions they have on the topic (70%) and to actively use their unique skills and abilities to aid understanding (65%). Just about half of the respondents thought the approach made them learn in new ways. While some respondents were undecided about their decision, less than 20% of them disagree with all three items.

3.1.4 Social learning

The four items coded into the social learning theme did not yield a high internal consistency value (internal consistency $\alpha = 0.61$ was attained after an item was deleted). Items retained probed whether CHAPL influenced them to engage in social learning, e.g., discussion and engaging others in exchanges of ideas about course topics. At least 70% of respondents agreed they were more likely to discuss topics outside of class and 61% agreed they were likely to interchange ideas with other

<table>
<thead>
<tr>
<th>Themes</th>
<th>Closed-response Items</th>
<th>Open-response Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding</td>
<td>Q1, Q14*, Q15*</td>
<td>Q22, Q23, Q24, Q25, Q26, Q27.</td>
</tr>
<tr>
<td>Integration</td>
<td>Q2, Q18*, Q19*</td>
<td>Q28, Q30, Q31, Q32, Q33, Q34</td>
</tr>
<tr>
<td>Application</td>
<td>Q3, Q16*, Q17*</td>
<td></td>
</tr>
<tr>
<td>Motivation</td>
<td>Q5, Q7, Q11, Q12, Q20*, Q21*</td>
<td></td>
</tr>
<tr>
<td>Social Learning</td>
<td>Q6, Q8, Q9, Q10</td>
<td></td>
</tr>
<tr>
<td>Task Value</td>
<td>Q13</td>
<td></td>
</tr>
<tr>
<td>Time on Task</td>
<td>Q4</td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td>Q29</td>
<td></td>
</tr>
</tbody>
</table>

* Comparison items.
ideas. Only 48% of respondents acknowledged that they discussed CHAPL-taught concepts and ideas with their instructor.

3.1.5 Task value
The two items coded into the task value assessed if the CHAPL approach made them value the professional relevance of topics taught, as well as if they spent more time on task. Reliability analysis showed that the items reached an internal consistency of $\alpha = 0.63$. More students agreed (61%) that they spent more time on task as a result of CHAPL, while few students disagree with CHAPL accentuating the professional relevance of topics taught (13%).

3.2 Analyses of unstructured responses
Responses to the open-ended survey items were analyzed in two-phases for themes common to our participants’ experiences in the CHAPL sessions. Five major themes emerged from the second phase of response analysis and coding. Nine responses indicated that the DLMs fostered active and meaningful engagement. Participants were actively and meaningfully involved in the learning process as opined in a response:

"the activities forced me to find information to apply to real scenarios."

Besides, in-class experimentation may have made the concept being learned less abstract as one respondent noted:

"learning in the group, we all can do something by our own hands, and understand the demonstration well" and "I feel the hands on activity will translate to working with the unit ops equipment"

Secondly, learning in groups with DLMs provided visual stimulation which in turn might familiarize learners with concepts being learned thus affording some level of situated learning [33]—visual learners might find it easier to connect the new learning with prior knowledge. Visualization in groups and discussing the phenomenon being learned with classmate colleagues helped to connect theory to practice as a respondent noted:

"there was much more discussion during the class period about the theory. We could then see the theory right in front of us being put to use," as well as "visualization of equipment is a big deal to understanding how they work."

Besides, students found that visualization stimulates learning; for example one respondent noted:

"Being able to see the things we were learning right in front of us was very valuable, and was more exciting to learn. I think this helped me feel a little more enthusiastic about the course and the material."

Another opined:

"... while the lecture taught me how to solve these problems, the hands-on helped me make sense of why these problems arise" and "I like to see what I'm learning right in front of me."

The third theme that emerged from the coding is topic relevance. It is intuitive that students will find cooperative learning that promotes situated learning to accentuate the relevance of topics being learned as well as participants’ perception of task value. These thoughts are corroborated in sample responses below:

"lecture help more on understanding the basic idea, but other activities help on applying it";

"I think they activities did a good job of teaching us how to apply the equations and principles to a real working system, and to understand how the theoretical models varied compared to the real system. I think understanding this will be useful in preparing us for professional practice."

Table 3. Summary of survey responses

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1. Understand basic principles of fluid mechanics and heat transfer</td>
<td>3.48 (1.20)</td>
<td>70%</td>
<td>4%</td>
<td>26%</td>
</tr>
<tr>
<td>Integration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2. Integrate principles of fluid mechanics with those of heat transfer</td>
<td>3.61 (0.99)</td>
<td>74%</td>
<td>9%</td>
<td>17%</td>
</tr>
<tr>
<td>Application</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3. Apply principles of fluid mechanics and heat transfer</td>
<td>3.70 (0.97)</td>
<td>74%</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>Motivation ($\alpha = 0.83$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q5. Am encouraged to answer my own questions</td>
<td>3.65 (1.19)</td>
<td>70%</td>
<td>13%</td>
<td>17%</td>
</tr>
<tr>
<td>Q7. Learn in new ways</td>
<td>3.30 (0.88)</td>
<td>52%</td>
<td>30%</td>
<td>17%</td>
</tr>
<tr>
<td>Q11. Make use of your unique abilities and skills to aid understanding</td>
<td>3.52 (0.79)</td>
<td>65%</td>
<td>26%</td>
<td>9%</td>
</tr>
<tr>
<td>Social Learning ($\alpha = 0.61$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q6. Discuss course topics outside of class</td>
<td>3.52 (0.85)</td>
<td>70%</td>
<td>17%</td>
<td>13%</td>
</tr>
<tr>
<td>Q8. Interchange ideas with other students</td>
<td>3.57 (0.59)</td>
<td>61%</td>
<td>35%</td>
<td>4%</td>
</tr>
<tr>
<td>Q10. Discuss ideas and concepts with the instructor</td>
<td>3.09 (1.04)</td>
<td>48%</td>
<td>26%</td>
<td>26%</td>
</tr>
<tr>
<td>Task Value ($\alpha = 0.63$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q13. Feel more prepared for work in the field</td>
<td>3.35 (0.93)</td>
<td>57%</td>
<td>30%</td>
<td>13%</td>
</tr>
<tr>
<td>Q4. Spend more time on task</td>
<td>3.30 (1.02)</td>
<td>61%</td>
<td>17%</td>
<td>22%</td>
</tr>
</tbody>
</table>
“I feel that through the hands-on learning, I have a better understanding of the physical meaning of the principles, which will likely be useful for unit-ops and related classes.”

Respondents also reported how preparation, or the lack of it, influenced learning in the CHAPL learning paradigm. Ahead of class, students are expected to have read extensively about the topic they are to learn. Students who showed evidence of class preparation found the session helpful. For example some noted:

“Yes. I think that future coursework will require group activity and lab work with groups. This has helped us interact and prepare for group work’’;
“I learned more from hands-on, group work. Because I can read [a] concept from [the] book first, then operate by myself and discuss with classmates’’ and;
“Yes, at least I am well prepared. I read all concept[s] before class just in case I can understand better in hands-on’’

Meanwhile lack of class preparation made the experiences cumbersome for some:

“Maybe because I felt like I was not really prepared before each module so I didn’t know what we were doing or what was I supposed to learn from them. I found them to be difficult and confusing, but it could be because I was not well prepared. ’’ and;
“I like the idea of hands on learning, but I think learning from other students is not always beneficial . . . an overall explanation prior to the module would had been very helpful.’’

Lastly, a number of students also expressed their dissatisfaction and frustration with the learning paradigm. Complaints took any one of two forms—either the student(s) did not quite prepare for the sessions or they experienced an issue with user friendliness. Some students complained about equipment failure or navigating the work sheet:

“Lack of preparation and explanation as well as malfunctioning lab machines made the entire thing a nightmare. ” and;
“. . . In contrast, the activities were frustrating . . . the worksheets were frustrating because I didn’t know how to do them and often the information in the book was incomplete . . . . so I didn’t do as well as I wanted to.”

Where students are unfamiliar with the concept being taught, they complained about time wastage. Besides, their complaint also seemed to partly suggest that the implementation itself was time wasting.

“The hands on seemed to take more time to figure out . . . and I felt that the teacher/sit-in teacher/graduate student did not spend enough time to make sure we understood the concepts . . . .” and
“. . . a lot of time was wasted setting up and trying to learn the modules.”

4. Discussion

The aim of this study was to explore the potential benefits of a nascent learning paradigm that combines the features of other proven active learning paradigms. Among other things, our intention is to optimize engineering programs to meet outcomes specified by the EC2000. Working in cooperative learning groups provides opportunity to hone communication skills and ability to work in multi-disciplinary teams—which are among the requirements specified in the Criterion [34]. Also in accord with the requirements, problem-based learning pro-

<table>
<thead>
<tr>
<th>Theme</th>
<th>Description</th>
<th>Evidence</th>
</tr>
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<tbody>
<tr>
<td>Active and meaningful engagement</td>
<td>Participants were actively and meaningfully</td>
<td>“the activities forced me to find information to apply to real scenarios.”</td>
</tr>
<tr>
<td></td>
<td>engaged in the learning process.</td>
<td>“. . . I feel the hands on activity will translate to working</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with the unit ops equipment”</td>
</tr>
<tr>
<td>Visual stimulation</td>
<td>“Seeing” the concept being taught motivated</td>
<td>“Being able to see the things we were learning right in front of us was</td>
</tr>
<tr>
<td></td>
<td>engagement and learning</td>
<td>very valuable . . . I think this helped me feel a little more enthusiastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>about the course and the material.”</td>
</tr>
<tr>
<td>Topic relevance</td>
<td>The topics taught in CHAPL session were more</td>
<td>“I feel that through the hands-on learning, I have a better</td>
</tr>
<tr>
<td></td>
<td>meaningful to students.</td>
<td>understanding of the physical meaning of the principles, which will</td>
</tr>
<tr>
<td></td>
<td></td>
<td>likely be useful for unit-ops and related classes.”</td>
</tr>
<tr>
<td>Preparation</td>
<td>Preparing for each CHAPL session improves</td>
<td>“I learned more from hands-on, group work. Because I can read [a]</td>
</tr>
<tr>
<td></td>
<td>derived learning benefits</td>
<td>concept from [the] book first, then operate by myself and discuss with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>classmates”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“. . . I found them to be difficult and confusing, but it could be because</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I was not well prepared.”</td>
</tr>
<tr>
<td>Dissatisfaction</td>
<td>Some students expressed dissatisfaction with</td>
<td>“. . . the activities were frustrating . . . the worksheets were</td>
</tr>
<tr>
<td></td>
<td>CHAPL</td>
<td>frustrating because I didn’t know how to do them and often the “information in the book was incomplete . . . .”</td>
</tr>
</tbody>
</table>

Table 4. Summary of Thematic Analysis
vides a paradigm to get students familiarized with how to identify, formulate and solve engineering problems. The Hands-on components of CHAPL may increase learners’ perceptions of task value and motivation for learning because it fosters active engagement.

Analyses of participants’ responses to the survey provide some interesting findings about the potential of CHAPL and considerations for future implementation. Respondents thought that CHAPL provided an opportunity for active and meaningful engagement. Such active engagement has been noted to promote meaningful learning—learners interact with hands-on equipment in the classroom and find immediate connection between reality and concepts being learned, as opposed to rote learning that is deficient in revealing misconceptions in learning [35]. Meaningful engagement is also crucial to enhance learners’ ability to understand engineering concepts and subsequently, to apply them in creative ways, as well as to integrate such concepts into other fruitful ideas across domains. This might explain why despite complaints about operational challenges using the DLMs, or failure to prepare, most students still agreed at least, that CHAPL has the potential to foster understanding, integration and application of engineering concepts.

Retaining students’ interest in learning topics in engineering courses would play a pivotal role in subsequent retention in engineering programs [36]. DLMs offer in-class experimentation that brings the concept being learned to life. The learner is able to mentally connect with the concepts being learned, thus minimizing the inherent abstractness of many engineering concepts. Some respondents noted that the paradigm provided visual stimulation. Being thus stimulated, learners may readily see the value of the learning task and the relevance of concepts being learned. About 60% of respondents in our study reported that the intervention impacted their perspective about the relevance of the course topics in CHAPL sessions to real work within the field. Task value is a motivational construct that has been noted to promote self-regulated learning and academic achievement [37]. Being so motivated may bolster learning engagement and improve students’ cognitive and emotional investment in their learning. This thought seems to have been corroborated by the number of students who agreed to spend more time on task, although spending more time on task might as well have been due to cognitive over-load as a result of increased student responsibility. Despite the possibility of implicit confounding factors however, some respondents’ indicate that they had more discussion on topics outside of class, coupled with those who thought that the CHAPL approach to learning might improve pre-class preparation seems to indicate the CHAPL pedagogy might be a very engaging approach to classroom learning.

Lastly, we found from our analysis that to be effective, CHAPL needs careful planning and implementation. Getting students to buy into alternative pedagogies especially when it puts higher responsibility for learning on them, might be challenging for various reasons, but poorly implementing such pedagogies may arouse stiff resistance. The lessons we learned from our implementation are based on reflections on participants’ recommendations. Listed below is a summary of recommendations for future implementation:

i. **Pre-training**: as indicated earlier, many concepts in engineering learning are inherently challenging to learn. Although students are expected to prepare for the class, their level of understanding of the concept cannot be assumed. Respondents indicated that a lecture or “pre-lab” prior to the module activity would be beneficial as one respondent noted:

> “Having a . . . day to explain the concepts behind the activity . . . would be much more beneficial”.

This observation reflects the views of Kirschner and colleagues that students should be given adequate preparatory knowledge before expecting any self-directedness [38]. To be effective, guided instruction may need to precede the problem-based cooperative learning for CHAPL.

ii. **Learning support**: students who are at different stages of their learning as such would require varying ranges of support. We observed that some students still needed instructor involvement in the learning process. Although we have responded to learner inquiries by engaging them in Socratic dialogues—e.g., pointing students to references that answer their questions, this approach does not quite work for all students. Learning support may depend on students’ prior knowledge, learning style and the complexity of the learning task. It then would be propitious to factor task complexity and students’ prior knowledge into such curricular design.

iii. **Equipment functionality and usability**: Some respondents indicated that malfunctioning equipment was a learning distraction. We acknowledge that we experienced equipment failures due to some technical glitches during the sessions. Such circumstances could increase learning frustration and erode students’ confidence in future teaching innovations.

iv. **Time factor**: Effective implementation could be
time intensive. We found that some students alluded to time being inadequate to work through activities in the workbook. While this might be true, we envisage that minimizing redundancy and qualitative pre-training might reduce learning frustration and optimize time usage. Time economics will as well depend on how efficient a cooperative group gets with time use; as noticed some students were wasting time on minor issues or getting distracted; however requiring submission of a completed worksheet at the end of the period may stimulate greater attention and productivity.

v. **Course credit**: We implemented this study in a 2-credit course. In compensation for time, some participants thought the work load was intensive and could have merited 3 credits. This might be as a result of students’ goal orientation. Where students hold performance goal orientation, they may be more concerned about how their end-course grade eventually influences their cumulative grade point [39]. In such cases, end-of-course performance may trump any desire for mastery of the material to be learned.

5. **Limitations and future directions**

While this is an exploratory study, our findings provide important insights for future studies. We drew on the small sample size available to us at the time and consequently we were unable to conduct a factor analysis on the survey items, the result of which could have been used to improve the validity of the survey. This lack of adequate sample size also limited our ability to conduct comparison studies that could answer questions about the effectiveness of CHAPL on different learning outcomes relative to different comparison groups. These preliminary survey results do suggest however that CHAPL does impact learners differentially on cognitive dimensions of Fink’s taxonomy—i.e. foundational knowledge, application and integration of such knowledge. Hence, they add credence to plans for conducting experimental studies directly comparing CHAPL and control groups in the future to evaluate these outcomes in an authentic learning context to provide more robust findings. Also, to improve external validity, studies on the comparative effectiveness of CHAPL must have adequate sample sizes to have sufficient statistical power for making substantive inferences. Furthermore, such studies should be replicated across different domains of engineering and the sciences. Of course a challenge to this kind of research might be the availability of appropriate DLMs for each concept being taught, worksheets and protocol for implementation. Therefore, intensive work is needed in expanding DLM availability through low-cost fabrication processes and creative development of DLM instruments for various engineering and science courses to represent physical and chemical processes with appropriate visualization and on-line sensing for rapid-format/real-time responses. Besides that, companion worksheets are needed to ease implementation and assessment tools for design validation in specific implementations.

5.1 **Conclusions**

In this study we examined students’ perspectives about a new pedagogy for teaching engineering concepts that we are proposing. Students who experienced similar cognitively demanding paired topics in fluid mechanics and heat transfer, taught by lecture or CHAPL, completed an end-of-course survey contrasting their experiences in the two types of learning sessions. Although the implementation of CHAPL had challenges ranging from students’ resistance to change and to concerns about logistics, most participants admit that the pedagogy has promising prospects for enriching the learning experience when properly implemented. Therefore, a compelling argument may be made for perfecting, enhancing and reducing costs of Desktop Learning Modules. Future studies that use randomized control trial would be needed to substantiate the validity of the CHAPL approach to teaching engineering concepts in the classroom. Such future assessment will further strengthen claims of validity of the CHAPL pedagogy if implemented on a larger sample size and use better measures of authentic learning in classes teaching a variety of other engineering concepts. We believe that more empirical evidence of the validity of the CHAPL will strengthen the case for a widespread dissemination of this pedagogy.

**Acknowledgments**—We gratefully acknowledge the support of NSF through grant numbers DUE 0618872 and DUE 1023121, a World Bank STEP Grant entitled “Implementing New Learning Pedagogies in Engineering Education Using Desktop Learning Modules” through collaboration with the Chemical Engineering Department at Ahmadu Bello University, and a Nigerian Education Trust Fund grant for support of lead researcher entitled “Heat Transfer and Fluid Dynamics Analysis of a Compact Multichannel Liquid-Gas Contactor and Application as a Hands-on Pedagogical Device in Chemical Engineering Education”. We gratefully acknowledge Prof. Richard (Dick) Zollars for agreeing to allow the DLM and CHAPL implementation into his classroom instruction format. We also acknowledge the efforts of machinist Gary K. Held, Dr. Paul B. Golter and undergraduate Jonathan Windsor who collectively spearheaded the design of the DLMs and associated cartridges. The participation of the students in this study is also highly appreciated.

**References**

1. R. M. Marra, B. Palmer and T. A. Litzinger, The effects of a first-year engineering design course on student intellectual
7. A. King, From sage on the stage to guide on the side, *College Teaching*, **41**(1), 1993, pp. 30–35.
Appendix I

ChE 332 Student Survey

CLOSE-ENDED ITEMS

In contrast to traditional lecture classes I found because of the mix of lecture and the new learning systems (Desktop Learning Module or DLM and allied activities) that I...

<table>
<thead>
<tr>
<th>Items</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Unsure</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand basic principles of fluid mechanics (FM) and heat transfer (HT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrate principles of fluid mechanics (FM) with those of heat transfer (HT)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Apply principles of fluid mechanics (FM) and heat transfer (HT)</td>
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<tr>
<td>Spend more time on task</td>
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<td></td>
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<td></td>
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<tr>
<td>Am encouraged to answer my own questions</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Items</th>
<th>More</th>
<th>Somewhat</th>
<th>The Same</th>
<th>Somewhat</th>
<th>Less</th>
<th>Much</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discuss course topics outside of class</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Learn in new ways</td>
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<tr>
<td>Interchange ideas with other students</td>
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<tr>
<td>Feel more isolated</td>
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<tr>
<td>Discuss ideas and concepts with the instructor</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Make use of your unique abilities and skills to aid understanding</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Feel challenged to create your own understanding</td>
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<tr>
<td>Feel more prepared for work in the field</td>
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</tr>
</tbody>
</table>

How strongly do you agree with the following statements about this course?

<table>
<thead>
<tr>
<th>Items</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Unsure</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hands-on group learning helped more than lecture to understand basic principles in this class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecture helped more than hands-on group learning to understand basic principles in this class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hands-on group learning helped more than lecture to apply principles of fluid mechanics and heat transfer (FM&amp;HT) in this class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spend more time on task</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecture helped more than hands-on group learning to apply principles of FM&amp;HT in this class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hands-on group learning helped more than lecture to integrate principles of fluid mechanics (FM) with those of heat transfer (HT) in this class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecture helped more than hands-on group learning to integrate principles of fluid mechanics (FM) with those of heat transfer (HT) in this class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hands-on group learning helped more than lecture in encouraging me to answer my own questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecture helped more than hands-on group learning in encouraging me to answer my own questions</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

OPEN-ENDED ITEMS

- Contrast your learning from the lectures with that from the activities (Hands-on, teammate facilitated learning (Jigsaw), group work and demonstration).
- Order the activities in this class (aside from lecture) from most useful (list this first) to least useful (last) and explain your ordering in not more than 3 lines.
Are there subsequent classes in which the principles and skills you learned in this class will be useful? Please list them.

Do you feel the hands-on group learning in this class better prepares you for this (these) subsequent class(es)? Please explain in not more than 3 lines

What about the hands-on active and cooperative learning would you like to modify?

Compared to lecture, how do you think the other activities prepare you for professional practice?

Compared to the other activities how do you feel the lecture prepares you for professional practice?

How would you compare lecture and the new learning system in terms of making you a more independent learner?

In what ways would you say element(s) of lecture and/or the new learning system has made you to care about the subject of fluid mechanics and heat transfer?

Overall how satisfied were you with the introduction of hands-on learning and associated activities in this course?
  - Very satisfied
  - Satisfied
  - Unsatisfied
  - Very unsatisfied

Please state your main reason

How much do you value group work?
  - Indispensable
  - Very much
  - It’s ok
  - Not very much
  - Not at all

Please explain your choice in not more than 3 lines

In which of the following ways would you say the new learning system has impacted you the most?
  - Basic knowledge of fluid mechanics and heat transfer principles
  - Application of fluid mechanics and heat transfer principles
  - Integration of fluid mechanics and heat transfer principles
  - Caring about fluid mechanics and heat transfer in everyday life
  - Appreciating the benefits of group work
  - Becoming a more independent learner
  - Other: (please specify)

In which of the following ways would you say the lecture has impacted you the most?
  - Basic knowledge of fluid mechanics and heat transfer principles
  - Application of fluid mechanics and heat transfer principles
  - Integration of fluid mechanics and heat transfer principles
  - Caring about fluid mechanics and heat transfer in everyday life
  - Appreciating the benefits of group work
  - Becoming a more independent learner
  - Other: (please specify)

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